Physiological response of natural plants to the change of groundwater level in the lower reaches of Tarim River, Xinjiang*

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Abstract Based on the analysis of the three-year (2000-2002) monitoring data of the four times intermittent stream water conveyance to the lower reaches of Tarim River where the stream flow was dried up for more than 30 years and the measurement of PRO, SOD and POD in plants collected from 24 vegetation plots, it is concluded that the stream water conveyance plays an important role in lifting groundwater level. The groundwater nearby the watercourse was raised from 5~8 m in depth before the stream water conveyance to 2.5~5 m after stream water conveyance. The physiological response of *Phragmites communis*, *Tamarix* spp. and *Populus euphratica* to the change of groundwater is sensitive and represents a grads change obviously. The growth of the plants in the lower reaches of Tarim River is stressed by drought to various degrees. Lengthways, the drought stress exposed to the plants increases with groundwater depth from the upper sections to the lower sections; and breadthwise, the drought stress exposed to the plants is increased with the increase of distance away from the river channel of stream intermittent water releases and of the groundwater depth. Combining the field investigation and the analysis of the plots, it is considered that the stress groundwater depths for the *Phragmites communis*, *Tamarix* spp. and *Populus euphratica* are 3.5 m, 5 m and 4.5 m respectively.

Keywords: **stream water conveyance, groundwater level, natural plants, physiological index, Tarim River.**

Natural plants in arid land play very important roles in both conservation of biodiversity and reduction of desertification. In arid land biological activity is limited and ecosystems are small and unstable, so change of groundwater levels directly influences the development, composition, and changes of vegetation[1~4]. When other ecological factors do not severely constrain plant growth, there exists an optimal groundwater level above which vegetation may develop well but below which the growth of plants is significantly limited. Nevertheless, the relationship between change of groundwater and vegetation status is complicated, representing a dynamic equilibrium between groundwater, soil, and vegetation. And the relationship between vegetation and groundwater has been studied for a long time[5~9].

The ecological environment in the arid areas of western China is extremely vulnerable, the contradiction between the ecological protection and the economic development is increasingly extrusive during the exploitation and utilization of water resources, and the sustainable development of the regional society and economy is seriously restricted. As a key element, water resources seriously affect sustainable development of both the local economy and conservation of local and regional environments[10~12]. Located in northwest China, the Tarim River is the longest inland river in the world, with a length of 1321 km. The Tarim River passes through a special region—the extremely dry area of the Taklamakan Desert, which is the third largest desert in the world. The Tarim River watershed is rich in natural resources but with a vulnerable ecological environment. Sustainability of the natural ecosystems in this arid area is highly dependent on the river and is extremely sensitive to variation in water supply. At the same time the river is also vital to the local economy. The ecosystem that is dominated by natural vegetation is badly affected. During the past 50 years, intensive exploitation of water resources has resulted in changes of the distribution of water, causing serious environmental problems in the Tarim River Basin. In the area of the head tributaries, serious problems of secondary soil salinization are developing. In the main stream area, there is reduced inflow from the source tributaries, increased salinity, decreased flow to the lower reaches, drying-up of lake levels, falling groundwater levels, encroaching desertification, and total degeneration of the natural vegetation.

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With the recent rapid development of the economy in the study area, potential ecological impacts related to the changing hydrological regime are of great concern to both the public and water authorities. From 2000 to 2002, the local government of Xinjiang, in Western China, conducted four intermittent water releases to the lower reaches of the Tarim River. The water was removed from Bosteng Lake, the largest inland fresh water lake in China, and passed through the Daxihaizi Reservoir. The intention is to supply and thus raise groundwater to its optimal level for plant growth, thereby restoring natural vegetation and protecting the "Green Corridor"[1)]. The releases were a successful test of a remediation strategy designed to restore the major riparian ecosystem in the Tarim River Basin. Such practices may be necessary for some years in the future because of the lack of precipitation. This paper presents research results on the relationship between shallow groundwater and vegetation in the riparian area, based on field data collected during and after five water releases. The first objective includes evaluating the effect on riparian vegetation of artificial changes, such special releases into a dried-up river channel. The second one is to determine the optimal depth of groundwater for restoring the local ecosystem and provide a scientific basis for efficient use of limited water resources.

