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Crusting cause changes in soil erodibility: assessment and consequences for erosion modeling. An example from Loess Plateau

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Abstract:

Erodibility is a key parameter in soil erosion models. It can be estimated using aggregate stability tests. Nowadays, it is usual to assess aggregate stability on samples taken from the plough layer. However, soil surface degradation under raindrop impact induces numerous changes that lead to crust formation. Hence, estimation of erodibility carried out on material collected from the plough layer may not be valid for crust, i.e. for the soil surface material that undergoes erosion at the first place. The purpose of the present study is to compare the stability of crusts to the stability of the underlying soil material and to assess explanatory factors through other soil and site properties. Paired samples (crust and underlying soil material) from seven Chinese field sites with different land uses were collected in Loess plateau. Aggregate stability (using Le Bissonnais' method, 1996), soil texture, soil organic matter content, CEC, pH and water content were measured. Statistical analysis shows large differences in stability between the crusts and their underlying material. For all the samples, the aggregate stability of crusts is larger than the stability of the underlying materials. The most important differences are observed for the fast wetting treatment (slaking). The other soil properties do not explain the differences in stability. Those results confirm the importance of estimating soil erodibility on the exact material that undergoes erosion, i.e. the soil surface material. Using material collected from the plough layer may lead to large bias in the results of soil erosion models.

Keywords: aggregate stability, crust, erodibility, loess plateau, field sampling

I. INTRODUCTION

Erodibility is a key parameter in soil erosion models. It has been showed that aggregate stability tests could be used to estimate both the erodibility and the size fractions that are available to crust formation and erosion processes. Nowadays, it is usual to assess aggregate stability on samples taken from the plough layer. However, soil top surface degradation under raindrop impact induces numerous changes that lead to progressive crust formation. Those changes induce differences between the plough layer and the soil surface properties.

Numerous studies (e.g. McIntyre, 1958; Malam Issa et al. 2004) showed that infiltration rate tends to decrease with crust development providing the water runoff at the soil surface and affecting soil erosion (Singer and Shainberg, 2004). In addition, soil crusting can greatly impair crop emergence and plant development (e. g. Lehrsch et al. 2005; Gallardo-Carrera et al. 2007). Soil gas emissions are also subjected to changes with crust development.

Hence, estimation of erodibility carried out on material collected from the plough layer may not be valid for crust, i.e. for the soil surface material that undergoes erosion at the first place. Darboux and Le Bissonnais (2007) showed large differences in aggregate stability between the sedimentary crust and the underlying material of a clay loam. However, this laboratory experiment by the experimental setup, which did not allow for the assessment of the factors explaining differences in aggregate stability.

The purpose of the present study was to compare the stability of crusts to the stability of the underlying soil material in the field and to assess explanatory factors through other soil and site properties.

II. MATERIAL AND METHODS

Paired samples (crust and underlying soil material) from seven field sites with different land uses were collected in Loess plateau, near the town of Xi'An in the north of China (table 1). For each site, 5 plots (one square meter large) were defined to collect samples.

The crust was collected independently of the underlying material (named hereafter "under crust"). Undisturbed samples of under crust were collected. Prior to sampling, the soil surface was described and the type of crust identified. For sedimentary crusts, the boundary between crust and under crust was usually clear. For structural crusts, the boundary appearing fuzzier, a thickness of about 5 mm was considered. The under crust was defined as the soil material between -1 cm and -5 cm (from the initial soil surface).

