DEVELOPMENT OF A LABORATORY TEST FOR RESPONSIVENESS OF SODIC SOIL STABILITY TO AMELIORANTS: LIME ($CaCO_3$), GYPSUM ($CaSO_4.2H_2O$) AND LIME/GYPSUM COMBINATIONS

John McL. Bennett[1], Richard S.B. Greene[1] & Brian W. Murphy[2]

[1]CRC LEME, School of Resources, Environment and Society, Australian National University, Canberra, ACT, 0200
[2]NSW Department of Infrastructure, Planning and Natural Resources, PO Box 445, Cowra, NSW, 2794

INTRODUCTION

Australian soils often slake and disperse upon wetting; the degree to which these processes occur determines soil stability. While slaking is usually associated with soils low in organic matter (Tisdall & Oades 1982), the phenomenon of dispersion occurs in sodic soils and provides a catalyst for structural breakdown (Sumner 1993). A further contribution to structural decline is continual stress on the soil through both chemical and mechanical processes such as tillage and rain-drop impact. If sodic soils are not properly managed for agriculture they become overly degraded and are much more limiting than other soils, especially if they have clay loam to clay textures. The resultant soil is highly adverse to plant growth and water infiltration causing crop yield reduction and poor pasture establishment (So & Aylmore 1993). This in turn increases the need to import stock feed and ultimately a severe reduction in economic benefit for the landholder.

Management techniques for sodic soils have traditionally involved the use of gypsum as an ameliorant. Gypsum adds calcium (Ca) to the exchangeable complex and soil solution, which in turn reduces the amount of exchangeable sodium (Na) (Quirk & Schofield 1955). The main aim of any ameliorant in a sodic soil is to sufficiently reduce the exchangeable Na percentage (ESP) and increase electrolyte concentration (EC) to levels that maintain soil stability. However, gypsum is a relatively expensive ameliorant for the average landholder and requires application every few years due to its high solubility (Valzano *et al*. 2001). These disadvantages prompted research into longer-term strategies. Chan & Heenan (1998) noted the impact of lime on stability of aggregates in a non-sodic soil where use of lime which had previously only been used as a remedial treatment for acidic soils. Lime, because of its high Ca content per unit of weight (i.e., 40 wt. %), provides an effective method to displace Na on the exchange sites in the soil. However, due to its comparatively low solubility, lime does not react strongly enough in the initial period. This has been addressed by the use of site specific lime/gypsum combinations where Valzano *et al.* (2001) have shown gypsum and lime to have a synergistic effect in which both the initial (i.e., gypsum dissolution) and long-term reactions (i.e., lime dissolution) occur with regards to supplying Ca to a sodic soil.

Furthermore, past research has been conducted through field trials and no laboratory framework exists to recognise soils that will be responsive to a given chemical ameliorant type and rate. The importance of a laboratory-based test is fundamental for the ability to offer site-specific management of sodic soils for landholders. Hence, this experiment was conducted with two aims: 1) to develop a methodology to predict the responsiveness of soil structural stability to lime, gypsum, and lime/gypsum combinations through comparison of aggregate tests; and, 2) to provide experimental evidence in the laboratory for the synergistic effects of gypsum and lime as suggested by the field experiments of Valzano *et al*. (2001).

SITE SELECTION & DESCRIPTION

All sites were situated in New South Wales (Figure.1) as a limitation imposed by time and expenditure.

1. The Tarcoon region (Brewarrina) samples were taken from scalded, reclaimed, and normal soil all within 100 m of one another. The climate is described as hot and dry. Annual precipitation (mean) at Brewarrina local hospital is recorded as 409.5 mm (BOM 2004). In addition, the occurrence of high daily summer temperature gives a resulting high evaporation rate and a reduced growing season. As a result the drought incidence is high for the Tarcoon region.

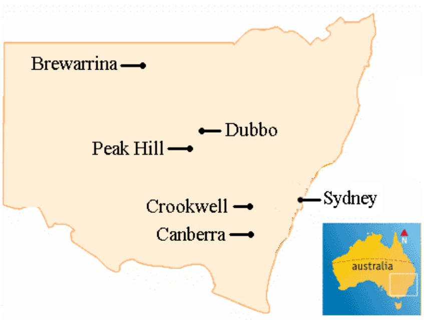

Figure 1: Site location to nearest populated town.