1 Material and methods

1.1 The study area

The Tarim River Basin is a closed catchment, where several tributaries drain into its interior, the Tarim depression. The mainstream catchment of the Tarim River basin is located below the confluence of the Hetian, Yarkand, and Akesu rivers. It is a unique freshwater ecosystem located near one of the largest deserts in China—the Tarim Desert. The study area is located on the section from the Daxihaizi Reservoir to the Taitema Lake in the lower reaches of Tarim River, which is situated in the zone between the Taklamakan Desert and Kuruk Desert (Fig. 1). Special environmental conditions are responsible for the fragility and instability of its ecosystem. The drainage basin is flat and the region is classified as extremely arid in a warm temperate zone. Total annual solar radiation varies from 5692 to 6360 MJ/m^2, with 2780 to 2980 cumulative sunlight hours. Annual-accumulated temperature (10 ℃) is from 4040 ℃ to 4300 ℃ with an average diurnal temperature range of 13 ℃ to 17 ℃. The annual precipitation varies in a range of 17.4 ~ 42.0 mm and strong wind occurs frequently. Obviously, the growth of plants could not be maintained by relying on the natural precipitation only. After the Daxihaizi Reservoir was built in 1972, the stream flow of the river section of 321 km in length downstream from it was completely cut off, and the lakes, Lop Nur Lake and Taitema Lake at the tail of Tarim River, were dried up in 1970 and 1972 respectively. Because there is no recharge of surface runoff in the lower reaches of Tarim River, the stream flow cut-off results in a serious drawdown of groundwater level here, and the groundwater level in most regions downstream from Yinsu is lowered to 8 ~ 10 m. Thus, some environmental problems occur, which include the serious degeneration of the natural vegetation relying on groundwater for existence, death of the herbs dominated by *Phragmites communis*, *Apocynum venetum*, *Athagi pseudathagi*, etc., degeneration of the shrubbery of *Tamarix chinensis* and the forests of *Popular euphratica* in large areas, serious wind erosion and land desertification as well as the seriously damaged ecosystems. The area of the "Green Corridor" between the Taklamakan Desert and Kuruk Desert is sharply reduced, and the National Highway No. 218 running through the "Green Corridor" is suffering from the sand drift disasters. The area in the lower reaches of Tarim River has become one of the regions with the most serious problems of exploitation and utilization of water resources and of the ecological environment in the arid areas of west China.

1.2 Monitoring of groundwater

The study was conducted at the reach from Daxihaizi Reservoir to Taitema nor in the lower reaches of the Tarim River (Fig. 1). Before the water input implemented in 2000, nine monitoring sections were built up in the area of water input of the Qiwenkuoer River. Starting from the Daxihaizi Reservoir the sections are Akdun (Ⅰ), Yahepu (Ⅱ), Yinsu (Ⅲ), Abudali (Ⅳ), Kardayi (Ⅴ), Tugmailai (Ⅵ), Alagan (Ⅶ), Yiganbjima (Ⅷ), and Kaogan (Ⅸ) (Fig. 1). The interval of distance between two neighboring sections of the first 6 sections is ca. 20 km, and of

1) The middle and lower sections of the lower reaches of Tarim River are located in the zone between the Taklamakan Desert and Kuruk Desert, the vegetation grew well previously in the zone, so it is called the "Green Corridor". The National Highway No. 218 passes through the "Green Corridor", and the Xinjiang—Qinghai Railway planned to build will also pass here.

the last three sections is ca. 45 km. In each section monitoring wells (8 ~ 17 m in depth) were set up with a distance interval of 100 ~ 200 m, in order to monitor the dynamic changes of the depth of the groundwater, and water and salt contents. In total 40 monitoring wells were built up. The sampling is conducted monthly in the no water-input period and 3 times in a month during the water-input period.