TABLE 1: SITES LOCALISATIONS AND LAND USE

| Site | Latitude ; Longitude | Land use | Slope |
|------|-------------------------------|-----------------------------------------------------------------------------------|-----------|
| A | 36°03.888' N ; 109°12.621' E | Cultivated corn field | 5° - 10° |
| B | 36°03.874' N ; 109°12.675' E | Apple orchard, shoulder of a terrace | 5° - 30° |
| C | 36°04.227' N ; 109°11.2260' E | Cultivated radish crop, foot of the slope, sampling in the ridges and the furrows | 5° - 13° |
| D | 36°5.149' N ; 109°81.958' E | Ziwuling experimental station, top of the slope | 5° - 10° |
| E | 36°05.450' N ; 109°81.947' E | Ziwuling experimental station, rill area, middle of the slope | 30° - 35° |
| F | 36°05.450' N ; 109°81.947' E | Ziwuling experimental station, gully area, 20 meters from the foot slope | 25° - 35° |
| G | 36°5.460' N ; 109°81.884' E | Ziwuling experimental station, gully area, 10 meters from the foot slope | 35° - 40° |

For each paired samples, different properties were assessed. Aggregate stability was measured using the Le Bissonnais method (Le Bissonnais 1996). Sampled aggregates were subjected to three tests: a fast wetting test, a slow wetting test and a mechanical test. Those three tests were designed to reproduce the processes involved in interrill erosion. The results were presented using the mean weighted diameter (MWD). Other soil properties were measured in the aim to explain stability differences between crust and underlying material. Soil texture was assessed using laser diffraction

granulometer. Organic carbon content, gravimetric water content, CEC and pH were also measured.

III. RESULTS AND DISCUSSION

Results of the aggregate stability tests showed large differences between the crusts and their underlying materials. For all the samples, the aggregate stability of crusts was larger than the stability of the underlying materials ().

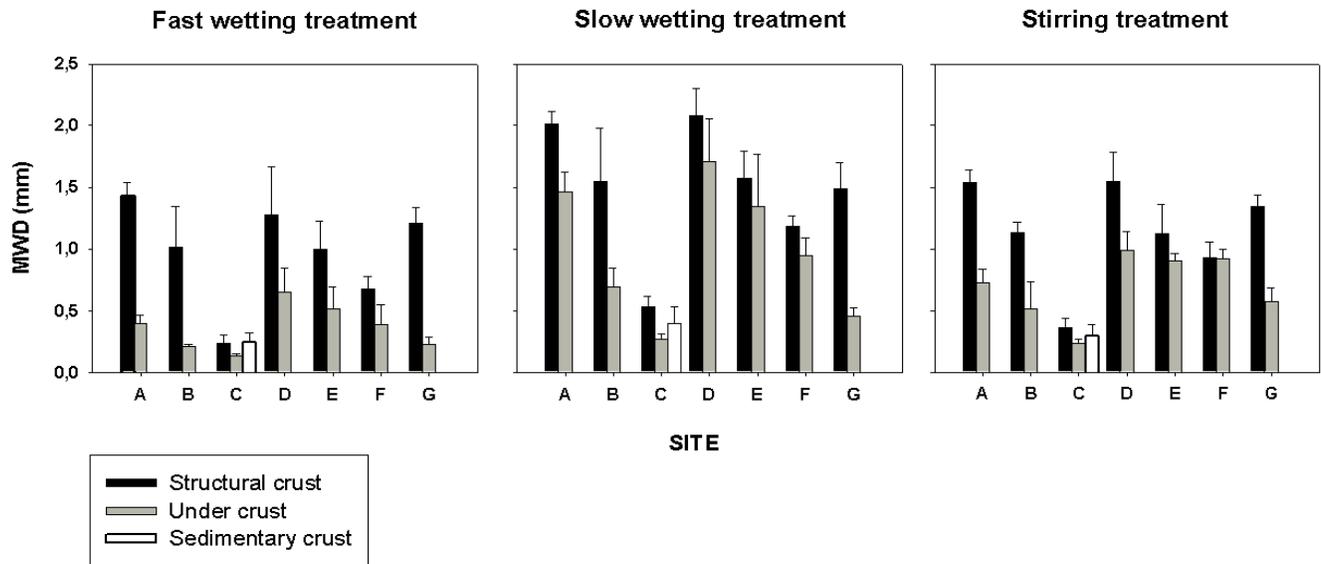


Figure 1: comparison between crust and undercrust stability on the different sites

The site C was the only one presenting a sedimentary crust. It showed the lowest aggregate stability (very unstable) and also the lowest differences between crusts and under crusts for each treatment. However, the stability treatments showed higher MWD values in the sedimentary crusts than in the underlying material. Those results are in opposition with the results presented by Darboux and Le Bissonnais (2007) who found lower stability in sedimentary crusts on a clay loam under simulated rainfalls.

