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Aggregate stability of a crusted soil: differences between crust and sub-crust material, and consequences for interrill erodibility assessment. An example from the Loess Plateau of China

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Summary

Soil interrill erodibility is a key component of soil erosion models. However, when using aggregate stability to assess soil erodibility, samples are usually collected from the plough layer, while soil erosion occurs at the soil surface. Hence, the potential changes in erodibility caused by crusting are ignored. Moreover, soil interrill erodibility is still difficult to predict accurately. This lack of prediction means that current erosion models use a constant erodibility value for a given soil, and thus do not consider potential heterogeneity of erodibility. This study was conducted (i) to assess the heterogeneity of aggregate stability for a crusted soil and (ii) to relate this heterogeneity to the aggregate stability of the underlying material (sub-crust) and to standard soil properties. A field study was conducted in a small area of the Loess Plateau in China in which the crust and the sub-crust were sampled. Standard soil properties (organic matter content, sand content, silt content, clay content, cation-exchange capacity, pH in water, and water content at the time of sampling) were measured as potential explanatory factors of aggregate stability. The results showed a large heterogeneity in aggregate stability among the sites, even though the sites had the same soil type. The mean weight diameter (MWD) of the crust varied between 0.33 and 2.04 mm while the MWD of the sub-crust varied between 0.23 and 1.42 mm. Soil texture and pH were very homogeneous among the sampling sites, whereas water content, organic matter content and CEC varied more. Even though some correlations existed (for example r = 0.57 between the MWD for slow wetting test and organic matter content), none of the standard soil properties was able to predict aggregate stability accurately. The aggregate stability of the crust was significantly greater than that of the sub-crust. The large differences in aggregate stability imply large

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differences in soil interrill erodibility. Because a single soil type was investigated, this finding proves that erodibility can vary greatly in space even for a given soil type. Soil interrill erodibility should be estimated from the exact material actually exposed to erosive forces, the soil surface material. Using the sub-crust would have led to greatly over-estimated erodibility and thus to a marked bias in erosion model predictions.

Résumé

L’érodabilité inter-rigole est un paramètre clef des modèles d’érosion du sol. Cependant, lorsque des tests de stabilité structurale sont utilisés pour évaluer l'érodabilité, les mesures sont habituellement réalisées sur des échantillons prélevés dans l’horizon labouré alors que l’érosion a lieu à la surface du sol. Ainsi, les changements potentiels d'érodabilité causés par la formation de croûte sont ignorés. De plus, l’érodabilité inter-rigole reste encore difficile à prédire avec précision. Ces difficultés conduisent les modèles d’érosion à utiliser une érodabilité constante pour un type de sol donné, et donc à ne pas considérer l’hétérogénéité potentielle de l’érodabilité. Cette étude a été conduite pour (i) évaluer l'hétérogénéité de la stabilité structurale pour un sol encroûté et (ii) relier cette hétérogénéité à la stabilité structurale du matériau sous-jacent (sous-croûte) et aux propriétés standards du sol. Une étude de terrain a été réalisée sur un secteur de surface limitée du Plateau de Lœss (Chine). Des échantillons provenant de la croûte et de la sous-croûte ont été collectés. Les propriétés standards (teneur en carbone organique, teneurs en sable, limon et argile, CEC, pH, et teneur en eau au prélèvement), ont été mesurées en tant que facteurs explicatifs potentiels de la stabilité structurale. Les résultats ont montré

une grande hétérogénéité de la stabilité structurale entre les différents sites alors que ces derniers présentaient le même type de sol. Le MWD de la croûte variait entre 0,33 et 2,04 mm tandis que le MWD de la sous-croûte variait entre 0,23 et 1,42 mm. La texture du sol et le pH étaient très homogènes entre les sites étudiés, tandis que la teneur en eau, la teneur en matière organique et la CEC variaient plus fortement. Bien que certaines corrélations aient été identifiées (par exemple r=0.57 entre le MWD du test à l'humectation lente et la teneur en carbone organique), aucune de ces propriétés n'a permis de prédire précisément la stabilité structurale. La stabilité structurale de la croûte était significativement supérieure à celle de la sous-croûte. Les grandes différences de stabilité structurale mesurées impliquent des érodabilités très contrastées. Comme un seul type de sol a été étudié, ce résultat prouve que l'érodabilité peut être très variable spatialement pour un type de sol donné. L'érodabilité inter-rigole du sol devrait être mesurée sur le matériau exact qui subit l'érosion, c'est-à-dire le matériau de surface. L'utilisation du matériau sous-jacent aurait engendré une forte surestimation de l'érodabilité et donc un biais important dans les prédictions d'un modèle d'érosion.

Introduction

In the context of soil erosion by water, interrill erodibility corresponds to the sensitivity of the surface material to detachment and transport by raindrop impacts and by sheet flow. Accordingly, interrill erodibility is a key component in erosion models (Gumiere et al., 2009; Wang et al., 2013). Currently, there is no unified definition of erodibility and those proposed are qualitative: there is thus a need for quantitative methods (Wang et al., 2013).

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Interrill erodibility can be estimated from standard soil properties such as soil texture or carbon content and using statistical functions (Alberts *et al.*, 1995; Renard *et al.*, 1997). Although such estimations are easy to carry out once the statistical function has been established, they postulate that samples with similar standard soil properties have similar erodibilities. Moreover, the ranges of validity of the statistical functions (the textures and carbon contents for which these functions can be used) are often limited and poorly known. Finally, erosion models typically use a single erodibility value for a given soil, hence postulating a small spatial heterogeneity of the erodibility (Renard *et al.*, 1997; Jetten *et al.*, 2003).

Another approach to characterize soil interrill erodibility is to measure aggregate stability in the laboratory (Le Bissonnais, 1996; Barthès & Roose, 2002). Aggregate stability corresponds to the ability of an aggregate not to break up into smaller fragments. A large aggregate stability of the top-soil induces a strong resistance of the surface aggregates against breakdown, and thus induces less particle detachment and transport by raindrop impacts and by sheet flow (Le Bissonnais, 1996; Bajracharya & Lal, 1998). Hence, even though a few models use this soil property currently (LISEM, De Roo *et al.*, 1996), aggregate stability is considered as a proxy of soil interrill erodibility, with a poor aggregate stability corresponding to a large potential erodibility and *vice versa* (Barthès & Roose, 2002; Gumiere *et al.*, 2009).

