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Effects of Regulated Deficit Irrigation on Soil Nutrients, Growth and Morbidity of *Panax notoginseng* in Yunnan High Altitude Areas, China

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ABSTRACT

This study investigated the responses of *Panax notoginseng* in a high-altitude area to regulated deficit irrigation at different growth stages (seedling stage, vegetative growth stage, flowering stage, and root weight gain stage) by observing indicators such as plant growth, soil nutrients, and morbidity. Conventional irrigation (70%-80% FC) was applied at the seedling stage and the root weight gain stage. Three regulated deficit irrigation levels (50%-60% FC, 40%-50% FC, and 30%-40% FC) were applied during the vegetative growth period, and three regulated deficit irrigation levels (70%-80% FC, 50%-60% FC, and 40%-50% FC) were used in the flowering period. Conventional irrigation was also applied throughout the growth stage as a control (CK). The results showed that the content of available phosphorus, available potassium, and nitrate-nitrogen in the soil was the lowest under the T4 treatment, and the cutting+main root length, rib length, root surface area, root volume, and main root diameter all reached their maximum values under this treatment. Under the T4 treatment, the total saponin content and total dry weight were the highest, the irrigation water use efficiency was the highest, and the *P. notoginseng* morbidity rate was the lowest. Morbidity was reduced by 53.42 percent in individuals who received the CK therapy, whereas total saponin content increased by 8.65 percent. The T4 therapy had the highest score of all the treatments in principal component analysis. As a result, planting *P. notoginseng* under the T4 treatment can effectively reduce irrigation water usage, enhance production and quality, and minimize the incidence of sickness in *P. notoginseng*.

INTRODUCTION

Panax notoginseng is an herbaceous plant in the Araliaceae family, which has strict requirements for its growth environment. It is mainly distributed in high-altitude areas of Yunnan, China (Huang et al. 2018). *P. notoginseng* is easily affected by its external environment during the planting process (Zu et al. 2017). Different water management modes will change the soil environment in the planting area, including the microbial communities and the soil nutrient and physicochemical properties (Tan et al. 2017). These changes may lead to reductions in *P. notoginseng* yield (Li et al. 2019). Therefore, the water management mode is an important controllable factor that plays a vital role in the *P. notoginseng* cultivation process.

At present, various new water management modes are in use, including limited irrigation (Xu et al. 2019), regulated deficit irrigation (Majid et al. 2020), and alternate root-zone irrigation (Huan et al. 2018). Regulated deficit irrigation, for example, refers to the use of various levels of water scarcity during a certain stage of the crop growth process to focus crop growth in the desired growth state while ensuring normal plant growth. The technique is primarily dependent on the crop's control and compensatory effects (Levin et al. 2017). Current research shows that a moderate water deficit is beneficial to the growth of *Jatropha curcas* L (Kheira & Atta 2009). Guo et al. (2015) and other studies on the effects of soil moisture on alfalfa root rot found that water significantly impacts the disease index of alfalfa root rot, and excessive water aggravates alfalfa root rot. Zhao et al. (2014) found in experiments that soil moisture affected root rot in potted *P. notoginseng*, and the morbidity of root rot and disease was positively correlated with soil moisture content. When the soil moisture content was 85% of the field water capacity, the morbidity of disease in *P. notoginseng* was the highest compared to that at all tested soil moisture levels.

In previous studies, the mechanisms of crop response to water deficit irrigation in low-altitude areas have been fully studied, but the responses of different crops and varieties to crop water deficit adjustment as well as the climatic conditions in high-altitude areas are significantly different (Luo et al. 2013). Research on the water consumption trends in *P. notoginseng* in high-altitude areas mainly focuses on the full growth stage, while the research on regulated deficit irrigation in various growth stages of *P. notoginseng* (seedling stage, vegetative growth stage, flowering stage, and root weight gain stage) lacks depth. Therefore, this study examined the effects of different levels of water deficit treatment during the vegetative growth period and flowering period of *P. notoginseng* on the growth, soil nutrients, and morbidity of *P. notoginseng*. The analysis model comprehensively evaluated the quality of *P. notoginseng* and identified the optimal planting method under the regulated deficit irrigation mode in each growth stage, to provide a basis for high-quality and high-yield water management for *P. notoginseng* in high-altitude areas of Yunnan.

