

The Effects of Different Water Deficit and Rehydration on Soybean Soil Enzyme Activity and Soil Available Nutrients During the Grain Filling Stage

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Abstract: To investigate the effects of different degrees of water deficit during the grain filling stage on soybean soil enzyme activity and nutrients, drought sensitive soybean Suinong 26 was used as the material. A pot experiment was conducted using four water gradients: soil moisture content of $70\% \pm 5\%$ of field capacity (normal irrigation, CK), $60\% \pm 5\%$ (mild water deficit, T1), $50\% \pm 5\%$ (moderate water deficit, T2), and $40\% \pm 5\%$ (severe water deficit, T3). Soil enzyme activity and available nutrients were measured. The results indicate that mild water deficit treatment in R5 stage can effectively promote soil enzyme activity and change the soil microenvironment. With the extension of water control time and the deepening of water control degree, soil available nutrients and soil enzyme activity significantly decrease. The activities of urease, alkaline phosphatase, sucrose, and available nutrients in the soil treated with T1 after rehydration were significantly increased compared to the water control period, while the activity of catalase did not change significantly throughout the entire treatment period. These findings indicate that mild water deficit treatment optimizes soil biological fertility during critical reproductive stages.

Keywords: compensatory effect; soil enzymes; soybeans; water stress

1 INTRODUCTION

Heilongjiang Province represents the primary soybean cultivation region in China, contributing to over one-third of the nation's total soybean output [1]. Nevertheless, the northeastern area is particularly vulnerable to climate change, with frequent meteorological disasters in recent years and an increasing number of autumn droughts [2-3]. The grain filling stage constitutes a crucial stage in soybean growth and development, during which inadequate water availability can result in incomplete grain filling, thereby adversely impacting yield. Soil serves as the immediate source from which plants acquire water and nutrients, the quality of soil nutrients can directly affect crop growth and development [4]. Furthermore, soil enzyme activity serves as an indicator of soil quality and the intensity of soil biochemical processes, playing an indispensable role in soil nutrient cycling [5]. Among them, the activities of phosphatase, invertase enzyme, catalase, and urease are highly representative of the soil fertility [6]. Hu Yanhui [7] studied the effect of drought stress on soil enzymes in oat roots, and found that drought stress has a significant impact on soil invertase enzymes, urease, and catalase, but excessive drought stress will reduce the activities of soil invertase enzymes, urease, and catalase. Zhang Jiangwei [8] conducted water stress during the wheat flowering period, and the results showed that under drought stress conditions, mild water stress can effectively increase the activities of soil urease, invertase enzymes, and phosphatase. Zhou Hangfei [9] studied the effects of drought and Cd stress on soil microorganisms and soil enzyme activity, and concluded that soil catalase shows significant differences under different water stress conditions, and its activity gradually decreases as the stress degree deepens. In the later growth stage of crops, water stress will reduce the activity of soil invertase enzymes, which may be due to the weakened nutrient absorption capacity of crops in the later growth stage, and the water deficiency will result in lower nutrient intake, thereby reducing the activity of soil invertase enzymes [10]. Relevant studies have shown [11-13] that soil enzyme activity is sensitive to changes in soil moisture, and appropriate water stress during the grain filling stage can help increase soil enzyme activity.

Soil nutrients denote the essential elements required

for plant growth, whose availability is primarily influenced by factors such as soil moisture, aeration, temperature, and pH. Among these factors, soil moisture exerts a predominant impact [14]. Soil moisture and nutrient availability are interdependent: moisture controls nutrient solubility and diffusion, while nutrient status affects water use efficiency. Optimal soil moisture conditions enhance the uptake efficiency of soil nutrients, whereas both excessive and insufficient moisture levels can adversely affect nutrient absorption [15]. Studies have shown that water deficiency during the middle growth stage and subsequent rehydration will increase the nitrogen absorption of crops, resulting in an overcompensation effect. The available potassium in the soil will decrease with the growth in irrigation water volume, and the reason may be that excessive water will cause the loss of potassium in the soil [16-18]. Wang Pengbo et al. [19] pointed out in their study on the effects of straw incorporation on soil enzyme activity and yield formation in dryland wheat in western Shanxi that the available phosphorus content in the soil has a positive impact on soil enzyme activity. Under suitable moisture conditions, the activation speed of soil fixed phosphorus increases, and the conversion rate of available phosphorus in the soil decreases.