The vegetation is broadly described as low *Eucalyptus* woodlands with a tussock grass and graminoid-dominated understorey (Dodson 1987) while the distribution of vegetation is sparse. The Tarcoon study sites are used only for grazing by sheep at a stocking rate of 0.4 Dry Sheep Equivalent (DSE) per hectare.

2. The soils from Genaren (Peak Hill) and Upper Bogan (Peak Hill) regions were selected as they were from an area known to have problematic sodic surface soils. These were the same source used by Valzano *et al.* (2001) and for this reason would assist in meeting the first aim of the study. In the past these soils would have been referred to as "transitional red-brown earths".

3. The Beni State Forest region (Dubbo) soil was taken from a Yellow Sodosol on the Pilliga Sandstone and is known to be highly degraded. This was selected to test the extent of experimental design.

In terms of climate Genaren, Upper Bogan, and Beni State Forest are relatively similar. The climate is broadly described as hot and dry, although not to the extent of the Tarcoon sites. The annual rainfall averages range between 403 mm to 470 mm across the sites (BOM 2004). Again, the temperature in summer is high with low relative humidity which results in high evaporation.

Vegetation on the Genaren and Upper Bogan sites is predominately native pastures with 10% ground cover due to sites being used for cropping prior to study. Beni State Forest, conversely, is an Ironbark/Bulloak forest with minor observable transient grazing by native herbivores

4. The Bevandale region (Crookwell) soil came from a Sodosol on Palaeozoic marine sediment (abyssal sediments), and is currently under study by Vanessa Wong (Australian National University PhD candidate). This soil is known sodic and shows clear signs of tunnel erosion.

Bevandale's climate is considerably different, being further south east of the Peak Hill district. The average rainfall per annum is 894.5 mm (BOM 2004) with a lower evaporation rate than the other sites. Winters consist of low drainage and excess water logging. Summers are still relatively hot and dry but not to the extent of the other sites.

Vegetation is predominantly native and introduced grasses where the samples were taken. The site had been used for grazing by introduced species prior to study.

METHOD

Experimental Design

The experiment was designed to:

1. Provide evidence to support conclusions from the study of Valzano *et al* (2001), which suggested the potential for lime and gypsum to have a synergistic effect on soil stability; and,
2. Develop a framework for testing the responsiveness of soils to gypsum and lime.

The application rates across the trials were: control; lime 5 t/ha; gypsum 5 t/ha; lime 5 t/ha and gypsum 5 t/ha; and, lime 10 t/ha and gypsum 10 t/ha. These were chosen on the basis of common field application rates. For each of the five trials three replicates were made.

Soil Preparation

Samples were taken to 10 cm depth to examine combined A-horizon effects. Soil was crushed and sieved to a threshold of 6.5 mm to replicate as closely as possible soil characteristics of a cultivated soil. Three replicates of 450 g treatment samples were measured for each soil. Replicates need to be of sufficient size to allow a measurable quantity of lime and/or gypsum to be added and mixed evenly throughout the soil; it is suggested that a larger quantity of soil be used, in this case 450 g. Application rates were determined as follows:

$$D = \frac{M}{V}$$

where D is density, M is mass and V is volume. Then, using an assumed bulk density of BD = 1 gcm^{-3}, an application rate of 10 t/ha results in 1g of ameliorant per 100 g of soil:

$$10 \text{ t/ha} = \frac{10 \times 10^6 \text{ g} \quad \text{(ameliorant)}}{10^9 \text{ g} \quad \text{(soil)}}$$

$$= 1 \text{ g of ameliorant per 100 g of soil}$$

The 450 g samples with applicants were shaken inside a cylindrical container in a rolling fashion for two minutes then sub-sampled into the 150 g trial replicates. Replicates were placed into plastic containers with lids to try and eliminate external interference such as settling of external dust particles in the replicates. Eight 5 mm breathing holes per lid were added to avoid sweating inside the container.

