

Eco-physiological response of *Populus euphratica* Oliv. to water release of the lower reaches of the Tarim River, China

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Abstract Eco-physiological and plant performance responses and acclimation of *Populus euphratica* Oliv. to water release of the lower reaches of Tarim River, China were investigated. Three representative areas and 15 transects were selected along the lower reaches of the Tarim River. The groundwater level and salt content as well as plant performance and the contents of proline, soluble sugar, and plant endogenous hormone (ABA, CTK) in leaves were monitored and analyzed before- and after-water release. The groundwater level was raised in different areas and transects by the water release program. The physiological stress to *P. euphratica* decreased after the water release. Our results suggested that the groundwater level in the studied region changed from –3.15 to –4.12 m, salt content of the groundwater from 67.15 to 72.65 mM, the proline content from 9.28 to 11.06 mM, the soluble sugar content from 224.71 to 252.16 mM, the ABA content from 3.59 to 5.01 ng/(g FW), and the CK content from 4.01 to 4.56 ng/(g FW)- for the optimum growth and recover of *P. euphratica* indicated by the plant performance parameters, and the efficiency of water release was the highest.

Keywords *Populus euphratica* · Tarim River · Eco-physiological response · Water release

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Introduction

The Tarim River is the longest continental river in China, with a length of 1,380 km. It flows south of Urumqi, the capital of Xinjiang autonomous region. This area of the Tarim River displays the climate typical of hyper-arid environments in the world. *Populus euphratica* is the only tree species that can grow in this hyper-arid environment. The natural forests of *P. euphratica* in the Tarim River watershed accounts for 89% of the total area in China and 54% of that worldwide. This watershed is the largest gene base of *P. euphratica* (Yang 2002). Due to the irrational utilization of water resources in the upper and middle reaches (Ragab and Prudhomme 2002), a cut-out of more than 300 km of the riverbed occurred in the late 1970s, resulting in withering of forest areas and degradation of the environment along both riverbanks. The central and local governments of China recognized this problem and invested RMB ¥10.7 billion (US \$1 ≈ RMB ¥8.2) to restore and reconstruct the environment of this district. One of the most important measures implemented was the ecological engineering of releasing water from the Bositen Lake to the lower reaches of the Tarim River. The project started on 15 September 2000. It insured the transfer of $3.50 \times 10^8 \text{ m}^3$ of water from Bositen Lake to the lower reaches of Taitema Lake every year (Chen et al. 2003).

Osmotic adjustment (OA) is one of the drought avoidance mechanisms involved in counteracting loss of turgor by increasing and maintaining a higher amount of intracellular compatible solutes. It has been proved to be most effective among all the stress adaptation mechanisms (Cushman 2001). Soluble sugar (Rekika et al. 1998) and proline (Mattioni et al. 1997)

levels have been demonstrated to increase under water stress and are potentially important contributors to OA. In some plants, the suppression in leaf stomatal conductance during drought has been reported to be independent of changes in water flux, and accumulating abscisic acid (ABA) may be responsible for these responses (Aguilar et al. 2000). Apart from ABA, cytokinin has also been investigated in drought stress studies (Incoll et al. 1990). In this study, proline, soluble sugar, and plant endogenous hormone (ABA, CK) levels in leaves are chosen as physiological parameters, and the number of leaves of each current-year shoot, shoot-length, leaf-blade size, leaf weight and stem diameter increase per day are chosen as plant performance parameters for evaluating the response of *P. euphratica* to the change in the environment.

The aim of the present work was to study the eco-physiological response and acclimation of *P. euphratica* during the water release period. Three representative areas were chosen at Yhepumahan, Alagan, and Yganbuqima (see Fig. 1) of the lower reaches of the Tarim River. Five transects were fixed at 100 m intervals along a vertical sampling line in each area. The groundwater level and salt content as well as the plant performance and physiological parameters were monitored and analyzed before and after water release. This was carried out to understand how physiological processes are influenced by the change in the groundwater level and salt content, and also to understand how *P. euphratica* acclimated to environmental changes through physiological mechanisms. It was necessary to characterize the plant physiological response to

water release and environmental recover. The results provide a scientific basis for the recover of ecosystems in hyper-arid areas.

Materials and methods

Description of the study area

The study areas are located in the lower reaches of the Tarim River (Lat. 39°38′–41°45′N; Long. 85°42′–89°17′E) between the Taklamakan Desert and Kuluke Desert (see Fig. 1). The mean meteorological conditions are summarized in Table 1. Precipitation occurs between June and August. The mean pan-evaporation is more than 2,700–3,100 mm annually and exceeds the precipitation by 50–60 times. The total annual solar radiation varies from 5,692 to 6,360 MJ/m², with 2,780–2,980 cumulative sunlight hours. The climatic conditions make the north of the Tarim Basin a typical hyper-arid region.

