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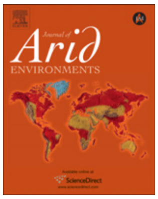

Hydraulic lift in *Populus euphratica* Oliv. from the desert riparian vegetation of the Tarim River Basin

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ABSTRACT

In the Tarim River Basin, the desert riparian forest vegetation is under high-temperature and aridity stress. However, the vegetation can grow continuously because of deep rooting that can reach groundwater, which can thus redistribute water into the upper soil profile. This paper describes patterns of hydraulic lift by *Populus euphratica* Oliv. and discusses its ecological effects. Our results show that the tap root sap velocity of *P. euphratica* Oliv. is positive during the day and night. However, a reverse sap flow was observed in the lateral roots during the night. The soil water content of the subsoil was higher than that of the topsoil at depths of 0–120 cm. When the sap flow of the lateral roots was reversed at night, the soil water content clearly increased. In particular, at depths of 60–120 cm, the soil water content at 4:00 was 28–38% greater than that at 16:00. The vapor pressure deficit was a factor that predominantly affected the root sap velocity, and the smaller vapor pressure deficit often facilitated a reverse sap flow in the lateral roots. Our findings demonstrate the hydraulic lift characteristics and ecological effects that occur in the desert riparian forest in extremely arid regions of middle Asia

1. Introduction

There are three primary natural sources of water for plants in arid regions: surface flow, precipitation, and groundwater (Chimner & Cooper, 2004; Flanagen & Ehleringer, 1991; Gries et al., 2003; Hipondoka et al., 2003; Horton & Clark, 2001; Lamontagne et al., 2005). However, the supply from surface flow (e.g., surface runoff, rivers, streams, lakes) is generally very limited, both spatially and temporally. Therefore, most arid vegetation relies on precipitation, groundwater, or a combination of the two. In the lower reaches of the Tarim River in China, the stream flow has completely dried up since 1970. The region has a dry, desert climate, with an annual precipitation of 17.4–42.0 mm, and predominantly dry and windy weather. Consequently, groundwater is the only water source for the vegetation in the lower reaches of the Tarim River (Li & Zhang, 2003).

In semi-arid and arid regions, such as the Tarim River Basin, not all plants have deep root systems. However, plants with shallow roots can also grow normally, just as those with deep roots can, and can absorb soil water from deep soils under long-term drought stress. This has been attributed to the adaptive strategies of drought-tolerant plants. One of these adaptive strategies is in the leaf structure (Yiotis et al., 2006). Another, more important, factor is the water sharing that occurs between deep-rooted and shallow-rooted plants, whereby deep-rooted plants supply a certain amount of water to shallow-rooted plants through “hydraulic lift” (Dawson, 1993). The hydraulic lift of root systems has been widely documented in different floral regions, including the semi-arid (riparian) and arid areas of North America (Hultine et al., 2003a, 2003b, 2004; Leffler et al., 2005; Ryel et al., 2002, 2003, 2004), temperate zone forests (Brooks et al., 2002, 2006; Domec et al., 2004; Warren et al., 2005), croplands (Wan et al., 2000), savanna forests in America and Africa (Ludwig et al., 2003, 2004; Moreira et al., 2003; Scholz et al., 2002; Zou et al., 2005), forests of Mediterranean-type regions in Australia (Burgess et al., 2000a, 2000b, 2001), and Amazonian trees (Lee et al., 2005; Oliveira et al., 2005; Rocha et al., 2004). These studies have verified and evaluated the processes, mechanism, and ecological significance of hydraulic lift, based on a broad spatiotemporal scale and many species. However, because little research has focused on the desert riparian forests distributed in middle Asia, such as that in the Tarim River Basin, it is still unclear whether the hydraulic lift effect also exists in this vegetation. Consequently, we have only limited knowledge about the water-use strategies of these plants.

The Tarim River is located on the northern border of the Taklimakan Desert of Xinjiang, China. In the past 50 years, local intensive economic and social development has vastly increased the consumption of water from the Tarim River, which has caused the stream flow in the lower reaches (at 321 km) to cease completely. Consequently, the groundwater table has dropped significantly,

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which has led to a serious decline in the natural vegetation in the affected area. Large patches of herbaceous plants, such as *Phragmites communis* Trirn, *Apocynum venetum* L., and *Alhagi sparsifolia* (B. Keller et Shap.), have died out. Large expanses of the *Populus euphratica* Olivier and *Tamarix* spp. plant communities have also degenerated. Wind erosion and land desertification processes have become very intense (Liu et al., 2007).

To preserve this endangered desert riverbank forest vegetation and restore the damaged ecosystem, the Ecological Water Conveyance Project (EWCP), which encompasses Bosten Lake to the Kongque River, was initiated in 2000 to recharge water into the lower reaches of the Tarim River. Implementation of the project has raised the groundwater table and promoted vegetation renewal (Chen et al., 2006). However, the limited water resources are very precious in arid regions. Therefore, understanding the water-use and-sharing mechanisms of plants in the region, and the maintenance of an appropriate groundwater depth, is necessary to circumvent succession towards vegetation types that are intolerant of additional moisture from groundwater, or succession towards swampy vegetation types (Oleg et al., 2001) in the lower reaches of the Tarim River. To ensure that the vegetation here can grow normally, a simple water-depth management plan is required to protect the vegetation. However, present research that focuses on the relationship between vegetation and groundwater depth does not consider the water-using strategies of plants, such as the hydraulic lift. Once there is experimental evidence of hydraulic lift and its ecological effects, our understanding of the appropriate groundwater depth will be extended and reformed. Therefore, groundwater depth can act as an important criterion of ecological water delivery.

