

# MANAGING SODICITY AND EXCHANGEABLE K WITH DEEP TILLAGE AND SOIL AMENDMENTS

Nilantha Hulugalle<sup>1,2</sup>, Bruce McCorkell<sup>2</sup>, Tim Weaver<sup>1</sup> and Lloyd Finlay<sup>1</sup>

<sup>1</sup>NSW Department of Primary Industries and Cotton Catchment Communities CRC, Australian Cotton Research Institute, Locked Bag 1000, Narrabri, NSW 2390, Australia

<sup>2</sup>NSW Department of Primary Industries and Cotton Catchment Communities CRC, Tamworth Agricultural Institute, 4 Marsden Park Rd, Calala NSW 2340, Australia

## ABSTRACT

High subsoil exchangeable sodium percentage (ESP) and salinity, and low exchangeable K concentrations are common constraints in many cracking clays. Recommendations for ameliorating sodicity include applying gypsum alone or in combination with deep tillage. Potassium deficiencies are usually managed by applying mineral fertilisers, although many farmers are interested in using animal manures as substitutes. The objective of this study was to quantify changes to sodicity-related soil properties and exchangeable K concentration due to applying gypsum, K fertiliser and cattle manure in a region with an erratic rainfall distribution. Soil was sampled from a rainfed trial in southern Queensland.

Cattle manure improved potassium availability by 0.16 t/ha and decreased ESP. Gypsum and K fertiliser application also decreased ESP, and the latter increased exchangeable K, albeit to a lesser extent than manure. Decrease in ESP was not, however, sufficient to reduce dispersion and improve drainage. Gypsum application did not overcome the effects of sodicity. Crop yields were unaffected by gypsum, manure or mineral fertiliser application, suggesting that their application may not be economically rational in an environment where rainfall is erratic.

## INTRODUCTION

High subsoil exchangeable Na concentrations (resulting in soils with poor subsoil structure, impeded drainage, waterlogging and high soil strength) and salinity, and low exchangeable K concentrations are common soil constraints in many dryland soils of the semi-arid sub-tropical regions of Eastern Australia (Dang *et al.*, 2006; Bell *et al.*, 2008). As a consequence, crops are shallow-rooted and prone to drought during periods of even moderate rainfall, and nutrient-related disorders such as premature senescence in cotton can occur. Sodicinity in clayey soils can be alleviated and potassium availability improved by applying amendments such as gypsum and manure (McKenzie *et al.*, 1991, 1993; Ghosh *et al.*, 2008, 2010). These positive responses appear, however, to be related to a ready availability of water, either as frequent rainfall or irrigation. The efficacy of these amendments under conditions of restricted water availability or erratic rainfall distribution patterns is less clear. The objective of this study was to quantify changes to several sodicity-related soil properties (e.g. structural stability, ESP, pH, EC<sub>1:5</sub> (electrical conductivity of 1:5 soil:water suspension), drainage) and exchangeable K concentration due to applying amendments such as gypsum, K fertiliser and cattle manure in a semi-arid cracking clay where rainfall distribution was erratic. Soil was sampled from an experiment in the southern Darling Downs of Queensland that had been established to evaluate the

potential benefits of several management practices recommended by regional advisers.

## MATERIALS AND METHODS

Soil properties were measured in an experiment located on a commercial farm near Brigalow (150.7889°E, 26.8422°S) in southern Queensland, Australia. Mean annual rainfall is 698 mm. Monthly rainfall and evaporation from 1 July 2005 to 31 May 2008 are shown in Figure 1. The soil in the experimental site was an alkaline, self-mulching, grey clay with high levels of subsoil salinity and sodicity, and is typical of many clays in semi-arid, sub-tropical northern New South Wales, and southern and central Queensland (Dang *et al.*, 2006). Soil properties in this site prior to application of experimental treatments are summarised in Table 1. Dryland wheat was sown during winter 2005, cotton during the 2006-07 summer and sorghum during the 2007-08 summer.