The properties of a given soil may change over a period of a few weeks or months because of crust development (Poesen, 1981; Bryan et al., 1989). In an agricultural context, the soil surface evolves from a seedbed (loose surface layer composed of clods and macro-aggregates) to successive stages of crusting that correspond to different types of crust (Bresson & Boiffin, 1990). The structural crust corresponds to a thin surface layer where the micro-aggregates resulting from the breakdown of surface clods are sealed together, and the sedimentary crust corresponds to a compact surface layer where the surface pores and micro-depressions are filled by small fragments resulting from the erosion and sedimentation processes. The presence of a crust can induce marked differences between the properties of the plough-layer and the soil surface. Numerous studies show that the infiltration capacities can be very different between the crust and the underlying material (e.g. Morin & Van Winkel, 1996). However, only a few studies have addressed the effect of a crust on erodibility (McIntyre, 1958; Poesen, 1981; Darboux & Le Bissonnais, 2007). Most of the studies using aggregate stability to assess erodibility are made with samples collected within the plough layer (Bullock et al., 1988; Bajracharya & Lal, 1998; Barthès & Roose, 2002; Legout et al., 2005), notwithstanding that interrill erosion occurs at the soil surface and thus depends directly on the erodibility of the crust and not on the erodibility of the plough layer material. For a clay loam soil, Darboux & Le Bissonnais (2007) did not find significant differences in aggregate stability between a structural crust and the seedbed material (without crust); but there were notable differences in aggregate stability between a sedimentary crust and the seedbed material (without crust). This finding led these researchers to conclude that estimations of erodibility for material collected from the plough layer may be invalid for the crust, resulting in a potential bias in the estimated erodibility. However, the results of this laboratory experiment had limited application, and did not attempt to assess the factors responsible for differences in aggregate stability, even though numerous factors have previously been identified (Amézketa, 1999). In the present work, a field study was conducted in a small area (7.5 km radius) of the Loess Plateau of China. The crust and the underlying materials were sampled in areas designated for different land uses. Aggregate stability was measured as a proxy of soil erodibility,

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along with standard soil properties known to be related to aggregate stability. We wished to test the hypotheses that crusts developped from a given soil type show different aggregate stabilities depending on the aggregate stability of the underlying material and on the standard soil properties. The research objectives were (i) to assess the heterogeneity of aggregate stability of crusted Luvisols within an area presenting a small spatial extent and (ii) to relate this heterogeneity to the aggregate stability of the underlying material and to the standard soil properties. The consequences for erodibility assessment and erosion modeling are discussed.

Materials and methods

Sampling sites

The Chinese Loess Plateau (northwest China) is recognized as the largest deposit of loess in the world. Silt particles resulting from wind erosion at the Tibetan Plateau and the Gobi desert have accumulated to an average thickness of 150 m. The silt loam soils that developed on this substrate are very homogeneous in both texture and chemical properties and are recognized to be very sensitive to erosion (Zheng, 2005). The experimental area was located in the Ziwuling area, in the hilly-gully region of the Loess Plateau (Figure 1). Altitude of the sampling sites varied between 1100 and 1300 m with an average annual temperature of 9° C and average annual precipitation of 577 mm. Soil samples were collected on seven field sites, selected in order to present the same soil type (silt loam Luvisols, *WRB*, developed on loessial material) but with different land uses, erosion conditions and environmental conditions such as altitude, slope position and orientation (Table 1). The sites (A, B, C and D) were geographically close together (located within a 7.5 km radius) (Figure 1). There were

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four sub-sites at D (D1, D2, D3 and D4) which were located along a 200-m long eroded hill slope. Table 1 provides details of the various land uses and locations.

Sampling method

Sampling was performed in September 2009 over a period of three consecutive days, beginning four days after the last previous rain event. For each site (A, B, C, D1, D2, D3 and D4), five plots (one square meter each) were defined to collect samples in order to take into account the spatial heterogeneity within each site. Prior to sampling, the soil surface was described, and the crust type was identified (Bresson & Boiffin, 1990; Belnap *et al.*, 2008). The soil surfaces had no obvious mosses or lichens and had a light colour, indicating little cyanobacterial development (Belnap *et al.*, 2008).

Paired samples (crust and underlying material) were collected from each plot at each site so that the crust was collected separately from the underlying material (hereafter referred to as ‘sub-crust’). All of the sites had a structural crust, but only site C had both structural and sedimentary crust. Therefore, only structural crust is considered hereafter. Because the lower depth of the structural crust was indistinct, a thickness of approximately 5 mm was considered to be the limit. The sub-crust was defined as the soil material between -1 and -5 cm from the soil surface. In all cases, three-to-five cm samples were collected using a sharp knife to cut through the material without affecting its structure. Soil samples from the crust and sub-crust were divided into five sub-samples in order to measure aggregate stability, organic matter content, CEC, pH and soil texture.

Measurements

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Aggregate stability Samples were oven-dried at 40^o C over two days and stored in a cold room at 4^o C for fifteen days before measurements. Aggregate stability was measured using a slightly modified version of Le Bissonnais' method (Le Bissonnais, 1996; ISO/DIS 10930, 2012), where air-dried samples from both crust and sub-crust were cut into 2–5 mm fragments with a sharp knife.

The three stability tests of Le Bissonnais (1996) (fast wetting, slow wetting and stirring) were designed to reproduce the processes involved in crust formation and interrill erosion (slaking, differential clay swelling and mechanical breakdown). Results of each test can be investigated separately to analyse the resistance of the material against each process. Because the three processes occur often simultaneously: the three MWD resulting from the three tests are commonly averaged.

Five-g sub-samples were dried at 40° C for 24 hours before the application of a test, and each test was replicated twice (instead of three times as in the original method). After the tests, the resulting fragments were sieved in ethanol. The results are presented using the mean weighted diameter (MWD). Each MWD corresponds to one of five classes of stability: MWD >2 mm corresponds to very stable material (very weak erodibility), between 2 and 1.3 mm corresponds to stable material (weak erodibility), between 1.3 and 0.8 mm corresponds to median stability (median erodibility), between 0.8 and 0.4 mm corresponds to unstable material (strong erodibility), and <0.4 mm corresponds to very weak stability (very strong erodibility) (Le Bissonnais, 1996).

Standard soil properties Standard soil properties were measured to explain differences in aggregate stability between the sites and between the crust and sub-

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crust. These were gravimetric water content, organic matter content, clay content, silt content, sand content, CEC and pH. Relationships between these variables and aggregate stability have frequently been reported in the literature (Wischmeier & Mannering, 1969; Tisdall & Oades, 1982; Amézketa, 1999; Zhang & Horn, 2001). Hence, these variables could be assumed to be suitable explanatory factors for the differences in aggregate stability between the crust and sub-crust materials of a given site and also between sites.

Clay, silt and sand contents were measured by laser diffraction granulometry, (Loizeau *et al.*,1994), with a Mastersizer 2000 (Malvern Instruments Ltd, Malvern, UK). Soil organic matter content was measured with the Walkey & Black (1934) method, cation-exchange capacity (CEC) with the ammonium rapid method (Mackenzie, 1951), and pH with a 1:2.5 soil:water ratio and a pH meter. Gravimetric water content was measured at the time of sampling: 10-g sub-samples were dried at 105° C over 48 hours. Measurements were performed on soil bulk samples for both crust and sub-crust materials. Each measurement was replicated twice.

Statistical analyses

Statistical analyses were performed using version 2.9.2 of software R (R Development Core Team, 2011). To avoid the assumption of normality of samples required for the use of parametric tests, a non-parametric test (Wilcoxon test) was used to compare the MWD and the standard soil properties of crust and sub-crust samples. We considered a significant threshold of 5%. The heterogeneity (dispersion) of the soil properties was quantified using the coefficient of variation, which is a normalized measure of dispersion. Linear correlation analyses (Pearson's coefficient) were performed to quantify the relationships between the standard soil properties and aggregate stability.

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To model MWD according to the soil properties, in other words to quantify the proportion of MWD (dependent variable) variability which is explained by independent variables, multiple regression analyses were conducted.