The objective of this study was to explore the hydraulic lift effect of *P. euphratica* Oliv., the constructive species of a desert riparian forest, using the heat ratio method (HRM) to continuously monitor root sap flow, and a gravimetrical method to analyze the corresponding soil water content. This research should provide a case study for the analysis of hydraulic redistribution in extremely arid inland-river regions.

2. Materials and methods

2.1. Study site

The field work was carried out at Yengsu in the lower reaches of the Tarim River, located in northwest China. This region is situated in the temperate continental zone and has a dry desert climate, with an annual precipitation of 17.4–42.0 mm, and predominantly dry and windy weather. The monitoring started in 17:00 of 9 Sep. and ended in 15:00 of 23 Sep., 2008. So the 15 consecutive diel (in the study areas, daytime from 8:00 to 21:00 that is just same with the sunrise and sunset time) monitoring data were collected. During the monitoring period, the sky was clear, with no precipitation events, but there were strong winds (average wind speed of 1.93 m/s, maximum wind speed of 5.30 m/s) at the end of the monitoring period. The study site has a flat terrain and a simple soil type, which is dominated by aeolian sandy soil. Several salt-adapted halophyte species, including *P. euphratica* Oliv., *Tamarix* spp., *Lycium ruthenicum*, *A. sparsifolia*, and *Salsola* sp., live along the riverbank in this area. Generally, the vegetation structure is very simple, with only a few plant species present.

2.2. Study species

We chose *P. euphratica* Oliv. as the study species because the tree is the constructive species of the riparian forest community, and because it has a huge and deep-rooted system; thus, the hydraulic redistribution and ecological significance of the tree would be more obvious. Three *P. euphratica* Oliv. trees, 50 m apart, with a diameter at a breast height of about 35–50 cm and a tree height of about 10–15 m, were selected for monitoring. We excavated the coarse root systems around the base of the three individuals, down to 1.2 m, to investigate their rooting distribution. The observation showed that all of these trees have a dimorphic root system. We monitored the sap flow in all of the tap roots and in the four lateral roots of each of the three trees.

2.3. Sap flow measurement and environmental variables

We used the heat ratio methods (HRM, ICT International Pty Ltd, Armidale, NSW, Australia) to take continuous monitoring of the sap flow in the roots of the study trees. A single HRM30 sensor consists of a 3-needle design, integrated into a microprocessor controlled Smart Interface, with a 5 m long cable. The two temperature needles from one sensor comprise one upstream-downstream pair, and each needle contains two thermocouples for the determination of sap velocity at two depths within the sapwood. Standard needles are 35 mm long, and have two thermocouples located 7.5 mm and 22.5 mm from the tip of the needle. Both thermocouples, within a single temperature needle, utilize one common constantan wire.

The soil around the base of each tree was carefully excavated, as carefully as possible to maintain the integrity of the root systems, to expose the proximal region of the large lateral roots (diameter >4 cm) and the tap root. In general, when the depth of the soil profiles reached 1 m, the target root was well-exposed. A single probe set was inserted into the tap root, and four probe sets were inserted into four lateral roots (diameter >4 cm). In all, one tap root and four lateral roots were instrumented on each tree. After installation, the probes were protected by plastic boxes, and were covered with approximately 20 cm of soil. In addition, the soil profile and roots were covered with a tarpaulin to prevent radiant heating by direct sunlight (Hultine et al., 2003b). Environmental variables, including the wind speed, leaf temperature, ground surface temperature, and relative air humidity, were measured with an auto-meteorological station (ICT International Pty Ltd). All the sap flow and meteorological sensors were connected to a data logger (SL5 Data Logger and DataBus System, ICT International Pty Ltd) by cable lines. The measurements were recorded every hour, during the period from September 10 to September 22. We calculated the heat pulse velocity by the equation (Burgess et al., 1998):

$$Vh = k/x \cdot \ln(v1/v2) \cdot 3600$$

where k is the thermal diffusivity of green (fresh) wood, x is the distance (0.6 cm in the study) between the heater and either temperature probe, and v_1 and v_2 are the increases in temperature (from initial temperatures) at equidistant points downstream and upstream, respectively, x cm from the heater. Thermal diffusivity (k) is assigned a nominal value of 2.5×10^{-3} cm^2 s^{-1} at the beginning of sap flow measurement, and this value is further resolved once the sapwood properties have been measured. All other corrections for probe misalignment and wounding (mechanical damage) were made according to Burgess et al. (2001). At the end of the study, we determined a precise baseline (zero flow) for the root sap flow by cutting all of the roots in order to stop the sap flow (Burgess et al., 2001).

In addition to the auto monitoring meteorological variables described above, the vapor pressure deficit was also calculated by leaf surface temperature and relative air humidity, with the following equation (Campbell & Norman, 1998):

$$VPD = a \cdot e^{(bT/T+c)} \cdot (1 - hr)$$

where VPD is the vapor pressure deficit, T is the leaf surface temperature, hr is the relative air humidity, and a, b, c are parameters 0.611 kPa, 17.502 and 240.97°C, respectively.