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A simplified and rapid technique to determine an aggregate stability coefficient in coarse grained soils

A. Bast [a,b,*], W. Wilcke [b], F. Graf [a,c], P. Lüscher [a], H. Gärtner [a]

[a] Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, 8903 Birmensdorf, Switzerland
[b] University of Bern, Institute of Geography, Hallerstrasse 12, 3012 Bern, Switzerland
[c] WSL Institute for Snow and Avalanche Research SLF, Flüelastrasse 11, 7260 Davos Dorf, Switzerland

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ABSTRACT

Soil aggregation determines soil structure and hence influences soil physical, chemical and biological processes. To express soil aggregate stability a variety of indices are discussed in literature. However, the available measures are more suitable to soils with low stone contents while there is currently no established method for stone-rich soils.

On an Alpine slope where soil texture is dominated by particles >2 mm in diameter, 108 soil samples were collected from the 0–20 cm layer and split into 0–10 cm ($n = 108$) and 10–20 cm ($n = 59$) layers, resulting in 167 analyzed subsamples. Two methods were used to determine soil aggregate stability: (i) A 'classical' wet sieving approach as basis for calculating the mean weight diameter (MWD), and (ii) a new technique (aggregate stability coefficient—ASC), adapted to soils with high stone contents and reducing work effort to a minimum.

The newly introduced ASC correlated closely with the MWD at all considered soil depths (0–20 cm layer: $r = 0.84$, $R^2 = 0.85$, $p < 0.01$, $n = 108$) showing a comparable precision.

The ASC is a useful aggregate stability indicator for stone-rich soils which can be used to evaluate near-surface soil stability, particularly in mountainous environments prone to erosion processes.

1. Introduction

Soil aggregate stability is an important soil property since stable aggregates promote the stability of soil structure (e.g. Amezketa, 1999; Horn et al., 1994). Consequently, soil aggregate stability can be seen as an indicator for soil quality (e.g. Amezketa, 1999; Nichols and Toro, 2011). Soil aggregates play important roles in many biotic and physicochemical processes within the soil system, like soil carbon storage, water and gas exchange, nutrient cycling, and erosion prevention (Bast et al., 2014; Le Bissonnais et al., 2007; Siddiky et al., 2012; Six et al., 2004; Tisdall and Oades, 1982). Some authors also postulate a positive correlation between aggregate stability and soil shear strength parameters, which include angle of internal friction Φ' and cohesion c' (Fattet et al., 2011; Frei et al., 2003; Graf et al., 2009). Since shear strength is a major control of mass movements, the stability of aggregates can be a valuable measure to determine near-surface slope stability (Bast et al., 2014). This topic is of special interest in soil eco-engineering, where living plants are used to accomplish engineering functions based on the development of a close and dense vegetation cover (Mitsch, 2012; Morgan and Rickson, 1995; Schiechtl and Stern, 1996). Eco-engineering measures gain more and more in importance for the restoration of degraded slopes, but in contrast to technical constructions, standardized techniques for quantifying the stabilizing effect of vegetation are still lacking (Bast et al., 2014).

Following Nimmo (2013), soil aggregates are clods or a group of primary soil particles, showing stronger coherence to each other than to those particles surrounding them. Soil aggregates are formed through the interdependency of aggregation and fragmentation, and chemical as well as physical forces are acting in manifold processes (Amezketa, 1999; Kemper and Rosenau, 1986; Nimmo, 2013; Six et al., 2004). To facilitate the measurement of aggregate size distribution or aggregate stability, aggregates need to be separated from each other without being destroyed. The technique and force needed to separate the aggregates should be adapted to the environmental conditions of the respective study site to have a practical relevance. In dry regimes, where aeolian processes dominate and erosion is mainly caused by wind, an analysis of dry aggregates is performed (Broersma et al., 1997; Chepil,

* Corresponding author at: Landscape Dynamics/Dendroecology, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, 8903 Birmensdorf, Switzerland. Tel.: +41 447392235; fax: +41 447392215.

E-mail addresses: alexander.bast@wsl.ch (A. Bast), wolfgang.wilcke@giub.unibe.ch (W. Wilcke), frank.graf@slf.ch (F. Graf), peter.luescher@wsl.ch (P. Lüscher), holger.gaertner@wsl.ch (H. Gärtner).

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1962; Kemper and Rosenau, 1986). For this purpose, Chepil (1962) developed a rotary sieve, allowing to separate samples of crumbled soil into dry aggregates of several size fractions. In contrast, a wet analysis is more adequate for humid regimes, where erosion is basically caused by rainfall and runoff (e.g. Amezketa, 1999; Nimmo, 2013). Manifold techniques exist to determine wet soil aggregate stability and aggregate size distribution (Amezketa, 1999; Kemper and Rosenau, 1986). The most common technique is based on a wet-sieving approach (Amezketa, 1999; Kemper and Rosenau, 1986) where a nest of sieves is moved up and down in water by a sieving apparatus simulating the natural stresses involved in the penetration of water into soil aggregates. This approach results in a distribution of different aggregate size fractions. To express this distribution as an indicator of stability, a variety of mathematical techniques exists (Kemper and Rosenau, 1986; Márquez et al., 2004). Most of them are based on the fact, that the specific weight of large aggregates is a more robust indicator for a good structure than the same weight of small aggregates (Kemper and Rosenau, 1986). The most frequently used indicator is the mean weight diameter (MWD), which was proposed by van Bavel (1950). Nichols and Toro (2011) presented an integrative approach by combining data from dry aggregates size distribution and water-stable aggregation and propose a whole soil stability index (WSSI).