Results

Heterogeneity of the aggregate stability For all the sampling sites, and for both crust and sub-crust, MWD was the largest for the slow wetting test (1.47 and 0.97 mm for the crust and sub-crust, respectively) and the least for the fast wetting test (0.98 and 0.36 mm for the crust and sub-crust, respectively) (Table 2).

When the mean of the three stability tests is considered, the MWD of the crust varied among the sites between 0.33 and 2.04 mm, with a coefficient of variation of 0.37 (Table 2). For crust material and for each stability tests, sites A (cultivated maize field) and D1 (Ziwuling experimental station, interrill area) had the largest MWD while site C (cultivated radish) had the smallest (Figure 2).

With the sub-crust, and again considering the mean of the three stability tests, the MWD varied between 0.23 and 1.42 mm, with a coefficient of variation of 0.47 (Table 2). For all the stability tests on these samples, site D1 had the largest MWD and site C had the smallest (Figure 2). Among the sites, the coefficients of variations were larger for the sub-crust samples than for the crust samples, except for the stirring test which had the same coefficient of variation (Table 2). For each site, samples were collected from five plots to consider intra-site heterogeneity. Considering the mean of the three stability tests, the intra-site coefficient of variations for the five plots taken at each site were larger for the sub-crust than for the corresponding crust samples for sites A, D1, D2, D3 and D4.

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Comparison of aggregate stability for paired crust and sub-crust samples

The aggregate stability of the crust was significantly different from that of the underlying material ($P = 2.10^{-10}$ for the mean of the three stability tests). For most of the paired samples, the aggregate stability of the crust was greater than that of the corresponding sub-crust, and the sub-crust samples were never more stable than their corresponding crust (Figure 2). The difference in aggregate stability between crust and sub-crust varied with the stability test. The fast wetting test had the the largest differences in MWD between crust and sub-crust (0.62 mm, Table 3). In order to study the relationships between the MWD of the crust and the MWD of the sub-crust material, a correlation analysis was undertaken for each aggregate stability test and for the mean of the three tests. The largest correlation coefficient ($r = 0.69$, $P = 5.10^{-6}$ significant) was found between the MWD of the crust and that of the sub-crust for the slow wetting test. The correlation coefficients were 0.43 for the fast wetting test ($P = 0.009$, significant), 0.48 for the stirring test ($P = 0.003$, significant) and 0.59 for the mean of the three tests ($P = 2.10^{-4}$, significant). However, these correlation coefficients were greatly influenced by the very small MWD of site C. Without site C, the correlation coefficients were only 0.52 for the slow wetting ($P = 0.003$, significant), 0.20 for the fast wetting ($P = 0.30$), -0.06 for the stirring test ($P = 0.75$) and 0.28 for the mean of the three tests ($P = 0.14$). The difference in aggregate stability between a crust and its sub-crust showed the crust was always more stable. The amplitude of this difference varied greatly both for a given site and among the sites (Table 3). For example, for the mean of the three tests, the inter-site coefficient of variation was 0.60 (Table 3a), whereas it ranged from 0.16 (site D4) to 0.90 (site D1) (Table 3b).

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Variability of standard soil properties

All samples had silt content between 65.5 and 73.1% and clay content between 10.0 and 14.4% (Figure 3) and thus belonged to the silt loam texture class (Soil Survey Division Staff, 1993). Clay content had little variability between the sampling sites. Silt content and sand content presented larger differences between sites, but their inter-site variability was small.

There were large differences in gravimetric water contents between crust and sub-crust. The water content of sub-crust was larger than that of crust whatever the site. Crust water content varied between 0.8% (site C) and 11.7% (site D4) while sub-crust water content varied between 10.8% (site D2) and 14.9% (site D4) (Figure 4d). Crust water content varied significantly between sites while sub-crust water content did not differ significantly among the sites (Figure 4d).

The organic matter content varied between 0.7% (site D4) and 1.9% (site B) (Figure 4a). The CEC varied between 16.6 cmol kg^{-1} (site C) and 27.5 cmol kg^{-1} (site A) (Figure 4b). The organic matter content and CEC varied significantly between sites. The pH, which ranged between 8.3 and 8.6, did not differ significantly between the sites (Figure 4c).

At both intra- and inter-site scales, the percentages of clay, silt and sand (Figure 3), organic matter content, CEC and pH (Figure 4) did not differ significantly between a crust and its corresponding sub-crust.

Relationship between standard soil properties and aggregate stability

A correlation analysis was performed between the aggregate stability (MWD) and the soil properties assumed to be potential explanatory factors (Table 4). This analysis

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was performed for the crust (Table 4a) and sub-crust (Table 4b) separately. In both cases, the largest correlation coefficients were found between the MWD of the slow wetting test (0.57, $P = 3.10^{-4}$, significant) and the organic matter content (0.56, $P = 4.10^{-4}$, significant).

Clay, silt and sand contents were not significantly correlated with any of the MWD values, either for the crust and sub-crust samples. For the crust, water content, organic matter content and CEC were significantly correlated with the MWD whatever the stability test (Table 4a). For the sub-crust, organic matter content, CEC and pH correlated significantly with MWD, except that organic matter content did not correlate significantly with MWD for the stirring test, and pH did not correlate with MWD for slow wetting test (Table 4b).

A multiple regression analysis was performed using the soil properties (organic matter content, CEC, water content and pH) wich were significantly correlated to aggregate stability. For the crust, among all the combinations tested the best regression was found for the mean MWD of the three tests as the dependent variable and the organic carbon content and CEC as explanatory variables:

$$\mathrm{MWD_{mean}(mm)} = 0.39\ (\pm 0.15) \times \mathrm{SOM}\ (\%) + 0.06\ (\pm 0.02) \times \mathrm{CEC}\ (\mathrm{cmol.kg^{-1}}) - 0.66\ (\pm 0.47). \qquad (1)$$

(the number in parenthesis is the standard error).

The coefficient of determination (R^2) was 0.38. The residual standard error for the estimated MWD was 0.36 mm at the 95% confidence interval. However, because organic matter content and CEC are significantly correlated, the relevance of the proposed relationship is questionable. When CEC is removed from the relationship, the model explained only 25% of the variance of the MWD for the mean of the three tests.

For the sub-crust, among all the tested combinations, the most statistically meaningful regression was found between MWD of the slow wetting test and organic matter content and pH:

$$\mathrm{MWD_{SW}(mm)} = 0.69\ (\pm 0.17) \times \mathrm{SOM}\ (\%) + 1.15\ (\pm 0.44) \times \mathrm{pH} - 9.62\ (\pm 3.70). \quad (2)$$

(the number in parenthesis is the standard error). The coefficient of determination (R^2) was 0.40. The residual standard error for the estimated MWD was 0.43 mm at the 95% confidence interval.

In order to link the differences in MWD between the crust and the sub-crust materials to the soil properties further, linear correlation analysis was performed (Table 5). Potential explanatory factors were the soil properties as before but also the difference between the crust and the sub-crust for a given soil property.