MATERIALS AND METHODS

Experimental Materials

The experimental site is located at Kunming University of Science and Technology, Kunming City, Yunnan Province, 24°84′50″N and 102°86′49″E, at an altitude of approximately 1983 m. The planting area has a subtropical-plateau mountain monsoon climate, and the annual temperature difference is low. A greenhouse with a length of 34.2 m, a width of 7.2 m, and a height of 2.5 m was built in the test area. In the greenhouse, the test soil was red loam, with a field capacity (FC) of 35 percent. The shed featured three layers of shading nets on the ceiling and two layers of shading nets all around it. The light transmission rate was 18%.

In the greenhouse, trenches with ridges between them were dug with a depth of 0.4 m and a width of 0.4 m before the test. The planting space was divided into ten ridges, each measuring 3 m in length and 1.5 m in breadth. Sprinklers were installed between every two ridges of the shed, with a 1.5-m spraying radius.

Test Design

Field trials were conducted with intact, pest-free *P. notoginseng* seedlings. The seedlings were arranged on each ridge at a distance of 0.05 m in the longitudinal direction and 0.05 m in the transverse direction. Each ridge was divided into three plots, and the area of each trial plot was 1 m×1.5 m.

The experiment was divided into four growth periods according to the growth process of *P. notoginseng*: seedling stage, vegetative growth stage, flowering stage, and root weight gain stage. Conventional irrigation (70%-80% FC) was applied in the seedling stage and root weight gain stage; regulated deficit irrigation was applied in the vegetative growth stage and the flowering stage.

Three irrigation levels were applied during the vegetative growth period: mild water deficit (50%-60% FC), moderate water deficit (40%-50% FC), and severe water deficit (30%-40% FC). Three irrigation levels were set during the flowering period: conventional irrigation (70%-80% FC), mild water deficit (50%-60% FC), and moderate water deficit (40%-50% FC). In addition, conventional irrigation throughout the growth stage of *P. notoginseng* was used as a control treatment (CK). In this experiment, a total of 10 water irrigation treatments were performed, and each irrigation mode was repeated 3 times for a total of 30 experimental plots. The specific irrigation water scheme is shown in Table 1. During the test, the soil water content was measured at 8 am every morning. When the water limit was lower than field capacity, irrigation was performed to the upper limit of field capacity. During the test, fertilizer was applied only once before the *P. notoginseng* seedlings were planted, and the amount of fertilizer was 1500 $kg \cdot hm^{-2}$ (Weifu water-soluble compound fertilizer imported from Israel).

Table 1: Irrigation treatment at different growth stages.

Treat	Seedling stage	Vegetative growth stage	Flowering stage	Root weight gain stage
CK	70%-80%	70%-80%	70%-80%	70%-80%
T1	70%-80%	50%-60%	70%-80%	70%-80%
T2	70%-80%	40%-50%	70%-80%	70%-80%
T3	70%-80%	30%-40%	70%-80%	70%-80%
T4	70%-80%	50%-60%	50%-60%	70%-80%
T5	70%-80%	50%-60%	40%-50%	70%-80%
T6	70%-80%	40%-50%	50%-60%	70%-80%
T7	70%-80%	40%-50%	40%-50%	70%-80%
T8	70%-80%	30%-40%	50%-60%	70%-80%
T9	70%-80%	30%-40%	40%-50%	70%-80%

Observation Indexes

Soil Nutrients and Moisture

The contents of nitrate nitrogen, available potassium, and available phosphorus in the red soil of *P. notoginseng* planted in each irrigation treatment were measured. The samples were obtained at the end of the growing period using earth-boring drills. Among them, nitrate-nitrogen in the root region of *P. notoginseng* was determined by ultraviolet spectrophotometry, available potassium was determined by flame photometry, and available phosphorus was determined by molybdenum antimony colorimetry. The soil moisture content in the root zone of *P. notoginseng* was measured daily with a TPIME-PICO64/32 soil moisture analyzer.

