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Research Article

Effects of Macromolecule Water Absorbent Resin on Physiological Characteristics and Water Use of Winter Wheat

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Abstract: Macromolecule water absorbent resin has functions such as water absorption, soil moisture conservation and soil improvement, as well as other functions. In this study, in order to explore the effect of macromolecule water absorbent resin on wheat roots and to determine the physiological characteristics of the leaves during different growth stages, a field experiment of the application of macromolecule water absorbent resin was conducted on the dry land. Root vigor and leaf relative water content (leaf water potential) and improved the photosynthetic physiological characteristics and increased yield and water production efficiency of the wheat. The root vigor with the application of a 54 kg/hm^2 dosage of macromolecule water absorbent resin was found to be the strongest in the jointing, booting and grain filling period and the leaf relative water content with this dosage treatment was also the greatest. During the jointing and booting periods, the photosynthetic rate, transpiration rate and leaf water use efficiency with the application of a 54 kg/hm^2 dosage of macromolecule water absorbent resin were found to be the highest. In summary, the effect of the application of a 54 kg/hm^2 dosage of macromolecule water absorbent resin was found to be the most effective.

Keywords: Leaf water potential, macromolecule water absorbent resin, photosynthetic rate, root vigor, water use

INTRODUCTION

During drought conditions, the moisture content has an important impact on the photosynthetic characteristics of wheat (Keck and Boyer, 1974; Tezara *et al*., 1999; Lawlor and Cornic, 2002; Li *et al*., 2006) and 90-95% of the wheat yield comes from its photosynthesis (Hu *et al*., 1986). The contribution of the photosynthetic product of the functional leaves to the wheat seeds is as high as 80%, especially at later growth stages (Zheng, 1991). The root systems are important organs involved in the absorption of water and nutrients for crops. Changes in the soil moisture affects the physiological characteristics and the growth and development of the root systems, while the growth and development of the root systems also directly affects growth of the stems and leaves of the aboveground parts of the crops and crop yields. The root system serves as an original site affected by the drought of the soil. First and foremost, the soil drought directly affects root metabolism, thereby influencing the life activities of the entire plant, the physiological conditions of which directly affects the drought resistance strength of the crops (Motzo *et al*., 1993; Asseng *et al*., 1998; Xue *et al*., 2003). Therefore, investigating the responses of the physiological characteristics of root systems to drought stress can allow for more efficient determination of drought resistance in plants (Sharp *et al*., 2004).

Macromolecule water absorbent resin is a type of material with low cross-linking density, high hydroexpansivity and strong water absorbing force (Yang *et al*., 2005) and is considered to be a good cementing agent for soil. It is able to improve soil structure (Cao *et al*., 2007; Sojka *et al*., 2007), promote the formation of cumularspharolith (Caesar-TonThat *et al*., 2008) and can also quickly absorb and maintain water with a weight of hundreds or even thousands of times that of the resin itself (Johnson and Veltkamp, 1985; Janardan and Singh, 1998). When there is soil drought and water shortage, the macromolecule water absorbent resin can release the absorbed water, which can then be absorbed by plant roots, which benefits its growth and development. At the same time, macromolecule water absorbent resin can significantly improve the water holding capacity of soil (Dong *et al*., 2004; Yang *et al*., 2006, 2007), inhibit invalid loss of soil moisture (Sun *et al*., 2001a) and improve the utilization efficiency of water resources (Zhang *et al*., 2009). Studies (Sun *et al*., 2001b; Wang *et al*., 2001; Yu *et al*., 2006) have shown that soil with the