Experiment Set-up

A controlled temperature, vented room was set to 20°C in order to eliminate variables introduced by changing temperature. Samples were stored on two five-shelved, open-faced cabinets. Each replicate sample was brought up to field moisture content, 40 % of sample weight, through a rain simulation device to avoid the effects of rapid wetting, in this case using a fine mist spray bottle. Samples were then placed into the controlled temperature room for three weeks. Sample weight was measured every two days in order to assess field moisture capacity; if any decrease had occurred it was remedied by adding the appropriate amount of moisture using the spray bottle. After three weeks the samples were taken out of the controlled temperature room and left to air dry as per Loveday & Pyle (1973) and Aggregate Stability in Water (ASWAT) guidelines.

Initial chemistry, EC and pH

The EC and pH were taken from a 1:5 water saturation that had been placed on an end over end shaker for one hour. These samples were stood over night then measured. This process was repeated for the 135 replicate samples at the end of the experiment.

The initial exchangeable cations were also taken from 1:5 water saturation using 5 g of soil in 25 ml of distilled water. For samples with an initial EC greater than 0.3 dSm^{-1} an ethynodiol wash was first applied to eliminate confounding effects from excess sodium during Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) analysis. The 1:5 saturation was then placed on an end over end shaker for an initial one hour period. Following this it was placed on a centrifuge at 1500 rpm for five minutes. The supernatant fluid was poured into a 100 ml flask. This whole procedure, excluding the initial ethynodiol wash, was repeated three times after which 25 ml of distilled water was added to the 75 ml in the flask obtain a 100ml extract which was then analysed using ICP-MS.

Loveday & Pyle Emerson Test

The modified Emerson test of Loveday & Pyle (1973) involves placement of air-dried aggregates (3-5 mm diameter) in a 100 ml beaker containing 50 ml of distilled water. After 2 h and 20 h immersion, a visual judgment was made of the degree of dispersion. For those samples that showed no dispersion, the soil was remoulded with a spatula for 1 min. Balls of soil with a diameter of 3-5 mm were formed and placed into the beaker with distilled water and the scoring was repeated at 2 h and 20 h as before.

Aggregate Stability in Water (ASWAT) Test

The ASWAT test (Field *et al.* 1997) is another version of the Emerson test, which is designed to reduce analysis time. In the ASWAT test, air-dried aggregates and remoulded samples were placed in a dish with distilled water. The scoring for visual assessment of dispersion was done as for the Loveday & Pyle Emerson test. For those aggregates that dispersed, the scores for the 10 min and 2 h assessment were added together and then added to 8, thus giving a range of values from 9 to 16. For the remoulded samples the 10 min and 2 h scores were added together giving a range of values 0 to 8.

Statistical Analysis of Emerson Tests

Correlations between ASWAT and Loveday & Pyle Emerson tests were obtained through the statistical program Minitab® 14. A Pearson's Sample Correlation Coefficient was used to show how closely correlated the two tests were. The original Emerson test was included as part of the Loveday & Pyle Emerson test.

RESULTS

Table 1 shows the original soil sample characteristics for the study. The initial exchangeable cations were taken to determine the initial ESP. The recorded EC and pH were indicative of soils with sodic properties. Note the amount of initial available Na levels. These are at considerably limiting levels for plant growth.

The comparison of ESP and EC allowed for the plotting of soils (1 to 9) onto the classification chart developed by Rengasamy *et al.* (1984) (Figure 2).

Figure 2 was further adapted to show EC and ESP rather than total cation concentration and sodium absorption rate. CFCi represents the critical flocculation concentration for spontaneous dispersion. CFCh represents the critical flocculation concentration for a soil under mechanical stress. Soils (1 to 9) from this study have been placed on respective points. Arrows indicate direction for placement of points that exceed chart boundaries.

Table 1: Initial soil characteristics.

