

## 4.2 THE EFFECTS OF ENERGY APPLICATION ON THE DISPERSION OF SODIC VERTISOLS

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### ABSTRACT

*In many soils, spontaneous dispersion occurs in the presence of high sodium adsorption ratio (SAR) and low electrical conductivity (EC). However, spontaneous dispersion often accounts for only a small percentage of potential dispersion in sodic Vertisols. For these soils, dispersion and the development of surface seals is strongly influenced by the application of mechanical energy. This experiment was conducted to investigate the relative effects of SAR, EC and energy application on the dispersion produced in two sodic Vertisols.*

*The effect of SAR and EC on the dispersion resulting from energy application was determined within the range of SAR-ECs that determine spontaneous dispersion at one end and spontaneous flocculation at the other. Soil suspensions were subjected to either end-over-end shaking or different rates of energy applied using an ultrasonic probe with dispersion of  $<2 \mu\text{m}$  and  $<20 \mu\text{m}$  material measured after treatment. Significant differences ( $P < 0.05$ ) in dispersed material were observed between the different rates of energy application for the same cumulative energy. Significant differences ( $P < 0.05$ ) were also found to be related to SAR and EC. Implications for the measurement of soil dispersion and the management of sodic Vertisols are discussed.*

**Keywords:** dispersion, aggregate stability, energy, sodicity, Vertisol

### Introduction

Crust formation in soils has been attributed to both spontaneous dispersion and the physical disruption and compaction of soil aggregates (Agassi *et al.* 1981). The mechanisms associated with spontaneous dispersion are well established with exchangeable sodium percentage (ESP) and electrical conductivity (EC) playing an important role (Quirk and Schofield 1955; McNeal *et al.* 1968). The physical disruption and compaction of aggregates is generally associated with the impact energy of falling water (McIntyre 1958; Loch and Donnollan 1983). However, it may also result from the action of water flow and particle abrasion (Hudson 1971) or from forces applied by agricultural machinery and implements (Tullberg 1990).

Agassi *et al.* (1985) investigated the relative effects of ESP, EC and rainfall energy on the subsequent reduction in hydraulic conductivity (HC) of both a loess and Vertisol. They showed that increasing rainfall energy significantly reduced the HC of the surface seal but that the effect was

dependent on the soil's ESP and the solution EC. As ESP increased and EC decreased, less total energy was required to produce the same reduction in HC. Thus, for these soils there is an interaction between the energy required for physical disruption and spontaneous dispersion processes.

Very little research has been conducted to investigate the relative importance of these mechanisms in the production of surface seals and crusts on Australian Vertisols. Loch (1982), using a Vertisol from the Darling Downs, Queensland, found that  $189 \text{ J m}^{-2}$  cumulative rainfall kinetic energy was required to produce a surface seal at a rainfall intensity of  $180 \text{ mm h}^{-1}$  while  $421 \text{ J m}^{-2}$  was required to produce a similar seal at  $52 \text{ mm h}^{-1}$ . This is consistent with the work of Glanville and Smith (1988) who found that the disruptive effect of rainfall impact on soils from the Darling Downs was an important component in determining aggregate breakdown. They also noted that surface slaking alone did not interfere with water entry into the soils studied. This is consistent with the work of Cook *et al.* (1992) who found that the HC of Vertisols

declined exponentially with increasing amounts of dispersed material ( $<20 \mu\text{m}$  and  $<2 \mu\text{m}$ ) present.

Rainfall simulators and water drop tests are commonly used for the investigation of aggregate stability in surface soils. However, the time and cost associated with the conduct of these tests prohibits their use for routine analysis. The pressures exerted on the soil surface by water drop impact have been characterized by Imeson *et al.* (1981) and Nearing *et al.* (1987) using piezoelectric transducers while the physical disruption of soil aggregates using pressure applied by ultrasonic transducers has been described by Edwards and Bremner (1964, 1967) and characterised by North (1976, 1979). These findings suggest that aggregate dispersion under ultrasonic energy should produce similar results to dispersion under raindrop impact. Imeson and Vis (1984) found that ultrasonic energy applied between 30 W and 36 W produced similar results to water drop tests for stable soils, but observed that the ultrasonic application was too aggressive for unstable soils. Rates of application greater than 36 W did not produce a distribution similar to water drop impact. This suggests that the pressure applied by raindrop impact in the field is smaller than the pressures exerted by the application of the high rates of ultrasonic energy used by these authors. However, the effect of lower rates of ultrasonic energy application still needs to be investigated.