The difference between MWD from crust and undercrust varied with the sites and the stability treatments. The most important differences were observed for the fast wetting

treatment (slaking) which is the most disruptive one. It means that the observed structural crusts were more slake resistant than the under crust aggregates. The sites B (apple orchard) and G (gully area) showed larger stability differences between crust and undercrust than the other, whatever the stability test.

The samples from the different sites presented almost the same texture (silt loam) and pH (8.4), whereas they presented important variability in aggregate stability and water content (table 2). Moreover, water content differences between crust and the underlying material is larger than the other studied explanatory factors.

TABLE 2: RESULTS OF THE EXPLANATORY FACTORS MEASUREMENTS

| Site | Water content (%) | | Organic matter (%) | | CEC | | pH | | Clay content (%) | | Silt content (%) | | Sand content (%) | |
|------|-------------------|-------|--------------------|-------|-------|-------|-------|-------|------------------|-------|------------------|-------|------------------|-------|
| | crust | under | crust | under | crust | under | crust | under | crust | under | crust | under | crust | under |
| A | 6.1 | 12.2 | 1.8 | 1.8 | 26.9 | 26.9 | 8.5 | 8.5 | 13.3 | 12.8 | 66.3 | 65.6 | 20.4 | 21.6 |
| B | 1.5 | 12.8 | 1.9 | 1.4 | 20.9 | 20.1 | 8.3 | 8.5 | 12.7 | 14.4 | 69.8 | 71.2 | 17.5 | 14.3 |
| C | 0.7 | 10.4 | 1 | 0.9 | 17.8 | 16.3 | 8.3 | 8.3 | 12.3 | 12.2 | 69.1 | 69.3 | 18.6 | 18.5 |
| D | 6.1 | 12.1 | 1.5 | 1.4 | 20.5 | 20.8 | 8.4 | 8.5 | 13.0 | 13.4 | 70.9 | 71.7 | 15.7 | 14.9 |
| E | 1.5 | 10.5 | 1.4 | 1.4 | 23.2 | 24.7 | 8.4 | 8.6 | 13.5 | 13.7 | 70.6 | 70.1 | 15.9 | 16.2 |
| F | 1.7 | 11.2 | 1.1 | 1.0 | 22.8 | 23.4 | 8.4 | 8.4 | 14.3 | 13.7 | 72.4 | 73.2 | 13.3 | 13.1 |
| G | 10.8 | 15.1 | 0.8 | 0.6 | 23.0 | 23.5 | 8.3 | 8.4 | 13.6 | 13.6 | 70.4 | 72.5 | 16.0 | 14.9 |