In summary, for this experiment, "Suinong 26" was used as the test material. The experiment was conducted in a pot culture manner, with different degrees of water deficit and rehydration treatments carried out during the grain filling stage. By measuring the activities of phosphatase, invertase enzyme, catalase, and urease, as well as the content of soil available nutrients, the compensatory effect after water deficit and rehydration was further understood. This provided a theoretical basis for water-saving and high-yield soybean production in the Heilongjiang region.

2 MATERIALS AND METHODS

2.1 Experimental Materials and Overview

This experiment was conducted in 2022 and 2023 in the rainproof plastic greenhouse of the National Cereal Engineering Technology Research Center in Daqing City, Heilongjiang Province. A pot experiment method was

adopted. The height of the pot was 33 cm and the diameter was 30 cm. The potting soil was black calcareous soil, taken from the off-campus experimental base of Heilongjiang Bayi Agricultural University. The basic nutrients contained $22.37 \text{ g}\cdot\text{kg}^{-1}$ organic matter, $74.75 \text{ mg}\cdot\text{kg}^{-1}$ alkali-dissolved nitrogen, $21.87 \text{ mg}\cdot\text{kg}^{-1}$ available phosphorus, $110 \text{ mg}\cdot\text{kg}^{-1}$ available potassium, and a pH of 8.13. The tested soybean variety was the drought-sensitive type "Suinong 26", provided by the National Cereal Engineering Technology Research Center.

2.2 Experimental Design

Before sowing, seeds with large and plump grains, uniform size and color and no dryness or insect damage were selected, disinfected with 5% sodium hypochlorite, then rinsed with sterile water and sown in the pots with 9 seeds each. The seedlings emerged during V1 period. Three uniform and vigorous seedlings were retained per pot.

During the soybean filling stage (R5), different gradient water deficit treatments were carried out. Samples were taken on the 5th, 10th, 15th days of water deficit, and on the 3rd and 10th days after rehydration. After controlling the water for 15 days during the granulation stage (R5), there was rehydration until the end of the ripening stage. A completely random experimental design was used with 4 treatments as follows: (1) CK: soil moisture content maintained at $70\% \pm 5\%$ of the field capacity; (2) T1: soil moisture content maintained at $60\% \pm 5\%$ of the field capacity; (3) T2: soil moisture content maintained at $50\% \pm 5\%$ of the field capacity; (4) T3: soil moisture content maintained at $40\% \pm 5\%$ of the field capacity. Before potting, base fertilizer was applied. The fertilizer amount was $150 \text{ mg}\cdot\text{kg}^{-1}$ N, $100 \text{ mg}\cdot\text{kg}^{-1}$ P_2O_5 , and $150 \text{ mg}\cdot\text{kg}^{-1}$ K_2O . The fertilizer was mixed with sieved soil and then used to fill the pots. Each pot was filled with 20 kg of sieved soil, and 2 kg of soil was covered after sowing. The weight of the potting was controlled at 5 p.m. (17:00) every day to artificially water each treatment to maintain its corresponding moisture content.

2.3 Collection of Soil Samples

The soybean roots and soil were extracted. First, the large chunks of soil at the root ends were removed, and then the soil that was not firmly attached to the plant was removed by shaking the roots. The tightly attached soil on the roots was collected by a sterile brush. Random samples were taken, mixed evenly, and placed in plastic bags, which were then brought back to the laboratory for processing. After air-drying and grinding, the samples were sieved through a 1mm soil sieve for the determination of soil enzyme activity and soil available nutrients.