This paper investigates the effect of ESP and EC on the amount of  $<20 \mu\text{m}$  and  $<2 \mu\text{m}$  material produced by the application of low rates of mechanical energy to two Vertisols. The effect of different methods of mechanical energy application is also investigated by comparing the dispersion produced by ultrasonic application and a modified end-over-end shaking technique.

## Materials and methods

### Soils

Two soils were used in this study: Delvin Grey Clay (UgS.24, Chromic Vertisol; Yates 1972) from the Gwydir Valley, New South Wales and Lawes Black Earth (UgS.15, Udic Pellustert; Schafer *et al.* 1984) from the Lockyer Valley, Queensland. These soils have similar clay contents but exhibit different stabilities under field conditions. Both soils were collected from a single bulk surface sampling, air dried under glasshouse conditions and crushed to pass through a 2-mm sieve. To create a range of sodic conditions within the same soil, sub-samples were prepared by loosely packing 300 g of air-dried soil into a buchner funnel and leaching with 2 L of solution ( $1000 \text{ mmol}_c \text{ L}^{-1}$ ) at either SAR 6, 12, 18 or 24. Soils were then flushed under vacuum with 2 L solution ( $1 \text{ mmol}_c \text{ L}^{-1}$ ) at the appropriate sodium adsorption ratio (SAR). Samples were allowed to drain freely for twelve hours before air drying under glasshouse conditions for 14 days. Samples were then crushed to pass through a 2-mm sieve and homogeneously mixed. The ESP of the treated soils was calculated from exchangeable cations determined using the ammonium acetate method (Thomas 1982) with the cation exchange

capacity (CEC) calculated as the sum of the exchangeable cations.

### Spontaneous dispersion and flocculation

Dispersion may be influenced by the application of energy where the soil solution has an EC below the critical flocculation concentration (CFC). However, where the EC of the soil solution is below the threshold electrolyte concentration (TEC), the total dispersion measured is a function of spontaneous dispersion and applied energy. To quantify the effect of energy application separately, it was necessary to identify the regions of spontaneous dispersion and flocculation for both soils and then produce soil suspensions with electrolyte conditions between these limits. The region of spontaneous dispersion was determined by wetting the air dry equivalent of 5 g oven-dried soil by immersion in 200 mL of solution at an SAR appropriate to each soil sample. Suspensions with EC ranging from  $0.015$  to  $5 \text{ dS m}^{-1}$  were used with samples left to equilibrate for 1 h after immersion. To ensure uniform mixing, suspensions were gently hand stirred with a glass rod for 10 s. The energy applied by hand stirring was considered negligible. After the appropriate period, the  $<2 \mu\text{m}$  material was sampled using the pipette withdrawal method. Spontaneous dispersion was defined as occurring in suspensions where more than  $0.03 \text{ g}$  of  $<2 \mu\text{m}$  material per unit mass of oven-dried soil was measured.

The region of spontaneous flocculation was determined by wetting the air dry equivalent of 5 g oven-dried soil by immersion in 30 mL of  $0.025 \text{ dS m}^{-1}$  solution at the appropriate equilibrium SAR for the soil sample. To ensure complete dispersion, samples were sonified using an ultrasonic probe for 480 s at 25 W. After sonification, samples were transferred into 250 mL beakers and made up to 200 mL with electrolyte solutions at the same SAR. The EC of the final suspensions ranged between  $0.025$  and  $25 \text{ dS m}^{-1}$ . Suspensions were left to equilibrate for 1 h before mixing uniformly by gentle hand stirring. Suspensions were then allowed to settle freely for the appropriate period before measuring the amount of  $<2 \mu\text{m}$  material present. Spontaneous flocculation was defined as occurring where more than  $0.03 \text{ g}$  of  $<2 \mu\text{m}$  material per unit mass of oven dried soil flocculated.

