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Soil water content variations and hydrological relations of the cropland-treebelt-desert land use pattern in an oasis-desert ecotone of the Heihe River Basin, China

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ABSTRACT

This study considered the cropland-treebelt-desert system in the arid inland river basin as an entire continuum to investigate the soil water content variation and hydrological relation. For this objective, the volumetric soil water content and plant root distribution was measured to 300 cm depth along a cropland-treebelt-desert site at the oasis-desert ecotone in the Heihe River Basin, China. The results showed that the mean soil water content in the 0–200 cm layer was greater in the cropland (8.88%) than that in the treebelt (5.78%) and desert (4.37%) as a result of frequent irrigation events. However, the cropland had noticeably lower mean soil water content below 200 cm depth (14.27%), compared to treebelt (18.07%) and desert (17.30%) with deeper roots to suck up groundwater. The decline process in soil water content pulse of the cropland and treebelt after irrigation event could be well described by an exponential decay function, and the soil water loss rate was greater in the cropland (0.45–0.70%/day) than that in the treebelt (0.32–0.47%/day). The hydrological relation between treebelt and cropland in the upper soil layer was mainly occurred by treebelt root water uptake from cropland. The biomass of fine treebelt root extended into the cropland decreased logarithmically with the distance from the cropland-treebelt interface, which resulted in the smaller soil water content in the cropland with more proximity to the treebelt. The hydrological relation in the lower soil layer among cropland-treebelt-desert was caused by groundwater recharge, as cropland irrigation raised up the groundwater level to replenish the deep soil layer. The results indicated that the percolation in the cropland was an important water source for the growth of treebelt and desert plants. This study could provide scientific basis for land use pattern design and water resources management in the arid inland river basin.

1. Introduction

Water resources play an important role in the development of oasis-desert ecosystems in the arid inland river basins (Wang and Cheng, 1999). A shortage of water resource in these areas has become an increasingly serious problem because of over-consumption by agricultural irrigation and human and industrial uses. This change substantially results in the response of hydrological cycles and degradation of the distinctive ecosystems (Wang et al., 2007a,b). Soil water is a critical component of the hydrological cycle and an essential mediator between land surface and atmospheric interactions (Mahmood and Hubbard, 2007). It is involved in many hydrological processes, including infiltration from rainfall, drainage to deeper layers, and discharge from groundwater, as well as root uptake and evapotranspiration. Soil water content is a typical indicator of water limitation in dryland ecosystems (Porporato et al., 2002).

Many studies have been conducted to examine the soil water content dynamics in the oasis-desert ecosystems of arid inland river basin. The studies typically focused on the soil water content variations and the influencing factors of single land use type, e.g., the cropland (Ji et al., 2007), grassland (Coronato and Bertiller, 1996), artificial forest (Knight et al., 2002) and desert (Li et al., 2008). The effects of soil texture, root distribution and groundwater recharge on soil water content variations were investigated (Dodd and Lauenroth, 1997; Kizito et al., 2007). The effects of land use and soil texture on spatial variability of soil water content were also conducted in the Chinese Loess Plateau (Fu et al., 2003; Hu et al., 2008, 2011; Huang et al., 2012). Singh et al. (1998) found that the soil water content profile in the shortgrass steppe was determined by the soil texture and root distribution, and it was higher in a clay loam site than that in a sandy loam site. Kizito et al. (2007) found that shrub had a positive effect on the field moisture regime as it had deep root distribution to compete with the crops for water from the deep soil layers and groundwater. Furthermore, it has

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recently been demonstrated that the soil water content was inversely correlated with the biomass of above ground vegetation (Wang et al., 2007a,b).

The combinations of land use or vegetation types had substantial effects on soil water content dynamics in arid and semi-arid regions (Ruiz-Sinoga et al., 2011; Valentin et al., 1999). In the oasis-desert ectone of an arid inland river basin, there are many representative land use patterns such as cropland-treebelt, treebelt-desert and cropland-treebelt-desert. The studies on soil water content variations among the agroforestry system are becoming prevalent because of the need to reduce agricultural water use (Campi et al., 2009). These studies primarily concentrated on comparing the water use of adjacent land use types and the hydrological interactions between them, such as cropland and treebelt (Ellis et al., 2005), or treebelt and pasture (Knight et al., 2002). The results showed that treebelt could use soil water from the adjacent cropland or pasture within a few metres' distance. This conclusion was supported by the findings of Woodall and Ward (2002) who reported that tree-crop competition for soil water reduced wheat growth and grain yield to a distance of 20–30 m from the trees. Livesley et al. (2004) found that soil water content in an alley cropping system varied spatially with the distance from a tree row.

