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Soil erodibility influenced by natural restoration time of abandoned farmland on the Loess Plateau of China

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ABSTRACT

Natural restoration age of abandoned farmlands has significant effects on near soil surface characteristics and thus affects soil erodibility. However, few studies have been conducted to investigate the potential effects of natural restoration age on soil erodibility on the Loess Plateau where many slope farmlands have been abandoned for soil erosion control in the past decades. This study was performed to quantify the effects of natural restoration age on soil erodibility reflected by soil cohesion (*Coh*), saturated conductivity (K_s), the number of drop impact (*NDI*), the mean weight diameter of soil aggregates (*MWD*), soil penetration resistance (*PR*), and soil erodibility *K* factor. One slope farmland (as the control) and six abandoned farmlands restored for 3 to 33 years were selected for soil indicators measurements. A weighted summation method was used to produce one comprehensive soil erodibility index (*CSEI*) to demonstrate comprehensively the temporal variation in soil erodibility with natural restoration age. The results showed that *Coh*, K_s, *NDI*, and *MWD* increased generally when the restoration age < 25 years, and then they were relatively stable till the restoration age of 33 years. While the *PR* and *K* decreased gradually with restoration age, and tended to stabilize after 19 years abandonment. *CSEI* decreased generally with natural restoration age and gradually leveled off after restored for 25 years. Compared to the control, soil erodibility (reflected by *CSEI*) of abandoned farmlands restored for 3, 6, 12, 19, 25, and 33 years decreased on average by 15.9%, 44.6%, 59.4%, 82.7%, 96.5%, and 100%, respectively. The temporal variation in soil erodibility was controlled greatly by the changes in biological soil crust thickness, plant litter density, root mass density, bulk density, texture and organic matter content driven by natural restoration. The natural restoration is an effective measure for decreasing soil erodibility on the Loess Plateau.

1. Introduction

The Loess Plateau, located in the northwestern China with an area of 6.2×10^5 km^2, is one of the most severely eroded regions in the world. The mean annual erosion rates ranges from 5000 to 10,000 Mg km^{-2} yr^{-1} due to the comprehensive effects of short heavy storm, easily erodible loess soil, steep slope, low vegetation cover, and irrational land use (Wang et al., 2015). Since 1980s, in order to control soil erosion, large amounts of biological, engineering, and tillage measures were implemented, e.g. natural vegetation rehabilitation, planting trees and grasses, check-dam construction, and terrace building (Zhao et al., 2013). Especially, the implementation of the "grain-for-green" project in 1999 has converted many steep croplands to grass, shrub or wood lands. Consequently, the eco-environment and the near soil surface characteristics (biological soil crusts (BSCs), plant litter, root system, and soil physicochemical properties) changed significantly (Wang et al., 2014a; Li et al., 2015; Sun et al., 2016a; Xiao et al., 2016; Wang et al., 2017a, 2017b; Wang et al., 2017c; Xiao and Hu, 2017).

BSCs form through intimate relationships between surface soil particles and micro-organisms, such as cyanobacteria, algae, lichens, and mosses (Poinying and Belnap, 2012; Wang et al., 2017d). BSCs are widely distributed on the surface of the abandoned farmlands on the Loess Plateau, and the mean coverage can up to 60% to 70% (Zhao et al., 2014). The components of BSCs in the abandoned farmland changed significantly with the succession on the Loess Plateau (Zhao et al., 2014). Plant litter can cover on soil surface and also can be incorporated into topsoil layer by soil splash, sediment deposition, and soil animal activities (Wilson et al., 2008; Blouin et al., 2013; Sun et al., 2016a).The litter density within top soil layer was controlled partially by plant litter type and its decomposition rate in the abandoned farmland (Sun et al., 2016a). Root system is an essential part of plants,

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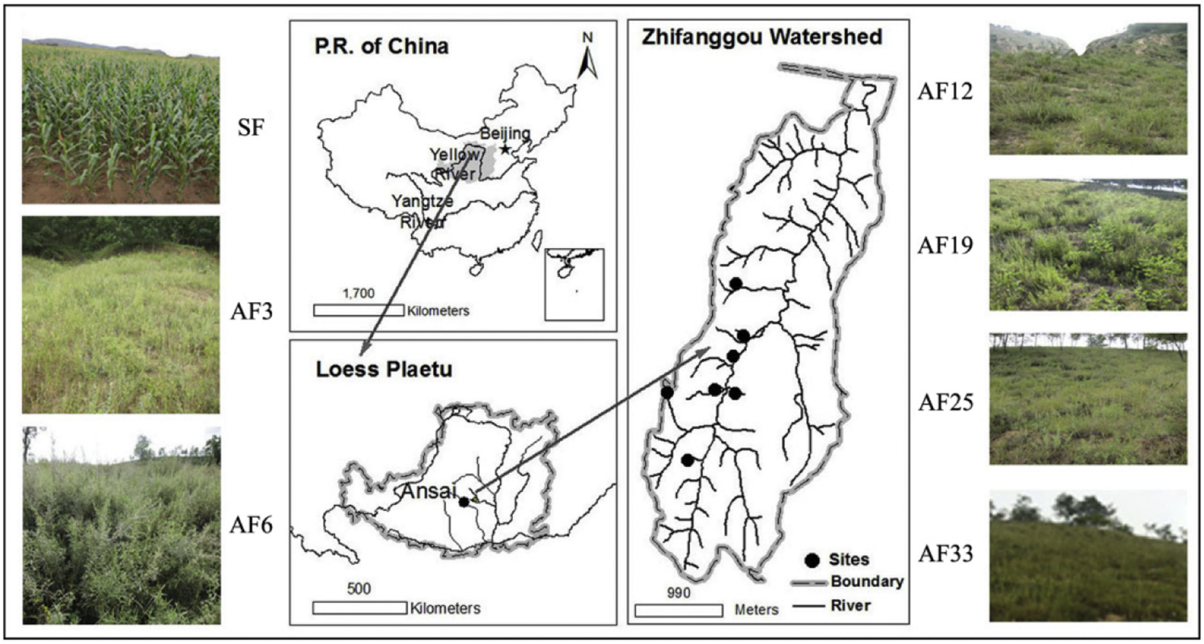