The experimental treatments, imposed after zero-tillage on individual plots 50 m x 24 m in three adjacent blocks, were as follows: (1) Ripping alone with two passes of a 6-tine ripper with a tine spacing of 0.35 m to an average depth of 0.5 m (local practice); (2) Deep application (0.5 m) of P, Zn and K; (3) Deep application (0.5 m) of P and Zn; (4) Surface application of cattle manure at a rate of 16 t/ha followed by incorporation to a depth of ~50-70 mm; (5) Gypsum (diameter of 0-4 mm) at a rate of 9 t/ha followed by ripping; (6) Gypsum (diameter of 0-4 mm) at a rate of 9 t/ha followed by ripping, and deep application of P, Zn and K. P was applied at a rate of 11 kg P/ha in the form of mono-ammonium phosphate (MAP), K at a rate of 55 kg K/ha as potassium sulphate, and Zn at a rate of 3.5 kg Zn/ha as zinc sulphate. The elemental composition of cattle manure was: 24.2 g/100g of C, 2.3 g/100g of N, 1.1 g/100g of P, 2.3 g/100g of K, 4.0 g/100g of Na, 3.0 g/100g of Ca and 1 g/100g of Mg; pH was 8.4 and EC<sub>1:5</sub> 2.2 dS m<sup>-1</sup>. The P, Zn and K treatments were carried out with a single pass of the 6-tine ripper with a fertiliser box mounted on the machine. Gypsum and manure were applied with a 12 metre wide spreader. Except for treatment 5 (gypsum alone), all treatments were repeated in every block. Treatment 5 was not implemented in block 3, implemented twice in block 2 and once in block 1. The treatments were imposed during April-May 2005, and soil sampled from the experiment during July 2005, and June 2006 and 2007 from the 0-0.1 m, 0.1-0.3 m, 0.3-0.6 m and 0.6-1.2 m depths in each plot.

Air-dried soil was passed through a 2 mm-sieve and the following tests carried out: pH (in 1:5 soil:0.01M CaCl<sub>2</sub> suspension); EC<sub>1:5</sub>; chloride and exchangeable Ca, Mg, K and Na (Loveday, 1974; Rayment and Higginson, 1992). ESP was calculated as: (exchangeable Na/Σexchangeable cations) x100]. Dispersion after immersion in water was determined with a hydrometer (ASTM 152H) on air-dried soil aggregates of 1-4 mm diameter. Complete dispersion of soil was achieved by adding a mixture of 2:1 10% sodium hexametaphosphate:1M sodium hydroxide followed by mechanical stirring with a milkshake mixer. Dispersion was measured only during 2005 and 2007. Drainage was estimated with the chloride mass

balance method in all treatments during 2005-2006 and 2006-2007 (USSL, 1954; Slavich *et al.*, 2002).

## RESULTS AND DISCUSSION

### **Soil properties**

Application of manure resulted in higher exchangeable K (50% higher relative to deep-ripping alone) in the in the 0.1-0.3 m depth (Table 2). The same treatment also reduced ESP (relative to ripping alone) in the 0.1-0.3 m, 0.3-0.6 m and 0.6-1.2 m depths. ESP was also lower in the same depths with deep incorporation of P, K and Zn, albeit to a lesser extent than manure. Overall, the decreases in ESP were small. The ESP changes were also not of a sufficient magnitude to reduce dispersion or increase drainage in any depth. Drainage out of the 0.3-0.6 m depth was low and out of the 0.6-1.2 m depth negligible (Table 2), indicating that there was very little water movement at depths > 0.3 m. Application of K in the form of manure or as mineral fertiliser appeared to be as effective as applying gypsum to reduce ESP. Relative to deep ripping alone or manure application, exchangeable K values were higher by a very small amount only in the 0.10-0.30 m depth, but not in other depths, where either mineral fertiliser or gypsum was combined with deep ripping. This is probably because the maximum operating depths of the tines were of the order of 0.5 m. Godwin (2007) notes that in clayey soils, the stable openings created by tines with operating depths of ~0.5 m rarely exceed 0.3 m. Consequently, the effects of the amendments incorporated with the tines were restricted to the 0.1-0.3 m depth.