Panax notoginseng Root System, Yield, Morbidity and Irrigation Water Use Efficiency

The fresh roots of *P. notoginseng* were washed, and the roots were scanned with an EPSON STD4800 scanner. The obtained images were analyzed using WinRHIZO software to obtain data such as root length, diameter, surface area, and volume. The roots, leaves, petioles, and stems of *P. notoginseng* were placed into different envelopes, and the envelopes were placed in an oven at 105°C for 30 minutes. Then, the temperature was adjusted to 50°C to dry the plant parts to a constant weight. Finally, the dry matter mass of the roots, stems, and leaves of *P. notoginseng* was obtained by weighing.

During the experiment, the number of diseased plants was checked every week. Diseased plants were dug up immediately, and the soil in the area was sprayed with a disinfectant.

morbidity = diseased plant number / total number of plants

The irrigation water use efficiency (*WUEi*) was calculated based on the farmland water balance.

Saponin Content

Five saponins (R_1, Rg_1, Re, Rb_1, R_d) were identified by Agilent 1260 series high-performance liquid chromatography. The chromatographic conditions were as follows: Vision HTC18 column (250mm×4.6mm, 5μm); detection wavelength of 203nm, column temperature of 30°C, the flow rate of 1.0mL.min-, and injection volume of 10μL. R_1 was notoginsenoside, and Rg_1, Re, Rb_1, and R_d were ginsenoside.

Data processing

The test results were analyzed and plotted using Microsoft Excel 2007. Correlation analysis, principal component analysis, and analysis of variance (ANOVA) were performed using IBM SPSS Statistics 22.0. The Duncan method was used for multiple comparisons (P = 0.05).

RESULTS AND DISCUSSION

Effects of Regulated Deficit Irrigation on Soil Nutrients in the Root Zone

Fig. 1 shows the response of available phosphorus, available potassium, and nitrate nitrogen in *P. notoginseng* soil to the treatments at the end of the growing period. The figure shows that the contents of available phosphorus, available potassium, and nitrate-nitrogen in the soil layer under the CK, T1, T2, and T3 treatments were not significantly different (P>0.05). During the flowering period, the available phosphorus, available potassium, and nitrate nitrogen in the different treatments were significantly different (P<0.05). The T3 treatment had the highest available phosphorus content, which was a significant increase of 6.76% compared with that in the CK treatment, but the phosphorus contents of T1, T5, T6, and T7 were not significantly different from that of the CK treatment. The T4 treatment had the lowest available phosphorus, which was significantly reduced by 3.61% compared with that in the CK treatment. The content of available potassium in the T9 treatment was the highest and showed a significant increase of 5.44% compared with that in the CK treatment. The differences in available potassium in the T2-T3 and T7-T9 soils were not significant. Compared