### Dispersion following energy application

To determine the effect of SAR, EC and rate of energy application on the amount of aggregate breakdown produced as a function of total energy applied, a series of trials using both soils were conducted. In each case, the air dry equivalent of 5 g of oven-dried soil was wet by immersion in 30 mL of the appropriate equilibrium SAR solution at the required EC. The total amount of energy that was appropriate for the treatment was then applied at the required rate of application. After treatment, the suspensions were transferred to 250 mL glass beakers and made up to 200 mL with solutions at the same SAR and EC. The amount of  $<20 \mu\text{m}$  and  $<2 \mu\text{m}$  material present was measured by the pipette withdrawal method.

Soil suspensions were prepared with SARs of 6, 12, 18 and 24. The EC of the suspensions were either  $0.07 \text{ dS m}^{-1}$  or  $0.26 \text{ dS m}^{-1}$  for the Delvin soil and  $0.3 \text{ dS m}^{-1}$  for the Lawes soil. These ECs were selected because they did not produce either spontaneous dispersion or flocculation in either soil. A low rate of energy input was applied using a modified end-over-end shaking technique whereas higher rates of energy input were applied by an ultrasonic probe in the manner described by Raine and So (1993). The modified end-over-end shaking technique involved placing the prepared suspensions on a shaker rotating at 20 rpm for periods of up to 72 h. By comparing results from the end-over-end technique for unstable soils with those obtained using the ultrasonic technique (unpublished data), the rate of ultrasonic energy application equivalent to the end-over-end technique was calculated as  $0.04 \text{ W g}^{-1}$ . The ultrasonic technique was used to apply energy at the rate of  $1.1 \text{ W g}^{-1}$  (measured calorimetrically) to both the Delvin and Lawes soils and at  $1.5 \text{ W g}^{-1}$  to the Lawes soil only. An analysis of variance was conducted on each trial to determine the significance of solution EC, SAR and energy application on the amount of dispersed material ( $<20 \mu\text{m}$  and  $<2 \mu\text{m}$ ) released.

## Results

The relevant properties of the soils used in this experiment are presented in Table 1. For both soils, spontaneous

dispersion was found to occur in the SAR 24 suspensions with  $\text{EC} = 0.015 \text{ dS m}^{-1}$ . However, spontaneous dispersion was neither observed in suspensions of lower SAR at the same EC nor in any higher EC treatments. Spontaneous flocculation for both soils was found to occur in suspensions with EC greater than the CFC of  $0.32 \text{ dS m}^{-1}$  at SAR 6 and  $0.55 \text{ dS m}^{-1}$  at SAR 24.

The application of  $0.04 \text{ W g}^{-1}$  energy to the Delvin soil suspensions resulted in significant differences ( $P < 0.05$ ) in dispersion due to the effect of both SAR and EC (Fig. 1). In each case, the lower SAR suspensions produced less dispersed material than the higher SAR suspensions. However, the effect of EC was only evident in the SAR 18 and 24 treatments where significantly ( $P < 0.05$ ) more material was released during energy application at the

Table 1. Relevant properties of the soils

Soil	$<2 \mu\text{m}$ ( $\text{g g}^{-1}$ )	2–20 $\mu\text{m}$ ( $\text{g g}^{-1}$ )	$>20 \mu\text{m}$ ( $\text{g g}^{-1}$ )	CEC ( $\text{cmol}_c \text{ kg}^{-1}$ )	Solution SAR	ESP (%)
Lawes	0.51	0.20	0.29	59	6	3.6
					12	6.6
					18	12.2
					24	15.7
Delvin	0.53	0.15	0.32	51	6	3.4
					12	6.9
					18	11.2
					24	14.7