Gypsum application increased  $EC_{1:5}$  in the 0-0.6 m depth, presumably due to increases in the concentrations of calcium and sulphate ions in the soil solution (McKenzie *et al.*, 1991, 1993). These increases in  $EC_{1:5}$  did not, however, reduce dispersion or increase drainage in the subsoil as the ESI, electrochemical stability index ( $EC_{1:5}/ESP$ ) values did not increase beyond the threshold value of 0.05 (30). McKenzie (1998) notes that when ESI falls below 0.05, significant structural instability occurs, which in turn leads to reductions in hydraulic conductivity and drainage rates. ESI was similar among all treatments and averaged 0.05 in the 0.1-0.3 m depth, 0.03 in the 0.3-0.6 m depth and 0.04 in the 0.6-1.2 m depth, but was increased by gypsum in the 0-0.1 m depth such that it increased from 0.10 with ripping alone to 0.25 with gypsum (average of both gypsum treatments). The relationship between ESI and dispersion index for this site suggests, however, that decreases in the latter would be small when ESI exceeds 0.10 (Fig. 2). In comparison with manure application, exchangeable Ca concentration was higher in the surface 0.10 m where ripping was combined with gypsum (Table 2). Significant differences in exchangeable Ca did not occur among other treatments or in other depths. pH, exchangeable Mg, dispersion index and drainage were not significantly affected by treatments (Table 2).

Overall the differences in soil properties among treatments were small in absolute terms. In comparison with ripping alone, the increase in exchangeable K with manure application was of the order of 0.16 t K/ha. The positive response to manure suggests that long-term cropping-related K depletion could be minimised by regular application of cattle manure; for example once every 5 years. It is notable that gypsum application, even at a rate of 9 t/ha, did not significantly reduce dispersion

and increase drainage (Table 2). The recommended rates for gypsum, based on economic and bio-physical parameters, range from 2½ to 5 t/ha for grey clays (McKenzie, 1998; McKenzie *et al.*, 1993). At the same time, there are significant costs associated with applying gypsum: the total cost of gypsum, spreading and ripping was of the order of \$AUS 209/ha whereas ripping alone costs \$AUS 41/ha<sup>1</sup>. Given the absence of a response to gypsum application and the associated costs, the practice of not applying gypsum, which goes against advisory services' recommendations, is a rational one in this soil type and environment. The poor response to gypsum may be related to the typically erratic rainfall patterns in this region (Fig. 1). Strong and positive effects of gypsum application have usually been reported where water availability, either through irrigation or frequent rainfall, and soil fertility were not limiting factors (McKenzie *et al.*, 1991, 1993).

### **Crop yields**

Due to poor rainfall during 2005 (Fig. 1) the wheat crop failed but cotton and sorghum yielded well due to adequate soil moisture (stored water from fallow + in-crop rainfall) in subsequent years. Crop yields were not affected by application of soil amendments. Mean yield of wheat grain (which was affected by drought) during 2005 was 1.8 t/ha, cotton lint during 2006-07 was 9.4 bales/ha (1 bale = 227 kg) and sorghum grain during 2007-08 was 9.4 t/ha. Lack of response to applied amendments may be related to the fact that they had only a small effect on ESP, and exchangeable K values in the surface, albeit low, were nonetheless higher than those suggested by Bell *et al.* (2008) as causing yield reductions in sorghum and cotton. These authors reported that a 10% reduction in yield of sorghum and cotton was not achieved until exchangeable K concentrations had fallen to 0.19 cmol<sub>e</sub>/kg and 0.3 cmol<sub>e</sub>/kg, respectively. They further noted that the threshold value for cotton may well be higher as their cotton crops yielded poorly due to sowing late with a low yielding variety. Potassium stress during boll-filling is thought to be a possible cause of premature senescence, and hence, yield decreases in cotton (Wright, 1999). It is likely, therefore, that organic waste products will significantly improve crop yields only when soil fertility, particularly potassium availability, is very low.