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application of an appropriate amount of macromolecule water absorbent resin can improve root vigor and promote the growth of crops. However, the studies conducted by Luo (2005) and Tan *et al*. (2005) illustrate that the application of too large a dosage of macromolecule water absorbent resin may affect the growth of the root systems and decrease their physiological functions. At the same time, macromolecule water absorbent resin may regulate the photosynthetic physiological process of wheat and increase the photosynthetic efficiency of its leaves (Yang *et al*., 2009) by improving the water conditions of the soil and adjusting the leaf relative water content or leaf water potential, thereby reducing or slowing down the stress degree of drought damage on crops. At present, there have been many research studies regarding the effects of macromolecule water absorbent resin on soil moisture (Zhang and Kang, 1999), the growth and development of plants (Alasdair, 1984; Woodhouse and Johnson, 1991; Huttermann *et al*., 1999), crop yield (Belanger *et al*., 1990) and physiological characteristics of crops (Yang *et al*., 2009). However, more in-depth research is needed regarding the mechanism of the system response based on the root systems of crops and the physiology of aboveground leaves.

In the semi-humid and frequent drought areas of the hilly arid area in western Henan Province, the amount of precipitation during the jointing period is low, while during the booting and the grain filling periods the amount of precipitation increases gradually. Advancing into the child-bearing period, water consumption also increases gradually and winter wheat in each period is still affected by water stress to some degree. According to the above characteristics, the effects of macromolecule water absorbent resin on the physiological characteristics of crops during the growth and development process were explored systematically during the different growth stages of winter wheat. In particular, its response to the physiological characteristics of the root systems, which are sensitive to drought stress and its effects on the physiological characteristics of aboveground leaves were studied. The results have important theoretical and practical significance, particularly for uncovering the mechanisms of the effects of the adsorbed water by the macromolecule water absorbent resin on the root systems of crops, as well as the physiological characteristics of leaves and the enhancement of the absorption and utilization of water by crops.

Therefore, the objective of the present investigative study was to verify the mechanism of the effects of macromolecule water absorbent resin on the utilization of water by winter wheat and provide a powerful basis for its reasonable application by systematically investigating the effects of the macromolecule water absorbent resin on root vigor, leaf relative water content and response to photosynthetic physiological characteristics.

MATERIALS AND METHODS

Experimental section:

Study area: The experiment was carried out on the dry land of the Yuzhou test base, of the national “863” project of water saving agriculture (113º03′-113º39′E and 33º59′-34º24′N), with an altitude of 116.1 m and an annual precipitation of 674.9 mm, of which more than 60% is concentrated in the summer season. The soil was cinnamon soil and the parent soil material was loess. The landscape was flat. The soil bulk density was 1.22g/cm^3 and the fertility of soil was uniform. The contents of organic matter, total nitrogen, hydrolyzable nitrogen, rapidly available phosphorus and available potassium in the plough layer were 12.3, 0.80, 47.82, 6.66 and 114.8 mg/kg, respectively. The previous crop was maize (*Zea may* L.). The mechanical composition of soil was as follows: sand grains (2~0.02 mm) accounted for 59.1%; powder particles (0.02~0.002 mm) accounted for 22.5%; and clay particles (<0.002 mm) accounted for 18.4%.

Experimental materials: Macromolecule water absorbent resin, white powder, used in this study was prepared by the Institute of Plant Nutrition, Environment and Resources, Henan Academy of Agricultural Sciences and contained the following major components: polyacrylamide, organic nutrients and rare earth elements. The wheat variety for test was a multi-spike type semi-winter medium variety Aikang 58.

Experimental design: In accordance with previous research studies, four dosages of macromolecule water absorbent resin were administered in the present study, of which there were as follows: treatment 1, with 0 kg/hm^2 for control; treatment 2, with 27 kg/hm^2; treatment 3, with 54 kg/hm^2; and treatment 4, with 81 kg/hm^2. A randomized block design was employed in the field. The area of the small plot was 5×6 m^2 and three duplicates were set. Pure nitrogen 100, ordinary superphosphate (P_2O_5) of 90 kg/hm^2 and K_2O of 75kg/hm^2 were used as the base fertilizer and this fertilizer was scattered evenly in the fields. The wheat seeds were sown in mid-late October, 2012 and the sowing rate of the wheat was 150 kg/hm^2. The macromolecule water absorbent resin was mixed with the fertilizer before the seeds were sown. First, the mixture was scattered in the area and then plowing and sowing were conducted. Top-dressing of 80 kg·hm^{-2} and 60 kg·hm^{-2} pure nitrogen was carried out during the jointing and grain filling periods, respectively. The collection of the root systems and leaves was conducted during the jointing period (March 25th), the booting period (April 20th) and the grain filling period (May 15th) of winter and tests for the determination of the photosynthetic and transpiration rates were carried out during the same time. No irrigation was conducted during the entire growth period of the wheat.