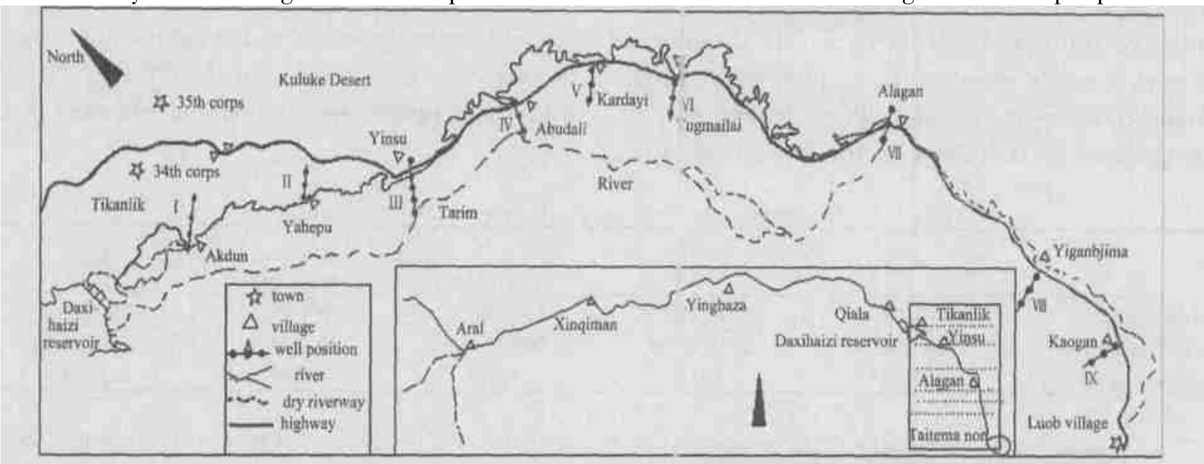

Fig. 1. Lower reaches of the Tarim River showing the nine monitoring sections.

1.3 Survey on the response of natural vegetation

The natural vegetation dominated by *Populus euphratica*, *Tamarix chinensis* and *Phragmites communis* in the lower reaches of Tarim River relies on the water supply for the existence and growth, and is in a long-term lack of water. Macroscopically, the vegetation is distributed in belts; it, however, has a low density and is distributed in patches in some areas, and that in large areas is in degenerating or dying status. Therefore, it is difficult to reflect the response of plants to the stream intermittent water releases with the surveyed data of the successive plant communities. Moreover, there is no replacement of the plant communities relying on the stream intermittent water releases because a "line-shaped" way is taken and there is no large-scale overflow in the stream water conveyances to the lower reaches of Tarim River. In this paper, the response process of the natural vegetation in the lower reaches of Tarim River to the stream intermittent water releases is researched and its response scope is revealed by combining the field investigation with the laboratory analysis and by analyzing the physiological properties of *Populus euphratica*, *Tamarix chinensis* and *Phragmites communis*.

1.3.1 Methods of investigation Based on the observation sections of groundwater and the distribution of natural vegetation, four sections the Yahepu (II), Yinsu (III), Kardayi (V) and Alagan (VII) were selected from the upper section to the lower section in longitudinal direction. In each section six plots were set up with a distance interval of 50 m. The order of the plots from river is 1, 2, 3, 4, 5 and 6.

1.3.2 Methods of testing Some representative trees of *Populus euphratica* near the groundwater-level monitoring wells were selected to pick 50 normally-growing leaves from the height of 2 ~ 2.5 m of each *Populus euphratica* tree, then the leaves were put into plastic bags, and stored in a simply-equipped refrigerator as soon as possible after they were sealed. Moreover, the change of groundwater level in the plots was also recorded for comparison.

Test of the physiological indexes of plants: The moderator of cellular water potential of proline (PRO), superoxide dismutase (SOD) and peroxidase (POD) were measured in the laboratory following the methods described in Refs. [13 ~ 15].

2 Results and analysis

2.1 Effect of intermittent water releases on the groundwater

In order to restore the "Green Corridor" of the lower reaches of the Tarim River, during 2000 to 2002, four times of intermittent water releases to the lower reaches of Tarim River had been performed (Table 1). The total time of the conveyances was 439 days, and the total volume of conveyed stream water was 10.0×10^8 m^3. According to the monitoring at each section, the response of the shallow groundwater level to the conveyances weakens downstream in longitudinal direction. Detailed analysis showed that the lifting of the groundwater level was the highest in the upper section (84%), the median in the middle section and the lowest in the lower section (12%). Fig. 2 shows the change of groundwater level before and after the intermittent water releases along the longitudinal sections in the lower reaches of Tarim River. It shows that the groundwater level is widely raised in the vicinities of the river channel of conveyances along with the performance of conveyances for the ecology in the lower reaches of Tarim River. At the upper section of Yinsu, for example, the depth of groundwater was lifted from 9.87 m before water input to 7.74 m after the first water input, 3.79 m after the second input, 3.61 m after the third and 3.16 m after the forth water input. The rising processes of the groundwater depth, however, are different due to the differences of the conveyance processes, duration and conveyed water volumes.

