ASSESSING AGGREGATE STABILITY IN SODIC SOILS USING LOW FREQUENCY MECHANICAL ENERGY

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Abstract
Aggregate breakdown and dispersion are fundamental components of soil structural decline. While sodic soils spontaneously disperse when wet, aggregate breakdown and dispersion of many soils under field conditions is often affected by the application of mechanical energies (eg rainfall, machinery and animal impacts). This paper reports on an experimental program using low frequency (< 4 khz) mechanical stresses to quantify aggregate breakdown characteristics. The effect of varying the waveform frequency, power and total energy applied to soils with a range of exchangeable sodium levels was investigated. Aggregate breakdown was assessed across seven size classes ranging from >500 um to <2 um. The results suggest that both the nature (frequency and magnitude) of the waveform stress applied and the duration of the energy application variously affect the breakdown induced within different aggregate size classes. This work confirms the presence of aggregate hierarchy within the soils studied and provides a quantitative basis for evaluating the relative strength of bond mechanisms operating at different levels of aggregation.

Introduction
Soil aggregate instability and dispersion is the single most important process leading to problems associated with soil erosion, structural decline and land degradation. The stability of the soil aggregates is a function of the attractive and repulsive forces arising from intermolecular and electrostatic interactions between the soil solution and soil particles (Rengasamy and Olsson, 1991). While a proportion of the clay material in sodic soils spontaneously disperse, the application of mechanical pressure is often required to produce complete dispersion and aggregate breakdown.

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 nature of the mechanical energy applied. The application of ultrasonic energy to soil-water suspensions for particle size analysis has been widely adopted (eg. Busacca *et a*l. 1984; Gregorich *et al*. 1988) and recently applied to aggregate stability assessments (eg. Raine and So, 1993; 1994; 1997; Field *et al*., 2004). Ultrasonic probes apply energy to soil-water suspensions at frequencies commonly in excess of 20 kHz. However, field processes affecting aggregate disruption (e.g. raindrop impact, cultivation) could be expected to apply pressure waves with variable frequencies well below the ultrasonic range. Hence, it would seem appropriate to investigate the effect of low frequency pressure waves on aggregate breakdown and dispersion.

Materials and Methods
Surface (0-20 cm) samples of a Red Ferrosol and Black Vertosol (Isbell, 1996) from the Darling Downs, Queensland, were collected. Both soils were uniformly mixed and sieved to remove aggregates larger than 2.36 mm in diameter. Two litres of sodium and calcium chloride solution (1000 $mmol_cL^{-1}$) with an SAR of 6, 15 and 24 were leached through 200 g soil samples packed into buchner funnels. A 1 $mmol_cL^{-1}$ solution at the appropriate SAR was then leached through the soil sample under vacuum to lower the electrical conductivity. The samples were allowed to drain freely and left to air-dry for fourteen days under glasshouse conditions. They were then homogenously mixed and passed through a 2.36 mm sieve a second time before being stored in air-tight containers ready for use.

Application of low frequency mechanical energy
Low frequency energy was applied to soil-water suspensions consisting of 15 g of soil and 75 mL of deionised water in a 100 mL beaker. A 10 mm x 3 mm diameter magnetic stirrer bar rotating at approximately 120 rpm was used to ensure uniform mixing within the suspension. An inverted V203 shaker table and PA25E amplifier (Ling Dynamic Systems, Royston, UK) were used to apply the low frequency pressure waves. The shaker table was attached to a 12 mm diameter stainless steel probe (surface area = 127 mm^2) inserted into the soil-water suspensions to a depth of 22 (±1) mm. A simple saw tooth waveform (either 400 Hz and 3200 Hz) was generated and controlled via a computer interfaced with a DAQ Card-1200 (National Instruments, USA). Altering the power of the waveform and the duration of application enabled the application of different total energies. Two power

levels were investigated (setting 2 and 6 on the amplifier) and durations of 300, 600 and 900 seconds were used. Three replications of each power, frequency and duration treatment were measured.

Measuring aggregate breakdown

Particle and aggregate sizes ranging from <2 μm to >500 μm were measured after the application of the energy treatment. The pipette withdrawal method was used to determine the amount of material in the <2 μm and <20 μm size fractions (Gee & Bauder 1986). For larger size fractions (i.e. 50-75, 75-125, 125-250, 250-375, 375-500 and >500 μm), a 1.8 m settling column (Loch, 2001) was used. The 20-50 μm size fraction was calculated by subtracting the mass of all the other size fractions from the initial mass of the sample. Statistical analyses were performed using Microsoft Excel. Significant differences between data means were identified at the 95% confidence interval using two-tailed, heteroscedastic Student's t-Tests.