The total precipitation during the growing period of the wheat was 209.9 mm. There was a total of 52.8 mm precipitation during the period of the sowing of the wheat in October until the end of December. The monthly rainfalls were 3.2, 12.9, 14.8, 23.5 and 80.5 mm, respectively from January of the following year until the harvesting of the wheat on the 2nd of June, respectively.

Determination items and methods:

Determination of root vigor: Samples of root systems with 10-15 cm were collected. The sampling times were during the jointing period (March 25th), the booting period (April 20th) and the grain filling period (May 25th). The samples were placed in a tank containing liquid nitrogen. Tests for the determination of the root vigor were conducted on the selected root tips after the samples of the root system were taken out using the method of TTC (Xiao and Wang, 2005).

Determination and calculation of the leaf relative water content: Ten mature leaves from the same sites were randomly extracted from each area and placed in sampling bags. The samples were placed in ice and quickly taken back to the laboratory. The leaves were wiped until they were dry with absorbent paper. The fresh leaves W_f were weighed on an electronic balance and then the blades were immersed into distilled water and soaked for 8 hours, so that the leaves could fully adsorb the water and reach a state of saturation. The leaves were then taken out and absorbent paper was used to absorb water on their surfaces. The weighing process of the leaves was conducted immediately and then the leaves were immersed for a repeated soaking in distilled water. Once again, when the leaves were removed from the water, the surface moisture was absorbed. The leaves were weighed again and this weight was considered to be the saturated fresh weight W_t. Finally, the blades were placed into a constant temperature oven for inactivation for 0.5 h at 105°C. The leaves were again dried at 80℃ to constant mass. The leaves were taken out and cooled and the dry weight W_d was determined. The leaf relative water content was calculated as follows:

$$R_{WC} = (W_f - W_d)/(W_t - W_d) \times 100\% \quad (1)$$

Photosynthesis and calculation of leaf water use efficiency: The net photosynthetic rate and the transpiration rate were measured by using a Li-6400 type photosynthetic apparatus produced by the LI-COR company of USA. The water use efficiency (the assimilated CO_2 by the plants per unit mass of water) was detected by adopting the method introduced by (Fischer and Turner, 1978; Powel, 1984):

$$W_{UE} = P_n/T_r \quad (2)$$

In the above equation: W_{UE} is the leaf water use efficiency, μmol/mmol; P_n is the photosynthetic rate, μmol/m^2/s; and T_r is the transpiration rate, mmol/m^2/s.

Calculation of water production efficiency: The water production efficiency (kg/mm·hm^2) = wheat grain yield (kg/hm^2)/water consumption of the wheat during the entire growth period of the wheat (mm) (Soil water storage (mm) of 0-200 cm soil layer before sowing + rainfall during the growing period of the wheat (mm) - Soil water storage (mm) of 0-200 cm soil layer when harvesting).

Data processing: The experimental results were the mathematical mean values of the three duplicates and the obtained data were analyzed by using statistics and the related Mathematical Statistical Software (DPS).

RESULTS AND DISCUSSION

Effect of the macromolecule water absorbent resin on soil moisture: Soil moisture has an important effect on crop physiological characteristics. As illustrated in Table 1, At the booting stage of wheat, soil moisture was highest, followed by jointing stage, that was lowest at grain filling stage, This demonstrated that wheat consumed more soil water during the grain filling stage to meet the needs of reproductive growth, which was suitable for synthesis of carbohydrates. In different growth stages of wheat, with the increase of macromolecule water absorbent resin, soil moisture content increased at first and then decreased, soil moisture with the dosage of 54 kg/hm^2 macromolecule water absorbent resin was highest, which was conducive to be better for wheat.