Table 1. A four intermittent water releases to the lower reaches of the Tarim River

	First	Second	Third		Fourth
			First phase	Second phase	
Starting (y/m/d)	2000/05/14	2000/11/03	2001/04/01	2001/09/12	2002/07/20
Ending (y/m/d)	2000/07/13	2001/02/14	2001/07/06	2001/11/17	2002/11/10
Water volume (10^4 m^3)	9883.18	22000	18400	19700	29300

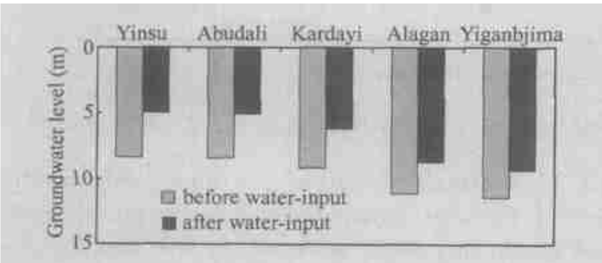

Fig. 2. The change of groudwater level in each section of the lower reaches of Tarim River.

2.2 The relationship between vegetation and groundwater level

Natural vegetation in the lower reach area of the Tarim River is mainly comprised of *Populus euphratica* and *Tamarix* spp. They rely mainly on shallow groundwater (or soil water) for their survival because of less precipitation and no surface runoff in this area. From Yinsu section to Taitema nor, with increasing groundwater depth, plant communities with three layers (tree, shrub and herb) had changed to communities with only a shrub layer. In Yinsu, Abudali, and the western part of Kardayi, trees (*Populus euphratica*), shrubs (*Tamarix ramosissima*, *T. hispida*, *Nitraria sibirica*, *Halimodendron halodendron*) and herbs (*Glyzyrrhiza inflata*, *Poacynum hendersonii*, *Alhagi sparsifolia*, *Phragmites communis*) were main species in the communities. *Populus euphratica* and *Tamarix* spp. were the dominant ones. In the eastern part of Kardayi, Tugmailai, Alagan, and Yiganbjima, plant communities consisted of trees (*Populus euphratica*) and shrubs (*Tamarix* spp., *Nitraria sibirica*) with a few herbaceous species (*Alhagi sparsifolia*); the plant community only consisted of shrubs with very poor growth, in the lower reaches of Kaogan. Some drought-tolerant species existed when the depth of groundwater was deeper. We found that coverage, density, and abundance of the plant communities decreased with the increase of the depth of groundwater level. Decreasing ranges of vegetation coverage and density were larger than equivalent ranges of species abundance (Fig. 3).

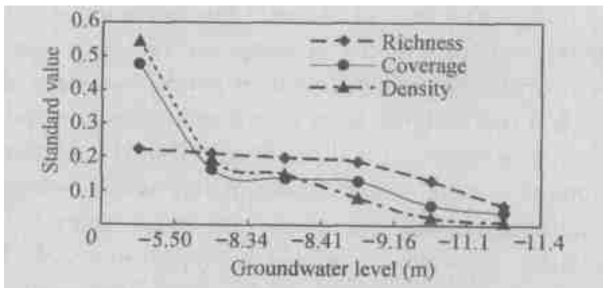

Fig. 3. The relationship between groundwater level and vegetation in the lower reaches of Tarim river.

2.3 Physiological response of plants to the change of groundwater level

The four water releases to the lower reaches of the Tarim River have resulted in a significant rise in groundwater level, which greatly benefits the growth of some drought-tolerant trees and shrubs. Water releases have obviously improved vegetation coverage in this area. The physiological responses of the plants to water release attenuated with increasing distance along the river channel. Some plants, such as *Glyzyrrhiza inflata*, *Alhagi sparsifolia*, *Apocynum venetum*, *Phragmites communis*, *Salosola* sp., *Scorzonera* sp., and *Karelinia caspica*, appeared again in profusion in some places along the lower reaches of the Tarim River. Some drought-tolerant trees and shrubs were restored together, when the groundwater reached an optimal depth for their growth. Also the PRO, SOD and POD contents of *Populus euphratica*, *Tamarix* spp. and *Phragmites communis* after the stream water conveyances showed different changes as described in the following.

