NSW research results

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Managing heavy clay soils to improve grain production in a high rainfall environment: Investigating soil amendments on soil properties and soybean yield – Codrington 2017/18

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Key findings

- Surface and subsurface soil tests showed very high magnesium (Mg) levels of 43.3% exchangeable Mg and cation exchange capacity (CEC) of 26 at 0–10 cm. Seven soil amendment treatments were applied before a soybean crop was sown over the site in December 2017.
- Treatments containing lime resulted in a significant increase in soybean yield in the first season.
- All treatments reduced the detrimental dispersion and slaking properties of the soil.
- Assessment of the soil chemical and physical properties, and grain yield will continue in 2018/19.

Introduction

Heavy clay soils have provided many challenges for grain growers in the high rainfall zone of north-eastern NSW. These soils typically have a high clay content, a very high bulk density and low soil permeability to water. This creates an environment where plant roots struggle to penetrate the soil and rainfall tends to run off rather than infiltrate the soil profile.

A troublesome heavy clay soil was identified at Paul Fleming's property at Codrington in north eastern NSW. Initial soil tests (0–30 cm depth) indicated that the surface soil was not sodic (2.1% exchangeable sodium). However, the surface soil was highly magnesic (43.3% exchangeable Mg), possibly explaining the poor soil structure. Subsequent soil tests taken deeper in the soil profile (30–60 cm) indicated elevated sodium (Na) levels (7.7% exchangeable sodium). Gypsum ($CaSO_2H_2O$) and lime ($Ca(OH)_2$) and combinations of the two were assessed to evaluate the efficacy of calcium-based amendments. Compost treatments were also included to evaluate organic amendments with combinations of organic matter and lime.

A replicated field experiment was conducted to measure the effect of soil amendments on soybean yield and on soil chemical and physical properties. This experiment aimed to identify a surface-incorporated soil amendment that can ameliorate a difficult-to-manage soil type and thereby increase crop productivity. The investigation of these amendments was prioritised by the *Advisory Group for the Coastal and Hinterland Grower Solutions* project to identify strategies to improve the productivity of grain crops in this region. This experiment was the first in a three-year project with on-going measurements this site.

Site details

A commercial grain farm with a heavy clay soil type was selected for the experiment. This is a dryland (rain-fed) production system in a rotation of maize, barley and soybean. Details of the site location and general attributes of the experimental design are described below. Soil chemical properties at the site are shown in Table 1.

Location	Casino–Coraki Road, Codrington, NSW Latitude: 153°12′53.62″E, Longitude: 29°25′01.39″S
Soil type	Heavy clay soil
Co-operator	Paul Fleming, Codrington, Coraki, NSW Australia
Soil type and nutrition	Red clay loam, pH_{Ca} 5.6 (0–10 cm), see Table 1 for soil chemical properties
Irrigation	Nil (rain-fed)
Trial design	Randomised block design, seven soil amendment treatments with three replicates
Row spacing	Two rows on a raised bed at 0.9 m row spacing, furrows at 1.8 m spacing.
Variety	Richmond⫚
Sowing date	15 December 2017
Plant population	300,000 plants/ha (bed top population)
Harvest date	23 April 2018
Farming system and bed preparation	The farming system uses a minimum tillage (strip-tillage) unit that incorporates stubble and forms a bed with furrows at 1.8 m spacing. Due to the wet harvest of the previous barley crop, the paddock was chisel ploughed and cultivated with a Lilliston® rolling cultivator twice before bed-forming and applying ameliorants. Two rows of soybean variety Richmond⫚ were sown into each bed using a disc opener Kinze® planter (90 cm row spacing). Trimble® GPS guidance was used when planting the experiment.
Fertiliser	Incitec Pivot Pasture 13® (0% N, 6.6% P, 12.5% K, 8.3% S, 15.0% Ca) was applied at planting at 110 kg/ha. Soybean seed was inoculated using liquid inoculant injected at planting.
Weed management	Dual Gold® at 1.4 L/ha (960 g/L S–metolachlor) was banded post planting the soybean crop and Spinnaker® at 100 g/ha (700 g/kg imazethapyr) was applied before canopy closure. A shielded sprayer was used mid-season to apply 2.5 L/ha of glyphosate to control weeds in the inter-row.
Rainfall and temperature	The growing season was favourable for soybean growth. Although January was a particularly dry month (Figure 1), there was sufficient soil moisture for the crop to continue growing.