Generally, the differences in stability between the crust and the sub-crust materials were positively correlated with (i) the crust organic matter content and the difference in carbon content between crust and sub-crust, (ii) the crust and sub-crust CEC and (iii) the crust water content. In addition, the differences in stability between the crust and the sub-crust materials were generally negatively correlated with the crust silt content. A multiple regression analysis was performed using the difference in aggregate stability between the crust and sub-crust materials as dependent variable and the soil properties and the differences between each property for the crust and sub-crust as explanatory variables. No statistically meaningful relationship was found.

Discussion

The aggregate stability of a crust is different from the aggregate stability of its sub-crust

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To the best of our knowledge, no study has investigated differences in aggregate stability between crust and its underlying material. However, differences in aggregate stability as a function of the crusting stage were investigated by McIntyre (1958) and more recently by Darboux & Le Bissonnais (2007). Using simulated rainfall in the field, McIntyre (1958) showed that crusting decreased the splash rate on sandy loams, concluding that the crust formation processes increased the resistance of soil surface against the breakdown induced by the raindrop impacts. This observation concurs with the results of the stirring test in the present study, where crust had larger MWD than its underlying material for most of the sites (Figure 2c). The same observations were found for the other stability tests (Figure 2b, 2c). Darboux & Le Bissonnais (2007) showed different results in a laboratory experiment. They measured the aggregate stability of a seedbed (non-crusted, initial material), a structural crust and a sedimentary crust, and showed that the stability of structural crust was similar to that of the seedbed. In the present study, the aggregate stability of the structural crust was usually very different from the aggregate stability of the sub-crust irrespective of the sampling site and the stability test. The differences between the results of these two studies may lie in the experimental conditions. Darboux & Le Bissonnais experiment (2007) used a soil with a different texture (11% clay, 58% silt and 31% sand) and well-controlled experimental conditions in a laboratory. The structural crust was formed very rapidly: starting from a seedbed (non-crusted material), they applied a single and intense simulated rain (30 mm.h^{-1}), and obtained a structural crust after only six minutes of rain. Moreover, samples were collected quickly after the rain ended. In our field conditions, crust formation was probably a more gradual and discontinuous process, depending on the duration and intensity of successive rainfalls.

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The present crust samples must therefore have gone through numerous cycles of wetting and drying that could lead to additional consolidation.

The amplitude of the difference in aggregate stability between crust and sub-crust varied according to the stability test (Table 3a). The fast wetting test was designed to reproduce the processes of slaking: during rapid wetting, the compression of air entrapped inside the aggregate ruptures the inter-particle bonds within the aggregate and producing small fragments leading to a small MWD (Le Bissonnais, 1996). Sub-crust material was very sensitive to slaking, leading to the smallest MWD, and to the largest differences in MWD between crust and sub-crust (Figure 2a). The amplitudes of difference were least for the differential swelling process involved in the slow wetting test and for the kinetic energy involved in the stirring test (Table 3a, Figure 2). Thus, the fast wetting test was the best discriminator between the crust and sub-crust MWD.

For a given site, water content at the time of sampling was the only variable showing significative differences between crust and sub-crust (Figure 4). However, none of the measured standard soil properties was able to explain the differences in aggregate stability between crust and sub-crust. The crust is directly exposed to atmospheric conditions and may be submitted to a larger amplitude of wetting and drying cycles than the sub-crust. As wetting and drying cycles are an important factor of aggregate stability variation (Cosentino *et al.*, 2006), we can hypothesize that difference in hydric history between crust and sub-crust may explain some of the difference in aggregate stability between these materials. Water content at the time of sampling did not give information about the hydric history of the soil, and thus, could not explain the differences in aggregate stability between crust and sub-crust. The differences may be explained by other variables. Because the crust and sub-crust

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originated from the same initial material (a seedbed for the cultivated fields), the differences in stability result necessarily from the crust formation processes. In addition, the presence of carbonates and their crystallization through wetting and drying cycles may also play a role in the crust reinforcement (Fernandez-Ugalde *et al.*, 2011). Those possibilities indicate a need for a time-monitoring of aggregate stability and other variables in both the crust and sub-crust.

Aggregate stability varied greatly even for sites located on the same soil type within a small area

In the present study, standard soil properties were not dominant factors controlling aggregate stability. Water content, organic matter content and CEC varied significantly among the sites (Figure 4). Because these variables are known to be related to aggregate stability (Wischmeier & Mannering, 1969; Tisdall & Oades, 1982; Amézketa, 1999; Zhang & Horn, 2001), it might have been expected that the variability in aggregate stability could be explained by these properties. None of these variables (or their combination) was able to satisfactorily predict the aggregate stability of the crust or sub-crust. At best, only 40% of the variability could be explained and this had a residual standard error of approximately 0.4 mm. Hence, the predicted MWD could be wrong by as much as two stability classes (out of five stability classes) (Figure 2). Consequently, these relationships have no practical use for prediction, and their use would probably lead to large flaws in the interpretations.

Land use and site environmental conditions may have caused the differences in stability among the sites without affecting the standard soil properties. Variables known to affect aggregate stability, but not commonly noted, include tillage, crop management or mulching through their effect on microbial activity and soil water

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content (Amézketa, 1999). Altitude, slope position and orientation influence local climate which can affect aggregate stability through soil hydric history (Amézketa, 1999; Cosentino *et al.*, 2006). The current experimental design did not allow us to study precisely the influence of topography or location. However, we can note that sites A and D1 that had the largest MWD for both crust and sub-crust were located on the lowest slopes. Even more than hydric history, topography can affect flow and transport history of the material which in return affects aggregate stability (Amézkéta, 1999). In future studies, variables such as the organic matter quality, microbial activity, wetting-drying cycles and topography may need to be considered.

The heterogeneity of the aggregate stability measured in the crust samples was less than that measured in the sub-crust samples. This finding was consistent in the inter-site comparison and often observed in the intra-site comparison. The crust had larger MWD on average and larger standard deviation than the sub-crust (Table 2). As the observed aggregate system is physically constrained by full dispersion of the particles (the MWD of a fully dispersed loamy soil may be around 0.2 mm), it may have been expected that CV values would decrease with increasing MWD. However, our analysis did not identify correlations between the standard deviation and the mean MWD, nor negative correlations between the mean MWD and the CV. Hence, the smaller heterogeneity of crust aggregate stability than of that of the sub-crust may not be related to the CV calculation. The development of the crust could have decreased the spatial heterogeneity of aggregate stability. This assumption has to be examined in future studies.

Consequences for erodibility assessment and erosion modelling

When used for erodibility assessment, aggregate stability is usually measured in the sub-crust material (Bullock *et al.*, 1988; Bajracharya & Lal, 1998; Barthès & Roose, 2002; Legout *et al.*, 2005). The finding that the crust is generally less erodible than the sub-crust strongly suggests that erodibility should be assessed on the material actually exposed to erosive forces: the soil surface. The common practice of using the underlying material, instead of the crust, would cause an over-estimate by at least one erodibility class in 60% of cases and by at least two erodibility classes in 30% of cases of our soil (Figure 2).