	Region & Soil Number	Sample Depth (cm)	pH (1:5)	CEC (cmol (+)/kg)	EC (1:5) (dS/m)	ESP (%)	Exchangeable Cations (cmol(+)/kg)			
							Ca	K	Mg	Na
1	Beni State Forest	0 – 10	4.6	8.5	0.2	30.8	0.3	0.1	5.5	2.6
2	Genaren	0 – 5	7.1	22.5	0.1	10.9	9.2	0.6	10.1	2.6
3	Genaren	5 – 10	7.6	24.3	0.1	11.7	9.8	0.6	11.0	2.9
4	Upper Bogan	0 – 5	6.8	20.5	0.1	11.9	6.0	0.5	11.6	2.4
5	Upper Bogan	5 – 10	6.0	20.1	0.4	12.1	5.9	0.5	11.3	2.4
6	Tarcoon - Normal	0 – 10	6.6	17.1	0.1	7.7	7.5	1.2	7.2	1.3
7	Tarcoon - Scalded	0 – 10	6.5	27.9	4.5	17.6	14.4	0.5	8.1	4.9
8	Tarcoon - Reclaimed	0 – 10	7.1	19.2	0.3	14.5	8.8	0.7	6.9	2.8
9	Bevandale	0 – 10	10.2	9.7	1.4	67.2	0.3	0.1	2.8	6.5

Figure 2 shows that all soils have sodic properties, with the exception of soil 7 which also has saline properties, i.e., saline/sodic soil. From Figure 2 it would be possible to make informed estimations as to which applications and rates are most likely to be beneficial to test on a given soil in the laboratory.

Over the three week period the gypsum and lime/gypsum combination trials generally, with exception to Soil 1 and Soil 9, all show a rise in EC sufficient enough to promote flocculation. This supports the Emerson score results and provides an indication of soil-specific requirements in terms of EC. The results can also be considered to indicate significant response of soils to ameliorant.

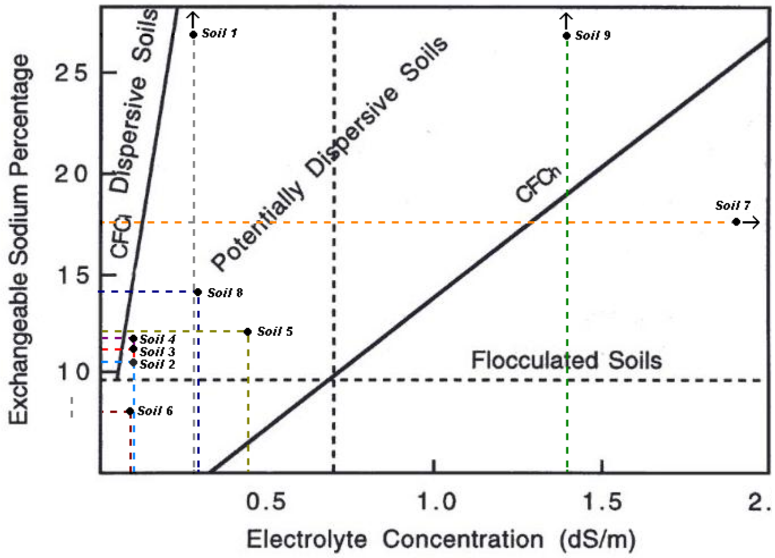

Figure 2: Chart for dispersive soil classification after Rengasamy *et al.* (1984) showing soils from this study.

The pH has also to shown change over the treatment period. These results suggest again a consistency with Valzano *et al.* (2001); lime and combinations causing pH increase and gypsum having a slightly acidifying effect.

The two most unstable soils were those of Beni State Forest (Soil 1) and Bevandale (Soil 9). Their final dispersion indices suggest that the application rate of ameliorant was insufficient to stabilise the soils.

ASWAT & Loveday & Pyle Emerson tests

Results show that these two dispersion tests are positively correlated with each other. Where differences occurred it was by no more than two dispersion index levels. Pearson's Sample Correlation Coefficient was used to calculate an r^2 value. The high correlation was consistent with the findings of Field *et al.* (1997). The ASWAT test slightly underestimates dispersion in comparison to Loveday & Pyle's (1973) test. The r^2 value for this study was $r^2 = 0.92$ where the value in the study of Field *et al.* (1997) was $r^2 = 0.94$. No different conclusions about soil stability were obtained through the ASWAT test than those drawn from the Loveday & Pyle Emerson test. Furthermore, as the ASWAT Test achieved significantly similar results to the more time consuming Loveday & Pyle Emerson test it can be observed that no disadvantage is incurred by using the shorter time period ASWAT form of Emerson test.

