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Influences of afforestation policies on soil moisture content in China's arid and semi-arid regions

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ABSTRACT

In exploring the effects of afforestation policies on soil water dynamics, soil moisture content was measured in two different rainfall events (within a lengthy drought period and during a drought-free period), up to 1.0 m depth, both at non-afforested and afforested sites situated in China's central region. The non-afforested sites included abandoned and cropped lands. These were compared to lands afforested with either poplar or apricot of different stand ages: 16- *vs*. 40-year for apricot, and 40-year primary planting *vs*. c. 30-year secondary planting for poplar. The results showed that at the 1.0 m soil depth profile, the average soil moisture content across all forested lands was consistently inferior to that of either arable or abandoned lands both in the absence of rain and after rainfall events. The arable and abandoned lands showed no difference in soil moisture content in the absence of rain (9.16% *vs.* 9.24%, respectively), whereas a significant difference did exist after rainfall events (18.31% *vs.* 16.99%). However, among all the investigated land types, primary and secondary poplar stands showed the highest soil moisture content levels both before (≈10.00%) and after rain (≈18.50%), whereas apricot stand soil moisture content levels were approximately 7.17%, and 15.86%, before and after rain, respectively. Stand age had a significant effect on soil moisture content, with a 16-year stand of apricot being 8.44%, but a 40-year stand being 5.89%. Given that in the present study, afforestation species and stand age together with rainfall events influenced soil moisture content, these factors should be considered in implementing afforestation, and in making accurate comparisons among land use types in arid and semiarid regions, where water is the key limiting resource.

1. Introduction

There is growing evidence and consensus that afforestation plays a key role in addressing the challenges of global climate change (Pacala and Socolow, 2004; Thomas et al., 2010; Ellison et al., 2017; Hardaker, 2018), because tree growth and stand regeneration can draw down atmospheric CO_2 (Humpenöder et al., 2014), and improve carbon sequestration (Humpenöder et al., 2014; Han et al., 2017). Afforestation has converted forsaken agricultural lands of poor soil fertility and productivity, and some naturally-vegetated but low-productivity lands to forest, thereby extending the lands' former short production cycles to the much longer ones of forested lands (Cao et al., 2011; Ren et al., 2016).

Socioeconomic and environmental devastation brought on by the extensive Yangtze River flooding events of 1998 focused considerable attention on nature conservation and environmental protection in China. In response, the 1999 "Grain for Green" (Tui Geng Huan Lin) Project aimed to return 32 million ha of cultivated hillside (slope ≥ 25°) lands across China to forestland by 2010 (Chen et al., 2010; Wang et al., 2011). This project was implemented at various scales, from village to township, and to province, with significant variation in eco-hydrological understanding, financial capacity, and management goals (Mcvicar et al., 2007). In concert with other afforestation policies (*e.g.*, Three-North Shelterbelt policy, National Forest Protection policy), China's goal is to increase national forest cover from 22.2% to 26% in 2050 (Wang et al., 2007). Current forest plantations in China cover about 0.69 million km^2, accounting for one third of the world's total forest plantation areas (Chen et al., 2016).

While studies suggest afforestation could offer significant ecological benefits, such as increasing soil enzymatic activity and decreasing soil bulk density and pH (Prietzel and Bachmann, 2012; Ren et al., 2016; Zhang et al., 2016; Zhang et al., 2017); controlling wind- and rain-driven soil erosion (Cao, 2008; Liu et al., 2018); improving plant cover, species diversity, and primary productivity (Lozano et al., 2014); and,

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regulating water use and soil moisture dynamics by altering evapotranspiration (ET), infiltration and surface runoff (Jia et al., 2017), these positive impacts come at a price in terms of soil water (Liu et al., 2008; Nosetto et al., 2005; Shangguan and Zheng, 2006; Chen et al., 2008; Yu et al., 2010; Cao et al., 2011; Cao and Zhang, 2015; Liu et al., 2018). Despite the many reports on the effects of afforestation on soil moisture content (θ), assessments based on ground-truthed observations remain lacking, and, accordingly, the regional impact of afforestation is still poorly understood (Jia et al., 2017). As in the absence of scientific consensus, it is very difficult to predict the likely effects of afforestation on specific locations, or to plan for such projects (Farley et al., 2005; Ilstedt et al., 2007).

Easily affected by root channels and the area of root channels due to land use or land cover changes (Wu et al., 2017), and closely tied to water table depth, Sciences θ is a vital component of the hydrologic cycle and soil moisture dynamics (Trabucco et al., 2008; Jia et al., 2017), and a commonly used parameter that plays an important role in land-vegetation-atmosphere interactions (Seneviratne et al., 2010). Therefore, understanding the hydrologic effects of afforestation on θ is important both in terms of water fluxes through the soil-plant-atmosphere continuum, and the water cycle and eco-hydrological processes of terrestrial ecosystems (Derak and Cortina, 2014). It is a particularly critical environmental parameter in arid and semi-arid regions, where soil water is the main resource limiting revegetation (Chen et al., 2010; Wu et al., 2016). In the present study, our hypothesis was that afforestation consumed more water than other land use patterns, and arboreal water consumption was negatively correlated to stand age.

2. Materials and methods

2.1. Study area

Located in central Gansu Province, China, (lat. 104°29′–105°31′E, long. 35°24′–36°26′N) at a mean altitude of 2025 m, Huining County covers an area of roughly 6439 km^2, and is subject to a mean annual temperature of 6–9 °C and a mean rainfall of 180–450 mm y^{-1}. The region is characterized by complex tectonic structures, most of which are based on metamorphic rocks and granites.