Change of the proline content: As a fine infiltration-regulating material, proline is characterized by the low molecular weight, high water-solubility, no electrostatic charge at physiological pH value, low toxicity, etc. Proline exists in plant bodies in a dissociative form. Our analysis and measurement showed that the PRO content of *Phragmites communis*, the main herbage in the lower reaches of Tarim River, increases with the drawdown of groundwater level from Plot No. 1 near the riverbank to Plot No. 6, 250 m away from the river channel (Fig. 4). The PRO content of *Phragmites communis* on Plot No. 6, which is the farthest plot from the river channel, is the highest (1.829 mg/g·DW), 35.4 times that on Plot No.2; the change of PRO content of *Tamarix chinensis* is not so obvious from Plot No. 1 to No.4, but the PRO content of *Tamarix chinensis* increases significantly on Plot No.5. The analysis on the change of proline in the bodies of *Populus euphratica* along the different sections revealed that the groundwater level is deep along the Alagan Section (Ⅶ) at the lower reaches, and the content of proline in the bodies of *Populus euphratica* increases obviously from Plot No. 1 to No. 6 with the increase of groundwater depth (Fig. 5). The content of proline in the bodies of *Populus euphratica* in the plots from No. 1 to No. 3 along three sections, i.e., the Yahepu Section (Ⅱ), Yinsu Section (Ⅲ) and Kardayi Section (Ⅴ), fluctuates to a certain extent, but its change has no obvious laws; it increases obviously along with the increase of the distance away from the river channel and the increase of groundwater depth from Plot No. 4, which indicates that the growth of *Populus euphratica* is stressed by drought. Proline accumulates rapidly in the bodies of *Populus euphratica* under drought stress, and the infiltration is regulated by the accumulated proline through the law of mass action so as to maintain the certain water content and expansion pressure momentum of cells and increase the drought-resistant capability and converse-succession-resistant capability of plants[16~18]. This is a kind of physiological regulation of *Populus euphratica* under drought stress.

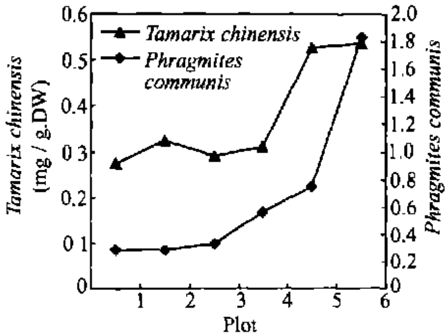

Fig. 4. The change of PRO content in *Tamarix chinensis* and *Phragmites communis*.

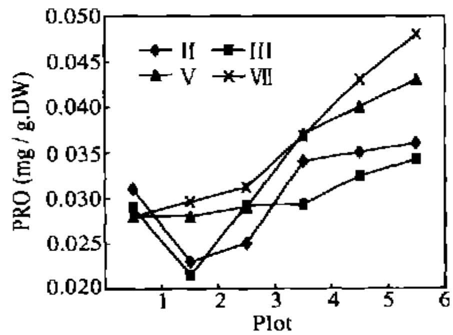

Fig. 5. The change of PRO content in *Populus euphratica* at each section along the river. Ⅱ, Ⅲ, Ⅴ and Ⅶ represent Yahpu, Yinsu, Kardayi and Alagan section respectively.

Change of the SOD activity: Drought stress can promote the accumulation of oxygen free radicals in the bodies of plants and damage the cell membrane systems and the biological macromolecules. SOD can eliminate the oxygen free radicals and avoid their damage. The comparison of SOD activity between *Phragmites communis* and *Tamarix chinensis* showed that the SOD activity of *Tamarix chinensis* is lower than that of *Phragmites communis*, and it is the lowest (17.74AU/g·FW only and 47.59AU/g·FW in maximum) on Plot No.5 (Fig. 6). The SOD activity in *Phragmites communis* from Plot No. 1 to No.6 is all high and increases with the increase of the distance to the river channel and the drawdown of groundwater level, and it is significantly higher than that in *Tamarix chinensis* on all the plots. The analysis on the SOD activity of *Populus euphratica* (Fig. 7) showed that the SOD activity in *Populus euphratica* is similar at all the sections, that is the change of SOD activity in *Populus euphratica* in the plots from No. 1 to No. 3 is not so obvious, but from No. 4 it is generally produced in an increasing trend. Lengthways, the SOD activity units of *Populus euphratica* increase with the increase of groundwater depth from the upper reaches to the lower reaches, the average SOD activity units of *Populus euphratica* are 52.82, 54.52, 57.12 and 60.72 from the Yahepu Section (Ⅱ) to the Alagan Section (Ⅶ) respectively, which accord with the change gradients of moisture content. The average SOD activity is the lowest at the Yahepu Section where the groundwater level is shallower and it is the highest at the Alagan Section where the groundwater level is deeper, and the moisture stress is most serious. The *Populus euphratica* suffers from the serious moisture stress at the Alagan Section.