The riverbank vegetation provides a natural defense against wind by obstructing sand movement. The flora of the region includes 14 families, 24 genera, and about 40 species of vascular plants. The plant cover includes (Zhang and Xia 1997; Chen et al. 2005): (1) *Populus euphratica*–*Phragmites communis* communities (with the associates *Tamarix ramosissima*, *Glycyrrhiza inflata*, *Poacynum hendersonii*, *Karelinia caspia*); (2) *Tamarix ramosissima*–*Phragmites communis* communities (with the associates *P. hendersonii*, *G. inflata*, *Asparagus neglectus*); (3) *Tamarix ramosissima*–*Halostachys caspia* communities (with the associates *P. communis*, *P. hendersonii*, *K. caspia*, *Lycium ruthenicum*). Due to the construction of reservoirs and development of irrigation in the upper and middle reaches for 30 years, the water flow into the lower reaches was reduced and the groundwater level was lowered greatly, down to 8–12 m deep. The natural vegetation, such as the shrub–grass vegetation, dominated by *T. chinensis*, *P. communis*, and the *P. euphratica* forest, rely on groundwater for their survival and growth. They have

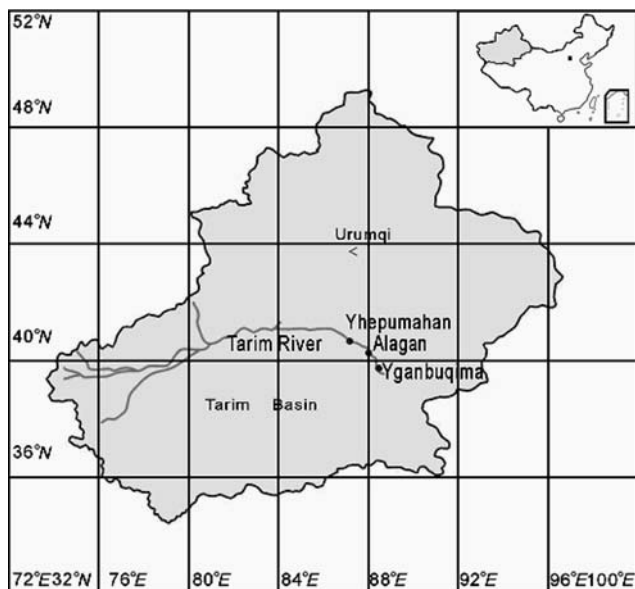


Fig. 1 Map showing three studied areas in the lower reaches of the Tarim River

Table 1 Features of climate in three areas to be studied

Location	Month	Temperature (°C)	Precipitation (mm)
Yhepumahan	January	−7.8	0
	July	25.5	50.1
Alagan	January	−7.8	0
	July	26.0	48.5
Yganbuqima	January	−8.1	0
	July	26.2	42.7

Data are collected by our group

seriously degenerated, and the sand dunes in the sand soils between the forests have become active.

Plant source

The first sampling (before-water release) was conducted from 1 to 20 July 2000, and after that, sampling (after water release) was conducted from July 1 to 20, every year thereafter. The data of years 2000 and 2005 were compared and analyzed. The species studied was *P. euphratica*. All plants selected were 8–10 m tall, about 50–55 years old, healthy and without infection. Care was taken to select the plants close to each other in each transect. Southwards-facing plants (receiving maximum light during the day) were used for measurements.

Measurement of plant performance

The number of leaves of each current-year shoot, shoot-length (cm), leaf-blade size (cm²), leaf weight (g), and stem diameter increase per day (mm) were measured for *P. euphratica* before and after water release (25 samples) in the natural forest of the three areas. Leaf-blade size was estimated as an ellipse from the maximum blade width (the largest distance between leaf edges) and the perpendicular width (the largest distance perpendicular to the maximum crown width), and corrective calculation was carried out using the ratio of the actual leaf area to estimated area from ten typical leaves of each plant. Current-year shoots of plants were cut, separated into leaf blades and stems, and dried at 80°C for 48 h, and the dry mass was recorded for each fraction. Stem diameter increase per-day was estimated using PhyTalk stem diameter variation sensor, RS-SD-56R (sPhyTech Ltd, Yad Mordechai, 79145, Israel).