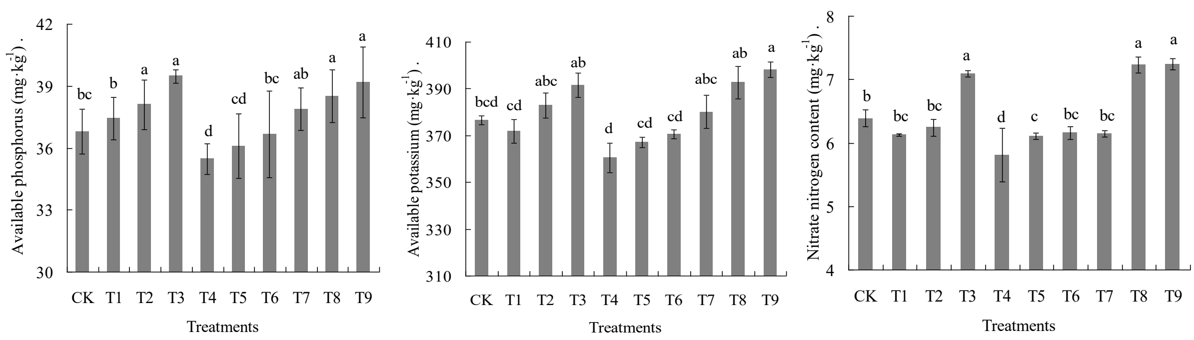

Fig. 1: Soil nutrients of *Panax notoginseng* underwater treatments.

with that in the CK treatment, the available potassium in the other treatments was reduced by 1.46% to 4.22%, and the T4 treatment had the largest reduction. The content of nitrate nitrogen was the lowest in the T4 treatment, which was significantly decreased by 9.08% compared with that in the CK treatment. The nitrate-nitrogen content was not significantly different among the T1, T2, T6, T7, and CK treatments. The T3, T8, and T9 treatments had the highest soil nitrate-nitrogen levels, which were significantly higher by 10.95% to 13.30% than that in the CK treatment.

Effects of Regulated Deficit Irrigation on Root Growth

Table 2 shows the root growth of *P. notoginseng* under the different treatments. The effects of each treatment on the growth indexes of *P. notoginseng* were significant ($P<0.05$). The cutting+main root length, rib length, root surface area, root volume, and main root diameter in the T4 treatment all reached maximum values that were significantly higher than those in the other treatments. The T7 and T9 treatment cutting+main root length, rib length, root surface area, root volume, and root diameter were all the lowest and were significantly reduced by 10.78%-11.04%, 6.31%-15.84%, 8.06%-10.81%, 11.51%-14.59%, and 20.68%-22.82%, respectively, compared with those of CK ($P<0.05$). In other treatments, the cutting+main root length was not significantly different from that in CK. Among them, the cutting+main root length in the T1, T2, and T5 treatments increased by 2.08% to 5.32% compared with that in the CK treatment, and those of T3, T6, and T7 decreased by 0.26% to 6.75% compared that in the CK treatment. In all treatments except T4, T5, and T9, the variation in rib length varied from -6.31% to 5.42% compared with the CK rib length, showing no significant difference. In all treatments except T3, T4, T8, and T9, compared with CK, the variation in root surface area was between -2.91% and 0.40%, showing no significant difference. The root volume in the T1, T2, T5, and T6 treatments showed no significant difference from that in the CK treatment, with a different range of 0.24% to 2.49%. In all treatments except the T3, T4, T8, and T9 treatments, the main root diameter was not significantly different from that in the CK treatment, with a difference between -6.54% and 2.01%.

Effects of Regulated Deficit Irrigation on Effective Components of *P. notoginseng*

Fig. 2 shows the distribution of saponins in *P. notoginseng* under different treatments. Under each treatment, the levels of the five saponins showed significant differences ($P<0.05$). In each treatment, the contents of Rg_1 and Rb_1 were higher, and the contents of Re and R_1 were lower. The contents of Rg_1 and R_1 in the CK treatment were the lowest and the highest, 0.06% and 3.07%, respectively. The Rg_1 and R_1 contents in the other treatments increased by 33.33% to 166.67% and 1.30% to 40.07%, respectively, compared with those in the CK treatment. The contents of Re in T1 and T4-T7 were relatively high and were 20.00%-40.00% higher than that in the CK treatment. The Rb_1 contents in T1, T2, and T4 were not significantly different from that in the CK treatment. The Rb_1 content in the T9 treatment was the lowest of all treatments at 2.54%, which was a significant decrease of 21.85% compared with that in the CK treatment. The other treatments had 3.08% to 19.08% less Rb_1 than the CK treatment. The T4 treatment had the highest Rd content of all the treatments, which was 39.57% higher than that of the CK treatment. The Rd contents in T1 and T5-T7 increased by 3.48%-24.35% and that in the other treatments decreased by 2.17%-43.91% compared with that in the CK treatment. The total saponin content in the T4 treatment was the highest and was significantly higher than that in the other treatments.