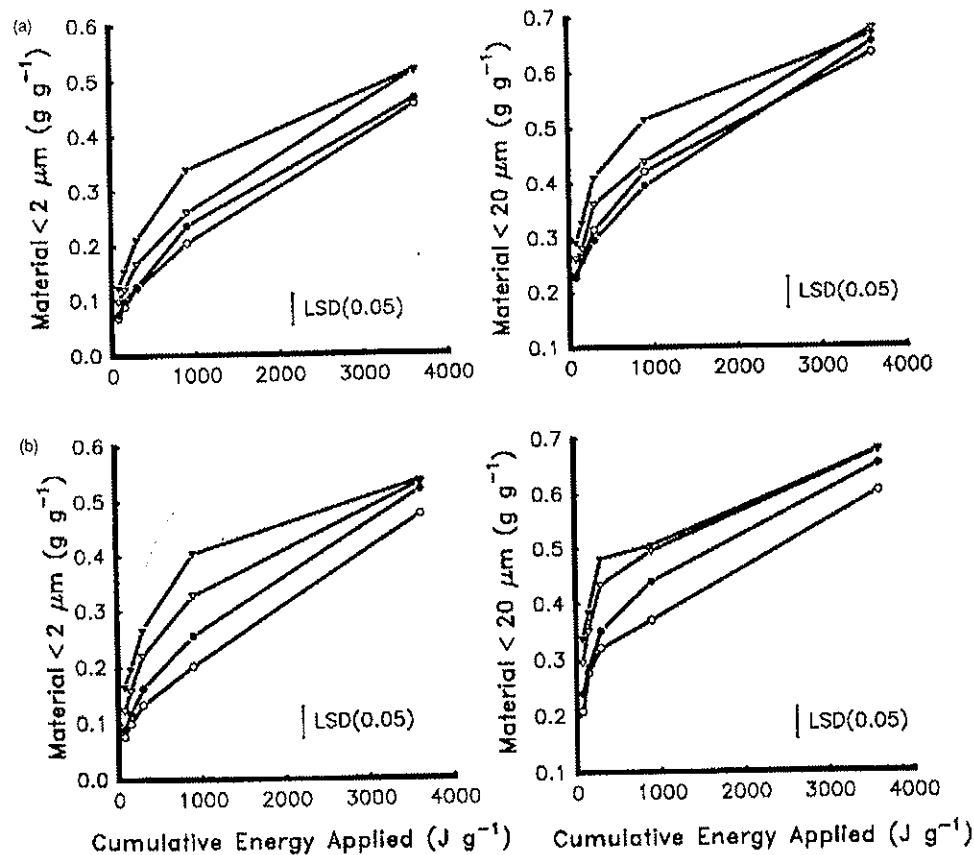


Fig. 1. Dispersion curves for Delvin soil suspended in SAR solutions (○ SAR 6; ● SAR 12; ▽ SAR 18; ▼ SAR 24) at either (a)  $\text{EC} = 0.26 \text{ dS m}^{-1}$  or (b)  $\text{EC} = 0.07 \text{ dS m}^{-1}$  with energy applied by a modified end-over-end shaking technique.

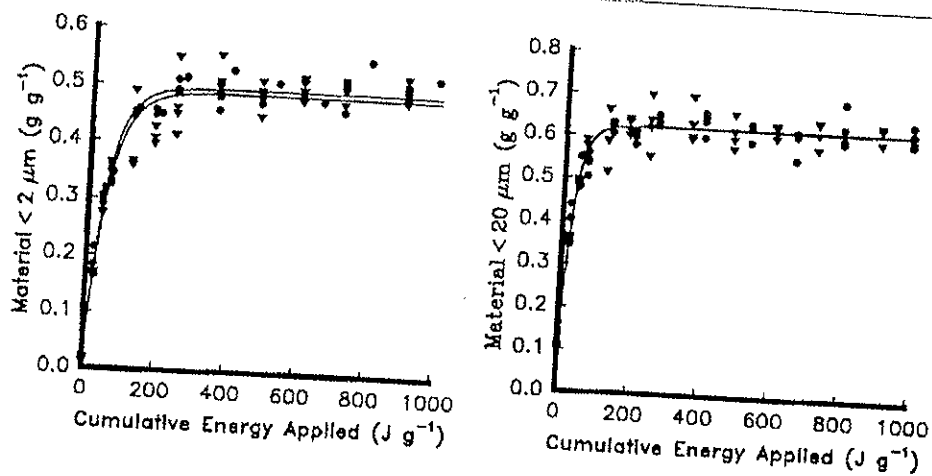


Fig. 2. Dispersion in Delvin soil the application of ultrasonic energy at  $1.1 \text{ J g}^{-1} \text{ s}^{-1}$  in either  $\text{EC} = 0.07 \text{ dS m}^{-1}$  ( $\bullet$ ), or  $\text{EC} = 0.3 \text{ dS m}^{-1}$  ( $\blacktriangledown$ ). Data for each EC represents SAR values from 6 to 24.