Measurement of groundwater level

The three areas were located at Yhepumahan, Alagan, Yganbuqima at an interval of about 75 km apart in the lower reaches of the Tarim River. Five transects were selected at 100 m intervals along a vertical sampling line with an average length of 500 m from the river-bank to the sand dunes in each area. The positions of the three areas and distances between the sample points were determined according to the GPS (GPS 12XL, Garmin Olathe, KS, USA). The height of the transects was 1 ± 0.1 m above the river water table and 2.5 ± 0.1 m above the river bottom. Within each transect, three wells were established for investigation. The groundwater level in these wells was monitored. The

collected water and plant samples were analyzed in our laboratory.

Estimation of groundwater salinity

The mean salinity of the groundwater was estimated through its electrical conductivity. After digestion by HNO₃, K⁺, Mg²⁺, Ca²⁺ and Na⁺ analysis was carried out using an inductively coupled argon plasma emission spectrophotometer (Jobin-Yvon JY 48). Cl⁻ was colorimetrically determined with ferric ammonium sulphate and mercuric thiocyanate following the procedure of Guerrier and Patolia (1989). The total sulfate in the water was analyzed using ion-chromatography.

Proline extraction

The proline content was estimated using the method of Troll and Lindsley (1955). The plant material was homogenized in 3% aqueous sulfosalicylic acid, and the homogenate was centrifuged for 10 min at 8,000g. The supernatant was used for estimating proline content. The reaction mixture consisted of 0.2 ml supernatant, 2 ml acid ninhydrin, and 2 ml glacial acetic acid, which was boiled at 100°C for 1 h. After termination of the reaction in an ice bath, the reaction mixture was extracted with 4 ml of toluene. The absorbance was at 520 nm.

Analysis of soluble sugars

Freeze-dried leaves (50 mg) were ground and extracted in 1 ml of 80% (v/v) ethanol. For recovery purposes, a known amount of ribitol was added to the extracts as an internal standard. The extracts were then boiled for 15 min and centrifuged for 5 min at 10,000g. The supernatant was removed and the pellet was extracted twice as above. The extracts were vacuum-dried at 45°C. The dried extracts were re-dissolved in 1.0 ml distilled water and purified using anion exchange (Sephadex QAE-A-25, Pharmacia Biotech, Sweden). The eluates (1.0 ml extract and 2 ml water washings) were vacuum-dried and re-dissolved in 300 µL of water. Hexose (glucose × fructose) and sucrose were analyzed at 35°C using an HPLC equipped with a 300 × 7.8 mm column (carbohydrate-H⁺, HYDERSIL, UK). H₂SO₄ (0.005 M) was used as the solvent at a flow rate of 0.6 ml/min.

Extraction and quantification of ABA using HPLC

Leaves (0.5 g) were ground with liquid nitrogen. Abscisic acid was extracted in 250 µL of methanol at 4°C

while being shaken overnight. Samples were centrifuged, and the supernatant was collected and vacuum-dried and subsequently dissolved in 30 μL of 10% CH_3CN . The ABA content was determined using HPLC analysis. An LC-10A TVP photodiode and ray detector (PDA), and a Shim pack CLC- C_8 (0.15 m \times 6.0 ϕ) were used. The flow rate was 1.5 ml/min. Detection was at 250 nm at 30°C. The solvent for the pump A was 10% CH_3CN after the pH value was adjusted to 3.0 with CF_3COOH . The solvent for pump B was 60% CH_3CN . The abscisic acid (ABA) standard was purchased from Aldrich. The peak was identified and quantified against the external standard.

ELISA analysis of cytokinins

Cytokinins were extracted with 70% ethanol from the green parts of leaves. The extracts were evaporated to the water phase at 45°C under vacuum. The aqueous phase was made alkaline to pH 8–9 with 2 N NaOH and then extracted with *n*-hexane. The hexane phases was extracted two times with *n*-butanol. The resulting extracts were evaporated to dryness, dissolved in 400 μl ethanol, treated for 30 min with polyvinylpyrrolidone, and passed through a 0.45 μm membrane filter.

Detection using antibody kits for zeatin (Z), zeatin riboside (ZR), dihydrozeatin (DZ), and dihydrozeatin riboside (DZR) was carried out according to the method of Vonk et al. (1986). The following cross-reactivity was found: Z/ZR kit –31.25% for Z, 100.00% for ZR, 7.87% for DZ; DZ/DZR kit –1.75% for Z, 1.60% for ZR, 39.50% for DZ and 100.00% for DZR. The concentration of total cytokinins is calculated as the sum of the four compounds (Z, ZR, DZ and DZR).

Statistical analysis

Statistical analysis was carried out using the SPSS statistical computer package (SPSS for Windows, standard version, 6.1). Statistical differences between areas and transects were analyzed by one-way analysis of variance (ANOVA).

