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Temporal stability analysis identifies soil water relations under different land use types in an oasis agroforestry ecosystem

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ABSTRACT

The spring wheat–shelterbelt–maize agroforestry ecosystem is one of the most common land use patterns occurring in oasis agriculture in the arid zones of northwest China. Soil water interactions were hypothesized to exist between adjacent land use types, and that these interactions could be analyzed by using the soil water content (SWC) measured at the most time-stable locations (MTSLs) under each land use type. Objectives of this study were to (1) identify the MTSLs for the different soil layers under each land use type and (2) to investigate the soil water relations between adjacent land use types using the SWC measured at the identified MTSLs. The SWC was measured in 2012 and 2013 at 10-cm depth intervals within 0–260 cm soil profiles at 36 locations along three transects that passed through spring wheat, shelterbelt, and maize subplots. A time-stability analysis of SWC was used to identify the MTSLs in the four different soil layers under each of the three land use types. The results indicated that temporal variations in soil water in the same soil layer among the three land use types tended to have similar patterns. The SWC of the different soil layers under maize exhibited the highest temporal stability among the three land use types. The SWC measured at the MTSLs identified for each soil layer under each land use type was proven to represent their mean SWC. Correlation analyses of the SWCs measured at the MTSLs between two land use types indicated that soil water relations occurred between adjacent land use types but not between those that were non-adjacent land use types by the correlation analyses of the SWCs measured at the MTSLs between two land use types. In the upper soil layer (0–200 cm), soil water relations were mainly affected by shelterbelt root water uptake from the adjacent cropland into which the tree roots had extended. In the lower soil layer (200–260 cm), the soil water relations among the three land use types were due to groundwater recharge, which was a result of crop irrigation that had raised the water table to a level at which it could replenish this soil layer.

1. Introduction

Sandy desertification is an important environmental problem confronting oasis-agricultural ecosystems (Luo et al., 2005). In order to protect the cropland against damage from sandstorms and dry thermal winds originating in deserts, shelterbelts have been planted around and within the oasis areas. However, perennial trees have greater water consumption than annual crops (Ong et al., 1992; Williams et al., 2009). In order to develop sustainable management systems of limited water resources, it is essential to know about the soil water variations and relations that occur within and among the different land use types that comprise an agroforestry ecosystem.

The Heihe River is one of the largest inland rivers in the arid zones of northwest China. The Heihe River Basin (HRB) supports oasis agriculture that is of great significance to the social and economic development of the region. One of the most common land use patterns used in the oasis agriculture is spring wheat–shelterbelt–maize agroforestry. Past studies of soil water under oasis agricultural systems have mainly focused on the relations between soil water and plant species diversity (Li et al., 2008), and on the spatial variability of soil water within the oasis-desert (Wang et al., 2007) and cropland–shelterbelt–desert ecotones (Shen et al., 2014). However, few studies have considered the spring wheat–shelterbelt–maize land use pattern as an entire continuum when investigating soil water variations and relations within it. Such knowledge would be of importance to the management of the limited basin water resources.

An agroforestry ecosystem refers to land use systems in which woody perennials are purposely planted in the same land management units as agricultural crops (Nair, 1985; Nestel, 1983). In such a system,

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the effects on soil water variations are more complex under the combination of trees and seasonal crops than under the same trees and crops when grown separately. Soil water variations within an agroforestry ecosystem depend on many factors, including the tree and crop species, the proportions of land area allocated to the crops and the trees, root distributions, soil properties, and the prevalent climate. Another factor is the proximity of the crops to the trees and/or the pattern of their distributions in relation to each other. Previous studies had shown that trees could extract water from the soil in adjacent cropland areas, and that this depended on the type of agroforestry system (Ellis et al., 2005; Knight et al., 2002; Malik and Sharma, 1990). The SWCs under crops were depleted to a greater extent by tree root water uptake as the distance from the trees became shorter (Huxley et al., 1994; Livesley et al., 2004; Shen et al., 2014; Woodall and Ward, 2002). Similar results were obtained for adjacent land use types by Ellis et al. (2005) who studied cropland and shelterbelt systems and by Knight et al. (2002) who investigated shelterbelt and pasture interactions.

Understanding the temporal variability of soil water is essential to water resources management. The concept of time stability, which was first proposed by Vachaud et al. (1985), is useful when investigating SWC variability over time. It enables the time-invariant relations between SWC (or another soil property) at a given spatial location and its basic statistical parameters to be characterized. Kachanoski and Jong (1988) developed the concept of time stability of soil water at specific sampling locations to encompass the temporal persistence of spatial soil-water distribution patterns, which was determined by using Spearman rank correlation analysis between successive time intervals. One of the most useful practical applications of the time stability concept is to find the most time-stable locations (MTSLs) that can then represent the mean SWC for a given area (Brocca et al., 2009; Grayson and Western, 1998; Hu et al., 2009, 2010; Martínez-Fernández and Ceballos, 2005; Liu and Shao, 2014).