2.4 Measurement Items and Methods

2.4.1 Determination of Soil Enzyme Activity

The determination of soil enzyme activity followed the method of Guan Songyin [20]. The determination of urease activity used the phenol sodium - sodium hypochlorite colorimetric method, the determination of alkaline phosphatase activity used the Phenolphthalein diphosphate colorimetric method, the determination of invertase

enzyme activity used the 5-Dinitro-2-hydroxybenzoic acid colorimetric method, and the determination of catalase activity used the ultraviolet spectrophotometry [21].

2.4.2 Determination of Soil Available Nutrients

Soil alkali-hydrolysable nitrogen was determined by the Alkaline hydrolysis diffusion method, available phosphorus was determined by the sodium bicarbonate extraction - molybdenum antimony resistance colorimetric method, available potassium was determined by the ammonium acetate extraction-flame photometry method. The specific methods were all in accordance with Baoshidan [22] "Soil Agricultural Analysis".

2.5 Data Processing

Data were statistically organized by Excel 2019, and single-factor analysis of variance (ANOVA) and Duncan multiple comparison were performed by SPSS 25.0. GraphPad Prism software was used for plotting.

3 RESULTS

3.1 The Effects of Varying Degrees of Water Deficit and Rehydration During the Bulking Period on Soil Available Nutrients

3.1.1 Effects of Different Degrees of Water Deficit and Rehydration During the Bulking Period on the Content of Soil Alkali-Hydrolyzable Nitrogen

Soil alkali-hydrolyzable nitrogen, also known as alkali-hydrolyzable nitrogen, can be directly absorbed and utilized by crops and is closely related to the growth advantage of crops. As shown in Fig. 1, on the 5th day of water control for Suinong 26, the content of alkali-hydrolyzable nitrogen in the T2 and T3 treatments decreased slightly by 2.2% and 1.2% compared to CK treatment, while the T1 treatment increased by 24.8% compared to the CK treatment.

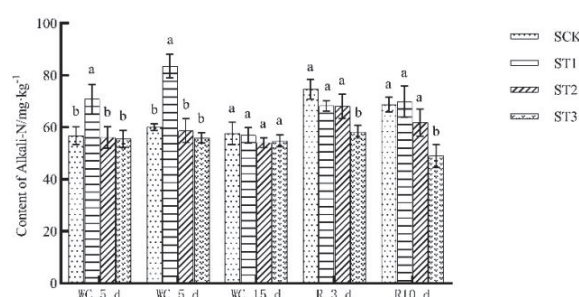


Figure 1 The impact of different water deficits and rehydration during the grain filling stage on the soil alkali-hydrolysable nitrogen content in soybeans

On the 10th day of water control, the content of alkali-hydrolyzable nitrogen in the T1 treatment was the highest at $83.55 \text{ mg}\cdot\text{kg}^{-1}$, achieving an over-compensation effect, and there were significant differences among all treatments. On the 15th day of water control, the trend of alkali-hydrolyzable nitrogen content was $\text{T2} < \text{T3} < \text{T1} < \text{CK}$, and the differences among the treatments were not significant. On the 3rd day of rehydration, the T1 treatment increased by 20.0% compared to the 15th day of water control, while the content of the T3 treatment was still the lowest,

decreasing by 22.0% compared to the CK treatment, with significant differences. This might be because under a long-term severe water deficit state, insufficient soil water supply led to a decrease in soil alkali-hydrolyzable nitrogen content, and rehydration could not timely alleviate the situation. On the 10th day of rehydration, the trend of alkali-hydrolyzable nitrogen content change was an initial increase followed by a decrease, and the differences among the treatments were not significant. Among them, the T1 treatment had the highest content, increasing by 1.7%, 11.7%, and 30.0% compared to the CK, T2, and T3 treatments, respectively.

In the same column, different lowercase letters represent significant differences ($P < 0.05$) among different treatments of the same factor. S: Suinong 26, WC: water control, R: rehydrate, the same is shown as below.