Results

Groundwater level and salinity of groundwater

Table 2 lists of groundwater level and salinity before and after release of water to the lower reaches of the Tarim River, respectively. The data show that groundwater level had been raised after water release

in the three areas. The effect of the engineering of a water release differed with vertical distances to the riverbank or horizontal distances from the center of a water sources. The highest groundwater level was –2.66 m, in the transect at 100 m vertical distance to the riverbank in the Yhepumahan area. In this work, the total salt content of the groundwater was used as an indicator of salt stress. The total salt concentration was calculated on the basis of seven ions. The salt content of groundwater at different areas and transects increased from 1.76 to 2.49 times when the groundwater level went up: the highest content (93.48 mM) was again at the transect 100 m from the riverbank in the same area.

Plant performance changes before and after water release

Table 3 shows the shoot characteristics of *P. euphratica* before and after water release to the lower reaches of the Tarim River, respectively. All plant performance parameters increased after water release. The maximum number of leaves per current-year shoot was 6.5 ± 0.5 at the transect 200 m from the riverbank in the Alagan area. The longest current-year shoot was 7.63 ± 0.68 cm at the transect 200 m from the riverbank in the Yhepumahan area. The greatest leaf-blade area and leaf weight were 18.37 ± 2.54 cm^2 and 0.912 ± 0.093 g at the transect 300 m from the riverbank in the Yhepumahan area. The greatest diameter increase per day of the shoot stem was 0.31 ± 0.03 mm at the transect 100 m from the riverbank in the Yganbuqima area.

Change in leaf proline content

The highest leaf proline content before and after water release was 35.62 mM at the transect 400 m from the riverbank and 24.28 mM at the transect 500 m from the riverbank in the Yganbuqima area, respectively (Fig. 2). The lowest leaf proline content before and after water release was 16.62 mM at the transect 100 m from the riverbank and 9.28 mM at the transect 300 m from the riverbank in the Yhepumahan area.

Change in leaf soluble sugar content

The highest soluble sugar content in the leaves before and after water release was 572.02 mM at the transect 400 m from the riverbank and 426.73 mM at the transect 500 m from the riverbank in the Alagan area, respectively (Fig. 3). The lowest content before and after water release was 392.60 mM at the transect

Table 2 Groundwater level and salt content being at different distance from the riverbank in the three areas (before and after water release)

Areas	Distance of transects to river bank (m)	Ground-water table (m) ^a	HCO ₃ (g/l)	Cl (g/l)	SO ₄ ²⁻ (g/l)	Ca ²⁺ (g/l)	Mg ²⁺ (g/l)	Na ⁺ (g/l)	K ⁺ (g/l)	Total Salt (mM) ^b
Yhepumahan	100 ^c	-5.14	0.236	1.872	0.524	0.167	0.352	1.328	0.384	37.56
	^d	-2.66	0.367	4.853	0.792	0.235	0.355	3.792	0.455	93.48
	200 ^c	-5.39	0.692	0.918	0.333	0.173	0.458	1.415	0.412	37.52
	^d	-3.15	0.713	3.766	0.479	0.367	0.422	3.722	0.437	79.54
	300 ^c	-6.36	0.704	1.372	0.354	0.115	0.292	0.817	0.217	38.15
	^d	-3.61	0.426	3.725	0.385	0.578	0.328	3.623	0.479	72.65
	400 ^c	-7.18	0.358	1.257	1.156	0.208	1.079	0.625	0.465	36.45
	^d	-3.79	0.623	3.625	0.572	0.208	0.287	3.254	0.532	71.64
	500 ^c	-7.25	0.303	1.012	0.425	0.283	0.729	1.852	0.422	35.97
	^d	-5.74	0.307	3.547	0.478	0.209	0.298	3.221	0.278	69.38
Alagan	100 ^c	-6.17	0.318	1.345	0.627	0.146	0.426	1.365	0.623	37.54
	^d	-3.16	0.357	3.887	0.655	0.239	0.379	3.654	0.427	81.54
	200 ^c	-7.62	0.425	1.037	0.373	0.352	0.373	1.728	0.355	36.62
	^d	-3.57	0.618	3.632	0.725	0.278	0.368	3.278	0.533	73.64
	300 ^c	-8.19	0.467	1.725	0.254	0.637	0.429	1.645	0.274	35.54
	^d	-4.58	0.329	3.564	0.643	0.364	0.287	3.156	0.278	68.53
	400 ^c	-8.26	0.395	1.602	0.735	0.128	0.516	1.179	0.532	32.85
	^d	-6.18	0.372	3.259	0.528	0.175	0.398	3.029	0.179	67.15
	500 ^c	-9.83	0.372	1.325	0.534	0.532	0.715	1.356	0.198	31.69
	^d	-6.82	0.462	3.617	0.674	0.438	0.277	2.997	0.352	66.25
Yganbuqima	100 ^c	-6.96	0.179	1.342	0.538	0.163	0.318	1.164	0.179	34.25
	^d	-3.97	0.248	3.523	0.628	0.265	0.291	3.425	0.635	69.28
	200 ^c	-7.65	0.256	1.105	0.624	0.113	0.275	1.532	0.635	34.63
	^d	-4.21	0.375	3.176	0.674	0.327	0.262	3.255	0.532	67.56
	300 ^c	-8.17	0.196	1.174	0.673	0.082	0.632	1.427	0.532	33.72
	^d	-5.27	0.524	3.109	0.574	0.355	0.327	3.296	0.179	67.26
	400 ^c	-8.25	0.259	1.072	0.438	0.194	0.148	1.357	0.728	33.64
	^d	-6.83	0.179	2.994	0.633	0.427	0.423	3.155	0.354	59.45
	500 ^c	-9.87	0.219	1.173	0.825	0.248	0.527	1.623	0.478	32.19
	^d	-8.17	0.528	2.987	0.615	0.433	0.533	3.042	0.518	57.24

