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Transpiration and early growth of tree plantations established on degraded cropland over shallow saline groundwater table in northwest Uzbekistan

A. Khamzina[a,*], R. Sommer[b], J.P.A. Lamers[a], P.L.G. Vlek[a]

[a] Center for Development Research (ZEF), Walter Flex Str., 3, 53113 Bonn, Germany
[b] International Center for Agricultural Research in the Dry Areas (ICARDA), P.O. Box 5466, Aleppo, Syria

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ABSTRACT

This study examined the early growth and water use of tree plantations established on a marginalized irrigated cropland in northwest Uzbekistan, where salinization of agricultural soils is widespread due to shallow saline groundwater tables. During the first two growing seasons in 2003–2004, the tree stands consisting of *Elaeagnus angustifolia* L., *Populus euphratica* Oliv., and *Ulmus pumila* L. were irrigated with 80 mm year^{-1}, and, in 2005, were left to rely on the shallow (0.9–2.0 m deep) groundwater with a salinity of 1–5 dS m^{-1}. Soil salinity increased but remained within the range of moderate-to-strong (4–14 dS m^{-1}) during the three years. In the course of the growing season, plantations transpired 0.1–7 mm day^{-1} in 2003 and 1–13 mm day^{-1} in 2004–2005, as determined with the Penman–Monteith model. In the absence of irrigation, the annual stand transpiration averaged 1250, 1030, and 670 mm for *E. angustifolia*, *P. euphratica* and *U. pumila*, respectively. In 2005, the leaf area index of *E. angustifolia* ranged from 5 to 10, surpassing that of the other two species more than two-fold. Differences in canopy conductance and transpiration were significant among the tree species and the decoupling coefficient at no time exceeded 0.3, indicating strong physiological control of transpiration. The vigorous juvenile growth and high transpiration under deficit irrigation and after irrigation was terminated, suggested that afforestation with well-adapted tree species is a viable land use option for degraded cropland. The plantation responses to increasing soil salinity must be monitored to determine potential leaching demands in the long run.

1. Introduction

Planting trees on degraded land has been effective in increasing the productive value of marginalized agricultural areas and in improving rural livelihoods by supplying valuable timber and non-timber products (Lefroy, 2002; Rockwood et al., 2004; Marcar and Crawford, 2004; Lamers et al., 2008). Forest plantations can also improve soil fertility by enhancing nitrogen and organic carbon contents (Danso et al., 1992; Guo and Gifford, 2002) and, through transpiration, mitigate elevated saline groundwater tables (Heuperman et al., 2002), the main cause of cropland salinization in many arid and semi-arid regions of the world (Katyal and Vlek, 2000).

Land degradation due to salinity has plagued about 75% of the irrigated area of the Aral Sea Basin (van Dijk et al., 1999). The Khorezm Region of Uzbekistan, one of the most densely populated areas affected by the desiccation of the Aral Sea was subject of the current study as an example of ubiquitous soil salinization and waterlogging (Ibrakhimov et al., 2007). Several multipurpose tree species were shown to be suitable for afforestation of degraded cropland in the region (Khamzina et al., 2006a, 2008, 2009; Lamers et al., 2008). They demonstrated relatively high transpiration rates (Khamzina et al., 2006b) which are desirable for plantings to discharge the groundwater (Heuperman et al., 2002). It has yet to be determined if the high transpiration potential of the promising tree species is sustained on the degraded cropland. Non-irrigated plantations in saline environments often exhibit low groundwater uptake, eventually resulting in slow growth (Stolte et al., 1997; Thorburn, 1997; Heuperman et al., 2002; Archibald et al., 2006). Very few studies based on non-destructive, direct and long-term measurements of tree transpirational capacity were conducted in arid regions of the Aral Sea Basin.

Among the approaches for estimating stand transpiration, the Penman–Monteith equation (Monteith, 1965) has been most useful (Allen et al., 1998) as it incorporates both, atmospheric and physiological factors influencing transpiration. The importance of the physiological control of transpiration is controversial as studies have successfully predicted canopy transpiration using

* Corresponding author. Tel.: +49 228 73 1715.
E-mail addresses: asia.khamzina@uni-bonn.de (A. Khamzina), r.sommer@cgiar.org (R. Sommer), j.lamers@zef.uzpak.uz (J.P.A. Lamers), p.vlek@uni-bonn.de (P.L.G. Vlek).