Table 2: The growth of *Panax notoginseng* roots under different water treatments.

Treat	Cutting+main root [cm]	Rib length [cm]	Root surface area [cm^2]	Root volume [cm^3]	Root diameter [mm]
CK	7.70±0.48bc	12.37±0.88c	50.13±1.58b	8.43±0.47bc	15.91±1.29b
T1	8.03±0.49b	12.90±0.58bc	50.17±2.35b	8.45±0.52b	16.23±0.67b
T2	7.86±0.31b	12.89±0.61bc	48.93±2.22bc	8.22±0.23bcd	15.20±1.16bc
T3	7.18±0.19cd	12.30±0.96c	46.50±2.11cd	7.58±0.34de	14.12±0.28c
T4	8.90±0.31a	15.13±0.79a	54.42±1.69a	9.30±0.24a	18.15±0.47a
T5	8.11±0.49b	14.12±0.85ab	49.64±1.58bc	8.40±0.39bc	14.87±0.45bc
T6	7.68±0.34bc	12.30±0.74c	50.33±1.78b	8.39±0.17bc	15.73±0.65b
T7	7.43±0.27bcd	13.04±0.66bc	48.67±1.54bc	7.66±0.36cde	15.53±0.71bc
T8	6.87±0.28d	11.59±0.52cd	46.09±1.79cd	7.46±0.48e	12.62±0.58d
T9	6.85±0.28d	10.41±0.92d	44.71±2.06d	7.20±0.64e	12.28±1.00d

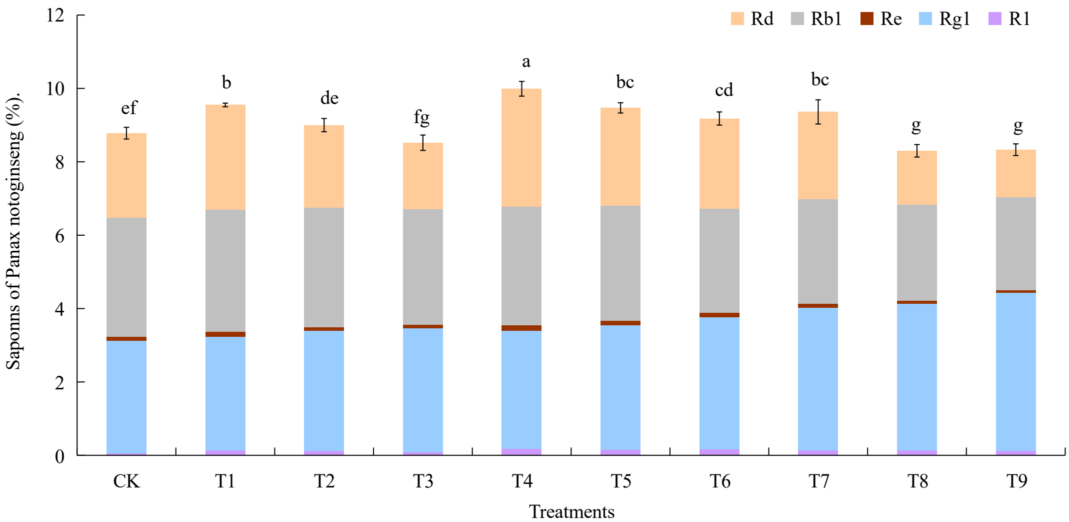

Fig. 2: The saponins of Panax notoginseng underwater treatments.

The total saponin content of the T8 treatment was the lowest of all the treatments. The total saponin content of the other treatments except for T3, T8, and T9 increased by 2.28%-8.65% compared with that in CK.