Values are expressed in mean ± SD

^a The values of groundwater level are means of three replications

^b The total salt concentration was calculated on the basis of seven ions. The values of salinity groundwater in each transect are means of three replications

^c Before-water release

^d After-water release

100 m from the riverbank in the Yhepumahan area and 224.71 mM at the transect 200 m from the riverbank in the Yganbuqima area, respectively.

Change in plant hormone content

Figure 4 indicates that the ABA content increased from 7.65 to 18.35 ng/(g FW) and the concentration of total cytokinins decreased from 3.25 to 0.38 ng/(g FW) with the vertical distance to the riverbank in the Yhepumahan area. The lowest content of ABA (2.37 ng/(g FW)) and the highest content of cytokinins (4.67 ng/(g FW)) were obtained at the transect 100 m from the riverbank.

In Fig. 4, the ABA content is shown as two peaks: the first one is at the transect 300 m [17.41 ng/(g FW)]

from the riverbank, and the second one is at the transect 500 m [21.47 ng/(g FW)] from the riverbank in the Alagan area. The CK content remains at very low level, the ABA content increases from 3.29 to 8.64 ng/(g FW), and the CK content decreases from 4.65 to 1.29 ng/(g FW) when the distance of the transect increases.

In Fig. 4, there are two peaks in the ABA content. The first one is at the transect 300 m [19.29 ng/(g FW)] from the riverbank, and the second one is at the transect 500 m [24.07 ng/(g FW)] from the riverbank in the Yganbuqima area. The CK content maintains at very low levels. The ABA content increases from 3.55 to 9.97 ng/(g FW), and the CK content decreases from 4.23 to 1.05 ng/(g FW) when the distance of the transect increases.

Table 3 Shoot characteristics of *P. euphratica* being at different distance from the riverbank in the three areas (before and after water release)