Table 1. Soil chemical properties for Codrington before soil amendment application – December 2017.

Analysis	Soil depth (cm)	
	0–10	30–60
pH (1:5 water)	5.7	6.3
pH_{Ca}	4.61	5.05
Electrical conductivity (1:5 water) dS/m	0.08	0.10
Electrical conductivity (saturated extract) dS/m	0.4	–
Chloride mg/kg	58	157
Organic carbon %	2.3	–
Nitrate nitrogen (as N) mg N/kg	14	7.0
Ammonium nitrogen mg/kg	<4	<4
Phosphorus (P) (Colwell) mg/kg	107	34
Phosphorus buffer index (PBI-Col)	374	237
Sulfur (S) as sulfate (MCP) mgS/kg	9.6	23
Cation exchange capacity (CEC) cmol(+)/kg	26	30
Aluminium (Al) (Amm-acet.) % of CEC	0.4	0.3
Aluminium (Amm-acet.) cmol(+)/kg	<0.1	<0.1
Calcium (Ca) (Amm-acet.) % of CEC	49.3	42.7
Calcium (Amm-acet.) cmol(+)/kg	16	14
Magnesium Mg) (Amm-acet.) % of CEC	46	45
Magnesium (Amm-acet.) cmol(+)/kg	13.3	13.5
Sodium (Na)(Amm-acet.) % of CEC	2.5	7.7
Sodium (Amm-acet.) cmol(+)/kg	0.65	2.31
Potassium (K) (Amm-acet.) % of CEC	1.7	0.7
Potassium (Amm-acet.) cmol(+)/kg	0.52	0.20
Available potassium mg/kg	201	77
Calcium/magnesium ratio	1.07	0.85
Potassium/magnesium ratio	0.04	0.01
Zinc (Z) (DTPA) mg/kg	4.4	–
Copper (Cu) (DTPA) mg/kg	2.8	–
Iron (Fe) (DTPA) mg/kg	476	–
Manganese (Mn) (DTPA) mg/kg	22.1	–
BSES phosphorus mg/kg	44.70	23.64
Potassium permanganate oxidisable carbon mg/kg	485	302

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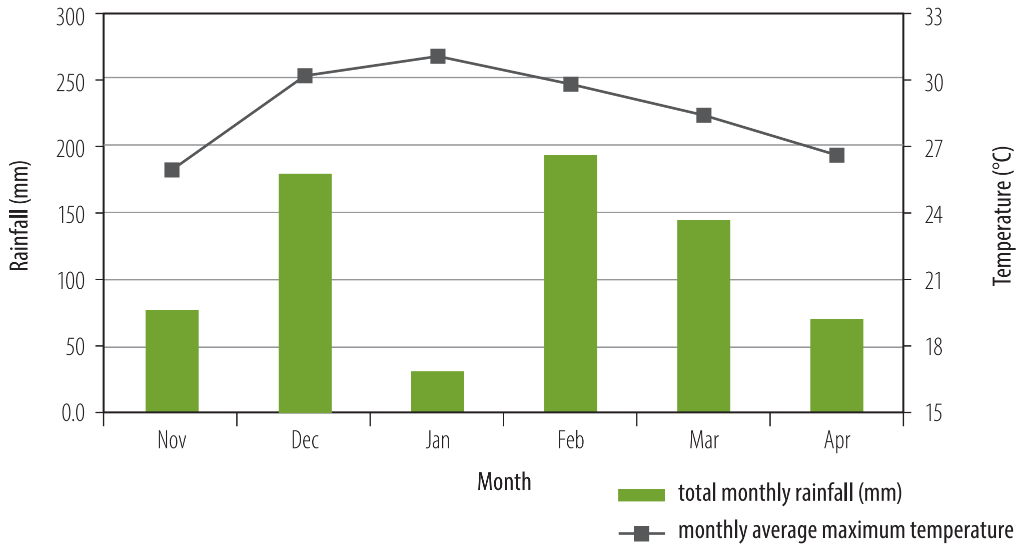

Figure 1. Average maximum temperature and monthly rainfall for Codrington, NSW, 2017/18.

Treatments

The experiment consisted of seven treatments, described in Tables 2 and 3, with three replications in a randomised complete block design. Individual plots consisted of three beds (5.4 m) wide and 12 m long. Treatments two, three and four were chosen to evaluate how effective calcium (Ca) amendments were on the soil and treatments six and seven were included to evaluate an organic matter amendment and the combination of organic matter and lime.

