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Effect of saline water irrigation on soil development and plant growth in the Taklimakan Desert Highway shelterbelt

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ABSTRACT

Water scarcity is a world-wide problem, especially in desert ecosystems. To overcome this shortage, saline groundwater is increasingly being used, although it has risks of increasing soil salinity and causing plant salt toxicity. In this study, we investigated the effects of saline water irrigation on soil properties and plant growth along the Taklimakan Desert Highway shelterbelt. The results showed that soil salts (about 8 mS cm^{-1}) and nutrients significantly accumulated at the soil surface (crust and 0–10 cm soil layers) with saline irrigation, but the soil salinization did not increase (<1.0 mS cm^{-1}) within the 40–60 cm soil depth where abundant lateral roots also germinated and extended horizontally. While the deepest main root system was 200 cm for *Tamarix*, it extended to about 150 cm for other two species studied (*Haloxylon* and *Calligonum*). More than 87% of the biomass of the lateral roots was present in the 20–80 cm soil depths for the three species; although no active absorbing roots were found within the 0–10 cm soil depths where the salts had accumulated. These findings indicated that saline water irrigation within artificial shelterbelts may be beneficial for soil nutrient accumulation and accentuates the potential uses of these sandy soils. After 7-yrs irrigation with nutrient accumulation, structured soil under shelterbelt has progressively formed, as indicated by increased soil aggregate size and stability. Saline water irrigation did not influence the normal growth of adaptive plants, which may be attributed to the plant adaptability to salt stress through root morphology adjustment. In summary, saline groundwater irrigation offers potential advantages and opportunities for plant growth on sandy soils evolution in a desert environment where saline groundwater is the sole water resource for plants.

1. Introduction

Global desertification is increasing at a rate of about 5–7 × 10^4 km^2 per year with an associated annual economic loss estimated at over 42 billion dollars (UNEP, 1997). Combating desertification, therefore, is an important and urgent global task. Forestation has been identified as a vital eco-engineering measure for combating desertification and has been widely implemented in major fragile regions and many desert ecosystems throughout the world (Wei et al., 2012). However, great difficulties have been encountered when forestation is attempted in mobile desert regions, such as the Taklimakan Desert, due to the lack of fresh water and extremely droughty environmental characteristics (Zhang et al., 2008; Huang and Pang, 2012).

In the arid and semi-arid ecosystems, water scarcity is becoming a world-wide problem of increasing severity (Chartzoulakis, 2005). To overcome this shortage, lower quality-water, such as saline groundwater, is widely used (Beltran, 1999; Feikema et al., 2010; Verma et al., 2012). However, saline groundwater typically contains solutes of varying concentrations, and its utilization may noticeably affect soil characteristics. Because of salt accumulation in the root zone, saline water irrigation normally result in increased soil salinization and greater salinity hazards to plant growth and survival in irrigated areas (Tedeschi and Dell'Aquila, 2005; Wang et al., 2011).

The Taklimakan Desert, the largest mobile desert in China, is located in the hinterland of the Tarim Basin in China. It has been

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called the "Dead Sea" since there are few organisms exist in its harsh environment characterized by very limited rainfall and strong evaporative potential (Lei et al., 2008). In 1997, a highway was built through the desert to access oil fields. Afterward, the Taklimakan Desert Highway shelterbelt (TDHS), so-called "Great Green Wall", was constructed in 2003 to limit sand drift onto the highway. By introducing several drought- and salt-tolerant plants, the mobile dunes have been successfully stabilized on both sides of the highway for more than 10 years. Remarkably, artificial shelterbelts play an important role in wind prevention and sand-fixation in desert ecosystems and greatly benefit ecological restoration, biodiversity protection and environmental protection (Wei et al., 2012). However, as a result of drip-irrigation with high salinity groundwater (2.8–29.7 g L^{-1}), in combination with high rates of evaporation, solute ions have accumulated and salt crusts have become widely distributed on soil surfaces in the shelterbelt. This may have a larger impact on plant growth and soil evaporation (Zhang et al., 2008).

Previous studies have addressed saline water irrigation and its influence on soil properties and plant growth (Beltran, 1999; Feikema et al., 2010; Verma et al., 2012). However, these studies have mostly focused on the negative impacts of soil salinity at the root zone and on salt toxicity (Muyen et al., 2011; Steele and Aitkenhead-Peterson, 2013), whereas the positive effects of saline water irrigation on sandy soil development and the survival of plants, such as soil nutrient accumulation, have been ignored. The saline water irrigation may input the nutrient components into soil. The artificial shelterbelts could be beneficial for the soil nutrient accumulation due to the vegetative litter decomposition, root growth and decomposition and other biogeochemical cycles (Schlesinger et al., 1996). This mechanism might be particularly important with regards to sandy soil development and the survival of drought-and-salt tolerant plants in arid areas such as the Taklimakan Desert. Consequently, research to evaluate the effects of saline water on soil and plants are essential for the TDHS sustainability. In this paper, our objectives are: (1) to determine the effects of saline water irrigation on Aeolian sandy soil development and (2) to clarify how the soil salinity induced by saline water irrigation impacts plant growth in the desert.