In summary, it can be stated that the technique used to analyze soil aggregate stability strongly depends on the purpose of the study and soil properties like texture. The methods described above were developed for soils with low stone contents. A ready to go method for determining aggregate stability in coarse grained soils, where the stone content exceeds 50% does not exist so far. Such environments, which are omnipresent in steep and alpine areas where most primary particles are larger than 2 mm, demand special requirements for soil sampling as well as the further processing.

Therefore, we propose a new method in which we modified the sieving technique to develop an aggregate stability coefficient (ASC) for coarse grained soils, which is easy to use and timesaving. To compare the ASC with the established MWD, we additionally quantified the MWD of the studied soil samples.

2. Material and methods

2.1. Study site

The study site *Patjänja Rüfe* (46°53′43.41 N, 9°44′30 E) is located in the Arieschbach catchment, Prättigau, Eastern Swiss Alps (Fig. 1a). The climate of the area is characterized as sub-oceanic (Ott et al., 1997) with a mean annual air temperature of 4.64 °C and a mean annual precipitation of 1170 mm/year (Bast et al., 2014). The local bedrock, the Prättigau Flysch, is covered by Quaternary sediments, in particular moraine-derived material, providing the parent material for the Cambisols, Luvisols and Regosols typically developed in this area (Ott et al., 1997). The natural vegetation cover is dominated by fir-spruce forests (*Abies alba* Mill. and *Picea abies* (L.) H. Karst).

The coarse grained, low-density deposits covering the Prättigau Flysch are particularly prone to erosion and superficial landslides. Torrential rains, frequently occurring within the region, led to high erosion rates and mass movements and, hence, to vast vegetation-free and steep talus slopes with Leptosols as typically occurring soil types. Since the 1990s extensive joint technical (e.g. debris retention dams, concrete check dams etc.) and soil eco-engineering measures (e.g. hedge brush layers) were applied in the catchment area to stabilize the slopes and minimize erosion and landslide processes.

The *Patjänja Rüfe* is an ENE-exposed talus slope, ranging in elevation between 1220 m and 1400 m a.s.l., and in inclination between 37° and 50°. The Leptosol developed on this slope has an average grain size composition (soil depth: 0–35 cm; $n = 6$; sampled in May 2010) of 792 ± 19 g kg^{-1} of gravel, 140 ± 14 g kg^{-1} sand, 49 ± 5.2 g kg^{-1} silt and 19 ± 2.9 g kg^{-1}clay (mean ± standard error) (Bast et al., 2014). Following the Unified Soil Classification System (USCS) all soil samples were classified as poorly graded gravel with silt (GP-GM) (ASTM-D422-63, 2000; ASTM-D2487-00, 2000) (Fig. 1b).

In May 2010 a soil eco-engineering experiment was established (Bast et al., 2014). One control and two treatments (in the following also myco and non-myco) were selected (Fig. 1b). The two treatments were stabilized (~700 m^2) with saplings of alder (*Alnus spp.*) ($n = 1200$), willow

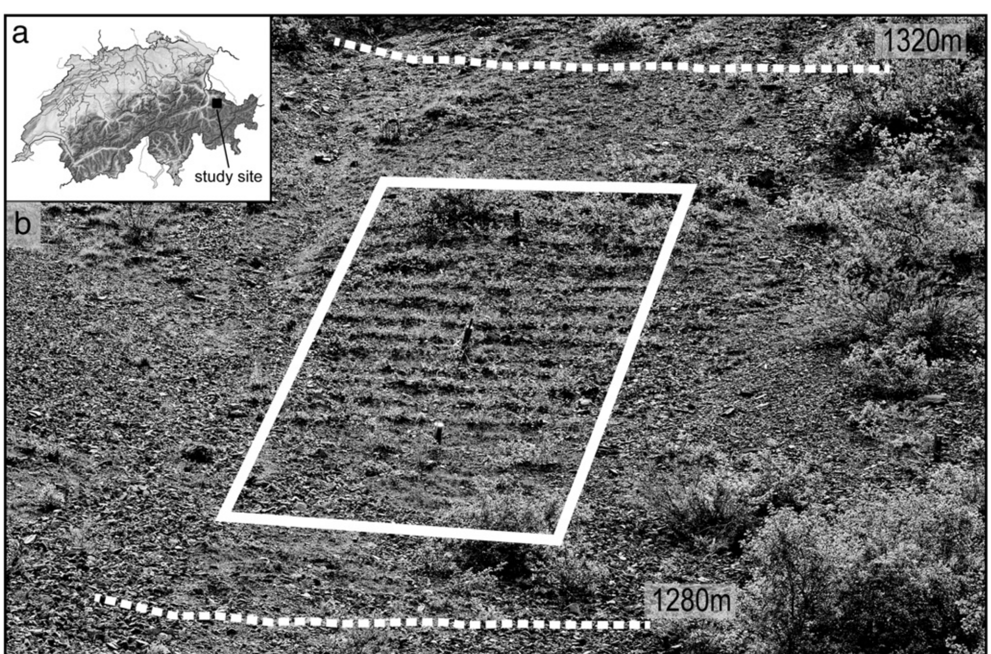

Fig. 1. a) Map of Switzerland, highlighting the study site Arieschbach catchment, Fideris, Eastern Swiss Alps. b) Photograph of the experimental site. The white dashed lines are contour lines [m a.s.l.]. One of the treatments (myco) is outlined (white rectangle). The coarse grained material of the soil is clearly visible at the surface, indicating the harsh properties of the environment and the difficulty to use soil standard procedures.