In erosion models, erodibility can be assessed with soil standard properties such as soil texture and organic matter content through statistical functions (Alberts *et al.*, 1995; Renard *et al.*, 1997). Such an approach assumes that samples collected from the same soil type have similar erodibilities (Gumiere *et al.*, 2009). Because a single soil type was investigated in the present study, a similar erodibility would have been expected. This was clearly not the case. This finding underlines the large uncertainty in the prediction of erodibility when assessed using standard soil properties. Currently, parameterization of erosion models sets a single erodibility value for a given soil and thus does not consider the variability of erodibility within a given soil. This over-simplification could explain part of the large inaccuracy in the predicted results of erosion models (Jetten *et al.*, 2003). Comparisons between the seven sites showed that the heterogeneity of the crust was less than that of the sub-crust. Using crust samples for erodibility assessment, would decrease the heterogeneity of the mapped erodibility (although this heterogeneity would remain large).

Conclusions

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Crust showed a greater aggregate stability than its underlying material. This finding emphasizes the importance of estimating soil interrill erodibility on the soil surface material. On a crusted soil, the use of material collected from the plough layer may lead to greatly over-estimated erodibility and thus bias the results of the erosion models. The large heterogeneity in aggregate stability among sites proves that erodibility can greatly vary in space, even when considering a small test area and a single soil type. From the present study, we conclude that interrill erodibility assessment should ideally be performed with a large sampling density, which could be impractical, leaving the construction of a sound erodibility map currently unattainable. The fact that standard soil properties were not able to accurately predict the observed differences in aggregate stability lead us to suggest investigating other variables such as (i) the soil hydric history linked to local climatic conditions, (ii) environmental factors such as topography and (iii) the physical processes involved in crust formation. Factors that affect the erodibility of the soil surface should be better understood so that reliable erodibility maps can be produced from a reasonably small set of measurements.

Acknowledgments

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References

Alberts, E. E., Nearing, M. A., Weltz, M. A., Risse, L. M., Pearson, F. B., Zhang, X. C., *et al.* 1995. Soil component. In*: USDA - Water Erosion Prediction Project. Hillslope Profile and Watershed Model Documentation.* (eds D. C. Flanagan & M. A. Nearing), pp. 7.1-7.47. USDA-ARS, National Soil Erosion Research Laboratory, West Lafayette, IN, USA.

Amézketa, E. 1999. Soil aggregate stability: a review. *Journal of Sustainable Agriculture*, **14**, 83-151.

Bajracharya, R. M. & Lal, R. 1998. Crusting effects on erosion processes under simulated rainfall on a tropical Alfisol. *Hydrological Processes*, **12**, 1927-1938.

Barthès, B. & Roose, E. 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. *Catena,* **47**, 133-14.

Belnap, J., Phillips, S. L., Witwicki, D. L. & Miller, M. E. 2008. Visually assessing the level of development and soil surface stability of cyanobacterially dominated biological soil crusts. *Journal of Arid Environments*, **72**, 1257-1264.

Bresson, L. & Boiffin, J. 1990. Morphological characterization of soil crust development stages on an experimental field. *Geoderma*, **47**, 301-325.

Bryan, R. B., Gover, G. & Poesen, J. 1989. The concept of soil erodibility and some problems of assessment and application. *Catena*, **16**, 393-412.

Bullock, M. S., Kemper, W. D. & Nelson, S. D. 1988. Soil cohesion as affected by freezing, water content, time and tillage. *Soil Science Society of America Journal*, **52**, 770-776.

Comment citer ce document :
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Cosentino, D., Chenu, C. & Le Bissonnais, Y. 2006. Aggregate stability and microbial community dynamics under wetting-drying cycles in a siltloam soil. *Soil Biology and Biochemistry*, **38**, 2053-2052.

Darboux, F. & Le Bissonnais, Y. 2007. Changes in structural stability with soil surface crusting: consequences for erodibility estimation. *European Journal of Soil Science*, **58**, 1107-1114.

De Roo, A. P. J., Wesseling, C. G. & Ritsema, C. J. 1996. LISEM: a single-event, physically based hydrological and soil erosion model for drainage basins. I: Theory, input and output. *Hydrological Processes*, **10**, 1107-1117.

Fernandez-Ugalde, O., Virto, I., Barre, P., Gartzia-Bengoetxea, N., Enrique, A., Imaz, M.J. *et al*. (2011) Effect of carbonates on the hierarchical model of aggregation in calcareous semi-arid Mediterranean soils. *Geoderma*, **164**, 203-214.

Gumiere, S. J., Le Bissonnais, Y. & Raclot, D. 2009. Soil resistance to interrill erosion: model parameterization and sensitivity. *Catena*, **77**, 274-284.

ISO/DIS 10930. 2012. Soil quality - Measurement of the stability of soil aggregates subjected to the action of water. International Organization for Standardization, Geneva, Switzerland.

Jetten, V., Govers, G. & Hessel, R. 2003. Erosion models: quality of spatial predictions. *Hydrological Processes*, **17**, 887-900.

Le Bissonnais, Y. 1996. Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *European Journal of Soil Science*. **47**, 425-437.

Legout, C., Leguédois, S. & Le Bissonnais, Y. 2005. Aggregate breakdown dynamics under rainfall compared with aggregate stability measurements. *European Journal of Soil Science*, **56**, 225-238.

Loizeau, J.L., Arbouille, D., Santiago, S. & Vernet, J-P. 1994. Evaluation of a wide range laser diffraction grain size analyser for use with sediments. *Sedimentology*, **41**, 353-361.

Mackenzie, R. C. 1951. A micromethod for determination of cation-exchange capacity of clay. *Journal of Colloid Science*, **6**, 219-222.

McIntyre, D. S. 1958. Soil splash and the formation of surface crusts by raindrop impact. *Soil Science*, **85**, 261-266.

Morin, J. & van Winkel, J. 1996. The effect of raindrop impact and sheet erosion on infiltration rate and crust formation. *Soil Science Society of America Journal*, **60**, 1223-1227.

Poesen, J. 1981. Rainwash experiments on the erodibility of loose sediments. *Earth Surface Processes &Landforms*, **6**, 285-307.

R Development Core Team. 2011. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. At: http://www.R-project.org

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K. & Yoder, D. C. 1997. *Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook 703, United States Department of Agriculture - U.S. Gov. Print.* Office, Washington, DC, USA.

Soil Survey Division Staff. 1993. *Soil Survey Manual*. Soil conservation Service. United State Departement of Agriculture. Handbook 18. At: http://soils.usda.gov/technical/manual/

Tisdall, J. M. & Oades, J. M. 1982. Organic matter and water stable aggregate in soils. *Journal of Soil Science*, **33**, 141-163.

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Walkey, A. & Black, I. A. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, **37**, 29-37.

Wang, B., Zheng, F., Darboux, F. & Römkens, M. J. M. 2013. Soil erodibility for water erosion. A perspective and Chinese experience. *Geomorphology*, **187**, 1-10.

Wischmeier, W. H. & Mannering, J. V. 1969. Relation of soil properties to its erodibility. *Soil Science Society of America Proceedings*, **33**, 131-137.

Zhang, B. & Horn, R. 2001. Mechanisms of aggregate stabilization on Ultisols from sub tropical China. *Geoderma*, **99**, 123-145.

Zheng, F. L. 2005. Effect of accelerated soil erosion on soil nutrient loss after deforestation on the Loess Plateau. *Pedosphere*, **15**, 707-715.