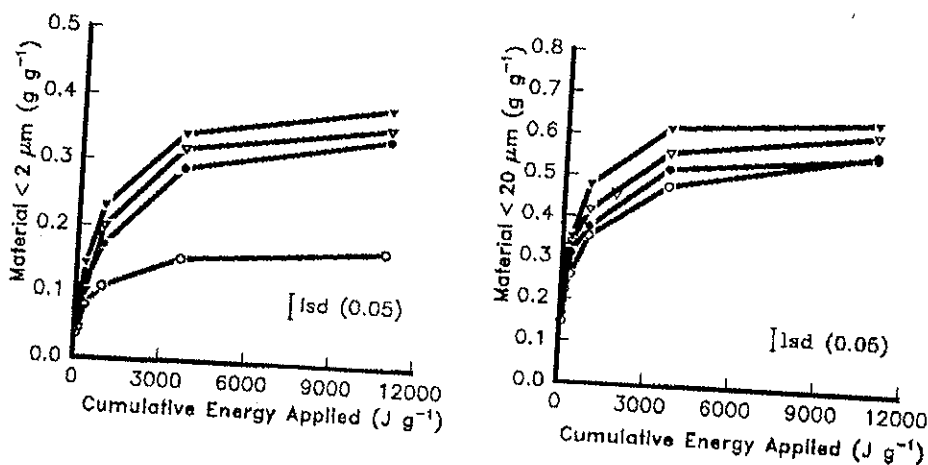


Fig. 3. Dispersion in a Lawes Black Earth suspended in electrolyte solution ( $\circ$  SAR 6;  $\bullet$  SAR 12;  $\nabla$  SAR 18;  $\blacktriangledown$  SAR 24;  $\text{EC} = 0.3 \text{ dS m}^{-1}$ ) produced by a modified end-over-end shaking input [ $0.04 \text{ J g}^{-1} \text{ s}^{-1}$  equivalent ultrasonic energy].

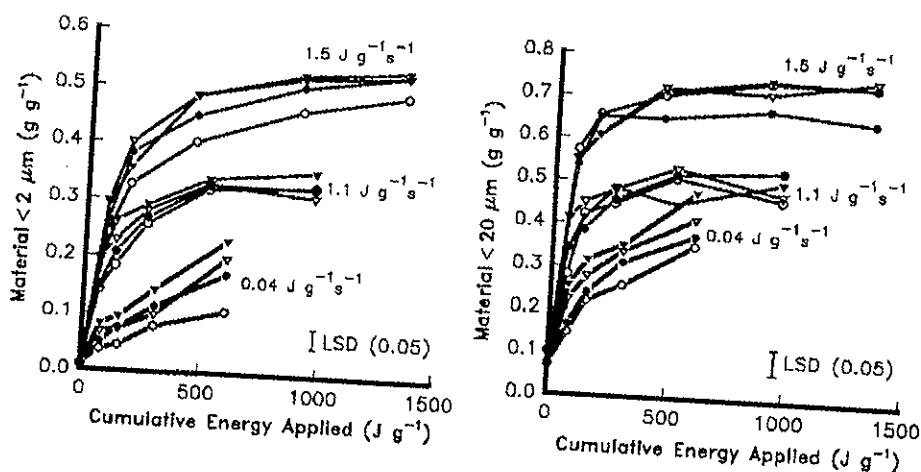


Fig. 4. Dispersion produced in a Lawes Black Earth suspended in electrolyte solutions ( $\circ$  SAR 6;  $\bullet$  SAR 12;  $\nabla$  SAR 18;  $\blacktriangledown$  SAR 24;  $\text{EC} = 0.3 \text{ dS m}^{-1}$ ) using a range of energies applied by a modified end-over-end shaking technique and an ultrasonic technique.

lower EC. The application of  $1.1 \text{ W g}^{-1}$  ultrasonic energy to the Delvin soil (Fig. 2) produced no significant differences ( $P < 0.05$ ) in the amount of dispersed material released, irrespective of either the SAR or EC of the suspension. Complete dispersion of the Delvin soil was achieved in this treatment with the application of  $200 \text{ J g}^{-1}$  total energy. However, complete dispersion of the Delvin soil using the end-over-end treatment required the application of more than  $4 \text{ kJ g}^{-1}$  total energy (Fig. 1).