Effects of Regulated Deficit Irrigation on Yield, Morbidity and Irrigation Water use Efficiency of *P. notoginseng*

Table 3 shows that the dry weight of the leaves, petioles, and stems was less than the root dry weight. The total dry weight in each treatment was greatly affected by the dry weight of the *P. notoginseng* roots. The dry matter mass of the leaves in the T4 treatment was significantly (7.29%) higher than that in the CK treatment. The dry matter mass of the leaves in the T8 and T9 treatments was the lowest, which was significantly lower (by 21.88% and 22.92%) compared to that in the CK treatment. Compared with that in the CK treatment, the dry matter mass of the leaves in the other treatments decreased significantly, by 5.21%-16.32%. Except in the T4 treatment, the dry weight of the stem and petiole in all treatments decreased by 3.38%-17.87% compared with that in the CK treatment. The dry weight of the stem and petiole in the T4 and T1 treatments increased by 24.06% and 20.43% compared with those in the CK treatment, and those in the other treatments decreased by 0.95% to 31.13% compared with those in the CK treatment. The total dry weight of *P. notoginseng* in the T1 and T4 treatments increased significantly, by 8.65% and 13.54%, respectively, compared with that in the CK treatment.

Table 3: Effects of irrigation modes on dry weight, irrigation water use efficiency, and Morbidity of *Panax notoginseng*.

Treat	Dry weight [g] leaves	Petioles and stems	Above-ground	Root	Total	Irrigation water use efficiency [$g \cdot m^{-2} \cdot mm^{-1}$]	Morbidity [%]
CK	0.96±0.03bc	0.69±0.02ab	1.65±0.04b	10.18±0.51b	11.83±0.55b	1.82±0.24e	14.83±0.45bcd
T1	0.98±0.06ab	0.67±0.02bc	1.65±0.07b	12.26±0.57a	13.91±0.63a	2.28±0.21b	12.71±1.24de
T2	0.88±0.02d	0.65±0.02bc	1.53±0.02c	10.03±0.75b	11.56±0.74b	1.83±0.12de	13.82±0.76cd
T3	0.81±0.04e	0.63±0.04cd	1.44±0.08d	9.74±0.51bc	11.18±0.57bc	1.80±0.26e	13.87±0.87cd
T4	1.03±0.04a	0.73±0.02a	1.76±0.03a	12.63±0.65a	14.40±0.63a	2.43±0.33a	7.15±0.64f
T5	0.91±0.03cd	0.67±0.04bc	1.58±0.07bc	10.09±0.77b	11.66±0.83b	2.05±0.18cd	7.96±0.80f
T6	0.89±0.02d	0.64±0.01bcd	1.53±0.03c	9.97±0.67b	11.50±0.64b	2.14±0.31c	10.74±0.62e
T7	0.80±0.04e	0.60±0.02de	1.40±0.05de	8.81±0.27cd	10.21±0.22cd	1.75±0.09e	15.85±0.86abc
T8	0.75±0.04ef	0.59±0.04de	1.34±0.05ef	7.96±0.34de	9.30±0.30de	1.51±0.09f	16.83±0.91ab
T9	0.74±0.02f	0.57±0.03e	1.30±0.04f	7.01±0.60e	8.32±0.60e	1.43±0.05f	17.97±1.41a

The T4 and T1 treatments had higher irrigation water use efficiencies than the other treatments, which were significantly increased by 34.68% and 24.54%, respectively, compared with that in the CK treatment. The water use efficiency of the T3 and T7-T9 treatments was 0.37% to 19.56% lower, respectively than that of the CK treatment. The water use efficiency in the other treatments was 4.43%-13.84% higher than that in the CK treatment.

The morbidity of *P. notoginseng* in the T7, T8, and T9 treatments was high, increasing by 6.60%, 13.19%, and 19.99%, respectively, compared with that in the CK treatment. The T4 treatment had the lowest morbidity, which was 53.42% lower than that of the CK treatment. The morbidity of *P. notoginseng* in the other treatments was 6.62% to 46.83% lower than that in the CK treatment.