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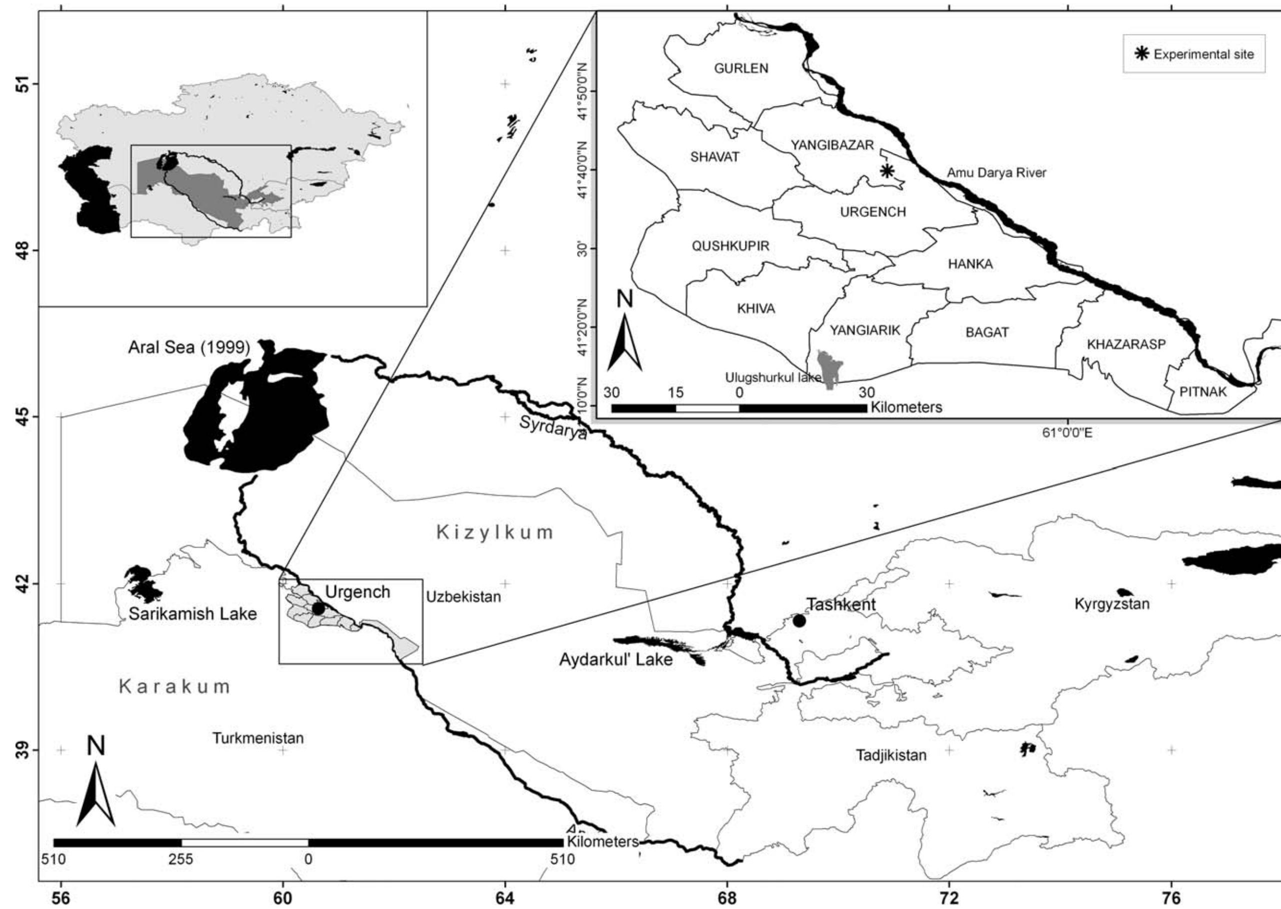

Fig. 1. Location of the Khorezm Region and the experimental site.

micro-meteorological techniques (Sommer et al., 2002). However, differences among species within a stand remain to be explained. Other studies showed that transpiration of different tree species was similar when trees were well-watered (Pereira et al., 2006) or exposed to similar natural growth conditions (Hatton et al., 1998; Landsberg, 1999). Yet, there is ample evidence of significant variation among species (Smith et al., 1998; Granier et al., 2000; Heuperman et al., 2002; Deans and Munro, 2004) resulting from physiological regulation of water loss (Meinzer, 1993). McNaughton and Jarvis (1983) elaborated a useful approach to quantify the stomatal control of transpiration by the use of a decoupling coefficient.

Regionally, the introduction of tree plantations may significantly alter landscape eco-hydrology (Ryszkowski and Kędziora, 1993; Tuteja et al., 2003; Marcar and Crawford, 2004). Thus the current study aimed at examining the early growth and water use of multipurpose tree species when planted on the degraded cropland. This information will be useful for water and energy balance studies and in assessment of the viability of afforestation as an alternative use of the marginal agricultural areas. Evidence of common transpirational behavior in different species would greatly simplify the assessment of tree water use. Therefore, the interest was to evaluate the species-related differences in water use and the importance of the physiological control of transpiration by trees planted on saline soils over the shallow saline groundwater table.

2. Materials and methods

2.1. Study region

The study was conducted in an experimental tree plantation established on degraded cropland in the Khorezm Region of Uzbekistan, at 41°65′N latitude, 60°62′E longitude (altitude 102 m a.s.l.). The region is an oasis within the transition zone of the Karakum and Kizylkum deserts and located in the lower reaches of the Amu Darya River, about 250 km south of the remainders of the Aral Sea (Fig. 1).

Khorezm belongs to the Central Asian semi-desert zone characterized by an extreme continental climate. The mean annual rainfall of 100 mm falls mostly outside the growing season (Fig. 2) and is significantly exceeded by the reference crop evapotranspiration of 900–1000 mm, as estimated with the FAO-56 Penman–Monteith method (Allen et al., 1998).

2.2. Experimental design

The experiment started in March 2003 and continued through October 2005, was laid out as a two factorial split-plot design which examined three irrigation techniques as the main factor and three tree species as the split factor. The irrigation treatments included: (1) drip irrigation applied at a "deficit" rate (80 mm year^{-1}), (2) drip irrigation applied at a "full" rate (160 mm year^{-1}), and (3) traditional furrow irrigation applied at the deficit rate. The furrow irrigation was applied fortnightly whereas the deficit and full drip applications were scheduled respectively once and twice a week. The irrigation took place only during the first two growing seasons (2003–2004) and was ceased thereafter. The plantations consisted of two local species, Russian olive (*Elaeagnus angustifolia* L.) and Euphrates poplar (*Populus euphratica* Oliv.), both naturally occurring in the riparian forest of Amu Darya delta, and Siberian elm (*Ulmus pumila* L.), which was introduced during last century and has been widely planted within the irrigated area since.