Areas	Distance of transections to river bank (m)	Number of leaves per shoot	Current-year shoot length (cm)	Leaf-blade size (cm ²)	Leaf weight (g)	Shoot stem diameter increasing per day (mm)	
Yhepumahan	100 ^a	4.2 ± 0.3	5.98 ± 0.62	14.11 ± 1.52	0.720 ± 0.075	0.12 ± 0.02	
		6.3 ± 0.5	7.22 ± 0.70	16.48 ± 1.77	0.838 ± 0.092	0.27 ± 0.03	
	200 ^a	2.5 ± 0.2	5.88 ± 0.65	12.19 ± 1.05	0.669 ± 0.052	0.11 ± 0.02	
		5.4 ± 0.5	7.63 ± 0.68	18.26 ± 1.72	0.898 ± 0.102	0.28 ± 0.03	
	300 ^a	3.2 ± 0.4	5.08 ± 0.54	10.72 ± 1.03	0.585 ± 0.052	0.12 ± 0.02	
		5.2 ± 0.5	7.62 ± 0.68	18.37 ± 2.54	0.912 ± 0.093	0.28 ± 0.03	
	400 ^a	3.0 ± 0.5	5.63 ± 0.58	10.52 ± 1.15	0.576 ± 0.051	0.09 ± 0.02	
		5.1 ± 0.5	6.88 ± 0.67	17.95 ± 1.63	0.793 ± 0.082	0.27 ± 0.03	
	500 ^a	2.2 ± 0.2	4.12 ± 0.50	9.23 ± 1.02	0.536 ± 0.051	0.09 ± 0.01	
		4.0 ± 0.4	4.88 ± 0.55	14.35 ± 1.35	0.722 ± 0.068	0.26 ± 0.03	
	Alagan	100 ^a	3.5 ± 0.4	4.87 ± 0.51	13.64 ± 1.45	0.622 ± 0.068	0.11 ± 0.02
			6.2 ± 0.5	7.56 ± 0.63	16.25 ± 1.78	0.819 ± 0.098	0.28 ± 0.03
200 ^a		3.4 ± 0.5	4.64 ± 0.52	12.52 ± 1.42	0.699 ± 0.064	0.11 ± 0.02	
		6.5 ± 0.5	7.38 ± 0.75	17.38 ± 1.82	0.872 ± 0.078	0.29 ± 0.03	
300 ^a		3.2 ± 0.4	3.93 ± 0.43	12.55 ± 1.36	0.651 ± 0.104	0.09 ± 0.01	
		6.2 ± 0.5	6.29 ± 0.68	16.37 ± 1.72	0.809 ± 0.098	0.30 ± 0.03	
400 ^a		3.1 ± 0.4	3.62 ± 0.25	10.32 ± 1.12	0.512 ± 0.062	0.09 ± 0.01	
		5.2 ± 0.5	6.48 ± 0.64	17.29 ± 1.82	0.865 ± 0.087	0.27 ± 0.03	
500 ^a		2.8 ± 0.3	3.43 ± 0.42	12.64 ± 1.35	0.635 ± 0.073	0.08 ± 0.01	
		4.8 ± 0.5	4.28 ± 0.72	15.57 ± 1.68	0.817 ± 0.083	0.26 ± 0.03	
Yganbuqima		100 ^a	3.5 ± 0.4	3.62 ± 0.44	11.38 ± 1.45	0.608 ± 0.082	0.11 ± 0.02
			6.2 ± 0.5	7.02 ± 0.65	16.22 ± 1.65	0.811 ± 0.075	0.31 ± 0.03
	200 ^a	3.8 ± 0.4	3.89 ± 0.47	11.09 ± 1.08	0.603 ± 0.064	0.10 ± 0.02	
		5.8 ± 0.6	6.89 ± 0.58	17.53 ± 1.68	0.882 ± 0.078	0.28 ± 0.03	
	300 ^a	3.0 ± 0.4	3.72 ± 0.53	12.01 ± 1.35	0.628 ± 0.064	0.09 ± 0.01	
		4.2 ± 0.5	5.75 ± 0.63	16.83 ± 1.72	0.829 ± 0.091	0.28 ± 0.03	
	400 ^a	2.8 ± 0.3	3.88 ± 0.41	12.35 ± 1.31	0.645 ± 0.073	0.09 ± 0.01	
		3.8 ± 0.5	5.24 ± 0.62	15.29 ± 1.68	0.804 ± 0.088	0.28 ± 0.03	
	500 ^a	2.7 ± 0.3	2.54 ± 0.32	10.66 ± 1.09	0.601 ± 0.073	0.09 ± 0.01	
		3.7 ± 0.5	4.53 ± 0.57	14.26 ± 1.72	0.802 ± 0.089	0.27 ± 0.03	

Values are means ± SD

^a Before-water release

^b After-water release

Fig. 2 The content of leaf proline at different vertical transect to riverbank of three areas. Each point represents the average of 10 measurements ± SD; Significant statistical differences [the content of leaf proline (ANOVA), $p = 0.01$] were found between transects

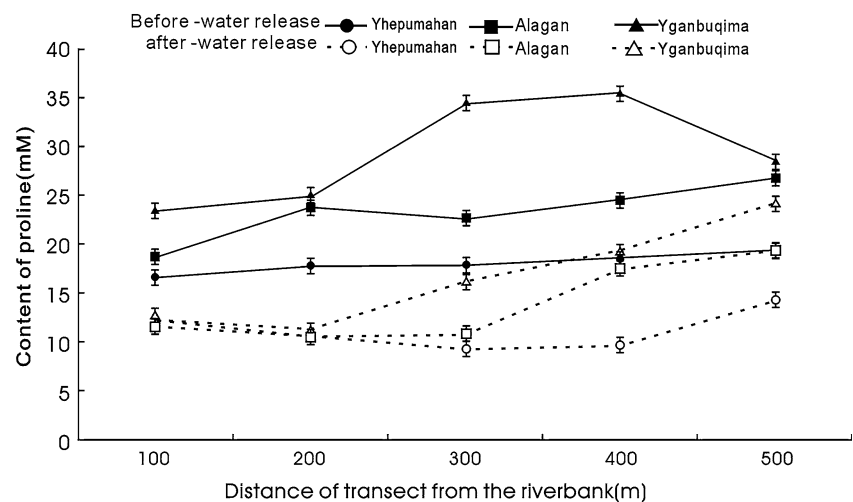


Fig. 3 Content of soluble sugars of leaf at different vertical transect to riverbank of three areas Each point represents the average of ten measurements \pm SD; Significant statistical differences [content of soluble sugars of leaf (ANOVA), $p = 0.01$] were found between transects