Comment citer ce document :
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Table 1 Site locations and land uses

Site	Geographic location (latitude; longitude)	Land use and slope position	Altitude / m	Orientation	Slope gradient (field scale)
A	36°03.888' N; 109°12.621’ E	Cultivated maize field, upslope	1053	E	5° - 10°
B	36°03.874' N; 109°12.675’ E	Apple orchard, shoulder of a terrace	1118	SW	5° - 30°
C	36°04.227' N; 109°11.226’ E	Cultivated radish crop, middle slope, sampling in ridges and furrows	1206	SE	5° - 13°
D1	36°05.149' N; 109°8.958’ E	Ziwuling experimental station, bare soil, upslope, interrill area	1270	SW	5° - 10°
D2	36°05.431' N; 109°8.951’ E	Ziwuling experimental station, bare soil, mid-slope, rill area	1245	SW	30° - 35°
D3	36°05.450' N; 109°8.947’ E	Ziwuling experimental station, bare soil, 20 m from foot slope, ephemeral gully area	1180	SW	25° - 35°
D4	36°05.460' N; 109°8.884’ E	Ziwuling experimental station, bare soil, 10 m from foot slope, gully area	1154	SW	35° - 40°

Table 2 Heterogeneity of the mean weighted diameter among the sampling sites (inter-site heterogeneity) for the fast wetting test, the slow wetting test, the stirring test and the mean of the three tests. Mean of the MWD corresponds to the mean of five plots with two replicates each, n=10.

	MWD of the crust					**MWD of the sub-crust**				
Stability test	**Min. /mm**	**Max. / mm**	**Mean / mm**	**σ[a] / m)**	**CV[b]**	**Min. / mm**	**Max. / mm**	**Mean / mm**	**σ / mm**	**CV**
Fast wetting	0.20	1.62	0.98	0.41	0.42	0.13	0.95	0.36	0.18	0.51
Slow wetting	0.41	2.22	1.47	0.52	0.36	0.22	1.93	0.97	0.52	0.54
Stirring	0.29	1.77	1.14	0.41	0.39	0.23	1.23	0.69	0.27	0.39
Mean of the 3 tests	0.33	2.04	1.20	0.44	0.37	0.23	1.42	0.68	0.32	0.47

[a]σ: standard deviation; [b]CV: coefficient of variation.

Table 3 Heterogeneity of the difference in mean weighted diameter between crust and sub-crust (a) among the sampling sites (inter-site heterogeneity) for all stability tests, and (b) for each site (intra-site heterogeneity) for the mean of the three stability tests. Mean of the MWD corresponds to the mean of five plots with two replicates each, n=10.

(a)

	Difference in MWD between crust and sub-crust				
Stability test	**Min. / mm**	**Max. / mm**	**Mean / mm**	**σ / mm**	**CV**
Fast wetting	0.10	1.04	0.62	0.35	0.56
Slow wetting	0.24	1.03	0.50	0.30	0.60
Stirring	0.00	0.81	0.45	0.32	0.71
Mean of the 3 tests	0.16	0.93	0.46	0.28	0.60

[a]σ: standard deviation; [b]CV: coefficient of variation.

(b)

	Difference in MWD between crust and sub-crust				
Site	**Min. / mm**	**Max. / mm**	**Mean / mm**	**σ / mm**	**CV**
A	0.61	0.90	0.80	0.12	0.22
B	0.44	1.24	0.77	0.30	0.39
C	0.09	0.27	0.16	0.07	0.45
D1	0.08	1.25	0.52	0.47	0.90
D2	0.08	0.59	0.31	0.27	0.87
D3	0.05	0.40	0.18	0.14	0.76
D4	0.83	1.13	0.93	0.15	0.16

[a]σ: standard deviation; [b]CV: coefficient of variation.

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Table 4 Correlations (Pearson's coefficient) between aggregate stability and standard soil properties (a) for the crust and (b) for the sub-crust.

(a)

MWD	Water content	Organic matter	CEC	pH	Clay content	Silt content	Sand content
Fast wetting	**0.35**	**0.50**	**0.50**	0.11	0.08	-0.31	0.21
Slow wetting	**0.32**	**0.57**	**0.46**	0.22	0.09	-0.18	0.11
Stirring	**0.45**	**0.42**	**0.56**	0.20	0.14	-0.16	0.06
Mean of the three tests	**0.36**	**0.52**	**0.52**	0.18	-0.10	-0.22	0.13

n= 35; α=5%: *r* = 0.32

bold = significant at the 5% level

(b)

MWD	Water content	Organic matter	CEC	pH	Clay content	Silt content	Sand content
Fast wetting	-0.11	**0.51**	**0.44**	0.19	0.12	0.09	-0.07
Slow wetting	-0.17	**0.56**	**0.44**	**0.41**	0.04	-0.12	0.11
Stirring	-0.05	0.22	**0.46**	**0.47**	0.28	0.29	-0.29
Mean of the three tests	-0.13	**0.49**	**0.48**	**0.41**	0.13	0.03	-0.04

N = 35; α = 5%: *r* = 0.32

bold = significant at the 5% level

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Table 5 Correlations (Pearson's coefficient) between the differences in aggregate stability between crust and sub-crust and the standard soil properties.

Difference in MWD	**Water content**			**Organic matter**			**CEC**			**pH**			**Clay content**			**Silt Content**			**Sand content**		
	C	U	C-U	C	U	C-U	C	U	C-U	C	U	C-U	C	U	C-U	C	U	C-U	C	U	C-U
Fast wetting	**0.40**	0.29	0.30	**0.40**	0.27	0.29	**0.45**	**0.45**	-0.16	0.04	0.16	0.09	-0.07	0.20	-0.21	**-0.46**	-0.26	-0.23	**0.37**	0.16	0.23
Slow wetting	**0.32**	**0.42**	0.09	0.18	-0.01	**0.42**	0.12	0.15	-0.10	-0.19	-0.07	-0.11	-0.21	0.25	**-0.35**	-0.22	-0.04	-0.25	0.23	-0.06	**0.36**
Stirring	**0.40**	0.26	**0.32**	**0.40**	0.29	0.29	**0.35**	**0.33**	-0.07	-0.01	-0.28	-0.06	-0.19	0.09	-0.21	**-0.48**	-0.32	-0.16	**0.42**	0.23	0.19
Mean of the 3tests	**0.36**	**0.30**	0.26	**0.34**	0.19	**0.37**	**0.33**	**0.33**	-0.12	-0.06	0.05	-0.10	-0.17	0.20	-0.28	**-0.41**	0.22	-0.23	**0.36**	0.11	0.28

C=crust; U=sub-crust; C-U=difference in soil property value between the crust and the sub-crust. N = 35; α = 5%: r = 0.32

Bold = significant at the 5%.

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Figure 1 Location of the study sites.

Figure 2 Aggregate stability of crust and sub-crust for (a) fast wetting, (b) slow wetting, (c) stirring tests and (d) the mean of the three tests for all sites. Each MWD corresponds to the mean of five plots with two replicates each, n=10. Bars represent standard errors.

Small letters above the bars correspond to paired comparisons between crust and sub-crust for a given site, and paired comparison between sites (Wilcoxon test, α=5%). VS: very stable; S: stable; M: medium; U: unstable; VU: very unstable (Le Bissonnais, 1996).

