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Photosynthesis of *Populus euphratica* and its response to elevated CO_2 concentration in an arid environment

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Abstract

The photosynthetic characterization of *Populus euphratica* and its response to the elevated carbon dioxide concentration ([CO_2]) were analyzed based on its net photosynthetic rate (P_n), stomatal conductance (g_s), intercellular CO_2 concentration (C_i), transpiration rate (T_r), and water use efficiency (WUE) at different groundwater depths measured by a portable gas exchange system (LI-6400) in the lower reaches of the Tarim River. The results showed that the elevation of [CO_2] decreased the g_s, and increased the P_n, C_i and WUE of *P. euphratica.* However, the effects of the elevated [CO_2] on g_s, P_n, C_i and WUE varied considerably with groundwater depth. The response of photosynthesis to rising [CO_2] was stronger at the greater groundwater depth (more than 6 m) than that at the shallower groundwater depth (less than 6 m). The critical groundwater depth required to maintain the normal survival of *P. euphratica* was less than 6 m. When the groundwater depth increased to more than 6 m, *P. euphratica* encountered moderate water stress, and the plant suffered severe water stress when the groundwater depth increased to more than 7 m.

Keywords: Photosynthesis; *Populus euphratica*; Groundwater depth; CO_2 concentration; The lower reaches of the Tarim River

1. Introduction

Photosynthesis is a very complicated physiological process, affected by the combined effects of the intrinsic properties of plants and environmental factors [1], of which light, water, carbon dioxide concentration and temperature are important variables [1,2]. Some studies show that the atmospheric CO_2 has increased by 1.5 ppm per year [3]. The IPPC IS92a emission scenario predicts that the atmospheric CO_2 will increase to 750 ppm by 2100 [4]. Therefore, plants will face a higher CO_2 environment. It is expected to alter the photosynthetic function of plants [5,6], especially those that grow in arid environments. The relationship between plant photosynthesis and environmental factors has been well characterized [7–11], yet the photosynthetic stimulation observed in the elevated [CO_2] experiments does not always match theoretical expectations [12,13]. Especially, the impact of the elevated CO_2 on photosynthesis in *Populus euphratica* in an arid environment has not been well characterized.

Populus euphratica is the oldest tree species of desert riparian forest, and is distributed widely in arid desert regions of 30°–50°N, e.g. midwestern Asia, North Africa and southern Europe. China has the largest range and number of *P. euphratica* in the world [14]. *P. euphratica* is a dominant tree species of the green corridor around the lower reaches of the Tarim River in China [15].

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The Tarim River is one of the longest arid inland rivers in the world. Its main stream is 1321 km in length and runs between the Taklimakan Desert and the Kuluke Desert. This is an extremely arid region with a continental warm temperate climate, dry and sandy soils, low annual rainfall and strong annual evaporation. Over recent decades, as a result of human activities and natural factors, the eco-environment of the lower reaches of the Tarim River has deteriorated markedly; the river flow has decreased rapidly and the groundwater depth has deepened sharply, which has exacerbated the water stress level in the environment of *P. euphratica* [16]. As a result of global warming, *P. euphratica* is bound to face multiple stresses, including high temperature, drought stress and high CO_2 concentrations. In order to understand the mechanism that underlies the response of photosynthesis in *P. euphratica* to the elevated CO_2, as well as to improve our ability to predict the effect of global climate change on the growth of *P. euphratica*, the alteration in photosynthesis in *P. euphratica* grown at different groundwater depths in response to rising CO_2 in the arid environment of the lower reaches of the Tarim River was analyzed. Additionally, our study was designed to provide scientific information to use as the basis for protecting and restoring the damaged ecosystem of the lower reaches of the Tarim River.