## CONCLUSIONS

Cattle manure improved exchangeable potassium concentration and decreased ESP under zero-tillage in a semi-arid sub-tropical cracking clay in a region with an erratic rainfall distribution. Gypsum and K fertiliser application also decreased ESP, and the latter increased exchangeable K, albeit to a lesser extent than manure. Decrease in exchangeable Na with manure, gypsum and K fertiliser was not of a sufficient magnitude to improve soil structural stability and increase drainage in this soil where subsoil ESP was very high. Gypsum application, even at a higher than recommended rate, did not significantly reduce dispersion and increase drainage. In comparison with deep ripping alone, crop yields were unaffected by gypsum, manure or mineral fertiliser application. Application of gypsum and K fertiliser at recommended rates may not, therefore, be the most rational practice in this soil and environment where rainfall distribution erratic. Further research is required to determine the most

<sup>1</sup> Spreading of fresh manure costs \$ AUS 193/ha.

appropriate mix of tillage systems, fertiliser and amendment types, rates, and placement, and crop sequences by which K deficiency and sodicity in semi-arid, sub-tropical soils can be best managed for sustainable crop production.

#### ACKNOWLEDGEMENTS

Funding for this research was provided by the Cotton CRC, Narrabri, NSW and CRDC, Narrabri, NSW. Our thanks to Wade Bidstrup for allowing us to sample from his trial and for his encouragement and support.

#### REFERENCES

Bell, M., Harch, G., Want, P., and Moody, P. 2008. Management responses to declining potassium fertility in Ferrosol soils, in M. Unkovich, ed., *Global Issues, Paddock Action, Proceedings 14<sup>th</sup> Australian Agronomy Conference, Adelaide, South Australia, 21-25 September 2008*. Australian Society of Agronomy, Adelaide, SA. [CD-ROM].

Dang, Y. P., Dalal, R.C., Routley, R., Schwenke, G.D., and Daniells, I. 2006. Subsoil constraints to grain production in the cropping soils of the north-eastern region of Australia, an overview. *Australian Journal of Experimental Agriculture* **46**, 19–35.

Ghosh, S., Hulugalle, N., Lockwood, P., King, K., Kristiansen, P., and Daniel, H. 2008. Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols. *Australian Journal of Agricultural Research* **59**, 1068–1074.

Ghosh, S., Lockwood, P., Hulugalle, N., Daniel, H., Kristiansen, P., and Dodd, K. 2010. Changes in properties of sodic Australian Vertisols with application of organic

Godwin, R.J. 2007. A review of the effect of implement geometry on soil failure and implement forces. *Soil and Tillage Research*, **97**, 331-340.

Loveday, J. (ed.) 1974. *Methods for the Analysis of Irrigated Soils*. Technical Communication no. 54, Commonwealth Bureau of Soils. Harpenden, UK.

McKenzie, D.C. (ed.). 1998. *SOILpak for cotton growers*, 3rd edition. NSW Agriculture: Orange, NSW.

McKenzie, D.C., Abbott, T.S., Anthony, D.T.W., Hulme, P.J., MacLeod, D.A., and Higginson, F.R. 1990. Management of subsoil degradation in an Australian Vertisol used for irrigated cotton production. *Transactions of 14<sup>th</sup> International Congress of Soil Science, 12-18 August 1990, Kyoto, Japan*, **VI**, 176-181.

McKenzie, D.C., Abbott, T.S., Chan, K.Y., Slavich, P.G., and Hall, D.J.M. 1993. The nature, distribution and management of sodic soils in New South Wales. *Australian Journal of Soil Research* **31**, 839-868.

Rayment, G.E., and Higginson, F.R. 1992. *Australian laboratory handbook of soil and water methods, 1st edition*. Inkata, Melbourne, Vic., and Sydney, NSW, Australia.

Slavich, P.G., Petterson, G.H., Griffin, D., 2002. Effects of irrigation water salinity and sodicity on infiltration and lucerne growth over a shallow watertable. *Australian Journal of Experimental Agriculture* **42**, 281-290.

USSL (United States Salinity Laboratory Staff). 1954. *Diagnosis and improvement of saline and alkali soils*, L.A. Richards, ed. *Agriculture handbook No. 60*. USDA, Washington DC.