Effects of macromolecule water absorbent resin on root vigor: As illustrated in Table 2, the root vigor decreased with the advance of the growth period of the wheat and the difference in the root vigor reached a significant level (p<0.05).

Table 1: Effect of macromolecule water absorbent resin on soil moisture in 0-20cm soil layer

Macromolecule absorbent resin /(kg/hm^2)	Jointing	Booting	Grain filling
0(CK)	12.0^{dB}	13.6^{dA}	10.4^{cC}
27	13.8^{bB}	14.0^{cA}	11.6^{bC}
54	15.6^{aB}	16.3^{aA}	12.7^{aC}
81	15.0^{bB}	15.7^{bA}	11.9^{bC}

Different capital letters in the same line meant significant difference among stages at 0.05 level. While different small letters in the same column meant significant difference among treatments at 0.05 level the same below

Table 2: Effect of macromolecule water absorbent resin on root vigor of winter wheat μg· $(g{\cdot}h)^{-1}$

Macromolecule absorbent resin/($kg{\cdot}hm^{-2}$)	Jointing	Booting	Grain filling
0(CK)	81.6^{cA}	64.2^{dB}	60.3^{dC}
27	99.1^{bA}	83.3^{bB}	73.4^{bC}
54	111.4^{aA}	87.5^{aB}	80.2^{aC}
81	98.3^{bA}	78.6^{cB}	70.6^{cC}

Table 3: Effect of macromolecule water absorbent resin on leaf relative water content (%)

Macromolecule absorbent resin /(kg/hm^2)	Jointing	Booting	Grain filling
0(CK)	86.3^{Ad}	84.2^{Ac}	82.1^{Bb}
27	92.6^{Ab}	88.4^{Bc}	86.1^{Ca}
54	93.9^{Aa}	91.2^{Ba}	86.2^{Ca}
81	91.1^{Ac}	89.3^{Ab}	86.3^{Ca}

The root vigor of the winter wheat exhibited a trend of increasing at first and then decreasing with the increase of the dosage of macromolecule water absorbent resin during the different growth periods. The root vigor of the group with the dosage of 54 kg/hm^2 macromolecule water absorbent resin was higher than those of the other groups, indicating that the macromolecule water absorbent resin provides a suitable water environment for wheat. This allowed an increase of the growth level of the root system and increased root vigor and the macromolecule water absorbent resin with a dosage of 54 kg/hm^2 was found to be the most ideal.

Effect of the macromolecule water absorbent resin on the leaf relative water content in winter wheat: The leaf relative water content can suggest the leaf water potential and the degree of water shortage in plants, which can better reflect the physiological state of the water in the cells and also the drought resistance of plants.

As illustrated in Table 3, the leaf relative water content of the winter wheat in the different growth periods were as follows: jointing period>booting period>grain filling period. The leaf relative water contents in the jointing, booting and grain filling periods all displayed a trend of increasing first and then decreasing with the increase of the dosage of macromolecule water absorbent resin. However, the differences of the effects of the macromolecule water absorbent resin decreased gradually with the advance of the growth period, suggesting that the response of the wheat to the macromolecule water absorbent resin was more sensitive in the early growth periods of the wheat and also that the resin improved the wheat's drought resistance. Of all the treatments, the effects of the macromolecule water absorbent resin with a dosage of 54 kg/hm^2 was determined to be the most ideal.

Effects of macromolecule water absorbent resin on the photosynthetic characteristics of winter wheat: In the changing growth periods of the wheat, the different demands for water led to variances in the photosynthetic rate, transpiration rate and leaf water use efficiency during the growth periods to some degree. Also, the macromolecule water absorbent resin had the ability to regulate the water state of the aboveground leaves by improving the water environment of the crop rhizosphere, thereby affecting the photosynthetic processes of the crops.