3.1.2 Effects of Different Water Deficits and Rehydration During the Bulking Period on the Soil Available Phosphorus Content of Soybeans

The effects of different degrees of water deficits and rehydration during the bulking period on the soil available phosphorus content of soybeans are shown in Fig. 2.

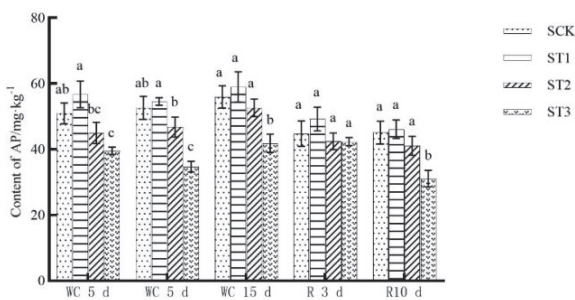


Figure 2 The impact of different water deficits and rehydration during the grain filling stage on the available phosphorus content in soybean soil

On the 5th day of water control for Suinong 26, due to water deficit, the soil moisture content decreased, and the change in soil available phosphorus content was very obvious. Among them, the content of the T1 treatment was the highest, followed by CK, and the content of the T3 treatment was the lowest. The content of the T2 and T3 treatments decreased by 11.6% and 22.4% respectively. Compared to the CK treatment, the differences were significant. On the 10th day of water control, the soil available phosphorus content in the T1 treatment was still the highest, and it increased by 3.7%, 14.2%, and 36.4% respectively compared to the CK, T2, and T3 treatments, and the differences were not significant. On the 15th day of water control, the overall trend of soil available phosphorus content was consistent with that on the 10th day, and the advantage of the T1 treatment significantly increased. This indicates that appropriate water deficit can help increase the available phosphorus content in the soil and even achieve super compensation. On the 3rd day of rehydration, the T2 and T3 treatments recovered compared to the CK treatment, but the contents were slightly lower than 5.2% and 5.3% of the CK treatment, and the differences were not significant. Although the content of the T1 treatment was slightly lower than that on the 15th day of water control, it was still the most dominant treatment, increasing by 10.0% compared to the CK

treatment. On the 10th day of rehydration, the effect of water deficit on soil available phosphorus content showed $T1 > CK > T2 > T3$. T1 was the most dominant treatment, and the soil available phosphorus content of the T3 treatment was the lowest. This phenomenon indicates that when the degree of water deficit is too strong, with the growth in time of water deficit, soil available phosphorus will be lost due to soil compaction, resulting in a decrease in soil available phosphorus content, and restoring water supply cannot alleviate this phenomenon.

3.1.3 Effects of Different Water Deficits and Rehydration on Soil Available Potassium Content in Soybean

As shown in Fig. 3, water deficits have a significant impact on soil available potassium content. On the 5th day of water control for Suinong 26, the trend of soil available potassium content was an increase followed by a decrease. The T1 treatment increased by 2.44% compared to the CK treatment, and the difference was not significant, while the T2 and T3 treatments decreased significantly by 5.1% and 14.2% respectively, and the difference was significant. On the 10th day of water control, the soil available potassium content in the T2 treatment was slightly higher than that in the CK treatment, which might be due to the stimulation of potassium absorption by the plant under soil water stress, resulting in a growth in its content. On the 15th day of water control, the trend of soil available potassium content was $CK > T1 > T2 > T3$, and it decreased significantly by 14.2%, 17.9%, and 21.4% respectively. Compared to the CK treatment, the difference was significant. On the 3rd day of rehydration, the trend of soil available potassium content was in increase followed by a decrease. The T1 treatment significantly increased its content due to the rehydration, which was 2.7% higher than the CK treatment, and the difference was significant. On the 10th day of rehydration, the soil available potassium content tended to be stable, with T2 and T3 treatments recovering to slightly below the CK treatment level, and T1 treatment being the treatment with the highest content. There was no significant difference among the treatments.