Figure 3 Crust and sub-crust contents in (a) clay, (b) silt, and (c) sand for all sites.

The data from each site correspond to the mean of five plots with two replicates each, n=10. Bars represent standard errors. Small letters above the bars correspond to paired comparisons between crust and sub-crust for a given site, and paired comparison between sites (Wilcoxon test, α=5%).

Figure 4 Crust and sub-crust values for (a) organic matter content, (b) CEC and (c) pH, for all sites. The data from each site correspond to the mean of five plots with two replicates each, n=10. Bars represent standard errors.Letters above the bars correspond to paired comparisons between crust and sub-crust for a given site, and paired comparison between sites (Wilcoxon test, α=5%).

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Algayer, B., Wang, B., Bourennane, H., Zheng, F., Duval, O., Li, G., Le Bissonnais, Y., Darboux, F. (2014). Aggregate stability of a crusted soil: differences between crust and sub-crust material, and consequences for interrill erodibility assessment. An example from the Loess Plateau of China. European Journal of Soil Science, 65 (3), 325-335. DOI : 10.1111/ejss.12134

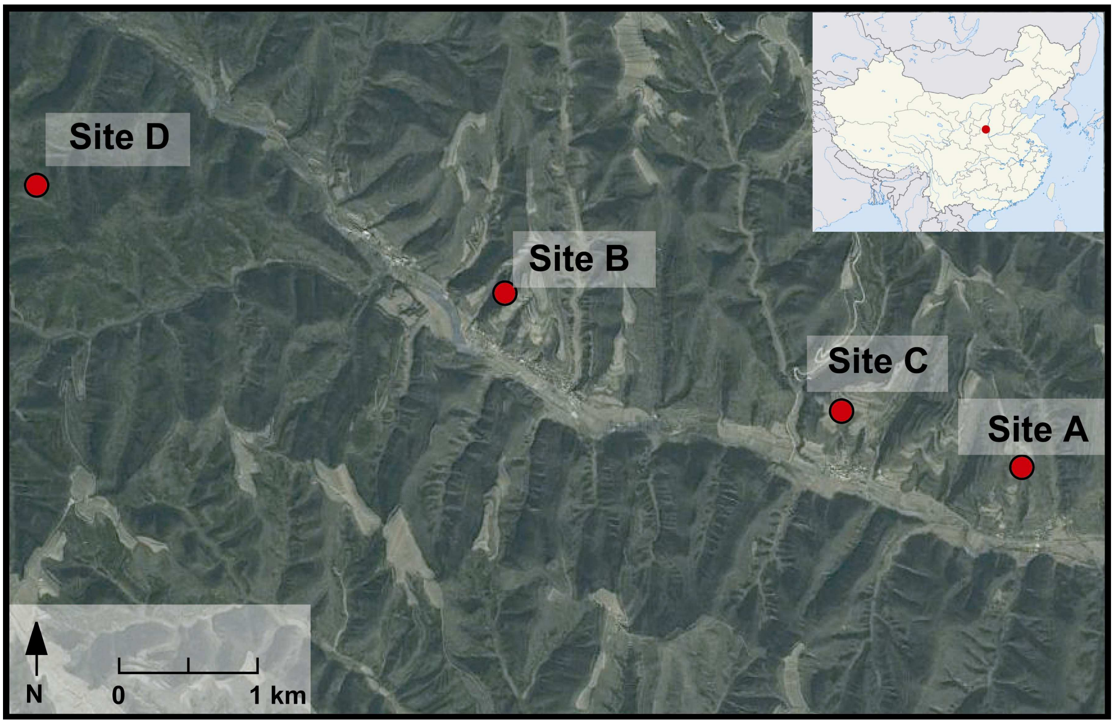

Figure 1 Location of the study sites.

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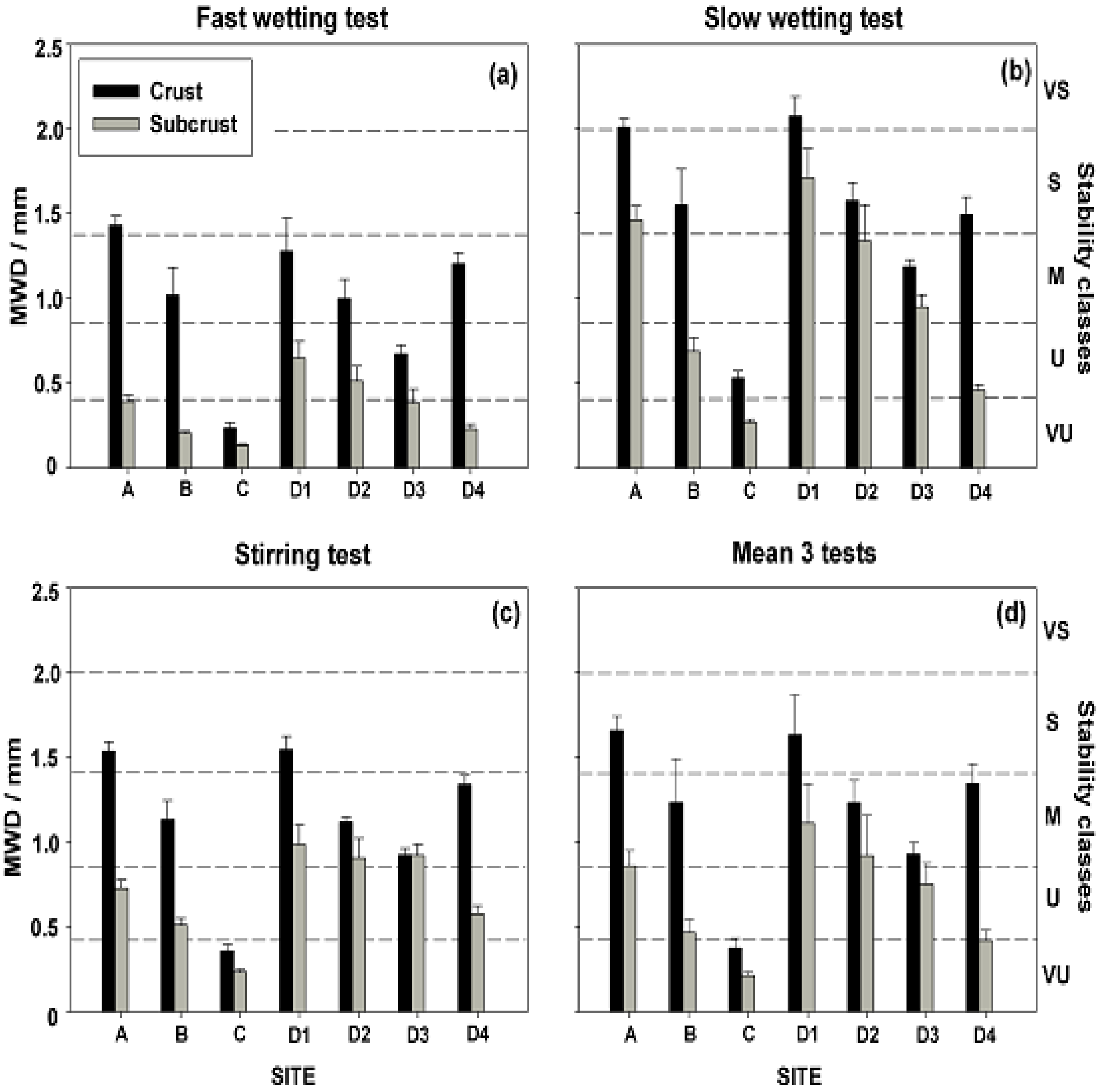

Figure 2 Aggregate stability of crust and sub-crust for (a) fast wetting, (b) slow wetting, (c) stirring tests and (d) the mean of the three tests for all sites. Each MWD corresponds to the mean of five plots with two replicates each, n=10. Bars represent standard errors.