Results and Discussion

Duration of energy application

Aggregate breakdown and dispersion generally increased as period of energy application increased (eg. Figure 1). However, there were differences in the rate of breakdown observed between the soil and energy treatments and significant (P<0.05) differences in the rate at which particular size fractions reached an apparent maximum due to the energy application. For example, significant aggregate breakdown occurred in Ferrosol equilibrated with SAR 24 water when a low frequency waveform (400 Hz) was applied for 300 seconds. However, increasing the duration to 600 seconds produced no significant difference in aggregate breakdown but increasing the duration to 900 seconds significantly increased breakdown across all size fractions less than 375 μm. Where the high frequency (3200 Hz) waveform was applied to the same soil, no significant aggregate breakdown occurred until after 600 seconds of energy had been applied (Figure 1b). This data confirms that the rate of breakdown within aggregates is not linear with increasing energy application. Similarly, it seems possible that some bonds operating within the aggregates may be able to resist periods of stress but progressively weaken before fracturing after the application of critical total energy applications.

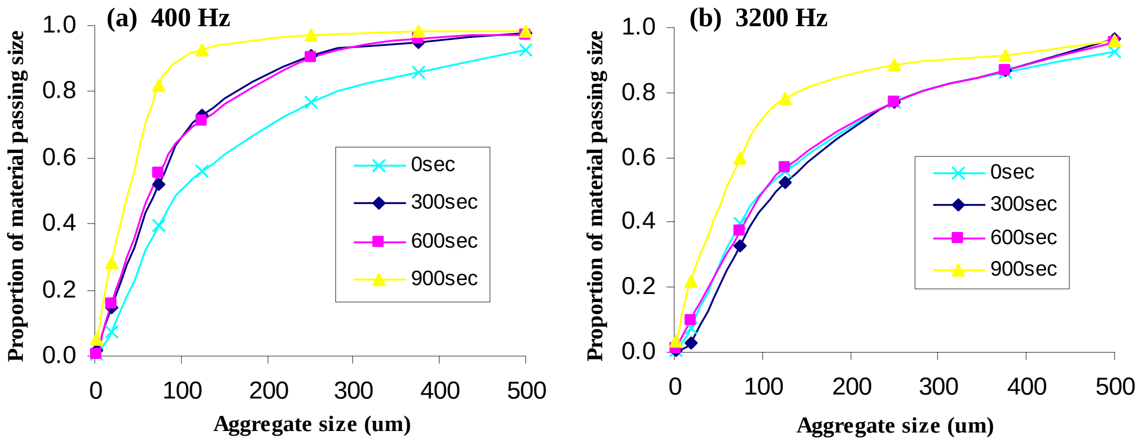

Figure 1. Increasing duration of mechanical energy application (power setting 2) increased aggregate breakdown in a Ferrosol equilibrated with SAR 24 water

Power level applied

Increasing the power setting of the energy applied generally increased the rate of aggregate breakdown across each of the size fractions (eg Figure 2). For the larger size fractions (eg greater than 250 μm), there was little difference in aggregate breakdown between the two power settings for any of the periods of energy application (Figure 2a). However, within the smaller size fractions (<250 μm), the two power settings exhibited differences in both the rate of breakdown and the maximum amount of aggregate breakdown measured confirming the presence of an aggregate bond strength hierarchy. This effect typically became more marked with decreasing size of the fraction measured and is consistent with earlier end-over-end shaking and ultrasonic findings (eg. Raine and So, 1997).

Frequency of waveform

The effect of frequency on aggregate breakdown was inconsistent between treatments, power settings and soils. For example, increasing the frequency applied at power setting 6 to the Vertosol equilibrated with SAR = 15 water increased aggregate breakdown across each of the size fractions (Figure 3). However, increasing the frequency when applied at power setting 2 to the Ferrosol equilibrated with either the SAR = 6 or 24 water decreased the aggregate breakdown. Similar inconsistencies were observed for other treatments (eg Figure 1). Inconsistencies in the interaction between power and frequency could be due to the physical limitations of the shaker table. As the frequency and power applied by the shaker table is increased, the probe is required to move up and down faster. By increasing the frequency, the probe may not physically have had enough time to oscillate fully at the higher power level. Hence a smaller energy and waveform may have actually been applied to the suspension.