Principal Component Analysis

The KMO statistic of saponin content in this study was 0.561, which is greater than 0.5. Bartlett's sphericity test P was 0.01, which is less than 0.05. Therefore, these data are suitable for principal component analysis.

Eigenvalue and Variance Contribution Rate

The characteristic root and contribution rate of the first principal component were 2.73 and 54.65%, respectively, and the characteristic root and contribution rate of the second principal component were 1.28 and 25.57%. The cumulative contribution rate was 80.22%, indicating that the first and second principal components can reflect the overall information from the original indicators and are suitable for the general analysis of comprehensive quality.

Principal component expression and comprehensive score

The principal component expression is:

$$P_{C1} = -0.082Z_{R1} - 0.221Z_{Rg1} + 0.187Z_{Re} + 0.233Z_{Rb1} + 0.205Z_{Rd} \quad (11)$$

$$P_{C2} = 0.650Z_{R1} + 0.279Z_{Rg1} + 0.219Z_{Re} - 0.152Z_{Rb1} + 0.178Z_{Rd} \quad (12)$$

$$Z_F = 0.681P_{C1} + 0.319P_{C2} \quad (13)$$

where P_{C1} is the first principal component score; P_{C2} is the second principal component score; Z_F is the comprehensive score; Z_{R1} is the notoginsenoside *R1*; Z_{Rg1} is the ginsenoside Rg_1; Z_{Re} is the ginsenoside *Re*; Z_{Rb1} is the ginsenoside *Rb1*; and Z_{Rd} is the ginsenoside *Rd*.

According to the principal component analysis, Rg_1, Re, and Rd had high loadings in the first principal component, but the first principal component score of Rg_1 was negative. For the second principal component, R_1 and Rg_1 had higher loadings, and their scores for the second principal component were positively correlated. The comprehensive evaluation scores for the quality components of saponins in the different treatments are shown in Fig. 3. Of the different water treatments, T4 scored the highest, T5 scored second highest, and T8 and T9 scored the lowest.

The research in this experiment found that the soil nutrient content of the soil in the T4, T5, and T6 treatments was lower, and the soil nutrient content of the soil in the T3, T8, and T9 treatments was higher. During the vegetative growth and flowering periods of *P. notoginseng*, a certain degree of regulated deficit irrigation can improve the soil available phosphorus, available potassium, and nitrate nitrogen absorp-