Wright, P.R. 1999. Premature senescence of cotton *Gossypium hirsutum*—predominantly a potassium disorder caused by an

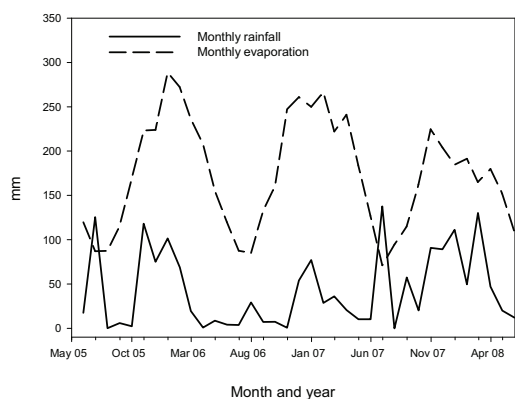


Fig. 1. Rainfall and evaporation during the experiment.

waste products. *Soil Science Society of America Journal*, **74**, 153-160.

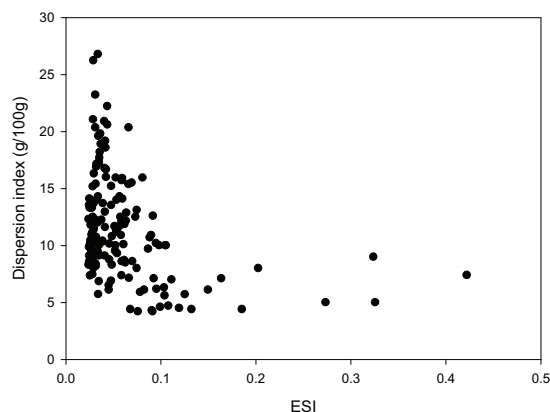


Fig. 2. Scatterplot of variation in dispersion index with electrochemical stability index, ESI in the 0-1.2 m depth. Data for 2005 and 2007 were pooled.

imbalance of source and sink. *Plant and Soil* **211**, 231-239

**Table 1.** Selected soil properties prior to application of experimental treatments. SOC, soil organic carbon; ESP, exchangeable sodium percentage, Cl, chloride; EC<sub>1:5</sub>, electrical conductivity of a 1:5 soil:water suspension; pH was measured in 0.01M CaCl<sub>2</sub> solution.

Depth (m)	pH	EC <sub>1:5</sub> (dS/m)	Clay (g/100g)	Silt (g/100g)	Sand (g/100g)	SOC (g/100g)	Effective CEC (cmol/kg)	ESP	Cl (mg/kg)
0-0.1	7.7	0.27	55	16	29	0.76	32.1	2.0	22
0.1-0.3	7.8	0.30	58	15	27	0.61	30.7	6.3	13
0.3-0.6	7.8	0.38	60	13	27	0.50	30.1	13.5	78
0.6-1.2	6.7	0.96	57	12	31	0.36	30.7	22.5	555