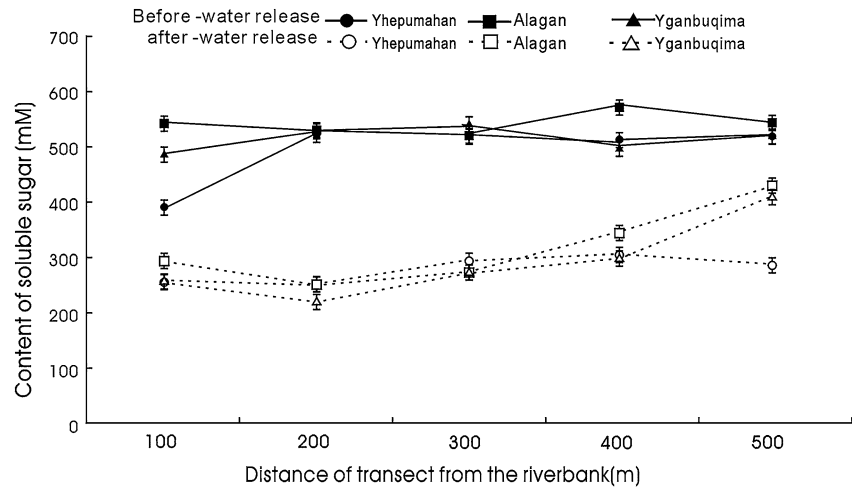
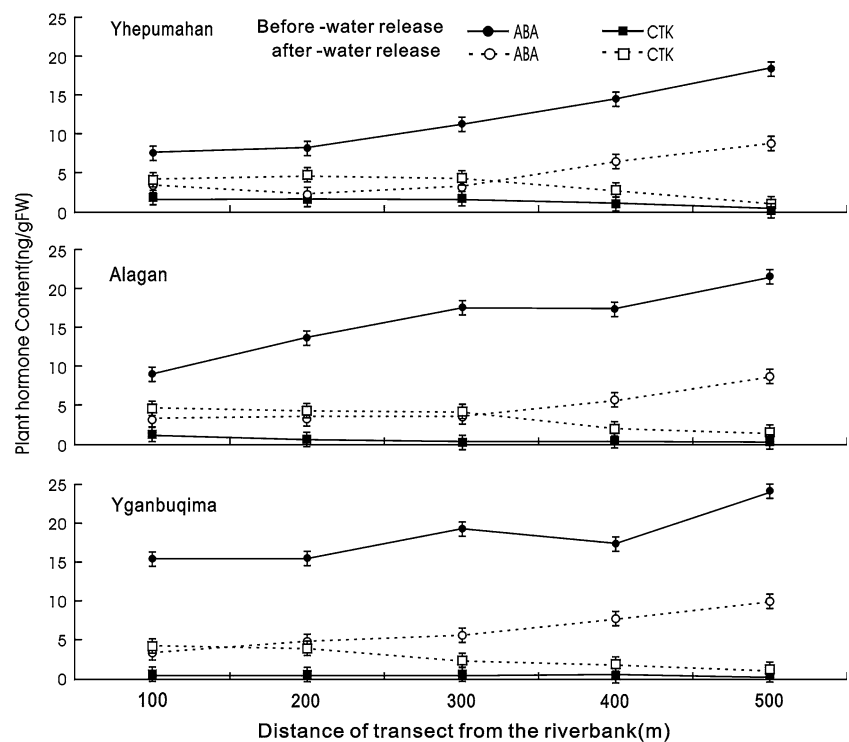


Fig. 4 Content of plant hormone of leaf at different vertical transect to riverbank of three areas Each point represents the average of 10 measurements \pm SD; Significant statistical differences [content of plant hormone of leaf (ANOVA), $p = 0.01$] were found between transects



Discussion

Upon analysis of plant performance parameters and their changes before and after water release, the growth of *P. euphratica* as indicated by these parameters improved upon water release. The number of leaves per current-year shoot increased from 1.36 to 2.16 times, the shoot-length from 1.18 to 1.94 times, the leaf-blade size from 1.17 to 1.71 times, the leaf weight from 1.16 to 1.69 times, and the stem diameter increase per day from 2.25 to 3.33 times as the groundwater table went up.