Effect of macromolecule water absorbent resin on photosynthetic rate of wheat: As illustrated in Table 4, the photosynthetic rates of the winter wheat with different treatments were as follows: the photosynthetic rate in the booting period was significantly increased, followed by that in the grain filling period and then the jointing period, with the differences being significant ($p<0.05$), thereby suggesting that the booting period is the most intense period of photosynthetic rate. The photosynthetic rate of the winter wheat increased first and then decreased with the increase of the dosage of the macromolecule water absorbent resin in the jointing, booting and grain filling periods. However, the photosynthetic rates of the winter wheat were all higher than that of the control and the differences were significant ($p<0.05$). During the above three periods, the photosynthetic rate with a dosage of 54 kg/hm^2 of macromolecule water absorbent resin was found to be the highest.

Effect of macromolecule water absorbent resin on transpiration rate of wheat: In regard to the transpiration rates, as shown in Table 4, the transpiration rate in the booting period was the largest, but there were no significant differences in the transpiration rates between the jointing period and the grain filling period ($p>0.05$). The differences in the transpiration rates between the control groups were not significant in the jointing period. However, the transpiration rates of the wheat in the groups with the treatments of macromolecule water absorbent resin were all significantly higher than those of the controls with the advance of the growth periods of the wheat. This suggests that the application of macromolecule water absorbent resin increases the transpiration rate of the wheat leaves. The reason for this may be that the macromolecule water absorbent resin improves the water environment of the soil and thereby enhances the adsorption of water by the root systems. Also, the water transferring to the leaves increased, therefore resulting in an increased transpiration rate.

Table 4: Effect of macromolecule water absorbent resin on photosynthetic characteristics in different growth stages of winter wheat

Macromolecule absorbent resin /(kg/hm^2)	Pn/ (μmol/m^2/s)			Tr/ (μmol/m^2/s)			WUE/(μmol/mmol)		
	Jointing	Booting	Grain filling	Jointing	Booting	Grain filling	Jointing	Booting	Grain filling
0(CK)	5.8^{cC}	11.8^{dA}	9.9^{dB}	2.0^{aB}	2.6^{bA}	1.8^{bB}	2.9^{aC}	4.5^{cB}	5.5^{cA}
27	6.9^{abC}	14. 3^{cA}	14.2^{bB}	2.3^{aB}	2.9^{aA}	2.2^{aB}	3.0^{aC}	4.9^{bB}	6.5^{abA}
54	7.2^{aC}	17.2^{aA}	15.2^{aB}	2.3^{aB}	3.1^{aA}	2.2^{aB}	3.1^{aC}	5.5^{aB}	6.9^{aA}
81	6.6^{bC}	16.2^{bA}	13.3^{cB}	2.1^{aB}	3.2^{aA}	2.3^{aB}	3.1^{aC}	5.1^{bB}	5.8^{cA}

Table 5: Effect of macromolecule water absorbent resin on water utilization and yield of wheat

Macromolecule absorbent resin/(kg/hm^2)	Water consumption/(mm)	Yield/(kg/hm^2)	Water production efficiency/(kg/mm/hm^2)
0(CK)	225.5^a	3590.5^c	15.9^d
27	217.3^a	4367.1^b	20.1^c
54	205.6^b	4735.4^a	23.0^a
81	200.2^b	4406.2^b	22.0^a