DISCUSSION

Soil Responses to Lime and Gypsum

Ameliorant application has improved structural stability and reduced dispersion. Additionally, the soils generally showed a greater structural response to lime/gypsum combinations. The only difference was noted with differing quantity of ameliorant added per hectare. In two cases: Beni State Forest (Soil 1); and, Upper Bogan (Soil 4), gypsum by itself (5 t/ha) caused a response that was equal to the lime/gypsum combination (5 t/ha of each, respectively) response. However the greater application (10 t/ha of each, respectively) of the lime/gypsum combination prompted a better response in both cases. This suggests that optimum combination would benefit from more combination laboratory trials (e.g., lime 2.5 t/ha and gypsum 1 t/ha).

Methodological Development

The method has been shown to detect the response of sodic soils to the addition of ameliorant. This effectively provides a means by which ameliorant application rate can be determined and implemented. Hence, a framework is established by which a sodic soil can be assessed in a timely fashion.

Overall, the results support the conclusions drawn by Valzano *et al.* (2001) that there is a synergistic effect of using lime and gypsum together on sodic soils. However, the results also show that the response of sodic soils to ameliorant type and application rate is dependant on site location or more specifically on soil characteristics.

Limitations

The development of this responsiveness test may have benefited further by inclusion of soil samples from throughout Australia. However, time and funding resources precluded this.

A further limitation is that the final exchangeable cations were not obtained which would have provided further means of evidence for a developed framework. Though, it is suggested that this would be consistent with the final developed responsiveness test as landholders would not be expected to expend such substantial funds for final cation analysis where aggregate stability tests (Loveday & Pyle Emerson test and ASWAT) in conjunction with EC and pH tests have been shown to be good indicators of ameliorant effect.

CONCLUSIONS

By providing evidence supporting the conclusions of Valzano *et al*. (2001), this study has validated a developed laboratory responsiveness test for structural stability to type and rate of ameliorant application. This means that advice for ameliorant type/combination and application rate can be provided in a significantly shorter time frame than a field trial can provide. In turn, this allows the land holder to take effective management action more quickly and thus improve crop yield and pastures more quickly. The ultimate result of this is economic gain for the landholder and an improvement in soil stability, helping to preserve this valuable resource.

REFERENCES

BOM 2004. Bureau of Meteorology. http://www.bom.gov.au /.

CHAN K.Y. & HEENAN D.P. 1998. Effect of lime ($CaCO_3$) application on soil structural stability of a red earth. *Australian Journal of Soil Research* **39**, 73-86.

DODSON J.R. 1987. Natural Vegetation. *In:* HARRIMAN R.J. & CLIFFORD E.S. eds. *Atlas of New South Wales. Central Mapping Authority, Bathurst.*

FIELD D.J., MCKENZIE D.C. & KOPPI A.J. 1997. Development of an improved Vertisol stability test for SOILpak. *Australian Journal of Soil Research* **35**, 843-852.

LOVEDAY J. & PYLE J. 1973. The Emerson Dispersion Test and its relationship to hydraulic conductivity. *CSIRO Australian Division of Soils Technology* **15**, 1-7.

QUIRCK J.P. & SCHOFIELD R.K. 1955. The effect of electrolyte concentration on soil permeability. *Journal of Soil Science* **6**, 163-178.

RENGASAMY P., GREENE R.S.B., FORD G.W. & MENHANNI A.H. 1984. Identification of dispersive behaviour and the management of red-brown earths. *Australian Journal of Soil Research* **22**, 413-431.

SO H.B. & AYLMORE L.A.G. 1993. How do sodic soils behave? The effects of sodicity on soil physical behaviour. *Australian Journal of Soil Research* **31**, 761-777.

SUMNER M.E. 1993. Sodic soils: New perspective. *Australian Journal of Soil Research* **31**, 683-750.

TISDALL J.M. & OADES, J.M. 1982. Organic matter and water stable aggregates in soils. *Journal of Soils Science* **33**, 141-163.

VALZANO F.P., MURPHY B.W. & GREENE R.S.B. 2001. The long-term effects of lime ($CaCo_3$), gypsum ($CaSO_4.2H_2O$), and tillage on the physical and chemical properties of a sodic red-brown earth. *Australian Journal of Soil Research* **39**, 1307-1331.