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Revegetation as an efficient means of increasing soil aggregate stability on the Loess Plateau (China)

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ABSTRACT

Soil aggregate stability influences several aspects of soil physical behavior, such as water infiltration and soil erosion (Amézketa, 1999). We investigated the soil aggregate stability characteristics in the framework of the 'Grain for Green' vegetation rehabilitation project at the Loess Plateau (China) by using the Le Bissonnais (1996) and the modified Yoder (1936) methods. Both non-grazed grassland and afforestation revegetations were considered.

The size distribution mode was always >2 mm for the fast wetting test (FW) in the non-grazed grassland communities. This fraction accounted for approximately 40% to 80% of the total soil weight. The wet stirring (WS) test showed a distribution similar to that determined by the FW test. For the slow wetting (SW) test, 80% or more of the non-grazed grassland soil fragments was >2 mm.

The mean weighted diameter (MWD) that was determined by the Le Bissonnais' method was different among the tests and land uses. For the FW test, all the plant communities were significantly different from that of the recently abandoned grazing on grassland at the 0–20 and 20–40 cm depths. In the *Artemisia sacrorum* community, the maximum MWD was approximately 3 mm for the 0–20 cm depth. There were no significant differences among the plant communities after 3 years of afforestation and 7 years of non-grazing of the grassland. The MWDs were lower in the afforestation area than in the non-grazed grassland area. The maximum MWD value from the FW test was approximately 1.8 mm and was significantly lower (<0.5 mm) for cropland. The MWD of the modified Yoder method was positively related to the slow wetting and wet stirring (WS) tests of the Le Bissonnais' method ($n = 20$ and $r = 0.83$ and 0.87, respectively).

In the Loess Plateau, revegetations by non-grazed grassland and afforestation are efficient means of increasing aggregate stability and decreasing soil erodibility. The aggregate stability under non-grazed grasslands is higher than that under afforestation. The effect of revegetation is persistent, which makes it a suitable long-term management practice. Compared with the modified Yoder's method, the FW test of the Le Bissonnais' method is better at determining aggregate stability differences among land uses and is recommended for future studies.

1. Introduction

Soil structure is a key soil property that impacts plant and animal life, moderates environmental quality changes through soil organic carbon sequestration, and impacts soil water quality. Soil structure can be defined in terms of form and stability (Bronick and Lal, 2005). Good soil structure is important for the productivity of sustainable agricultural and for the preservation of environmental quality (Peng et al., 2004). Soil structure depends on the presence of stable aggregates. In fact, aggregate stability influences several soil physical processes, such as

Abbreviations: FW, fast wetting; SW, slow wetting; WS, wet stirring; MWD, mean weighted diameter; St.G., *Stipa grandis* P. Smirn (56 years); St.B., *Stipa bungeana* Trin Ledeb (36 years); At.S., *Artemisia sacrorum* Ledeb (25 years); Th.M., *Thymus mongolicus* Ronn. (15 years); Hi.O., *Hierochloe ordorata* Beauv (7 years); Ab.G., recently abandoned grazing on grassland (3 years); C.K.26, *Caragana korshinskii* Kom. (26 years); C.K.16, *Caragana korshinskii* Kom. (16 years); A.G.3, abandoned grazing land (3 years); Cr., slope cropland (0 year).

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Table 1
Geographic and vegetation characteristics of the sampling sites for the revegetation gradient of non-grazed grassland.

Sample site name	Revegetation duration (years)	Elevation (m)	Geographical coordinates ψ(N), λ(E)	Slope (°)	Dominant species	Accompanying species
St.G.	56	2058	36°15.143′ 106°23.204′	10°	*Stipa grandis*	*Artemisia frigida* Willd. *Potentilla acaulis* L. *Medicago ruthenica* *Potentilla angustiloba*
ST.B.	36	2097	36°15.223′ 106°22.935′	14°	*Stipa bungeana*	*Artemisia sacrorum* *Thymus mongolicus* *Leymus secalinus* *Potentilla bifurca*
At.S.	25	2082	36°15.751′ 106°23.415′	17°	*Artemisia sacrorum* Ledeb *Stipa grandis* P. Smirn	*Stipa bungeana* *Heteropappus altaicus* *Thymus mongolicus*
Th.M.	15	1903	36°11.957′ 106°24.592′	12°	*Thymus mongolicus* Ronn. *Stipa bungeana* Trin Ledeb	*Carex rigescens* (Franch.) V. Krecz *Medicago ruthenica* (Linn.) Trautv *Astragalus scaberrimus* Bunge
Hi.O.	9	2080	36°15.807′ 106°23.238′	10°	*Hierochloe ordorata* *Leymus secalinus*	*Artemisia scoparia* *Thymus mongolicus*
Ab.G.	3	2078	36°15.807′ 106°23.226′	6°	*Leymus secalinus* (*Georgi*) Tzvel.; *Hierochloe ordorata* (Linn.) Beauv.	*Artemisia scoparia* *Thymus mongolicus* *Potentilla bifurca*