In the Lawes soil, significant differences ( $P < 0.05$ ) in dispersed material were observed between the SAR treatments where energy was applied using the end-over-end shaking treatment (Fig. 3). However, complete breakdown of the dispersible material in this soil required the application of more than  $12 \text{ kJ g}^{-1}$  for the SAR 12, 18 and 24 treatments and was not possible in the SAR 6 treatment at this rate of energy application. Using the ultrasonic technique, complete breakdown of the Lawes soil required  $500 \text{ J g}^{-1}$  total energy

applied at  $1.5 \text{ W g}^{-1}$  and more than  $5 \text{ kJ g}^{-1}$  applied at  $1.1 \text{ W g}^{-1}$  (Fig. 4). The effect of SAR on the dispersion produced at the higher rates of energy application in the Lawes soil was not as pronounced as that produced at the low rate of energy application.

### Discussion

The  $<2 \mu\text{m}$  material in the Delvin soil can be completely dispersed using both the low energy end-over-end shaking and high energy ultrasonic techniques. However, the Lawes soil can only be completely dispersed by the high energy ultrasonic treatment. This implies that the Delvin soil has weaker bonds than the Lawes soil and is consistent with the relative field stabilities observed in these soils. At low rates of energy application, the degree of dispersion was influenced by differences in solution SAR and EC. This suggests that the effect of solution SAR and EC on the field stabilities of these soils under energy application is of greater importance where the rate of energy application is small.

The large effect of both total energy applied and the rate of energy application on the amount of dispersed material released in both soils is consistent with the results from rainfall simulation studies on a similar range of soils (Agassi *et al.* 1985; Glanville and Smith 1988). As energy is the dominant external influence on dispersion, the most effective method of reducing the dispersibility of these soils, particularly at high Na levels, would be to reduce the rate of energy application. This is consistent with current management practices such as stubble mulching and cover cropping which reduce rainfall impact energy. However, this work also shows that the effect of sodicity and energy application on dispersion is highly dependent on the nature of the soil studied.

The SAR and EC of the soil solution directly affects repulsive particle interactions within the soil matrix. Where the EC is less than the TEC, spontaneous dispersion occurs. However, where the system has an EC greater than the TEC, dispersion will occur only under the influence of mechanical energy. As the EC of the soil solution is increased or the SAR decreased, the repulsive forces between clay particles decrease. Thus, the mechanical stress required to induce dispersion is also expected to increase. This is consistent with the end-over-end shaking results for the Lawes soil (Fig. 3) where decreasing the solution SAR from 24 to 6 increased the bond strength beyond the maximum disruptive stress applied during this treatment. Thus, the ultimate maximum dispersion produced by a particular rate of energy application indicates the amount of material within the aggregate with a bond strength inferior to the disruptive stresses applied.

For both soils, a larger total amount of energy was required for complete breakdown at a low rate of energy application than at the higher rates of energy application. This could be explained by a consideration of the magnitude of the disruptive stresses developed within the system. The application of energy to a soil-water system

induces a range of stresses within the system. However, the magnitude of the stresses produced will increase as the rate of energy application is increased. As dispersion will not occur unless the stress applied to an aggregate is greater than the strength of the bonding mechanisms operating within that aggregate, a larger rate of energy application has a greater probability of inducing stresses sufficiently large to induce aggregate breakdown. Thus, at a higher rate of energy application, we could expect that the soil will disperse more rapidly and complete dispersion will be achieved with a smaller total energy application.

This work implies that where laboratory procedures are required to predict actual field dispersion rather than provide an index to dispersibility, it is necessary that these procedures are conducted with a total energy application and rate of energy application in a system with an electrolyte composition and concentration which is a reasonable representation of the field conditions.

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