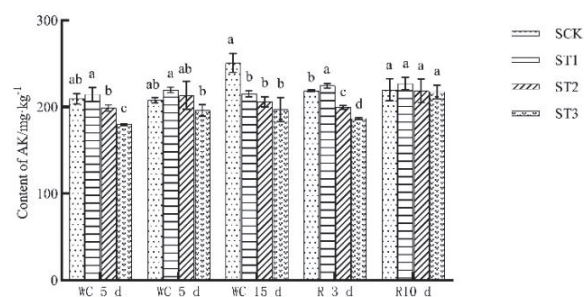


Figure 3 The impact of different water deficits and rehydration during the grain filling stage on the available potassium content in soybean soil

3.2 Effects of Varying Degrees of Water Deficit and Rehydration During the Bulking Period on Soil Enzyme Activity

3.2.1 Effects of Different Degrees of Water Deficit and Rehydration During the Bulking Period on Soil Phosphatase Activity in Soybean

Soil phosphatase activity is significantly affected by the level of soil moisture content. As shown in Fig. 4, on the 5th day of water control for Suinong 26, the soil

phosphatase activity was the highest in the T1 treatment, followed by the CK treatment, and the lowest in the T3 treatment. Among them, the T1 treatment increased by 16.1% compared to the CK treatment, while the T3 treatment decreased by 29.5% compared to the CK treatment, with significant differences. On the 10th day of water control, the T1 treatment decreased compared to the 5th day of water control, but was still higher than the CK treatment, while the T2 and T3 treatments decreased by 8.5% and 14.6% compared to the CK treatment, respectively, with significant differences. On the 15th day of water control, the soil phosphatase content showed an overall downward trend; this indicates that under a long-term water deficit state, phosphatase activity is greatly affected by water content, resulting in a gradual decrease in enzyme activity with the decrease in soil water content. The CK treatment increased by 10.8%, 11.9%, and 27.2% compared to the T1, T2, and T3 treatments, respectively. Only the T1 treatment had a non-significant difference compared to the CK treatment. On the 3rd day of rehydration, the trend of soil phosphatase activity was consistent with that on the 15th day of water control, but the T1 treatment recovered compared to the 15th day of water control, increasing by 7.5%. On the 10th day of rehydration, the trend of soil phosphatase was T3 < T2 < CK < T1. The T2 treatment recovered to the level of the CK treatment, while the T3 treatment had the lowest enzyme activity, with a decrease of 13.2% compared to the CK treatment, and the difference was significant.

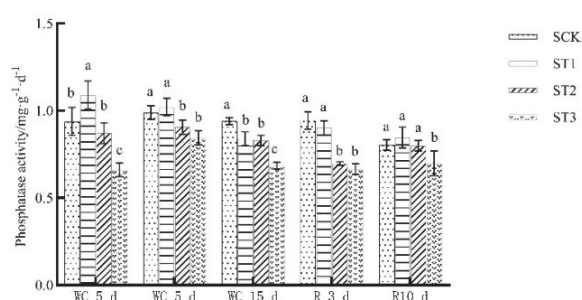


Figure 4 The impact of different water deficits and rehydration during the grain filling stage on soil phosphatase activity in soybeans

3.2.2 Effects of Different Water Deficits and Rehydration During the Bulging Stage on Soil Urease Activity in Soybean

Significant effects were observed on soil urease activity under different levels of water deficit treatments. As shown in Fig. 5, on the 5th day of water control for Suinong 26, the changes in soil urease activity were T1 > T2 > CK > T3, and there were significant differences among all treatments. On the 10th day of water control, the enzyme activity content increased overall, with the content of T1 treatment being the highest, increasing by 19.0% compared to CK treatment, and the difference was significant. On the 15th day of water control, the enzyme activity showed a downward trend, with CK > T1 > T2 > T3. The treatments T1, T2, and T3 were significantly reduced by 10.4%, 16.8%, and 39.7% compared to CK treatment. On the 3rd day of rehydration, the trend of enzyme activity changed to first increasing and then decreasing. This indicates that after restoring water supply,

the soil urease activity in the mild water stress state achieved an overcompensation effect. The T1 treatment was significantly increased by 52.9% compared to CK treatment. On the 10th day of rehydration, the enzyme activity decreased overall but the trend was consistent with that on the 3rd day.