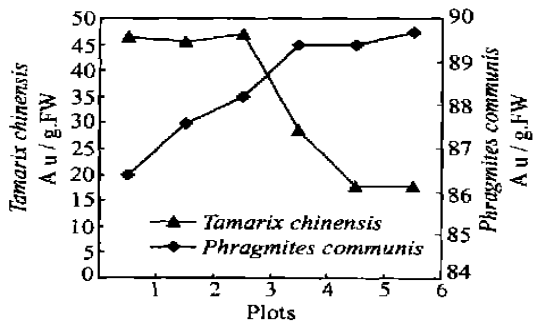

Fig. 6. The change of SOD in *Tamarix chinensis* and *Phragmites communis*.

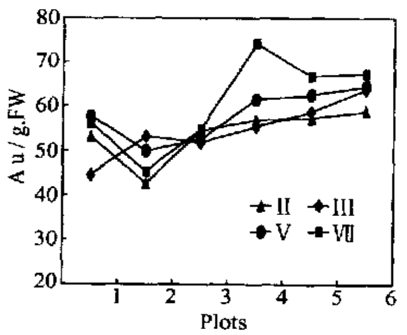

Fig. 7. The change of SOD content in *Populus euphratica* at each section along the river. Ⅱ, Ⅲ, Ⅴ and Ⅶ represent Yahepu, Yinsu, Kardayi and Alagan section respectively.

Change of the POD activity: Under an extreme environment, the metabolizing of active oxygen in the plant bodies is strengthened; thus the accumulation of active oxygen or of free radicals of other peroxides occurs, which can damage the cell membranes. The coordinated action of POD, SOD, etc. can prevent plants from damage of free radicals of peroxides to the cell membrane systems, and is one of the important enzyme-guarding systems in plant bodies. The measured results of POD of *Populus euphratica*, *Tamarix chinensis* and *Phragmites communis* showed that the POD in *Phragmites communis* reduces with the increase of distance to the river channel and the drawdown of groundwater level from Plot No.1 to No.6, which contrasts significantly with the increase trend of SOD. Under the drought stress, the increase of the activity of POD and SOD in plant bodies plays an important role in the existence of plants under the different groundwater depths. Simultaneously, a temporal and quantitative mutual-compensation of the change of SOD and POD under the drought stress environment is also revealed. The change of POD in *Tamarix chinensis* is not so obvious from Plot No. 1 to No. 3, indicating that the groundwater level is suitable for the growth of *Tamarix chinensis* at these sites (Fig. 8). The change process of POD activity in the leaves of *Populus euphratica* at all the plots of the different sections (Fig. 9) POD activity in the *Populus euphratica* at the first 4 plots increases with the increase of groundwater depth and to the maximum at Plot No.4, then it decreases gradually and to the minimum at Plot No.6. The change trends of POD activity in *Populus euphratica* at all the plots of the Kardayi Section (Ⅴ) and Alagan Section (Ⅶ) are similar, i.e. the "M-shaped", and they are generally in a decreasing status.

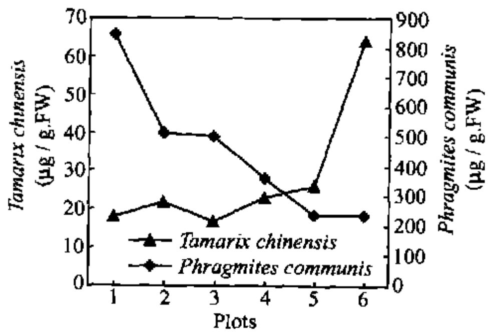

Fig. 8. The change of POD in *Tamarix chinensis* and *Phragmites communis*.

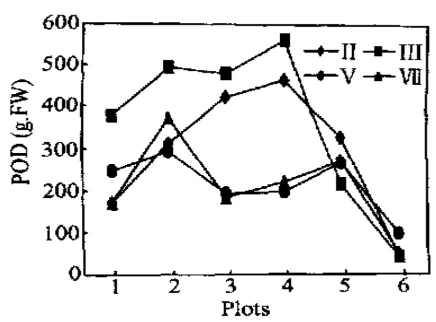

Fig. 9. The change of POD content in *Populus euphratica* at each section along the river. Ⅱ, Ⅲ, Ⅴ and Ⅶ represent Yahepu, Yinsu, Kardayi, Alagan section respectively.