Agroforestry systems are commonplace in all ecological and geographical regions of world (Nair, 1993). Therefore, understanding of soil water relations among the different land use types of such agroforestry systems is important in order to increase the water use efficiency of the whole system as well as the crop productivity. We hypothesized that soil water interactions existed between adjacent land use types, and that these interactions could be analyzed by using the SWC measured at the MTSLs under each land use type. The main objectives were to: (1) identify the MTSLs for the different soil layers under the three land use types comprising the agroforestry ecosystem and (2) to investigate the soil water relations between adjacent land use types using the SWC measured at the identified MTSLs.

2. Materials and methods

2.1. Study area

The study area is at the Linze Ecological Observational and Experimental Station (39°21'N, 100°07'E), which is located in a desert-oasis ecotone in the middle reach of the HRB of Northwest China (Fig. 1). The site is characterized by continental arid temperate climate conditions, with a mean annual precipitation of 116.8 mm (1965–2000), about 90% of which falls during the rainy season between June and September. The mean annual air temperature is about 7.6 °C, and varies between the mean minimum temperature of −27.8 °C in December and the mean maximum temperature of 39.1 °C in August. The mean annual open water evaporation is about 2365 mm (Chang et al., 2006). The mean frost-free period is 165 days, and the relative humidity ranges from 7.3% to 80.9% (Chang et al., 2006). The area is densely vegetated with crops (mainly maize, *Zea mays* and spring wheat, *Triticum spp.*) and shelterbelts consisting mostly of Gansu Poplar (*Populus gansuensis*).

2.2. Experimental design and measurements

An 80 m × 16 m experimental plot was established that included three subplots along its length. In sequence, these were a spring wheat subplot, a shelterbelt subplot, and a maize subplot with length of 22, 36, and 22 m, respectively (Fig. 2). Thus, the shelterbelt was bordered to the south by spring wheat and to the north by maize. The shelterbelt had nine rows of Gansu Poplars, which were planted in 1980

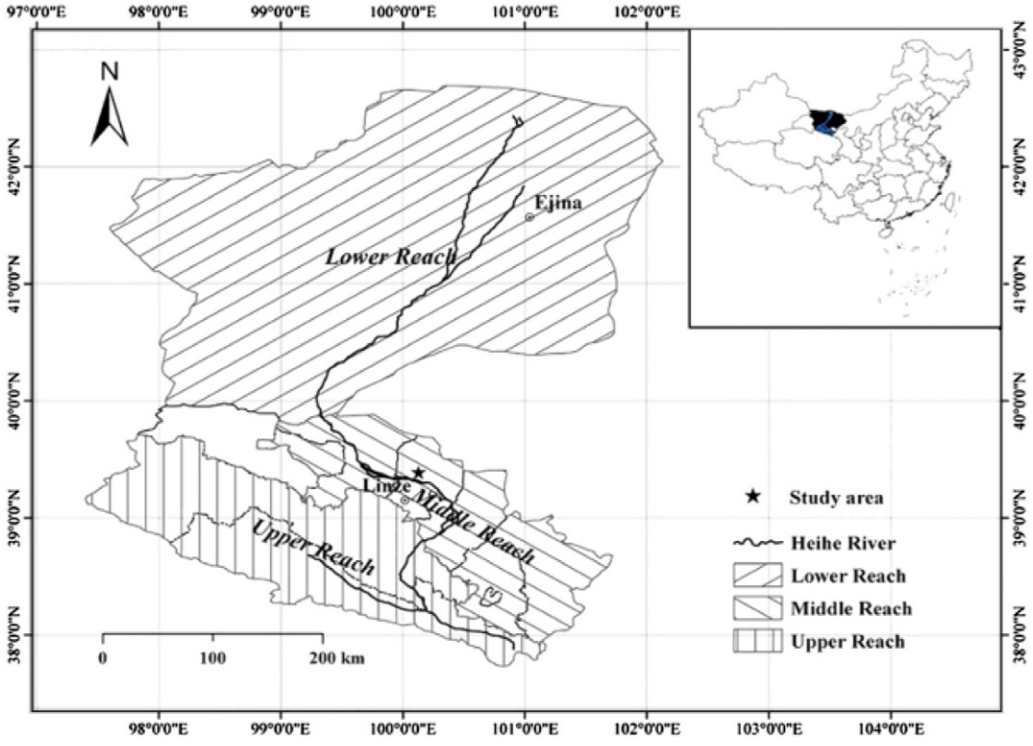

Fig. 1. Location of the study area in the Heihe River basin, China.