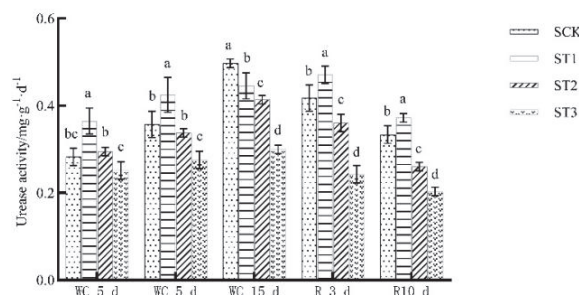


Figure 5 The impact of different water deficits and rehydration during the grain filling stage on soil urease activity in soybeans

3.2.3 Effects of Different Water Stress and Rehydration During the Seedling Stage on the Activity of Soil Sucrose Enzyme in Soybean

The effects of different water stress and rehydration treatments on the soil invertase enzyme activity of soybeans are shown in Fig. 6. On the 5th day of water control for Suinong 26, the invertase enzyme activity in the T1 treatment had an advantage, increasing by 35.4%, 32.6%, and 37.9% compared to the CK, T2, and T3 treatments, respectively. It has significant differences. On the 10th day of water control, the difference in enzyme activity between the T1 treatment and the CK treatment decreased, while the enzyme activity of the T2 and T3 treatments decreased significantly compared to the CK treatment, reducing by 11.7% and 33.6%. On the 15th day of water control, the trend of soil invertase enzyme activity was consistent with that on the 10th day. On the 3rd day of rehydration, the T2 and T3 treatments recovered compared to the water control period, with the T1 treatment having the highest activity. Compared to the CK treatment, it increased by 6.1%, with no significant difference. On the 10th day of rehydration, due to different degrees of long-term water deficit, the soil invertase enzyme activity showed differences after rehydration. In the mild water stress treatment, the soil invertase enzyme would have a super-compensation effect, with the T1 treatment increasing by 6.4%, 6.9%, and 27.2% compared to the CK, T2, and T3 treatments, respectively.

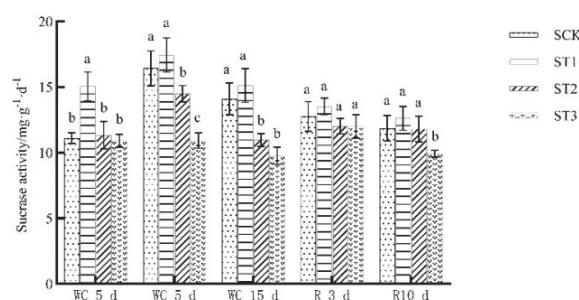


Figure 6 The impact of different water deficits and rehydration during the grain filling stage on soil sucrose activity in soybeans

3.2.4 Effects of Different Water Deficits and Rehydration During the Bulking Stage on the Activity of Soil Catalase in Soybean

As shown in Fig. 7, the activity of soil catalase showed a relatively stable trend with changes in different water stress and rehydration conditions. There was almost no difference among the various treatments. On the 5th day of water control for Suinong 26, the trend of catalase activity was a decrease followed by an increase. The enzyme activity content was the lowest in the T3 treatment and the highest in the CK treatment. On the 10th day of water control, the enzyme activity in the T3 treatment remained the highest, increasing by 1.3%, 0.4%, and 2.2% compared to the CK, T1, and T2 treatments respectively. On the 15th day of water control, the trend of catalase activity was T1 > T3 > T2 > CK, and there was no significant difference among the various treatments. On the 3rd day of rehydration, the enzyme activity in the CK treatment was the lowest, and the enzyme activities of the other three treatments were comparable.

