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Changes of soil hydraulic properties under early-stage natural vegetation recovering on the Loess Plateau of China

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ABSTRACT

The changes of soil hydraulic properties under early-stage (from several years to a few decades) natural vegetation recovering are not well understood in semiarid zones. We hypothesized that early-stage vegetation recovering can change measurably soil hydraulic properties and this would behave differently from long-term (from several decades to hundreds of years) vegetation recovering. This study investigated the dynamics of soil hydraulic properties under natural vegetation recovering of different ages (1, 5, 9, and 16–20 years) as compare to cropland and 30-year-old secondary grassland (two controls) on the semiarid Loess Plateau. The hydraulic properties included dry bulk density, total porosity, and near-saturated hydraulic conductivity at the potential of −0.5, −1, −3 and −5 cm of water. The results showed that the increases of vegetation species, coverage and aboveground biomass did not improve soil hydraulic properties. Specifically, dry bulk density increased while total porosity and near-saturated hydraulic conductivity at various potentials decreased with the increase of abandonment years. Moreover, we found that it would take at least 20 years to reverse the decreasing trend for soil hydraulic conductivities. These results suggest that vegetation recovering may not necessarily ameliorate soil hydraulic properties.

1. Introduction

Since the initiation of a large-scale ecological conservation program termed "Grain for Green" project in western China in 1999, land cover has been recovering on the Loess Plateau where it is well known for serious erosion (Zhang et al., 2013). Abandoning of sloping cropland is one of the primary management policies in this region to recover vegetation (Jiao et al., 2007). Over recent years, increasing croplands has been abandoned due to the economic and policy-driving factors (Fu et al., 2006). Nowadays diverse land use patterns exist in the Loess Plateau including cropland, abandoned cropland at various ages, natural grassland and forest, artificial vegetation, and so forth. Land use change can disrupt surface hydrology and water balance (Foley, 2005). This can be partly attributed to the alteration of soil hydrological properties (Scheffler et al., 2011) which determine the partitioning of precipitation into subsurface storage and surface runoff to stream networks (Price et al., 2010; Zimmermann et al., 2006).

A large literature has shown that land use and land use change have important effect on soil hydraulic properties (e.g. Agnese et al., 2011; Beerten et al., 2012; Bormann and Klaassen, 2008; Elsenbeer et al., 1999; McQueen and Shepherd, 2002; Price et al., 2010; Scheffler et al., 2011; Wang et al., 2013; Zeng et al., 2013), although a few observed insignificant effect (Hu et al., 2009; Zhou et al., 2008). On the one hand, land clearing or deforestation would increase soil compaction and then deteriorate soil infiltrability and hydraulic conductivity (Lal, 1996; Price et al., 2010; Scheffler et al., 2011; Zimmermann et al., 2006). On the other hand, vegetation regrowth tends to ameliorate soil structure and improve hydraulic properties. Several efforts have shown that the conversion of cropland/pasture to native grassland/forest decreased soil bulk density and increased hydraulic properties (Beerten et al., 2012; Li and Shao, 2006; Peng et al., 2012; Wang et al., 2012).

Although increasing interests regarding the effects of land use change on soil hydraulic properties have risen in recent years, most of these studies mainly focused on the long-term effects of vegetation succession from a few decades to several hundred years. Only a few studies have attempted to investigate the response of soil hydraulic properties to early-stage vegetation restoration. Hassler et al. (2011) reported that secondary forest of 5–8 years of age showed no significant difference of saturated hydraulic conductivity with pasture (original land use) while secondary forest of 12–15 years old held significantly higher saturated hydraulic conductivity than pasture in Panama. However, the study site of Hassler et al. (2011) was located in a tropical forest where it showed distinct climate and soil conditions with semiarid zones. Li et al. (2010) and Wang et al. (2012) investigated the changes of saturated hydraulic properties at various stages of artificial and secondary grassland on the Loess Plateau of China. However, vegetation succession

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in their studies was affected greatly by human disturbances including mowing and grazing. Therefore, the results in their studies did not represent the true changes of soil hydraulic properties under natural vegetation recovering.

Over recent years, widespread vegetation recovering occurs in many arid and semiarid regions around the world wherein the Loess Plateau is a typical one. Therefore, there is an urgent need to understand systematically the changes of soil hydraulic properties under early-stage natural vegetation recovering on the Loess Plateau. This study defined "early stage" as from several years to a few decades as opposed to the "long term" (several decades to hundreds of years) used in previous studies (Li and Shao, 2006; Peng et al., 2012; Wang et al., 2012). Based on the field experiences, we hypothesized that early-stage natural vegetation recovering can also measurably alter soil hydraulic properties and this would behave differently with long-term vegetation recovering. This study aimed to test the hypothesis by investigating the soil hydraulic response to early-stage natural vegetation restoration of different ages (1, 5, 9, and 16–20 years) as compared to cropland and 30-year-old secondary grassland in the semiarid Loess Plateau. Soil dry bulk density, total porosity, and near-saturated hydraulic conductivity at different potentials were used for analyses. Near-saturated rather than saturated hydraulic conductivity was used for analysis here because it is more important in the Loess Plateau region where infiltration-excess runoff is the main type of overland flow.