**Table 2.** Effect of applying soil amendments during 2005 on average soil properties from 2005 to 2007.

Management practice	0-0.1 m	0.1-0.3 m	0.3-0.6 m	0.6-1.2 m	P <	LSD
<b>Exchangeable Ca (cmol<sub>c</sub>/kg)</b>						
Ripping alone	25.5	22.4	17.7	11.8	0.05	1.8
Deep incorporation of P and Zn	25.7	21.8	17.9	12.8		
Deep incorporation of P, K and Zn	24.9	21.6	16.4	12.8		
Manure	24.1	22.5	18.1	12.7		
Gypsum	26.3	22.9	17.6	13.1		
Gypsum and deep incorporation of P, Zn and K	25.7	22.1	16.9	12.8		
<b>Exchangeable Mg (cmol<sub>c</sub> kg<sup>-1</sup>)</b>						
Ripping alone	7.5	10.2	13.4	13.3	n.s.	-
Deep incorporation of P and Zn	7.9	10.1	12.5	13.4		
Deep incorporation of P, K and Zn	7.7	9.4	12.8	13.9		
Manure	7.0	9.0	12.6	13.1		
Gypsum	7.2	9.3	12.1	13.0		
Gypsum and deep incorporation of P, Zn and K	7.6	9.4	12.7	13.2		
<b>Exchangeable K (cmol<sub>c</sub>/kg)</b> (Values in parentheses were sqrt transformed)						
Ripping alone	0.8 (0.91)	0.3 (0.53)	0.2 (0.42)	0.1 (0.33)	(0.001)	(0.06)
Deep incorporation of P and Zn	1.0 (0.98)	0.4 (0.60)	0.2 (0.44)	0.2 (0.40)		
Deep incorporation of P, K and Zn	0.8 (0.89)	0.4 (0.60)	0.2 (0.41)	0.1 (0.36)		
Manure	1.2 (1.10)	0.3 (0.53)	0.2 (0.41)	0.1 (0.36)		
Gypsum	0.9 (0.93)	0.4 (0.61)	0.2 (0.43)	0.1 (0.34)		
Gypsum and deep incorporation of P, Zn and K	0.9 (0.94)	0.4 (0.60)	0.2 (0.41)	0.1 (0.32)		
<b>ESP</b>						
Ripping alone	2.0	7.2	13.8	22.3	0.01	1.1
Deep incorporation of P and Zn	2.0	7.2	14.4	22.4		
Deep incorporation of P, K and Zn	1.5	5.7	12.5	20.8		
Manure	1.2	5.1	11.5	20.0		
Gypsum	1.2	5.2	13.1	20.5		
Gypsum and deep incorporation of P, Zn and K	1.7	6.1	13.6	21.2		
<b>EC<sub>1:5</sub> (dS/m)</b>						
Ripping alone	0.20	0.28	0.37	0.81	0.001	0.07
Deep incorporation of P and Zn	0.21	0.30	0.37	1.15		
Deep incorporation of P, K and Zn	0.21	0.26	0.34	1.07		
Manure	0.18	0.25	0.36	0.89		
Gypsum	0.33	0.40	0.38	0.89		
Gypsum and deep incorporation of P, Zn and K	0.37	0.36	0.41	1.04		
<b>pH</b>						
Ripping alone	7.6	7.6	7.6	6.7	n.s.	-
Deep incorporation of P and Zn	7.6	7.5	7.5	6.5		
Deep incorporation of P, K and Zn	7.6	7.5	7.6	6.6		
Manure	7.6	7.6	7.6	6.8		
Gypsum	7.5	7.5	7.6	6.9		
Gypsum and deep incorporation of P, Zn and K	7.5	7.5	7.6	6.7		
<b>Dispersion index (g 100/g)</b>						
Ripping alone	9.0	11.7	10.8	17.7	n.s.	-
Deep incorporation of P and Zn	10.0	11.2	10.4	17.2		
Deep incorporation of P, K and Zn	9.3	10.3	9.2	18.6		
Manure	9.1	11.6	10.0	15.2		
Gypsum	11.5	9.9	10.3	15.4		
Gypsum and deep incorporation of P, Zn and K	11.1	10.2	10.6	15.5		
<b>Drainage (2005-06)</b> (Values in parentheses are sqrt transformed values of (drainage+10))						
Ripping alone	45 (7.42)	32 (6.47)	9 (4.38)	4 (3.71)	n.s.	-
Deep incorporation of P and Zn	43 (7.30)	31 (6.46)	4 (3.71)	-1 (2.93)		
Deep incorporation of P, K and Zn	59 (8.32)	35 (6.68)	8 (4.23)	3 (3.67)		
Manure	33 (6.56)	11 (4.62)	4 (3.75)	-1 (2.95)		
Gypsum	36 (6.78)	23 (5.70)	15 (4.96)	3 (3.65)		
Gypsum and deep incorporation of P, Zn and K	52 (7.89)	27 (6.10)	3 (3.64)	-5 (3.2)		
<b>Drainage (2006-07)</b> (Values in parentheses are sqrt transformed values of (drainage+10))						
Ripping alone	36 (6.77)	18 (5.29)	6 (3.99)	0 (3.15)	n.s.	-
Deep incorporation of P and Zn	33 (6.54)	17 (5.16)	10 (4.47)	3 (3.62)		
Deep incorporation of P, K and Zn	43 (7.29)	20 (5.48)	7 (4.16)	5 (3.91)		
Manure	35 (6.73)	15 (4.96)	9 (4.36)	-6 (2.11)		
Gypsum	40 (7.04)	20 (5.47)	10 (4.47)	4 (3.76)		
Gypsum and deep incorporation of P, Zn and K	26 (5.98)	15 (5.03)	6 (4.05)	5 (3.88)		