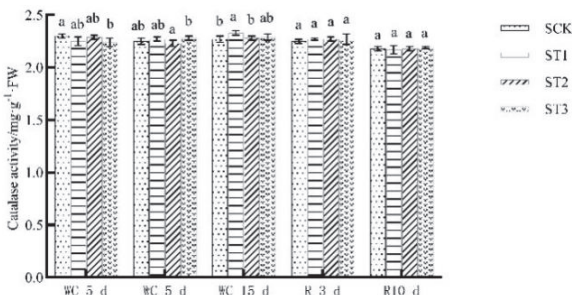


Figure 7 The impact of different water deficits and rehydration during the grain filling stage on soil catalase activity in soybeans

On the 10th day of rehydration, there was no

significant difference among the various treatments. This might be because the bulking stage is the late growth stage, and changes in soil moisture content do not cause significant fluctuations in soil catalase activity.

3.3 Effects of Different Water Deficits and Rehydration During the Bulb Formation Period on Yield and Yield Components

The yield in 2022 is shown in Tab. 1. The trend of plant height was T1 > T2 > CK > T3 treatment. Among them, T1 and T2 treatments increased by 18.5% and 6.2%, respectively. Compared to the CK treatment, it has significant differences. There were significant differences among the stem thickness of various treatments. The stem thickness of T1 treatment was the largest, with an average of 10.8 ± 0.93 cm. The trend of node number change was consistent with that of plant height, which might be due to the sufficient water supply after rehydration, increasing the water absorption of the plants and promoting plant growth. The overall trend of single plant pod number and single plant grain number was consistent, with the maximum value in T1 treatment, and significant differences compared to CK, T2, and T3 treatments. The yield of T1 treatment was 4.3%, 2.5%, 22.6%, and 44.1% higher than that of CK, T2, and T3 treatments, respectively, and it has significant differences. The performance in 2023 was consistent with that in 2022, further confirming the conclusion.

The changes in yield trends in 2022 and 2023 are parallel to the changes in soil enzyme activity and soil available nutrients, both of which show that the mild water deficit treatment (T1) achieved maximum yield, indicating that soil available nutrients and soil enzyme activity play a decisive role in yield under water deficit treatment.

Table 1 The impact of different water deficits and rehydration during the grain filling stage on soybean yield and yield components

| | handle | Plant heigh / cm | Syem diameter / mm | Pitch number | Number of pods per plant | Number of grains per plant | Yield per plant / g |
|------|--------|------------------|--------------------|----------------|--------------------------|----------------------------|---------------------|
| 2022 | SCK | 59.50 ± 1.26c | 10.23 ± 0.38ab | 15.33 ± 0.47b | 22.50 ± 1.50a | 51.33 ± 4.03b | 10.73 ± 0.50a |
| | ST1 | 68.90 ± 1.98a | 10.8 ± 0.93a | 17.67 ± 0.47a | 25.33 ± 0.47a | 61.00 ± 3.56a | 11.19 ± 0.72a |
| | ST2 | 63.17 ± 0.95b | 8.88 ± .77bc | 15.67 ± 0.94b | 19.47 ± 0.94b | 50.67 ± 1.70b | 8.66 ± 0.33b |
| | ST3 | 47.06 ± 0.36d | 8.26 ± 0.32c | 14.67 ± 0.47b | 18.00 ± 0.82b | 42.67 ± 0.94c | 6.07 ± 0.43c |
| 2023 | SCK | 60.50 ± 1.30a | 9.67 ± 0.69b | 16.00 ± 0.82ab | 24.33 ± 1.70a | 53.67 ± 2.49ab | 10.81 ± 0.64a |
| | ST1 | 65.90 ± 5.45a | 11.41 ± 0.73a | 17.00 ± 0.82a | 25.00 ± 2.16a | 59.33 ± 4.78a | 11.35 ± 0.87a |
| | ST2 | 62.63 ± 3.19a | 9.02 ± 0.60b | 15.67 ± 0.47ab | 23.67 ± 2.05a | 49.33 ± 1.70b | 9.91 ± 0.62ab |
| | ST3 | 50.76 ± 2.52b | 8.90 ± 0.23b | 14.67 ± 0.47b | 20.33 ± 1.25b | 45.67 ± 2.87b | 9.10 ± 0.47b |