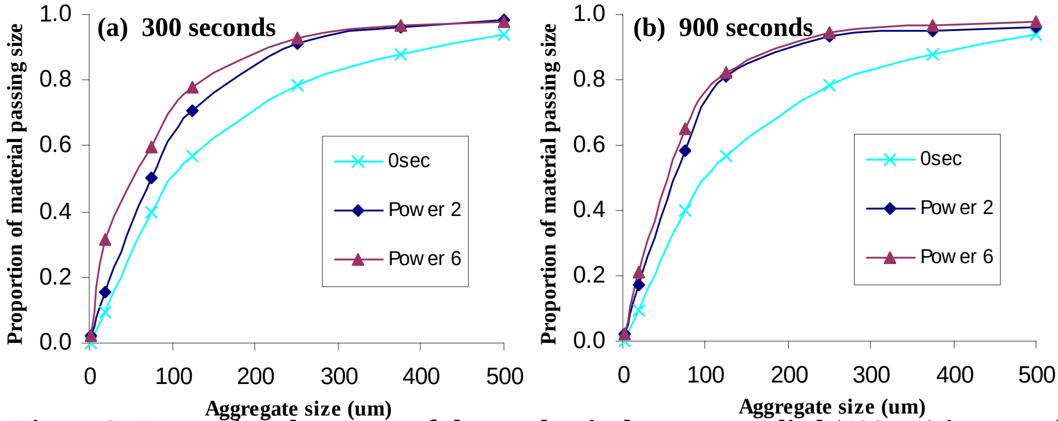

Figure 2. Increasing the power of the mechanical energy applied (400 Hz) increased aggregate breakdown in a Ferrosol equilibrated with SAR = 6 water

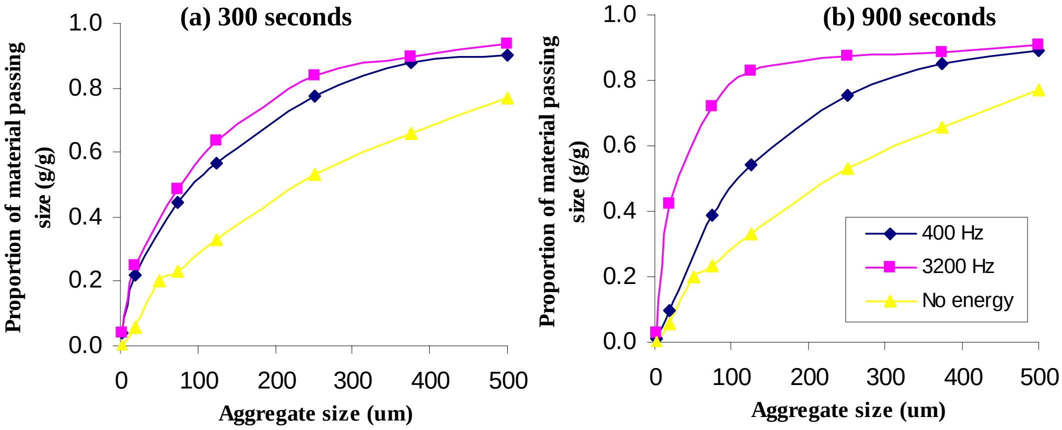

Figure 3. Increasing frequency of mechanical energy applied (power setting 6) increased aggregate breakdown in a Vertosol equilibrated with SAR = 15 water