Many plant species respond rapidly to stressors by increasing the concentration of compatible solutes involved in osmoregulation and in protection of proteins and membranes under conditions of low water potential (Shevyakova 1983). Aspinall and Paleg (1981) summarized the unique role of proline in plants subjected to water and salt stress. Stress-mediated changes in proline biosynthesis (Bogges et al. 1976), including hydrolysis of proteins (Dungey and Davies 1982) and oxidative degradation processes (Rayapati and Stewart 1991), can result in increased proline levels of plants exposed to different stresses, the degradation of pro-

line was almost completely inhibited in stressed plant material. Free proline accumulation seems to be a widespread stress response in higher plants (Gzik 1996). Our results support the idea in that the free proline content decreases at every transect in the three research areas and the physiological stress to *P. euphratica* was reduced after water release. When the groundwater level went up, however, the salinity of groundwater rapidly increased, and the effect of water release was weakened by the increasing salt stress to the plant. According to the proline accumulation data, *P. euphratica* suffered the minimal stress, including water and salt stress, at the transect 300 m from the riverbank in the Yhepumahan, where the groundwater table is -3.61 m, the total groundwater salt content is 72.65 mM and leaf proline content is 9.28 mM.

In all plants studied, the carbohydrate concentration increased when the plants were subjected to stress, and the stimulation of sugar accumulation was proportional to the osmotic adjustment (Sanchez et al. 1998). It has been suggested that under water stress, soluble sugars can function in two ways, which are difficult to separate: as osmotic agents (Bohnert et al. 1995) and as osmo-protectors (Ingram and Bartels 1996). As an osmotic agent, the increased sugar, induced by water stress, was significantly correlated to osmotic adjustment and turgor maintenance. As osmo-protectors, sugars stabilize proteins and membranes, most likely substituting the water in the formation of hydrogen bonds with polypeptide polar residues (Crowe et al. 1992) and phospholipid phosphate groups (Strauss and Hauser 1986). Sugar accumulation is also a water stress signal in higher plants. From the soluble sugar data, it was seen that the stress to *P. euphratica* had been reduced after water release, the optimal place for plant growth being at a distance of 200 m from riverbank in the Yganbuqima area, where the groundwater level is -4.21 m, the total groundwater salt content is 67.56 mM, the leaf soluble sugar content is 224.71 mM, and the leaf proline content is 11.06 mM.

Hormonal substances may be involved in transmitting information about the water status of the soil and roots to the whole plant. As a response to water deficit, there is an increase in the endogenous ABA levels that rapidly limits water loss through transpiration by reducing stomatal aperture. ABA is also involved in other aspects of stress adaptation such as cold acclimation and root morphogenesis in response to stress (Campalans et al. 1999). Apart from ABA, cytokinin has been investigated in drought stress studies. Masia et al. (1994) have suggested that a decrease in cytokinin transport from root to shoot occurs during the onset of drought stress, and low cytokinin levels can

result in stomatal closure of leaves (Bano et al. 1993). It has been reported that drought can result in reduction of leaf cytokinin concentrations in drought-susceptible cultivars of tomato (Pillay and Beyl 1990) and in rice seedlings (Bano et al. 1993). This is in an agreement with the results of our study: *P. euphratica* could not get enough water for its normal physiological needs in the Tarim Basin climate in this season before the water release programme. High levels of ABA [from 7.65 to 24.07 ng/(g FW)] and low levels of CK [from 1.93 to 0.17 ng/(g FW)] in leaf induce the plant to close the stomata to avoid water loss. This is the acclimation of this plant to the hyper-arid environment, but this kind of acclimation has its limitation. The ABA content [from 3.59 to 9.87 ng/(g FW)] in the leaves decreased and the CK content [from 1.05 to 4.56 ng/(g FW)] increased after the water release programme. Thus the living conditions of the plant had been improved.

Conclusion

Our results suggest that with the following values for eco-physiological parameters: groundwater level: -3.15 to -4.12 m, groundwater salt content: 67.15 – 72.65 mM, leaf proline content: 9.28 – 11.06 mM, leaf soluble sugar content: 224.71 – 252.16 (mM), leaf ABA content: 3.59 – 5.01 ng/(g FW) and the leaf CK content: 4.01 – 4.56 ng/(g FW), the growth and recover of *P. euphratica* were optimum, also as indicated by plant performance parameters. Within these ranges, water release was highly efficient. Beyond these ranges, particularly a higher groundwater table will not be beneficial to *P. euphratica*. Excessive water release would also be a loss to the river, which is a very important source of water in such a hyper-arid area, and will result in the enhancement of secondary basicity in the soil.

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