2. Materials and methods

2.1. Study site

The study site is located in two adjacent small watersheds (37°15′ N, 118° 18′ E) of the Loess Plateau where widespread vegetation recovering has been going on. These two small watersheds are named Yuanzegou watershed (0.6 km^2) and Mazilenggou watershed (0.7 km^2), respectively. According to Gao et al. (2011), this area has a semiarid continental climate with: mean annual precipitation of 505 mm, and 70% of them falls in late summer and early autumn; a mean annual temperature of 8.6 °C, with mean monthly temperatures ranging from −6.5 °C in January to 22.8 °C in July. These two watersheds showed similar slope angles, elevation, and soils. Both of them are covered by loess soils which belong to silt loam (Inceptisols, USDA). All samples fell within the range of 10% to 30% sand, 60% to 70% silt, and 10% to 25% clay content. The field capacity and permanent wilting point of the loess in this study site is 24.3% and 8.8% (volumetric water content, hereafter), respectively.

These two small watersheds were totally agricultural watersheds twenty years ago. Thereafter, part of croplands began being abandoned gradually and now diverse land use types exist in these two watersheds including cropland, abandoned cropland of various ages, grassland and jujube orchards (Fig. 1). Cropland has been cultivated for several decades and is usually tilled twice (seeding in early May and fertilizer application in late August) per year. Except for cropland, the other land uses were subject to little human disturbance. The overall information of soil, topography and vegetation species was shown in Table 1.

2.2. Sampling design

The abandonment ages of croplands were determined according to field survey and interviewing with local farmers. In general, abandoned croplands of 1 year of age (ACL1), 5 years of age (ACL5), 9 years age (ACL9), and 16–20 years of age (ACL16) were selected to analyze the effects of early-stage vegetation recovering on soil hydraulic properties in terms of soil dry bulk density, total porosity, and near-saturated hydraulic conductivities. Soil hydraulic properties were also tested in cropland and grassland of 30–35 years of age which served as controls. Cropland was set as the original land use type before revegetation; grassland was set as the land use type of long-term revegetation. Two sites (hillslopes) were selected for each land use type and thus a total of 12 sites were selected for all land use types. Previous studies indicated that slope positions can result in strong spatial variability of soil hydraulic properties (e.g., Bodner et al., 2008). Therefore, soil hydraulic properties for different sites were measured only at upper positions (5 m away from hillslope top) of the corresponding hillslopes to diminish the spatial variability induced by slope positions. Moreover, three repeats were conducted for soil hydraulic properties at each site and the distance to each other was around 2 m. An illustration has been drawn to show the locations of measurement points at one hillslope (Fig. 2). In order to test the effects of vegetation recovering on hydraulic conductivities through statistical analysis, the 6 measurements (2 sites × 3 repeats) for each variable were pooled together for each land use type.

Wetness conditions could affect significantly soil hydraulic conductivity (Hu et al., 2012). Therefore, two periods with different soil wetness conditions were selected for measurements. The dry condition was selected in early August with mean surface soil moisture (0–10 cm) of

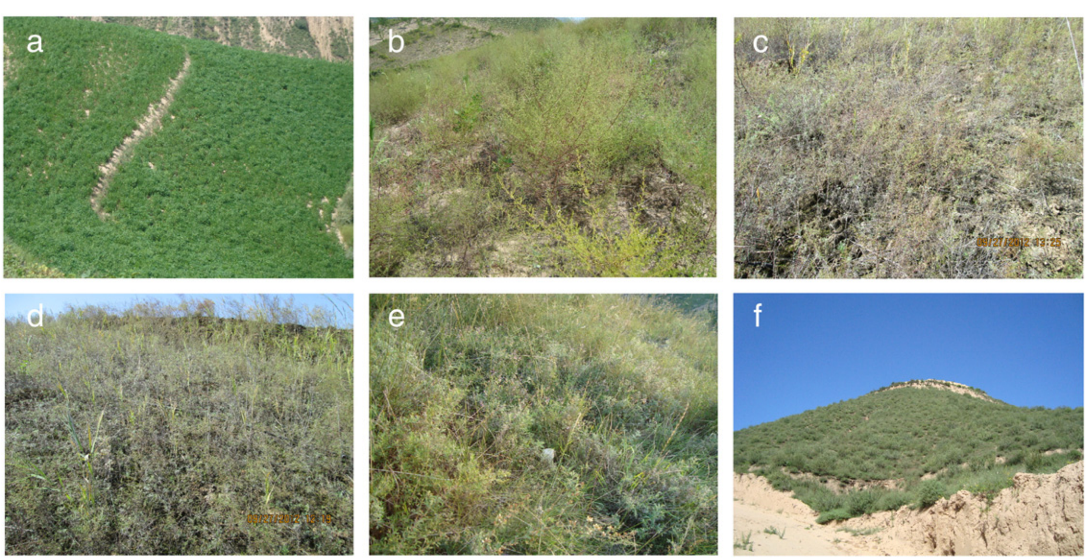

Fig. 1. Photos of different land use types in the study site, (a) cropland, (b) abandoned cropland of 1 year age (ACL1), (c) abandoned cropland of 5 year age (ACL5), (d) abandoned cropland of 9 year age (ACL9), (e) abandoned cropland of 16–20 year age (ACL16), (f) grassland.