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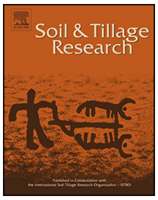

Soil structure breakdown following land use change from forest to maize in Northwest Vietnam

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ABSTRACT

Conversion of forest to agricultural land for maize cultivation is known to negatively affect soil fertility. However, limited knowledge is available of the impact on aggregate stability and interconnected soil properties. The aims of the present study were to (1) quantify soil aggregate stability, (2) assess aggregate stability changes after land use change, and (3) determine the interactions of aggregate stability with clay, soil organic carbon (SOC), exchangeable Ca^{2+} and Mg^{2+}, and soil erosion rates. The topsoils of three soil types in Northwest Vietnam were analyzed in chronosequences (0–18 y after land use change from forest to continuous maize) by two methods: Wet sieving and sonication. By differentiation of these aggregate stability measurements, the impact of both methods on aggregate size distribution could be quantified separately and compared. The sonication method indicated a more homogeneous disaggregation whereas the wet sieving method was more suitable to detect low aggregate stabilities. Soil aggregate stability declined simultaneous with a decrease of SOC and exchangeable Ca^{2+} and Mg^{2+}, which both declined with increasing time since land use change. The Alisol and Luvisol chronosequences were 1.9 times more stable under primary forest than under maize (shown by sonication) whereas the Vertisol chronosequence was 2.5 times more stable under primary forest (shown by wet sieving). Over the 18 y chronosequence the topsoils had 1.6 kg m^{-2} lower SOC and 3.2 g kg^{-1} lower Ca^{2+} contents. This study highlights the destabilization of soil in interaction with a degradation of relevant chemical soil properties with differentiated aggregate stability methods.

1. Introduction

Aggregate stability is a critical soil property for soil fertility. By degradation of soil structure plants are deprived of physical support, water, essential nutrients and oxygen (Dexter, 1988; Lal, 2001). Soil structure can be stabilized by organic matter, clay, polyvalent exchangeable ions like Ca^{2+} and Mg^{2+} and cementing agents such as $CaCO_3$ (Amézketa, 1999). The potential degradation of soil structure as a result of deforestation and subsequent land use due to growing land demand is a challenge in tropics and subtropics. In Vietnam 10% of the total area is affected by degradation of soil structure (Van Lynden and Oldeman, 1997). This study therefore evaluates the effect of land use change on soil aggregate stability and interrelated properties to understand whether soil structure was destabilized.

Because of the complexity of soil aggregate formation and the huge size scale from nm to cm, a variety of methods has been developed to measure soil aggregate stability (Amézketa, 1999; Six et al., 2004). Unlike end-over-end shaking, drop shatter, exposure to chemical detergents and many other methods, only ultrasonic vibration avoids chemical contamination (Edwards and Bremner, 1967; Genrich and Bremner, 1974) together with enabling the homogenous application of a quantifiable and adjustable amount of energy to the soil (North, 1976; Raine and So, 1994). Aggregated soil particles resist stress induced by ultrasonic vibration depending on the number and strength of bonds holding them together (Skidmore and Powers, 1982). Hence, the energy required for breaking interparticle bonds can be used as a measure of the stability of those aggregates (Mentler et al., 2004). To quantify aggregate stability accordingly, the unquantifiable breakdown due to water immersion and the mechanical stress of sieving

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(Fristensky and Grismer, 2008) has to be differentiated from the breakdown due to sonication. In this study, both wet sieving and sonication were therefore applied sequentially to assess their effect on soil aggregates separately.

Deforestation due to land use change generally increases soil organic carbon (SOC) decomposition and decreases formation of new SOC, leading to a net decline of SOC stocks (Lal, 2001). Land use change to agricultural land also involves tillage, which disrupts soil aggregates and exposes former physically protected SOC to decomposition (Conant et al., 2007; Häring et al., 2013a). Furthermore, a structurally degraded soil is more vulnerable to the mechanical impact of rain drops (Renard et al., 1997), which induces further degradation. Häring et al. (2013a) reported that the land use change from primary forest to maize fields in Northwest Vietnam accounted for 47.1 to 63.5 % SOC loss within the top 30 cm. Although the negative effect of decreasing SOC on aggregate stability is widely accepted (Amézketa, 1999; Six et al., 2002), the binding mechanisms of SOC within aggregates across size, time and land use changes in subtropical and tropical climates are still being debated (Amézketa, 1999; Lobe et al., 2011; Six et al., 2004). In addition, studies often lack a standardized quantified aggregate stability measurement. Therefore, the aims of the present study were to (1) quantify aggregate stability after land use change by wet sieving and sonication and (2) determine the interactions of aggregate stability with clay, SOC, exchangeable Ca^{2+} and Mg^{2+}and cumulative erosion rates.