4 DISCUSSION

Soil nutrients are the main source of mineral elements required for crop growth and development, and an irreplaceable and important component of soil ecosystems. The growth and development of crops, as well as the establishment of yield, rely on the continuous supply of soil nutrients as important nutrients. Moisture is one of the main factors determining the effectiveness of soil nutrient content. Maihol et al. [23] found that when soil moisture content is scarce, nitrogen transport is the main driving force of soil capillary action. However, when soil moisture content is abundant, the combined effect of capillary action and gravity promotes nitrogen transport to deeper soil layers, increasing the risk of nitrogen leaching and hindering the efficiency of nitrogen fertilizer utilization.

This is consistent with the results of this experiment. On the 10th day of the mild water deficit treatment, the alkali hydroxide nitrogen content reached the maximum value in the experiment, achieving an over-compensation effect. Water deficit also helps crops convert potassium fertilizer in the soil, which improves potassium fertilizer utilization efficiency and increases dry matter accumulation, thereby increasing yield [24]. On the 15th day of water deficit treatment in this experiment, the content of available potassium showed a gradually decreasing trend, which was inconsistent with the results of Zhao Yanling [24]. This indicates that a prolonged water deficit treatment is not conducive to the transformation of available potassium in the soil, causing the fixation of active potassium elements and further leading to a decrease in available potassium content. Phosphorus in the soil can enhance root vitality

and improve water use efficiency. Zhang Xinying [25] pointed out that although water absorption and phosphorus absorption by roots are two separate channels, sufficient supply of phosphorus in plants can alleviate the damage caused by water deficit to plants. Moreover, the content of available phosphorus in soil can indirectly affect the activity of soil catalase [26]. In this study, the trend of soil available phosphorus content remained to increase first and then decrease, and in all treatment periods, the content of soil available phosphorus under mild water deficit treatment was the largest, indicating that appropriate water deficit and rehydration treatments during the grain filling stage can help increase the content of available nutrients in the soil and promote the absorption of soil nutrients by plants. This is consistent with the results of Zhang Zhongxue et al. [27].

Soil enzymes can promote soil metabolic processes and actively participate in various biochemical reactions in the soil. On the one hand, soil enzymes can promote the transformation of soil organic matter [28]; on the other hand, soil enzymes can provide nutrient elements for plants. Research by Zhang Bin et al. [29] has shown that under conditions of water deficit during the grain filling stage, the activities of soil sucrase, urease, and alkaline phosphatase can be increased, which is an effective way to increase oat yield. This study found that water deficit treatment has a significant impact on soil urease, phosphatase, and sucrase. During short-term water control, mild water stress can effectively increase soil urease, phosphatase, and sucrase activity in Suinong 26. However, under severe water stress treatment, prolonged water stress can lead to a decrease in soil enzyme activity, and its activity does not recover to the control level after rehydration. This indicates that moderate water stress is beneficial for improving soil enzyme activity. Wang Hui et al. [30] found in their study on the effect of water and nitrogen combination on soil enzyme activity in the rhizosphere of red beans with different drought tolerance that water deficit can increase soil catalase activity and urease activity during flowering and podding periods. And the changes in urease activity in the rhizosphere of drought resistant varieties are greater. The inconsistent performance of catalase activity in this experiment may be due to the relatively small influence of soil moisture content on hydrogen peroxide during the late growth stage, resulting in insignificant differences in catalase changes.

5 CONCLUSION

Water deficit and rehydration treatment during soybean grain filling stage can improve soil nutrient utilization efficiency and promote increased soil enzyme activity. Soil enzyme activity and soil nutrients mutually promote and influence each other, thereby further promoting the accumulation of soybean biomass and increasing soybean yield. The analysis of this experiment shows that compared with the control, mild water deficit and rehydration treatment are the optimal treatments, which can not only ensure stable and high yields of soybeans, but also provide scientific guidance and theoretical basis for the establishment of efficient water-saving irrigation systems.

Acknowledgments

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