Encouraged by National Farmland to Forest policies, Huining county saw the onset of large-scale afforestation in 1999, with most trees having been planted between 2000 and 2003. By the end of 2015, the county's total afforested area reached 706.7 km^2, representing a forest coverage rate of approximately 12.47%. Influenced by the quality of seedings, high sapling maintenance costs and water deficiency issues, tree survival rates were very low in the county's northern and central regions, and highest in the south due to its greater precipitation, where sampling was undertaken. In all, four sites were selected for investigation (Fig. 1). Soils at all selected sites were of a loessial type, with pH between 7.5–7.8, soil bulk density between 1.0–1.3 Mg m^{-3}, silt and sand being about 60%, field capacity between 13–25%, and permanent wilting point between 3-8%.

2.2. Experimental design

To explore the effect of afforestation on θ, non-forested land use patterns, including arable lands, and abandoned lands (Fig. 2), were also surveyed during the period of July to September 2017. The main crops of southern Huining county are wheat (*Triticum æstivum* L.), potato (*Solanum tuberosum* L.), maize (*Zea mays* L.), and flax (*Linum usitatissimum* L.). Industrialization and urbanization driving migrant workers to leave the land for urban jobs, families moving to Huining and other cities for better educational opportunities, and young people no longer returning after their college graduation, has, as elsewhere in the world, led to the abandonment of large swaths of what were originally arable lands of greater or lesser yield potential (Lasanta et al., 2000; Terres et al., 2015). Most of the abandoned tracts of land in the study area had been abandoned between 5 and 10 years, while a few were abandoned over 20 years. Given the difficulty in identifying the year in which a farm was definitively abandoned, abandoned lands were divided into two types: ≤5 years, and > 5 years.

Within the study region two species were most often employed in afforestation: poplar (*Populus tremula* L.) and apricot (*Prunus armeniaca* L.). In 1978, under the Three-North (Northeast, North Central, and Northwest China) Forest Shelterbelt Program — the earliest large-scale afforestation program in China (Wang et al., 2011) — poplar stands, which were to eventually form a pure ecological forest, were planted. However, about 10 years later, most of these forests were harvested by locals for building materials, with only a few remaining well-protected. Accordingly, the original forests (about 40 years old) and secondary forests (about 30 years old) currently co-exist (Fig. 2). With the goals of reducing soil erosion and helping farmers maintain their incomes by selling almonds, apricot forests were also planted in 1978, and later in 2001, and they can be regarded as eco-economic forests.

Sampling began after an unprecedented 3-month drought in July 2017. Such a rare local meteorological phenomenon led to any previous precipitation being fully depleted by plants and soils in all investigated lands. This offered a particular insight into the effect of afforestation (*vs.* other land use patterns) on groundwater. Roughly a month after initial soil sampling, rain fell inconsistently over a period of about 25 days, never allowing soil to dry out as fall approached. Moist soil samples were then taken on three sunny days after the rainfall event.

On arable and abandoned lands, soils were sampled from three

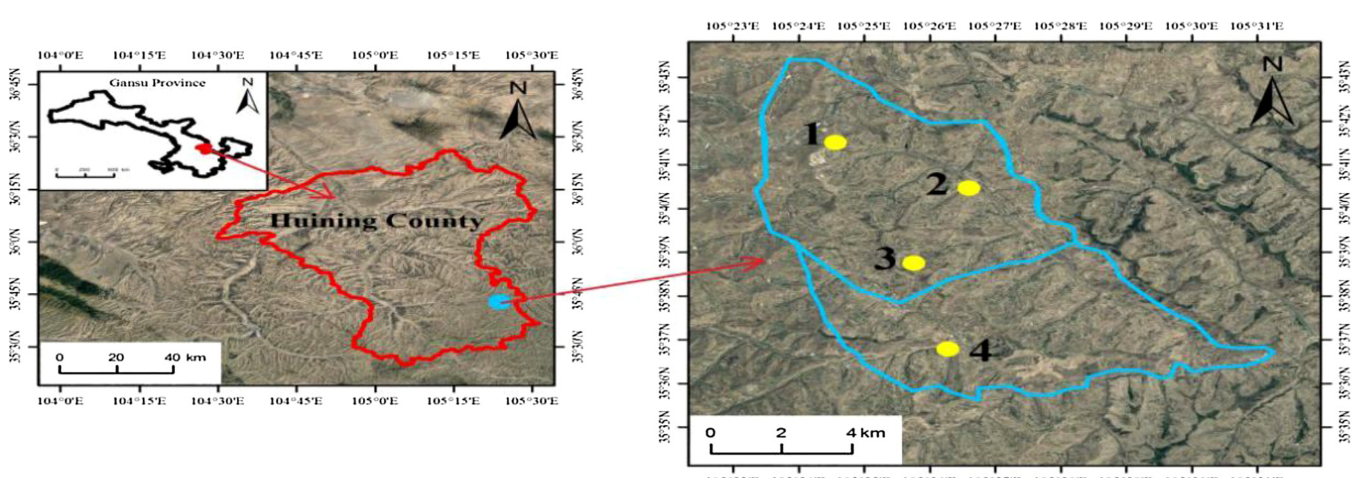

Fig. 1. Location of soil sampling sites in Huining County, Gansu Province, China.