It was hypothesized that (i) the differentiated wet sieving and sonication method provides a quantifiable and standardized index for soil aggregate stability measurements, (ii) with increasing time since land use change the aggregate stability decreases, and (iii) aggregate stability decreased with decreasing clay, SOC and exchangeable Ca^{2+} and Mg^{2+}.

2. Material and methods

2.1. Study area

The soil samples were selected from Häring et al. (2013a,b, 2014). The sample area is located in Northwest Vietnam with an average temperature of 20.7 °C and a rainfall of 1259 mm. The parent material of the chronosequences on a Cutanic Alisol (Chromic) (A0–A16), a Haplic Vertisol (Chromic) (V0–V21) and a Cutanic Luvisol (L0–L18) (IUSS Working Group WRB, 2006) were Triassic limestone, Triassic clayey shale and Cretaceous marl, respectively. The sites comprised one reference site under primary forest and three sites, which were deforested 5–21 y before sampling. Maize had been cultivated continuously since deforestation (Table 1). The mineral composition of clay fractions of forest sites as analyzed by X-ray diffraction revealed that all soils contained Kaolinite, whereas Alisol and Luvisol were dominated by mixed-layer smectite-vermiculite structures in addition to smaller amounts of mixed-layer illite-smectite und chlorite. The clay mineralogy in the Vertisol was dominated by illite and smaller amounts of mixed-layer illite-vermiculite.

2.2. Sampling and analysis

From each site, three field replicates of soil samples were taken parallel to the contour line in 2 m intervals in the top 10 cm. All soil samples were air dried to minimize the effect of different initial water contents on soil aggregate stability after immersion in water (Dexter, 1988) and subsequently sieved <2 mm.

Data on soil texture (Häring et al., 2014) and SOC contents (Häring et al., 2013a), were obtained from the previous work (Table 1).

The cations were released from the sample by mixing with ammonium acetate and flame emission spectrophotometry (Ca^{2+}) and atomic absorption spectroscopy (Mg^{2+}). To calculate stocks, the SOC content was multiplied with the topsoil depth of 10 cm and respective bulk density, determined by core sampling of three undisturbed soil samples in 200 cm^3 steel cylinders. Cumulative erosion data determined by ^{137}Cs was adapted from Häring et al. (2013b, 2014).

2.3. Soil aggregate stability

To assess aggregate stability, the weight of the <2 mm soil samples was determined after three treatments with increasing disruptive force (dry sieving, wet sieving, sonication and wet sieving) and fractionated into microaggregates <90 μm, mesoaggregates 90 to 250 μm and macroaggregates >250 μm (Oades and Waters, 1991; Tisdall and Oades, 1982). Soil samples were sieved with an automatic wet sieving machine (Murer et al., 1993; DIN 19683-16 2009).

2.4. Sonication

To quantify the amount of energy applied to the soil, an ultrasonic device was calorimetrically calibrated according to North (1976). Therefore, a sonotrode of 1.4 cm diameter and

Table 1
Soil type, land use and soil properties in the top 10 cm of three chronosequences from Northwestern Vietnam. Data according to Häring et al. (2013a, 2014).

Sample name	Land use	Sand (63–2000 μm) (g kg^{-1})	Silt (2–63 μm) (g kg^{-1})	Clay (<2 μm) (g kg^{-1})	Bulk density (g cm^{-3})	SOC[a] (%)
Alisol chronosequence – Cutanic Alisol (Chromic)						
A0	Primary forest	58	324	679	0.86	4.62 (±0.57)
A5	5 y maize	51	336	613	0.94	3.96 (±0.13)
A12	12 y maize	43	383	574	0.94	2.54 (±0.13)
A16	16 y maize	26	303	671	1.06	2.84 (±0.12)
Vertisol chronosequence – Haplic Vertisol (Chromic)						
V0	Primary forest	68	420	548	1.18	2.08 (±0.55)
V13	13 y maize	58	519	422	1.41	1.33 (±0.07)
V18	18 y maize	91	466	443	1.39	1.20 (±0.03)
V21	21 y maize	84	523	393	1.26	1.24 (±0.03)
Luvisol chronosequence – Cutanic Luvisol						
L0	Primary forest	57	418	583	0.98	4.83 (±0.66)
L5	5 y maize	46	413	526	0.93	3.80 (±0.24)
L12	12 y maize	60	388	552	0.94	2.57 (±0.19)
L18	18 y maize	66	379	555	1.08	2.67 (±0.04)

[a] Means ± SD; n = 3.