Small letters above the bars correspond to paired comparisons between crust and sub-crust for a given site, and paired comparison between sites (Wilcoxon test, α=5%).

VS: very stable; S: stable; M: medium; U: unstable; VU: very unstable (Le Bissonnais, 1996).

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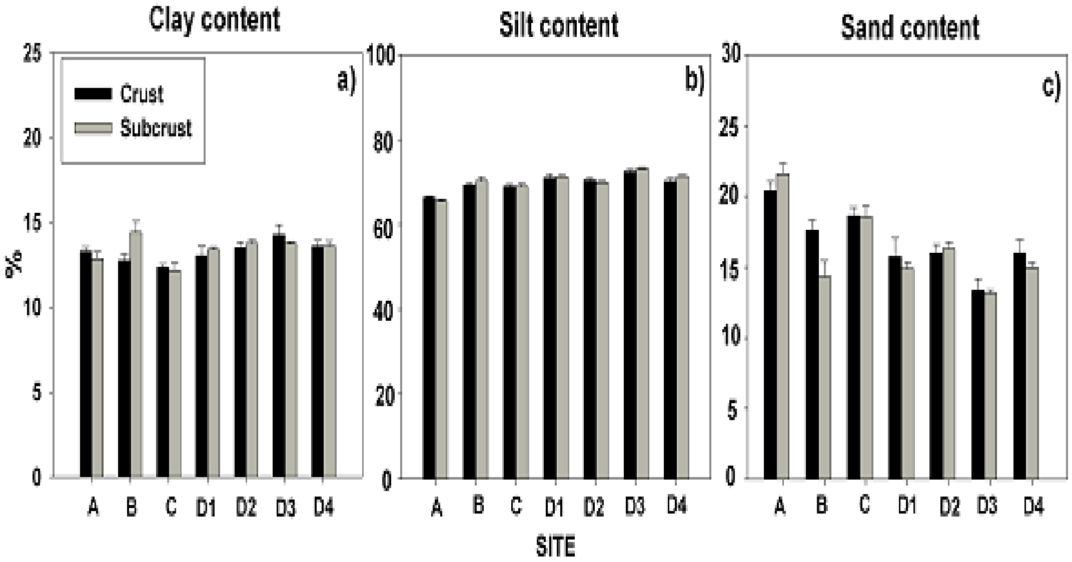

Figure 3 Crust and sub-crust contents in (a) clay, (b) silt, and (c) sand for all sites.

The data from each site correspond to the mean of five plots with two replicates each, n=10. Bars represent standard errors. Small letters above the bars correspond to paired comparisons between crust and sub-crust for a given site, and paired comparison between sites (Wilcoxon test, α=5%).

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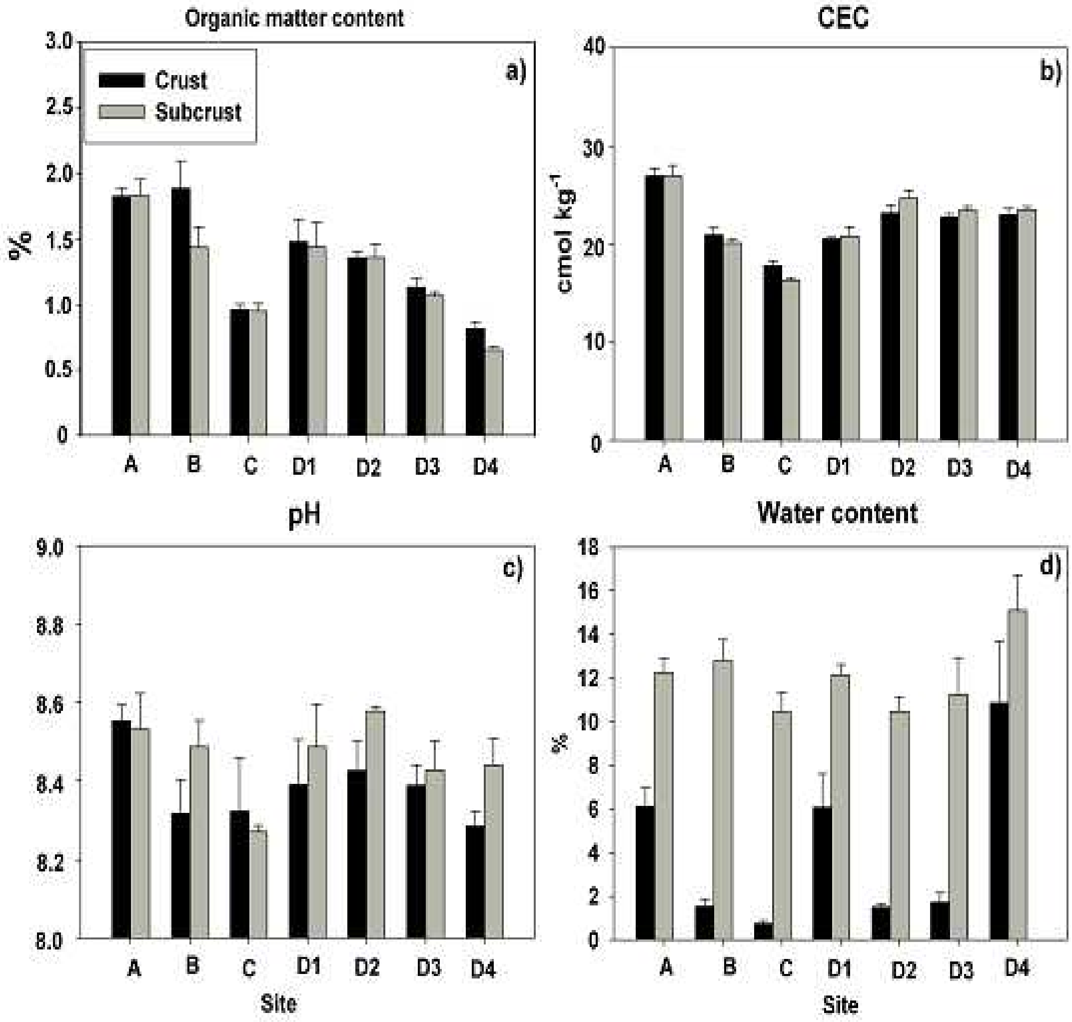

Figure 4 Crust and sub-crust values for (a) organic matter content, (b) CEC and (c) pH, for all sites. The data from each site correspond to the mean of five plots with two replicates each, n=10. Bars represent standard errors.Letters above the bars correspond to paired comparisons between crust and sub-crust for a given site, and paired comparison between sites (Wilcoxon test, α=5%).

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