2.4 Analysis on the stress groundwater depth of the natural plants

The vegetation in the lower reaches of Tarim River is mainly composed of the non-regional xerophytes. In a drought stress environment, the groundwater and soil moisture are the main water sources for maintaining the existence and growth of the natural plants, such as *Populus euphratica*, *Tamarix chinensis* and *Phragmites communis*. Therefore, determining the minimum water consumption for maintaining the ecological safety in the lower reaches of Tarim River is of significance. The groundwater depth for maintaining the growth of the natural vegetation is called the ecological groundwater level, and the groundwater depth at which the growth of plants is stressed by drought is called the stress groundwater level. In the lower reaches of Tarim River, the natural plants are severely degenerated and the natural vegetation dominated by *Populus euphratica*, *Tamarix chinensis*, *Phragmites communis*, is under the stress of drought to varying degrees because the stream flow has been cut off for a long time and a continuous drawdown of groundwater level occurs.

The analysis on the change of the content of PRO and SOD in *Phragmites communis* revealed that *Phragmites communis* is very sensitive to the change of groundwater level (Figs. 4, 6). In the area from Plot No.1 to No. 3, the changes of the PRO content and the SOD activity in *Phragmites communis* are small when the groundwater depth is at 2.5~3.0 m, implying that the groundwater level is suitable for the growth of *Phragmites communis*. When the groundwater depth is down to 3.5 m, a threshold for the growth of *Phragmites communis*, the PRO content and the SOD activity in *Phragmites communis* increase rapidly, from 0.327 mg/g · DW and 88.18 AU/g·FW to 0.569 mg/g · DW and 89.37 AU/g·FW respectively, which are the physiological responses of the plants to the drought stress. These observations indicate that under drought stress the infiltrating-regulation materials can be accumulated in plants so as to reduce the infiltration potential, maintain the expansion pressure of cells and the normal supersession in the plant bodies. These revealed that the growth of *Phragmites communis* is stressed when the groundwater level is deeper than 3.5 m.

The groundwater depth for growing *Tamarix chinensis* is deeper than that of *Phragmites communis* in the arid environment. Fig. 4 shows that the PRO content of *Tamarix chinensis* on Plot No. 5 dose not increase until the groundwater depth is down to 4 m, and so is POD. The POD content of *Tamarix chinensis* hardly responds to the change of groundwater depth from Plot No. 1 to No. 4, revealing that the groundwater depth here is suitable for the growth of *Tamarix chinensis*. Whereas the POD content in *Tamarix chinensis* on Plot No. 5 and No. 6 increases remarkably from 26 μg/g · FW to 64 μg/g · FW, which reveals that the growth of *Tamarix chinensis* is stressed by drought when the groundwater level is deeper than 5 m.

The physiological responses of *Populus euphratica* are different at the different groundwater level, and are closely related to the change of groundwater level (Figs. 5, 7 and 9). Transversally, the PRO content in the leaves of *Populus euphratica* increases with the drawdown of groundwater level. The change of the physiological properties of *Populus euphratica* is not so obvious when the groundwater depth varies in a range of 2.5 ~ 3.5 m, and the accumulation of PRO content and the SOD activity in the leaves of *Populus euphratica* increase obviously when the groundwater depth is down to about 4 m, which reveals that the growth of the *Populus euphratica* is stressed by drought; lengthways, the change of the PRO content and the SOD activity in the leaves of *Populus euphratica* accord with the change of the moisture gradient from the Yahepumahan Section (Ⅱ) to the Alagan Section (Ⅶ), the *Populus euphratica* at the Alagan Section is under the greatest stress and has the highest average SOD activity, whereas the *Populus euphratica* at the Yahepumahan Section (Ⅱ) has the lowest SOD activity, which is closely related to the deep groundwater level and the high moisture stress of *Populus euphratica* along the Alagan Section (Ⅶ). Along the Alagan Section (Ⅶ), groundwater depth is 6.45 ~ 10.16 m after the stream water conveyances, a rapid and abnormal accumulation of PRO content in the leaves of *Populus euphratica* occurs at the site where the groundwater depth is at 9 ~ 10 m, the PRO content in *Populus euphratica* is as high as 0.0368 mg/g · DW, and the SOD activity increases as well, which might be caused by the fact that the infiltration potential in the bodies of *Populus euphratica* reduces when a shortage of moisture occurs through the infiltrating-regulation of PRO so as to continuously absorb water from the environment with a low water potential. All these reflect the violent impacts on the accumulation of

PRO content in the leaves of *Populus euphratica* under the different gradients of groundwater level and also the intensive degree of drought stress suffered by *Populus euphratica*. The investigated and measured results in the plots during the period from 2000 to 2002 reveal that the thresholds for stress and critical groundwater depths of *Populus euphratica* are 4 m and 9 m respectively[19].