Fig. 1. Location of study area. SF is the slope farmland. AF is the abandoned farmland, and the number is the natural restoration age in years.

and its development is regulated greatly by vegetation species (Gyssels et al., 2005). Root density changed significantly with natural restoration age of abandoned farmland on the Loess Plateau (Wang et al., 2013b). Soil physical and chemical properties are important constitutes of near soil surface characteristics, and are influenced significantly by natural restoration (Sun et al., 2016a; Gao et al., 2017; Wang et al., 2017a, 2017b). Any changes in these near soil surface characteristics caused by natural restoration might result in changes in soil erodibility (Wang et al., 2013a; Wang et al., 2014a, 2015).

Assessment of soil erodibility is needed for predicting soil loss, and understanding soil erosion processes and mechanism. It describes the resistance of soil to water erosion produced by soil internal properties. The *K* factor in Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) is commonly used to quantify soil erodibility (Wang et al., 2013a). However, the direct measurement of *K* factor via unit plot is costly and time-consuming. As a consequence, it is frequently estimated by some models during the past several decades, such as the nomograph model (Wischmeier and Smith, 1978), Erosion/Productivity Impact Calculator model (EPIC) (Williams et al., 1984), and a formula, only involving the geometric mean diameter, proposed by Shirazi and Boersma (1984).

Meanwhile, soil erodibility can also be reflected indirectly by some soil physicochemical properties from different directions, such as soil cohesion (*Coh*) (Wang et al., 2014b), saturated conductivity (K_s) (Li and Shao, 2006), the number of drop impact (*NDI*) (reflected soil aggregate stability) (Cerda, 1998; Liu et al., 2003), the mean weight diameter of soil aggregates (*MWD*) (An et al., 2013), and penetration resistance (*PR*) (Parker et al., 1995). Among them, the *MWD* is the most frequently used parameter to assess soil erodibility, while the other parameters are rarely applied, though they are closely related to soil erodibility on the Loess Plateau. *Coh* and *PR* describe the ability of soil resisting the horizontal and vertical external shear stress. K_s reflects soil infiltration properties, which is closely correlated with flow shear stress. *NDI* simulates the effect of splash on soil aggregates. *MWD* expresses the ability of soil aggregates resisting disaggregate when they are immersed in water.

All these indicators of soil erodibility are influenced greatly by near soil surface characteristics. *Coh* increases significantly with the developments of roots and BSCs (Wang et al., 2013b). K_s increases with root density, litter density, sand and organic matter contents, but decreases with BSCs thickness, soil bulk density and clay content (Hu et al., 2012; Wang et al., 2013b; Li et al., 2015; Wang et al., 2017a, 2017b). The stability of water aggregate can be reflected by both of *NDI* and *MWD*, which increases with root density, soil clay and organic matter contents (Tisdall and Oades, 1982; Zhang and Horn, 2001; Six et al., 2004; Bronick and Lal, 2005; Cantón et al., 2009; Blankinship et al., 2016; Haydu-Houdeshell et al., 2018). Generally, *PR* increases with soil bulk density, clay and silt contents under a given soil water content, but decreases with soil moisture (Laboski et al., 1998). *K* factor declines with BSCs thickness, litter density, root density, organic matter content, but increases with soil silt and water contents (Wang et al., 2013a; Wang et al., 2013b; Li et al., 2015).

All these above mentioned near soil surface characteristics are related to the chronosequence of natural restoration (Li and Shao, 2006; Wang et al., 2013b; Zhao et al., 2014). Therefore, a significant temporal variation is likely existed in soil erodibility due to the variations in near soil surface characteristics of abandoned farmland with natural restoration. Up to date, most of studies only assessed soil erodibility with natural restoration age by *MWD* (An et al., 2013) or *K* factor (Zhu et al., 2010). However, both *MWD* and *K* factor only reflect the changes in soil erodibility with natural restoration age from specific directions as mentioned above. Thus more parameters (*Coh*, K_s, *NDI*, and *PR*) are needed to quantify the potential effects of natural restoration age on soil erodibility completely. Moreover, the effects of natural restoration age on soil erodibility are closely related to regional conditions of climate, topography, soil, and vegetation species. Few studies have been conducted to investigate the potential effects of natural restoration age on soil erodibility on the Loess Plateau, where a great amount of farmlands have been abandoned in the past 20 years to control soil erosion. Therefore, it is very necessary to quantify the quantitative effects of natural restoration age on soil erodibility using multi-parameters beside the commonly used *MWD* and K factor.

The purposes of this study were: (a) to quantify the temporal variation in soil erodibility (reflected by *Coh*, K_s, *NDI*, *MWD*, *PR*, and *K*) with natural restoration age, (b) to determine the quantitative changes in soil erodibility with natural restoration age using an integrated comprehensive index, and (c) to identify the dominant factors influencing the temporal variation in soil erodibility in abandoned farmland on the Loess Plateau of China.