2. Materials and methods

2.1. Study area

This study was conducted in the Taklimakan Desert Highway shelterbelt (TDHS; Fig. 1), which is an extremely arid area with a mean annual precipitation of <50 mm, annual pan evaporation of >3000 mm (Lei et al., 2008). The mean air temperature is 12 °C, with a maximum of 45.6 °C in August and a minimum of −22.2 °C in January. The blowing of sand is a serious problem, as the area is characterized by a mean annual wind speed of 2.5 m s^{-1}, a maximum instantaneous wind speed of 20.0 m s^{-1} and more than 130 days for sand-shifting. The vegetation community structure is very sparse, and most areas have no vegetation (Li et al., 2008). The soil is typical sandy soil with very limited nutrient content. The soil basic physical properties are presented in Table 1.

The Taklimakan Desert Highway distances 556 km connecting Luntai to Minfeng, and then the highway extends to the Central Asia countries as a part of Central Asia Continental Bridge (Fig. 1). To reduce wind erosion and keeps the highway from being blocked by sand, the artificial shelterbelt was completed in 2005 by initially planting three species (i.e., *Haloxylon*, *Tamarix* and *Calligonum*) in a preliminary experiment (Wang et al., 2008). Finally, the TDHS built from Xiaotang to Minfeng with 436 km long and 72–78 m wide (Fig. 1). It presents an excellent example of the benefits of ecological restoration for biodiversity protection and the prevention of desertification (Fig. 2). Saline groundwater was selected for drip irrigation, and the irrigation was applied twice a month from March to October during vegetation periods. This long-term irrigation has resulted in a significant salt crust formation within the shelterbelt soil surface layer (Zhang et al., 2008).

2.2. Sampling and analysis

Field soil sampling was conducted along the Highway shelterbelt in September of 2012 (Fig. 1). Seven sampling sites with differences in groundwater salinity (3.6–26.2 g L^{-1}) were selected to investigate the effects of different salinity irrigations on soil chemical properties. The soil was sampled five times at each site using an auger at eight depths of 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 60–80 and 80–100 cm.

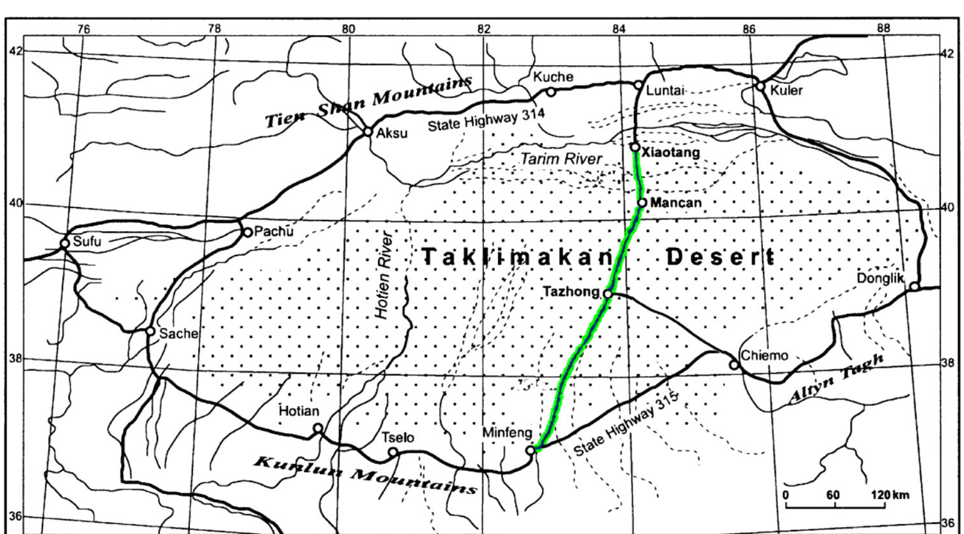

Fig. 1. Map of the Taklimakan Desert highway and the sampling sites. *Notes*: The black line represents the desert highway which crosses the Taklimakan Desert from Luntai to Minfeng. The green lines on both sides of the highway represent the artificial shelterbelt. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)