Towards a fundamental understanding of soil aggregate breakdown under applied mechanical energies

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Introduction

Soil aggregate instability and dispersion is the single most important process leading to problems associated with soil erosion, structural decline and land degradation. In the ordered systems described by aggregate hierarchy theory, breakdown occurs when sufficient mechanical stress has been applied to overcome the attractive forces within the aggregates. Smaller structural units also necessarily possess greater bonding energies than their larger counterparts. Where the stresses applied to the aggregate are less than the maximum stress required to fracture all of the structural hierarchical levels, incomplete disruption occurs.

Traditional empirical techniques (e.g. end-over end-shaking, wet sieving) used in the measurement of clay dispersion and soil aggregate stability typically use only a single stability measurement and the results obtained and conclusions drawn are highly dependent on the mechanical energy applied. The stresses applied in these systems may also be different to those produced under field conditions (e.g. raindrop impact, cultivation) resulting in hierarchical breakdown inconsistent with field observations. This paper reports on the use of ultrasonic and low frequency pressure waves to assess aggregate breakdown within dilute soil-water suspensions. It also reports on a method to measure the waveforms applied to soils under rainfall simulation and the potential to simulate these stresses in soil-water suspensions.

Materials and Methods

The stresses applied to dilute soil-water suspensions of three Lockyer Valley and Darling Downs soils were varied by altering the amplitude and frequency of applied longitudinal waveforms and the total energy applied. A Branson Sonifier 250 (Branson, CT) was used to apply up to 12 kJ of ultrasonic (20 khz) energy to the soil-water suspensions at either 8.9 or 25.0 W. Similarly, a mechanical shaker table was used to apply up to 2.5 kJ of low frequency (100-3200 hz) energy to the soil-water suspensions at < 2.5 W. In each case, aggregate breakdown was measured by the release of <2 μm and <20 μm sized material.

An investigation of the potential to reproduce the stresses and aggregate disruption associated with raindrop impact was conducted by recording the waveform sequence produced by simulated rainfall and applying this waveform to soil-water suspensions using the shaker table. Disruption at the <2 μm and <20 μm levels were compared to that measured under rainfall simulation for periods up to 1800 s.

Results and Discussion

No significant ($P<0.05$) differences were found in the amount of <2 μm and <20 μm sized material released due to changes in either frequency or power where the energy was applied at <200 hz. Increasing the frequency from 200 to 1600 hz increased the amount of <20 μm sized material but did not affect the amount of <2 μm sized material released. Increasing the power within the 800-3200 hz frequency range also increased only the amount of <20 μm sized material released. However, increasing the frequency from 1600-3200 hz increased both <2 and <20 μm sized material released. In all cases, the amount of <2 and <20 μm sized material released was substantially less than that released by the application of the ultrasonic energy. However, significant differences in the aggregate disruption produced by the ultrasonic energy were related to the power applied.

These results confirm the presence of aggregate hierarchy and the importance of frequency, power and the total energy applied on the resultant aggregate breakdown at each level of hierarchy. It also suggests that in order to quantitatively describe aggregate breakdown at specific hierarchical levels, the assessment technique must accurately reproduce the frequency, power and total energy applied under field conditions. This explains why traditional empirical methods of aggregate stability assessment do not provide an accurate reflection of aggregate breakdown at each hierarchical level under field conditions and typically provide no more than an index of stability.

No significant difference was found between the amount of <2 μm and <20 μm sized material released under rainfall and that produced when similar mechanical waveforms and total energy were applied using the shaker table. This suggests that it is possible to accurately reproduce mechanical stresses experienced in the field under laboratory conditions and that there is potential for the development of rapid, quantitative aggregate stability assessment techniques.

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Conclusions

The frequency and amplitude of the applied mechanical waves, and the total energy applied, affect aggregate breakdown. Hence, to accurately reproduce aggregate breakdown at each hierarchical level under field conditions, the mechanical stress conditions imposed in the field need to be reproduced exactly. A method of simulating the mechanical energy associated with raindrop impact has been proposed and evaluated.

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