2. General situation of the study area

The lower reaches of the Tarim River stretch from Qiala in Yuli County to Taitema Lake in Ruoqiang County. The channel bed stretches from east to south on alluvial fans along the Taklimakan and Kuluk deserts. The ground-surface is remarkably flat, and the elevation decreases from north to south. Water seeps from streams into the alluvial fans, which can recharge shallow aquifers. The region is classified as an extremely arid warm temperate zone. The annual precipitation varies in the range 17.4–42.0 mm, and the total annual potential evaporation is approximately 2500–3000 mm. Total solar radiation varies between 5692 and 6360 MJ/m^2 per year, with cumulative daylight hours ranging from 2780 to 2980 h. Annual cumulative temperature $\geqslant$10 °C varies between 4100 and 4300 °C, with an average diurnal temperature ranging from 13 to 17 °C. Strong winds blow frequently in the region. The construction of the Daxihaizi Reservoir in 1972 reduced the water flow into the Tarim River and dried up a length of 321 km in its lower reaches. The groundwater level fell greatly, to a depth of 8–12 m, as a result of the lack of recharging through surface runoff. The soil has been seriously desertified and plant life has seriously degenerated in the region.

3. Materials and methods

3.1. Materials

In conjunction with the establishment of an ecological emergency water supply in 2000 from Bosten Lake to the lower reaches of the Tarim River to restore the riparian vegetation, nine study sections were established. Forty groundwater monitoring wells of 15 m depth and 44 plant plots were established to allow the measurement of the groundwater depth and vegetation responses to the ecological emergency water supply (Fig. 1). In this study, experiments were conducted in Yhepumahan along the lower reaches of the Tarim River. Plant plots of 50 × 50 m were established at different groundwater depths, and were placed at transects of 50, 150, and 250 m from the riverbank. The ground-surface of the plots was remarkably flat with the elevation having little change. In each plot, five trees (*P. euphratica*) of about 50–55 years old, 8–10 m in height, healthy and free of diseases and pest damage were studied. Within each transect, a 15 m deep well was installed for monitoring the groundwater depth by the method of electrical conduction.

3.2. Measurements of the response of photosynthesis in *P. euphratica* to [CO_2]

Four fully expanded, healthy and mature leaves in the middle parts of a tree crown were selected for measurement from each tree. Photosynthetic light-response curves were measured on clear days in June 2006 using a portable gas exchange system (Li-6400, LiCOR, Lincoln, NE, USA) at different [CO_2] (360 ppm and 720 ppm) controlled by a CO_2 injecting system. The light source used was a 6400-02B LED, and was set to 0, 20, 50, 100, 400, 600, 800, 1000, 1200, 1500, and 2000 μmol m^{-2} s^{-1}, individually. Each leaf was measured three replications, and the mean was used. Meanwhile, net photosynthetic rate (P_n), stomatal conductance (g_s), intercellular CO_2 concentration (C_i), air CO_2 concentration (C_a), transpiration rate (T_r), photosynthetically active radiation (PAR), leaf temperature (T_l), air temperature (T_a) and air relative humidity (RH) were automatically recorded by the portable gas exchange system. Water use efficiency (WUE) was calculated from the ratio P_n/T_r.

3.3. Models

The light-response curve of photosynthesis was fitted with a non-rectangular hyperbola [17]:

$$P_n = \frac{\phi I + P_{max} - \sqrt{(\phi I + P_{max})^2 - 4\phi\theta I P_{max}}}{2\theta} - R_d$$

where P_n is the photosynthetic rate; ϕ, the initial slope of the curve; I, photosynthetic photon flux density (PPFD); P_{max}, the light-saturated rate of photosynthesis; θ, the convexity and R_d, the dark respiratory rate. First, from the linear regression of the photosynthetic rate on PPFD at 0–200 mmol.m^{-2} s^{-1}, ϕ, R_d, light saturation point (LSP) and light compensation point (LCP) were obtained from the slope and Y-intercept, respectively. Then, a non-rectangular hyperbola was fitted to the whole curve using the ϕ