Soil Crusting Under Intense Rainfall as Influenced by Cohesive and Wetting Factors

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Introduction

- Deleterious land practices such as deforestation, slash and burn agriculture, and seasonal fires in the Caribbean expose the soil surface to the direct impact of intense tropical rainfall.
- The susceptibility of the exposed soil to aggregate disintegration and the associated crusting depends on the cohesive strength of soil binding factors and the magnitude of disruptive forces of rapid wetting and raindrop impact produced by the intense rainfall.
- We hypothesize that clay and organic matter (OM) concentrations in soils subjected to varying pre-wetting conditions influence aggregate cohesion and crust formation.

Objectives

- Quantify the effects of wetting conditions on the resistance of soils of varying levels of clay and OM to crusting under continuous intense simulated rainfall events typical of the tropics.
- Investigate the relationship between shear and crust strength with splash detachment (SD) and aggregate breakdown (AB) of soils of varying levels of clay and OM subjected to different wetting conditions and exposed to intense rainfall.

Methods & Materials

- Six soils from Trinidad were selected to give a combination of three concentrations of clay (low, <200 g kg^{-1}; medium, 200-450 g kg^{-1}; and high, >450 g kg^{-1}) and two concentrations of organic matter (low, ≤ 30 g kg^{-1} and high, >30 g kg^{-1}).
- Samples in columns 7.3 cm in d and 5 cm high were either left dry or pre-wetted with mist at slow (7.5 mm h^{-1}) and fast (75 mm h^{-1}) wetting rates and equilibrated to matric suction of -0.033 MPa and -0.066 MPa.
- SD and AB were determined after exposing the soil columns to 120 mm h^{-1} rain for 10 min.
- Shear and Crust strength were determined with a drop cone penetrometer (Towner, 1973).

Results and Discussion

- Slow (7.5 mm h^{-1}) and fast (75 mm h^{-1}) pre-wetting of the soils to the different antecedent water contents (0.5FC and FC) significantly increase shear strength than exposing initially dry soil samples to the intense simulated rainfall (Fig. 1)
- Pre-wetting aids clay movement and orientation and careful removal of intra-aggregate entrapped air encouraging soil cohesion (Wuddivira et al., 2009).
- Fast wetting decreases effective stress the component of the matric suction holding particles together (Horn et al., 1994). This decreases inter-particle contact points and bonding, weakening shear strength.

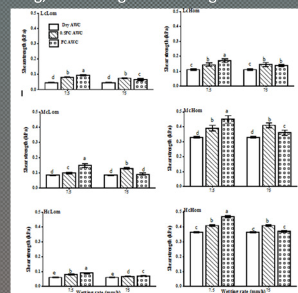
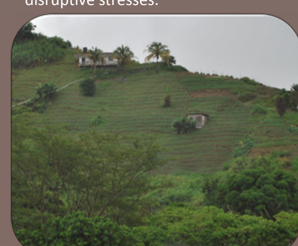


Fig. 1. Effects of wetting rate (WR) and antecedent water content (AWC) on shear strength of six soils designated as low (L), medium (M) and high (H) clay (c) at low and high organic matter (om) concentrations under intense rainfall. Values followed by the same letter on each sub-figure are not statistically significant at P = 0.05. Error bar indicates the standard error of the mean.

- Crust strength significantly increased as clay content increases in the low OM soils (Fig. 2), indicating that the effect of disruptive forces in generating finer particles is stronger on medium and heavy than on light textured soils.
- In soils where clay content is medium (200-450 g kg^{-1}) to high (>450 g kg^{-1}) and smectitic mineralogy is the principal contributor to high CEC, aggregates succumb easily to disruptive forces of slaking and raindrop impact.
- If in the same texture range, high CEC is jointly contributed by smectites and high OM (>30 g kg^{-1}), cohesive bonding and effective stress are improved leading to higher shear strength under disruptive stresses.



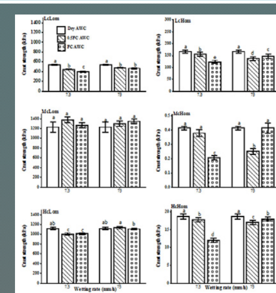


Fig. 2. Effects of wetting rate (WR) and antecedent water content (AWC) on crust strength of six soils designated as low (L), medium (M) and high (H) clay (c) at low and high organic matter (om) concentrations under intense rainfall. Values followed by the same letter on each sub-figure are not statistically significant at P = 0.05. Error bar indicates the standard error of the mean. **Note: Variation in y-axes scale of the sub-figures is to be able to keep the low crust strength values of the high organic matter soils visible.**

- The nonlinear power model yielded the best fits for the relationship between SD (r^2=0.851, Fig. 3a) and AB (r^2=0.795, Fig. 3b) with shear strength. The power model explains 85% and 80% of the variability in SD and AB respectively.
- The power model mechanistically revealed that erodibility decreases as shear strength increases up to a threshold shear strength after which SD and AB do not decrease further but may become non-existent with increase in shear strength.
- The model separated the soils into two groups of aggregates of medium and high clay high in OM that sheared, splashed and broke minimally and of aggregates of low, medium and high clay low in OM that sheared, splashed and broke heavily (Fig. 3).
- The model indicates that soils with shear strength of <0.2 kPa crust and erode heavily while a minimum shear strength of 0.3 kPa, induced at the medium clay level with high OM, is required to decrease the crust formation and erodibility to zero under intense rainfall (Fig. 3).

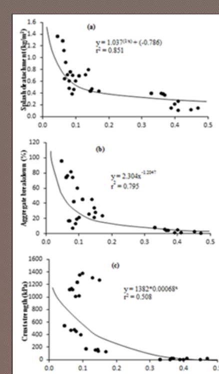


Fig. 3. (a) Splash detachment, (b) aggregate breakdown and (c) crust strength as functions of shear strength of the six soils designated as low (L), medium (M) and high (H) clay (c) at low and high organic matter (om) concentrations.

Conclusions

- Pre-wetting prior to soil exposure to intense tropical rainfall alleviates shearing stresses by increasing points of particle contact, bonding and effective stress.
- At mid-range clay concentration, high organic matter (>30 g kg^{-1}) increased the resistance of soils to shearing stresses of intense tropical rainfall
- Joint contribution of clay and OM to soil CEC alleviates crusting.
- Interaction rather than the individual effects of clay and organic matter control the erodibility of these soils.

References

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Acknowledgements

Technical Support of this research was provided by Melissa Atwell, Dexter Bristol and Conrad Calliste .