Table 2. Soil amendment treatments.

Treatment number	Soil amendment
1	Control (no amendment applied)
2	Gypsum (2.5 t/ha) + lime (5 t/ha)
3	Gypsum (5 t/ha)
4	Lime (5 t/ha) per annum (3 years)
5	Gypsum (5 t/ha) annually (3 years)
6	Compost (15 t/ha)
7	Compost (15 t/ha) + lime (5 t/ha)

Table 3. Soil amendments specific properties.

Amendment	Specific properties
Gypsum	21% calcium; 15.5% sulfur as sulfate
Lime	% calcium; neutralising value; fineness
Compost	11.3% organic carbon; 24.9% organic matter, 1.21% total nitrogen; 39.4% moisture

Figure 2. The experiment site after amendments applied and before incorporation (13 December 2017).
Photo: N. Ensbey, NSW DPI.

Results and conclusions

Soil analysis – treatment pre-application

Soil analysis confirmed that the surface soil at the site (0–10 cm depth) was not sodic (Table 1), however, Mg accounted for 43% of the CEC. In some clay soils a high Mg value can result in poor soil physical properties with the Mg acting in a similar way to Na. The tendency of the soil to form a surface crust was evident. The subsoil at the site (30–60 cm depth) is sodic (7.7% exchangeable Na, Table 1) and this was associated with a high Mg percentage of the CEC. These subsoil characteristics indicate poor soil physical properties in the subsoil with reduced permeability and poor internal drainage.

Calcium-based amendments are typically used as ameliorants on sodic soils and act by the Ca replacing Na and Mg on the cation exchange complex. On neutral to alkaline soils, gypsum is typically used. On acidic soils lime, or a combination of lime and gypsum, are applied to ameliorate acidity.

Because the surface soil is strongly acidic and the subsoil is mildly to moderately acidic (Table 1), lime treatments were included, as lime increases soil pH as well as supplying Ca. A yield response to lime could be attributed to one or both of these effects. Gypsum treatments were also included for comparison.

Plant biomass, grain yield and quality

The site was assessed on 16 January (31 days after sowing) for emergence and visual effects from the treatments. Germination and emergence were even across the site. There were no clear effects on growth, except that the treatments containing lime (treatments two, four and seven) appeared to have slightly more vigorous growth than the control plots. No quantitative measurements were made at this stage.

There was a high standard of crop management across the site and the crop was harvested on 23 April 2018. Analysed results of yield, quality and crop biomass are presented in Table 4.

Table 4. Soybean yield (@ 12% moisture), seed quality and peak crop biomass.

Treatment number, description		Yield (t/ha)	Seed size (g/100 seeds)	Protein[#] (%)	Oil[#] (%)	Peak crop biomass[#] (t/ha)
4	Lime 5 t/ha	4.43	21.6	40.1	22.4	7.14
7	Compost 15 t/ha + lime 5 t/ha	4.33	21.6	39.2	22.9	7.59
2	Gypsum 2.5 t/ha + lime 5 t/ha	4.12	20.6	40.2	22.5	7.95
1	Control – no amendment	3.80	19.5	39.4	22.9	7.07
3	Gypsum 5 t/ha once	3.76	19.8	40.1	22.6	7.65
5	Gypsum 5 t/ha annually	3.70	19.3	39.8	22.9	7.98
6	Compost 15 t/ha	3.65	19.8	40.8	22.1	7.69
	standard error	0.11	0.33	1.0	0.52	0.36
	l.s.d. ($P<0.05$)	0.32	1.03	ns	ns	ns
	NHST	0	0	0.92	0.93	0.47

[#] dry matter basis
ns: not significant; NHST: nil hypothesis sum total value for spatial analysis. Differences between values that exceed the estimate of least significant difference (l.s.d.) can be regarded as statistically significant at the 5% critical value ($P<0.05$).
Statistical analysis by Stephen Morris, Biometrician NSW DPI.

There was no significant difference in crop biomass between treatments, but there was for yield. All treatments containing lime produced significantly higher yields than the control treatment. The gypsum and the compost alone treatments did not yield more than the control. Grain protein and oil content were not significantly different between treatments.