TABLE 3: CORRELATIONS (PEARSON' COEFF.) BETWEEN STABILITY TESTS AND THE EXPLANATORY FACTORS

| | | Water content | | Organic matter | | CEC | | clay content | | silt content | | sand content | |
|-------------------------|-------|---------------|-------|----------------|-------|-------|-------|--------------|-------|--------------|-------|--------------|-------|
| | | Crust | Under | Crust | Under | Crust | Under | Crust | Under | Crust | Under | Crust | Under |
| MWD Fast wetting | Crust | 0,35 | 0,2 | 0,5 | 0,49 | 0,5 | 0,62 | 0,08 | 0,24 | -0,31 | -0,19 | 0,21 | 0,11 |
| | Under | -0,03 | -0,11 | 0,31 | 0,51 | 0,21 | 0,44 | 0,3 | 0,12 | 0,21 | 0,09 | -0,27 | -0,07 |
| MWD slow wetting | Crust | 0,32 | 0,16 | 0,57 | 0,58 | 0,46 | 0,58 | 0,09 | 0,24 | -0,18 | -0,17 | 0,11 | 0,07 |
| | Under | 0,06 | -0,17 | 0,41 | 0,56 | 0,35 | 0,44 | 0,25 | 0,04 | -0,01 | -0,12 | -0,07 | 0,11 |
| MWD stirring | Crust | 0,45 | 0,2 | 0,42 | 0,42 | 0,56 | 0,63 | 0,14 | 0,28 | -0,16 | -0,08 | 0,06 | 0,01 |
| | Under | 0,12 | -0,05 | 0,07 | 0,22 | 0,33 | 0,46 | 0,43 | 0,28 | 0,39 | 0,29 | -0,44 | -0,29 |

The organic matter content and aggregate stability were positively correlated, especially for the slow wetting treatment (table 3). We observed similar correlations between the CEC and MWD. The water content was not significantly correlated with the stability. We observed the lowest correlations between the clay content and the MWD. The silt content presented low negative correlations with the MWD. Globally, the statistical analysis did not found significative relationships between the stability variations and the studied explanatory factors.

The difference in stability between crust and underlying material was positively correlated with the crust water

content, and negatively correlated with the crust silt content (table 4). Neither the soil organic matter nor the clay content variation could explain the differences between the stabilities of the crust and the underlying material. The low links observed between stability variations and the chosen explanatory factors can be explained by the punctual aspect of our study in time. Indeed, we measured the explanatory factors values at the time of sampling, and a monitoring of the factors variation (e. g. water content) could possibly give larger relationships with the aggregate stability variation.

TABLE 4: CORRELATIONS (PEARSON' COEFF.)FOR STABILITY TESTS DIFFERENCES BETWEEN CRUST AND UNDERCRUST AND THE EXPLANATORY FACTORS

| | Water content | | | Organic matter | | | CEC | | | Clay content | | | Silt content | | | Sand content | | |
|------------------------------------|---------------|-------|------|----------------|-------|------|-------|-------|-------|--------------|-------|-------|--------------|-------|-------|--------------|-------|------|
| | Crust | Under | C-U | Crust | Under | C-U | Crust | Under | C-U | Crust | Under | C-U | Crust | Under | C-U | Crust | Under | C-U |
| Difference MWD fast wetting | 0,40 | 0,29 | 0,30 | 0,40 | 0,27 | 0,29 | 0,45 | 0,45 | -0,16 | -0,07 | 0,20 | -0,21 | -0,46 | -0,26 | -0,23 | 0,37 | 0,16 | 0,23 |
| Difference MWD slow wetting | 0,32 | 0,42 | 0,09 | 0,18 | -0,01 | 0,42 | 0,12 | 0,15 | -0,10 | -0,21 | 0,25 | -0,35 | -0,22 | -0,04 | -0,25 | 0,23 | -0,06 | 0,36 |
| Difference MWD stirring | 0,40 | 0,26 | 0,32 | 0,40 | 0,29 | 0,29 | 0,35 | 0,33 | -0,07 | -0,19 | 0,09 | -0,21 | -0,48 | -0,32 | -0,16 | 0,42 | 0,23 | 0,19 |

IV. CONCLUSIONS

The samples from the crust presented higher values in aggregate stability than the underlying material. However, the chosen explanatory factors can not explain those variations in stability. This work emphasized the need in

monitoring the soil crust stability variation in comparison to the stability of the underlying material.

Those results also confirm that using material collected from the plough layer may lead to large bias in the results of soil erosion models. Soil erodibility has to be estimate on the soil surface, which correspond to the exact material that undergoes erosion.

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