Effect of macromolecule water absorbent resin on leaf water use efficiency of wheat: In terms of the leaf water use efficiency, as illustrated in Table 4, the leaf water use efficiency in the grain filling period was the highest; the leaf water use efficiency in the booting period was high; and the leaf water use efficiency in the jointing period was the lowest and these differences in the rates were significant (p<0.05). In the jointing period, the leaf water use efficiency increased with the increase in the dosage of macromolecule water absorbent resin. However, the differences between different treatments were not found to be significant (p>0.05). The leaf water use efficiency increased at first and then showed a decrease with the increase of the amount of macromolecule water absorbent resin in the booting period. However, all were significantly higher than that of the controls (p<0.05). The leaf water use efficiency with the treatment of 54 kg/hm^2 of macromolecule water absorbent resin was the highest. The leaf water use efficiency with the treatment of 27 and 81 kg/hm^2 of macromolecule water absorbent resin also showed significant differences. However, in the filling period, the leaf water use efficiency with the treatment of 54 kg/hm^2 was still found to be the highest and there was no significant difference found in the leaf water use efficiency between the group with the treatment of 81 kg/hm^2 and the control group. This indicated that, although the application of the macromolecule water absorbent resin increased the transpiration rate of the wheat, the increased extent of the photosynthetic rate was more significant than that of the transpiration rate. Therefore, the amount of assimilated CO_2 for transpiration of per unit of water was high, i.e. the leaf water use efficiency was increased.

In summary, the macromolecule water absorbent resin increased the photosynthetic rate, transpiration rate and the leaf water use efficiency of the winter wheat in the various growth periods and both the photosynthetic rate and leaf water use efficiency in the group with the dosage of 54 kg/hm^2 of the macromolecule water absorbent resin were the highest, thereby suggesting that the dosage of the macromolecule water absorbent resin can more efficiently adjust the assimilation of leaves' CO_2 and H_2O and promote the accumulation of organic matter.

Effect of macromolecule water absorbent resin on water utilization and yield of wheat: The effect of the macromolecule water absorbent resin on the physiological characteristics of the wheat was ultimately reflected in the wheat yield and water production efficiency. As shown in Table 5, water consumption during the entire growth period of the winter wheat was significantly reduced with the increase in the dosage of the macromolecule water absorbent resin. Meanwhile, the yield during these periods and the water production efficiency both exhibited a trend of increasing at first and then decreasing. This suggested that the application of the macromolecule water absorbent resin into soil improves the water environment of the soil and slows down damage to the wheat due to drought stress. Also, the effects of the dosage of 54 kg/hm^2 of the macromolecule water absorbent resin showed an increase in yield production and water saving and were found to be the highest, the 31.9% yield production was increased, along with the 44.7% water production efficiency was improved compared with those of the controls.

Correlation analysis of the physiological index, yield and water production efficiency of wheat in different growth periods of wheat: As illustrated in Table 6, the root vigor, leaf relative water content, photosynthetic rate and leaf water use efficiency in different growth periods of the wheat were positively improved through the wheat yield and water production efficiency. However, the degrees of correlation in the different growth periods of wheat were varied to some extent. The photosynthetic rate was positively correlated with the yield of the wheat in different growth periods (p<0.05) and the correlation was found to be the highest in the strain filling period (R^2 = 0.9615, (p<0.05). The correlation among the root vigor, leaf water use efficiency and wheat yield in the booting

Table 6: Relationships of photosynthetic rate, leaf water use efficiency, root vigor and leaf relative water content with yield and water productive efficiency of wheat at different growth stages

Item		Jointing	Booting	Grain filling
Yield	Photosynthetic rate	0.9441*	0.9078*	0.9615*
	Leaf water use efficiency	0.8388	0.9046*	0.6957
	Root vigor	0.9694*	0.9501*	0.9502*
	Leaf relative water content	0.9511*	0.9899**	0.8852
Water production efficiency	Photosynthetic rate	0.8041	0.9812*	0.8411
	Leaf water use efficiency	0.9632*	0.9097*	0.4918
	Root vigor	0.8871	0.8185	0.8266
	Leaf relative water content	0.8223	0.9783**	0.8701

"*" and "**" indicate significant relationship at $p< 0.05$, $p<0.01$, respectively

period was higher, reaching a significant level ($p<0.05$) and also the positive correlation between the leaf relative water content and the wheat yield was extremely significant ($p<0.01$). The correlation between the water production efficiency and various physiological indexes in the grain filling period did not reach a significant level. The distributions between the water production efficiency, photosynthetic rate and leaf relative water content in the booting period indicated significant variations ($p<0.05$) and a highly significant positive correlation ($p<0.01$). It showed significant positive correlation with the leaf water utilization efficiency during the jointing and the booting periods ($p<0.05$).