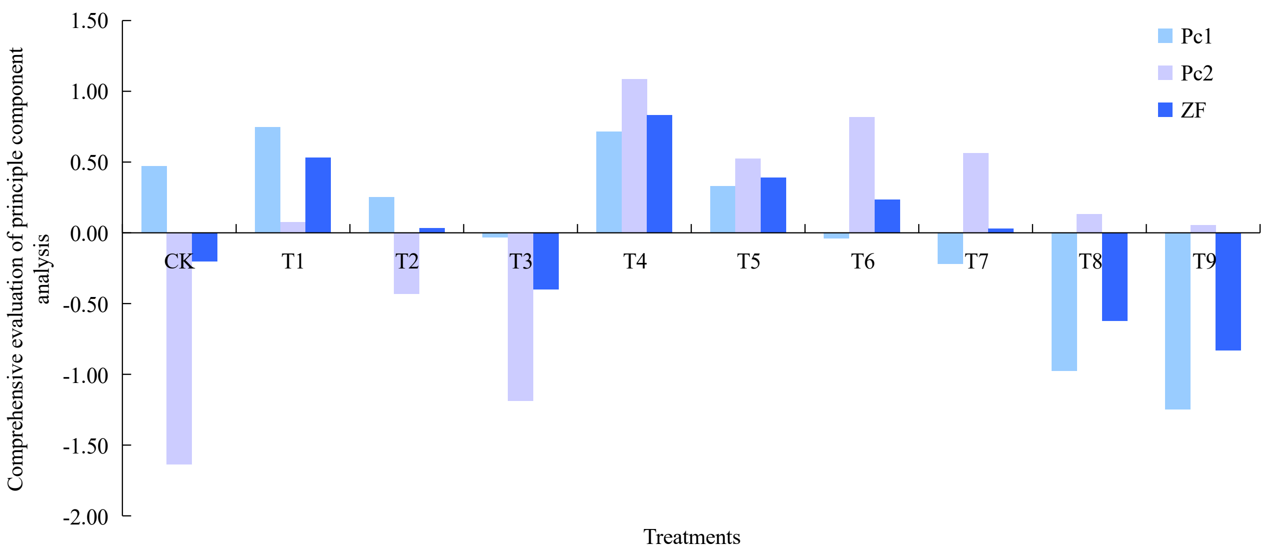

Fig 3: Comprehensive evaluation of principal component analysis of quality indexes of *Panax notoginseng* saponins.

tion capacity of *P. notoginseng*, thereby reducing the levels of these elements in the soil (Zu et al. 2017). Excessive water deficiency limits the transport and distribution of nitrogen, phosphorus, and potassium in the soil to *P. notoginseng*, which is consistent with the research on wheat by Meng et al. (2016).

This study found that the severe water deficit treatment limits root elongation reduces the root volume and root surface area, and reduces the root diameter (Hayrettin & Demir 2012, Shi et al. 2015). A mild water deficit treatment during the vegetative growth and flowering periods can improve the dry matter quality of *P. notoginseng*. This is because *P. notoginseng* has a certain resistance to stress. A certain degree of water stress stimulates the roots of *P. notoginseng* to absorb soil nutrients (Zhao et al. 2014), and the nutrients absorbed at the same time are transported to the stems, leaves and other organs, resulting in an increase in the final yield during the root weight gain stage. Severe water deficiency in the vegetative growth period and mild or moderate deficit irrigation in the flowering period significantly reduced the yield, which mainly occurred because the vegetative growth period is the key period for aboveground growth, and the severe water deficit affected *P. notoginseng* recovery (Kheira & Atta 2009). Except for the ginsenoside Rg_1, the contents of each saponin in the T4 treatment were significantly higher than those in the other treatments. In the determination of the various saponins in the T8 and T9 treatments, it was found that except for R1 and Rg_1, the other saponin indicators were at low levels. This shows that different saponin types have different responses to water demand. The use of severe deficit irrigation during the vegetative stage prevented the accumulation of some saponin content (Zhao et al. 2014).

The T1 and T4 treatments improved irrigation water use efficiency, and the T8 and T9 treatments had the lowest irrigation water use efficiency. This was because the growth of *P. notoginseng* could not be restored because of the severe deficit irrigation during the vegetative growth period and the slight rehydration during the flowering period. This also shows that moderate water deficit irrigation can significantly increase irrigation water use efficiency (Meng et al. 2016). Huang et al. (2014) performed irrigation experiments on jujube seedlings and found that higher water levels could lead to the aggravation of seedling diseases. The results of this study indicated that both higher and lower moisture levels increase the incidence of morbidity in *P. notoginseng*. A severe water deficiency easily leads to growth inhibition, and higher water availability leads to an imbalance in the proportion of the microecological environment, causing roots to rot and increasing morbidity.

CONCLUSION

Regulated deficit irrigation at different growth stages affects the yield, quality, soil nutrients, and morbidity of *P.notoginseng* in high-altitude areas. The results of this study indicated that under the T4 treatment, the contents of available phosphorus, available potassium, and nitrate-nitrogen in the soil and the morbidity of *P. notoginseng* were lower than those in the other treatments, and the root morphology, total saponin content, total dry weight, and irrigation water use efficiency were higher than those of other treatments. Compared with those in the CK treatment, morbidity decreased by 53.42%, irrigation water use efficiency increased by 34.68%, total dry weight increased by 24.06%, and total saponin content increased by 8.65% in the T4 treatment. Based on the comprehensive evaluation of the above correlation analysis and principal component analysis, regulated deficit irrigation was beneficial to the growth of *P. notoginseng* under the T4 treatment.

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