St.G.: *Stipa grandis* P. Smirn (56 years); St.B.: *Stipa bungeana* Trin Ledeb (36 years); At.S.: *Artemisia sacrorum* Ledeb (25 years); Th.M.: *Thymus mongolicus* Ronn. (15 years); Hi.O.: *Hierochloe ordorata* Beauv (7 years); Ab.G.: recently abandoned grazing on grassland (3 years).

water infiltration and soil erosion (Amézketa, 1999; Le Bissonnais et al., 2007). Specifically, aggregate stability impacts the movement and storage of water in soils, soil aeration, soil erosion, biological activity, and crop growth (Zhang and Miller, 1996). Thus, aggregate stability affects a wide range of physical and biogeochemical processes in natural and agricultural environments. Maintaining high soil aggregate stability is essential for preserving soil productivity and for minimizing soil erosion and environmental pollution that result from soil degradation. Arshad and Cohen (1992) proposed that aggregate stability is one of the physical soil properties that can serve as a soil quality indicator. Hortensius and Welling (1996) included aggregate stability in the international standardization of soil quality measurements. Aggregate stability is also used as an indicator of soil structure (Six et al., 2000).

Human activities have impacted Chinese ecosystems for millennia (Fu et al., 1999, 2002). In the last century, fragmentation and degradation of ecological environments accelerated due to increasing population pressure. To prevent further deterioration of natural ecosystems, the Chinese government has launched a series of nationwide conservation projects. These projects, such as the 'Grain for Green' project, focus on the rehabilitation and recovery of damaged ecosystems (McVicar et al., 2007; Stokes, et al., 2010). The impacts of human activity at the Loess Plateau can be attributed to continuous and widespread stress, such as over-grazing and large-scale monocultures (wheat and maize) (Fu et al., 2000). In this area, soil erosion is a major threat. One of the most urgent tasks for achieving sustainable agricultural development is the recovery of natural vegetation (Li et al., 2005). Among other impacts, revegetation could increase aggregate stability and decrease soil erodibility. Soil water-stable aggregation research has been conducted at the Loess Plateau in relation to soil erosion (for example, Wang et al., 1994; Zha et al., 1992). According to this research, soil water-stable aggregation best reflects the ability of soils to resist erosion at the Loess Plateau. However, few papers are available regarding the evolution of soil water-stable aggregation during natural revegetation (e.g., Guo et al., 2010). Hence, the effect of revegetation on soil aggregate stability needs to be confirmed. At the Loess Plateau, two types of revegetation practices have been implemented: non-grazed grassland and afforestation, but no comparison between these revegetation types have been carried out yet.

Numerous research studies regarding soil aggregate stability on the Loess Plateau have been conducted (for example, Gao, 1991; Zhu, 1982). While many methods have been designed to measure aggregate stability, most of the results from the Loess Plateau have been obtained using a method based on Yoder (1936). These studies showed that the fraction of soil aggregates > 0.25 mm is strongly related to soil erodibility (Gao, 1991; Zhu, 1982). Wet sieving by Yoder's method involves several mechanisms of soil aggregate breakdown (Le Bissonnais, 1996). Other methods, such as that of Le Bissonnais (1996), have been designed to separate the mechanisms (such as slaking and differential clay swelling) and to provide more information regarding soil aggregation. The Le Bissonnais (1996) method recently became an ISO standard (ISO/DIS, 10930, 2012). Thus, it is important to compare the capabilities of the Le Bissonnais (1996) method with those based on the Yoder (1936) method.

The objectives of this study were to (1) investigate the changes in soil aggregate stability during vegetation rehabilitation in the Loess Plateau of China, (2) assess which revegetation practices improve soil aggregate stability the most, and (3) compare the suitability of the Le Bissonnais' method with that of the modified Yoder's method for the Loess Plateau soils.

Table 2
General situation of selected plots for the revegetation gradient of afforestation.

Plot name	Revegetation duration (years)	Elevation (m)	Slope (°)	Topography	Dominant species	Soil type
C.K.26	26	1670	25	Middle slope	*C. korshinski*	Typic loessic orthic primosols
C.K.16	16	1670	18	Middle slope	*C. korshinski*	Typic loessic orthic primosols
A.G.3	3	1675	16	Upper slope land	*Stipa bungeana, Artemisia sacrorum* Ledeb, *Thymus mongolicus* Ronn.	Typic loessic orthic primosols
Cr.	0	1620	<5	Slope farmland	Wheat	Typic loessic orthic primosols

C.K.26: *Caragana korshinskii* Kom. (26 years); C.K.16: *C. korshinskii* Kom. (16 years); A.G.3: abandoned grazing land (3 years); Cr.: slope cropland.