The Heihe River is one of the largest inland rivers in the arid zones of northwest China. The studies on soil water content in the oasis-desert ecotone of the basin mainly focused on the relationship between soil water content and plant species diversity, and the spatial variability of soil water content and vegetation along the oasis-desert ecotone. Li et al. (2008) found that the shallow soil water content mainly influenced the diversity of herbaceous species, especially the annual and ephemeral plants, whereas the diversity of woody species evidently depended on deeper soil water content. The soil water content and vegetation existed strong distribution pattern of spatial heterogeneity representing a random distribution on a small scale (<100 m) and a mass distribution structure on a larger scale (100–3100 m) (Wang et al., 2007a,b). Despite these studies, the comparison of soil water content variations in different layers among cropland, treebelt and desert, and the integrated effects of irrigation, land use type and groundwater fluctuation on soil water content variations should be substantially addressed. Furthermore, there were few studies considering the cropland-treebelt-desert land use pattern as an entire continuum to investigate the inside soil water content dynamics and hydrological relations, which are very useful for the management of basin water resources.

In this study, a cropland-treebelt-desert field site with shallow groundwater table was selected. The volumetric soil water content and plant root distribution was measured to the depth of 300 cm in the site during the maize growing season in 2012. The main objectives were to (1) compare profile distribution and temporal variations of soil water content between these three land use types, (2) investigate the water exchange among the cropland-treebelt-desert land use pattern, and (3) discuss the soil water content variations and hydrological relations in this land use pattern.

2. Materials and methods

2.1. Study area

The study area is located in a desert-oasis ecotone in the middle reach of the Heihe River Basin, in Linze County of Gansu province, China (39°21′ N, 100°07′ E, altitude 1374 m) (Fig. 1). The area has a continental arid temperate climate with an average annual rainfall of 116.8 mm. The potential evaporation is 2390 mm year^{-1}, and the

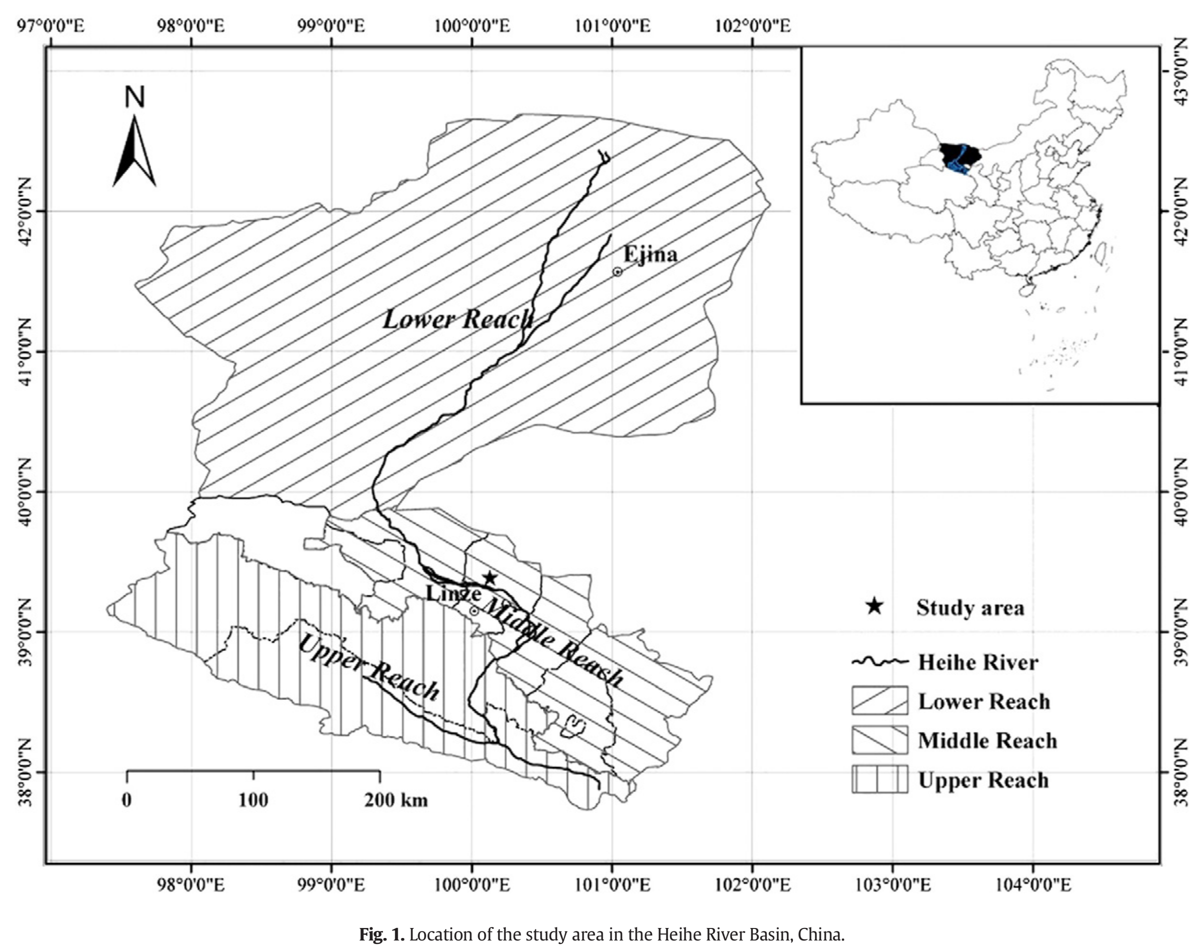

Fig. 1. Location of the study area in the Heihe River Basin, China.