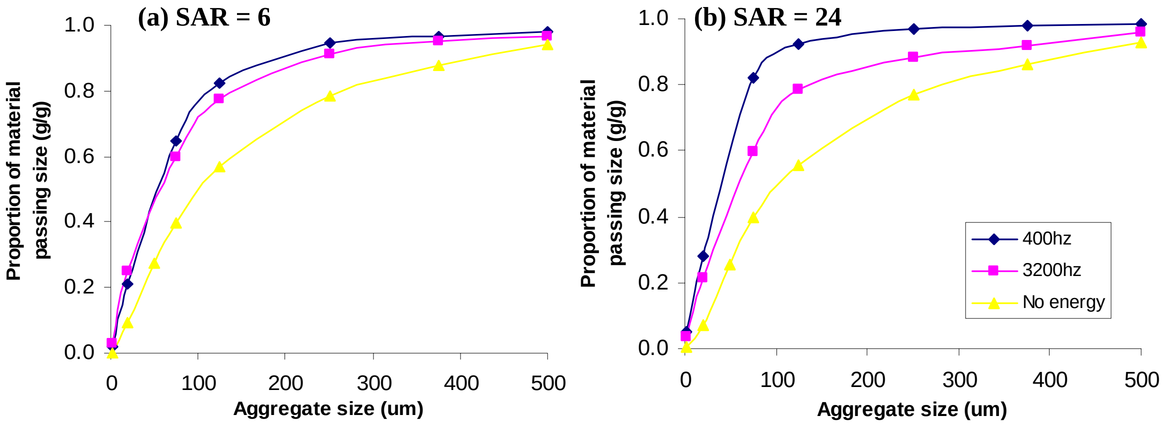

Figure 4. Increasing frequency of mechanical energy applied (power setting 2 for 900 sec) decreased aggregate breakdown in a Ferrosol equilibrated with (a) SAR = 6 and (b) SAR= 24 water

Level of Sodicity

Higher levels of soil sodicity generally resulted in significantly (P<0.05) increased release of <2 and <20 µm sized material as the mechanical energy was applied. This is consistent with the results obtained using ultrasonic sytems by Raine and So (1995). However, in some cases (eg Figures 4 and 5) the higher sodium levels were also associated with a significant increase in the release of aggregates and material up to 250 µm in size. This suggests that increasing sodium may also play some role in reducing the strength of inter-aggregate bonding in these larger size fractions.

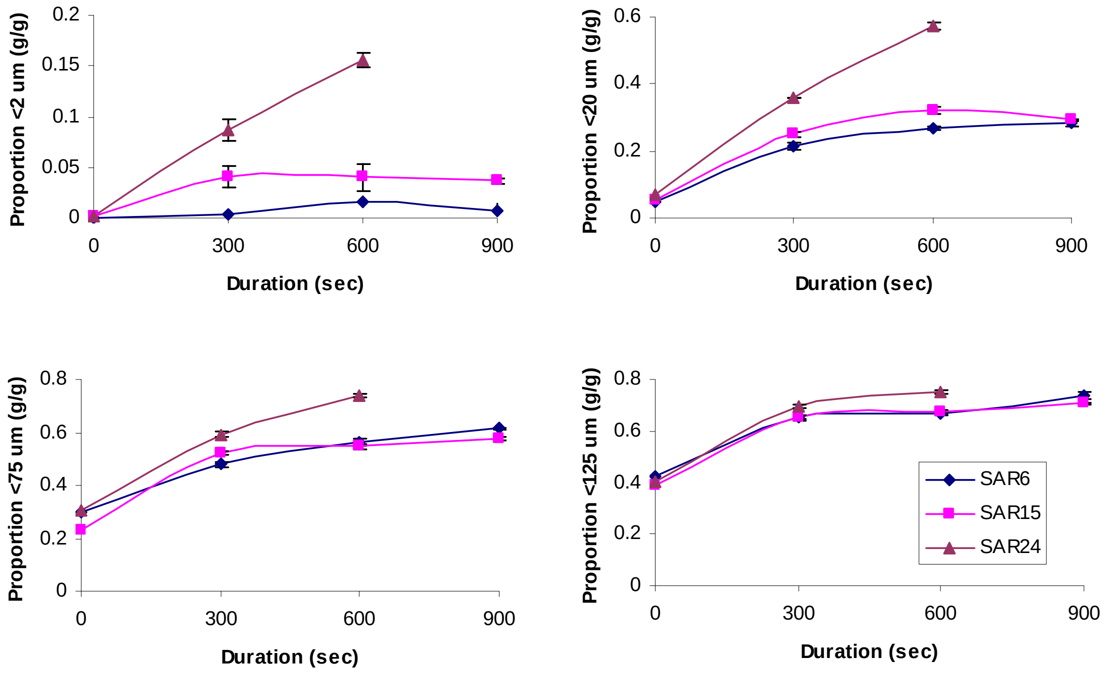

Figure 5. Effect of low frequency (400 hz) energy applied at power setting 2 on aggregate breakdown in a black vertisol equilibrated with SAR = 6, 15 or 24 water.

Conclusions

This work has confirmed that low frequency mechanical energy can be used to identify differences in aggregate stability across a range of aggregates up to 500 µm in size. Increasing the duration of the energy application typically increased aggregate breakdown. The rate of aggregate breakdown and maximum proportion of material in each size fraction was influenced by the frequency and power of the mechanical energy applied suggesting that these variations influenced the magnitude of the stresses induced within the aggregate. Further research is required to quantitatively describe the stress and/or energy applied to the soil via the low frequency apparatus and to investigate the potential to mimic under laboratory conditions the mechanical energy stresses applied to soils under field conditions.

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