3 Discussion and conclusions

(1) The trees of the *Populus euphratica* are stressed by drought in most areas in the lower reaches of Tarim River. According to the field investigation and the analysis on the physiological response of *Populus euphratica* to the change of groundwater level, it is revealed that, breadthwise, the degree of drought stress suffered by *Populus euphratica* is increased with the increase of distance away from the river channel of stream water conveyances and of the groundwater depth; and lengthways, the degree of drought stress suffered by *Populus euphratica* is increased from the Yahepu Section (Ⅱ) at the upstream river section to the Alagan Section (Ⅶ) at the downstream river section. A similar change is also revealed by the measured data of the length of the-same-year branches, number of the leaves on the-same-year branches, coronal size and canopy density of *Populus euphratica*[19, 20]. It is estimated that, in the arid environment in the lower reaches of Tarim River, the stress groundwater depths of *Phragmites communis* and *Tamarix chinensis* are 3.5 m and 5.0 m respectively, and the stress and critical groundwater depths of *Populus euphratica* are 4.5 m and about 9.0 m respectively based on the investigation in the plots and the analysis on the change of the accumulation process of PRO, POD and SOD enzyme activity of the plants under the different groundwater depths.

(2) SOD and POD of *Populus euphratica* are the protective enzymes of membrane systems. The analysis on the response of POD and SOD in plant bodies to the drought stress shows that POD and SOD have a temporal complementarity, a POD activity occurs when the moisture stress is weak; the SOD activity is stimulated and increased with the increase of the degree of moisture stress, but the POD activity becomes weak. The analyzed results show that the change of the physiological and ecological properties of *Populus euphratica*, *Tamarix chinensis*, *Phragmites communis*, etc. are the same, that is the POD activity is high when the drought stress is relatively weak, and the POD activity is low but the SOD activity increases when the drought stress is serious. Therefore, from the point of view of the functions, SOD may be the functional replacer of POD. The joint effect of the two protective enzymes protects effectively the health of the membrane systems, and the physiological mutual-compensation of the plants is a physiological adaptability in the severe environment of drought stress. The physiological complementarity of *Populus euphratica* is a kind of physiological adaptability to the severe environment of drought stress.

(3) The existence of the plant dominated by *Populus euphratica* in the lower reaches of Tarim River relies on mainly the shallow groundwater. Therefore, the growth, degeneration and regeneration of the plants here are closely related to the change of groundwater level. The monitoring results of the intermittent stream water conveyances to the lower reaches of Tarim River show that the groundwater level near the river channel is gradually raised along with the implementation of the stream water conveyances. The groundwater level near the river channel along the upper and middle sections of the lower reaches of Tarim River is raised from 5~8 m in depth before the stream water conveyances to 2~4 m, and the growth of the natural vegetation dominated by *Populus euphratica*, the main community-building species in the lower reaches of Tarim River, is obviously improved. The plants near the river channel of stream water conveyances grow well, but the growth status of the vegetation far away from the river channel becomes poor. So conveyances are important to the growth of plants, and it is of practical significance for restoring the plants and protecting the ecological environment in the lower reaches of Tarim River. It must be pointed out that the vegetation in the middle and lower parts of the "Green Corridor" is mainly composed of the non-zonality xerophyte, which relies on the groundwater for their existence. The main factors affecting the growth of plants are the moisture and salt content in soils in the arid areas[21, 22]. The moisture and salt content in soils are related to the groundwater depth. If the groundwater is too shallow, the salt in groundwater will be accumulated in topsoil under evaporation, which is disadvantageous for the growth of plants; if it is too deep, the lost soil moisture cannot be effectively supplied by groundwater, thus the soil can be dried up, which re-

sults in a degeneration of vegetation. Therefore, it is of great significance for rationally utilizing the water resources and maintaining the ecological status in the lower reaches of Tarim River. However, the rational and optimal ecological groundwater depth in the lower reaches of Tarim River needs to be further determined.

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