CONCLUSION

- The results showed an abnormality of plant metabolism and the root vigor was decreased under drought stress conditions (Liu *et al*., 2002; Ge *et al*., 2005; Zhang *et al*., 2006). The macromolecule water absorbent resin became a small reservoir for the absorption and utilization of water by the root systems of the crops, via improving the soil's water environment and slowly releasing water into the soil near the root systems of the crops. This kept the percentage of moisture in the rhizosphere soil in good condition, promoted the normal physiological metabolism of the root systems and the normal physiological activities of the aboveground crop parts, as well as slowing down and improving potential damages due to drought stress in the crops (Yu *et al*., 2006). Previous studies (Liu *et al*., 2006; Tian *et al*., 2009) have shown that an appropriate amount of macromolecule water absorbent resin could potentially regulate the permeability of the crop root systems, increase the root vigor (Zhao *et al*., 2006; Zhang *et al*., 2009) and biomass of root systems and promote the improvement of drought resistance in crops. However, if an excessive amount of macromolecule water absorbent resin was applied, the cell membrane permeability was increased and the root vigor decreased. The present study revealed that the application of macromolecule water absorbent resin in the hilly dry farmland areas of Yuxi in Henan Province, significantly increased the root vigor and the leaf relative water content of the wheat and enhanced the ability of drought resistance in the wheat crops with the macromolecule water absorbent resin dosage range of 30-90 kg/hm^2.
- There were certain differences in the physiological characteristics of the root systems of the wheat during the different growth periods. Liu *et al*. (1993) investigated and pointed out that the root vigor of the wheat before winter was enhanced with the decrease of soil water, while the wheat's root vigor before winter was reduced with the decrease of soil water after the jointing stage. The research of (Wu and Todd, 1985) demonstrated that the membrane of the wheat's root system was relatively permeable and it was increased with the enhanced drought stress and the advancement of the growth periods. The present study discovered that the winter wheat's root vigor and the leaf relative water content were decreased with the advancement of the growth periods, indicating that the growth of wheat in the vegetative growth phase was vigorous and the vigor of the root system was high. When the wheat shifted to the period mainly concerned with reproduction and growth, the root vigor decreased, which were found to be related to the physiological characteristics of the winter wheat crop.
- Macromolecule water absorbent resin can be used as an effective method to alleviate drought. The application of the macromolecule water absorbent resin not only can promote the storage of rainfall water in the soil, it can also increase the soil's moisture content, reduce ineffective evaporation in the soil and reduce crop water consumption. In addition, its application can alleviate the adverse effects of water stress on plants and promote normal growth and development by improving the leaf relative water content in crops and the photosynthetic physiology characteristics within a certain dosage range. The present investigation showed that the application of macromolecule absorbent water resin significantly increased the photosynthetic and transpiration rates and the water use efficiency of winter wheat. The photosynthetic rate and leaf water use efficiency were found to be the highest in the group treated with a dosage of 54 kg/hm^2 of the macromolecule absorbent water resin. Finally, the macromolecule water absorbent

resin significantly increased the wheat yield and water production efficiency of the wheat, among which the yield increasing effect and water saving effect were found to be the highest in the group treated with a dosage of 54 kg/hm^2 of the macromolecule absorbent water resin. Furthermore, 31.9% of crop production was increased and 44.7% of water production efficiency was increased compared with those of the controls.

- The correlation analysis results among the root vigor, leaf relative water content, photosynthetic rate, leaf water use efficiency, wheat yield and water production efficiency during the different growth periods demonstrated that the wheat's drought resistance can be improved by the application of an appropriate amount of macromolecule water absorbent resin, in order to increase the wheat's root vigor during the different growth periods and promote improvement of the leaf relative water content, photosynthetic rate and leaf water use efficiency. Ultimately, these improvements lead to increasing the wheat yield and water production efficiency.

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