Both lime and gypsum supply Ca, however, as an increase in yield was only observed in the treatments containing lime, it is unlikely that this is due to a Ca response. The response to lime could be due to either a response to the amelioration of potential toxicities, such as Al and/or Mn, or a response to an increase in the soil pH level. Since soil test results for the unamended soil indicated low levels of exchangeable Al (Al value of 0.3% of the effective CEC), amelioration of Al toxicity is unlikely to be the reason for the response to lime. Additionally, the soybean plants in the control plots showed no symptoms of Mn toxicity. Therefore, it appears that the yield increase is likely due to an increase in soil pH due to applying and incorporating lime.

The responses recorded in this experiment could have implications for soybean production on the predominantly acidic cropping soils of the NSW north coast.

Soybean yield in this experiment was only weakly correlated with soil pH_{water} as shown in Figure 3.

Post-harvest chemical soil properties – surface layer (0–10 cm)

After the crop was harvested, soil samples 0–10 cm and 10–30 cm deep were collected (August 2018). For each depth, five soil cores from each plot were composited, mixed and a subsample taken for soil chemical and physical properties. All plots, except those from treatment 5, were sampled as, at this stage of the experiment, treatments three and five were identical in the amount of gypsum applied. Soil physical properties were assessed using the Emerson dispersion test, slaking test and cone penetrometer readings.

In the 0–10 cm surface soil layer, all the treatments containing lime (treatments two, four and seven) significantly increased soil pH (i.e. ≥0.5 for pH_{water} and ≥0.62 for pH_{Ca}, Table 5) compared with the untreated control. Compost and gypsum treatments had no significant effect on soil pH. There was no significant effect from the treatments on organic carbon, a measure of organic matter content. For the rate of compost applied in this experiment (15 t/ha) the amount of organic matter applied is very small in relation to the amount of organic matter already present in the soil, therefore, an increase in soil organic carbon from these compost treatments was not expected at this stage of the experiment.

The significant increases in plant available sulfate sulfur, CEC and exchangeable calcium are consistent with the treatments imposed.

Although there was no significant effect from the treatments on the Ca:Mg ratio in the unamended soil (Table 1), there was a trend for the ratio to increase in treatments where Ca was applied as lime (Table 5).

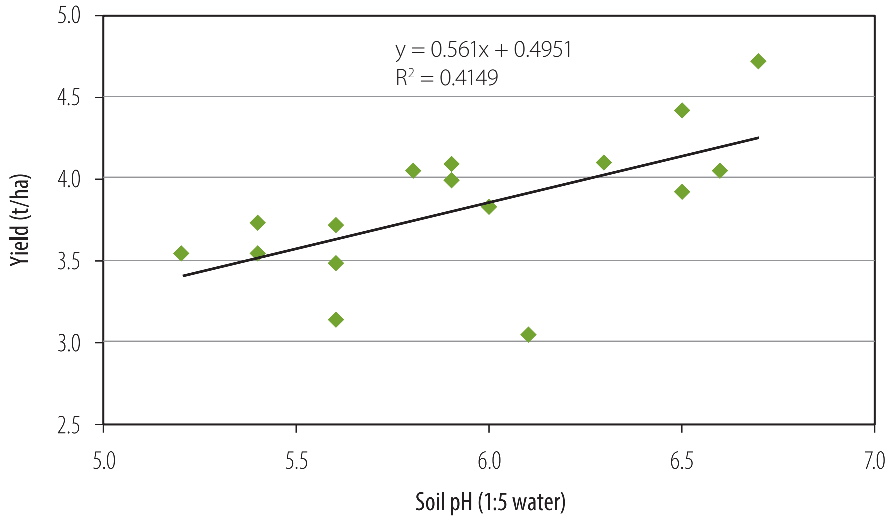

Figure 3. Relationship between soil pH and soybean yield.
Note plotted values are for individual plots.
Analysis by Dr Bob Aitken, consultant soil scientist.

Table 5. Effect of soil amendments on soil surface (0–10 cm), taken after harvest (August 2018) and eight months after treatment application.

Soil property (0–10 cm)	**Treatment**						**l.s.d.**	***P***
	1 Control	**2 Gypsum (2.5 t/ha) + lime (5 t/ha)**	**3 Gypsum (5 t/ha)**	**4 Lime (5 t/ha) annually**	**6 Compost (15 t/ha)**	**7 Compost (15 t/ha) + lime (5 t/ha)**		
pH_{water}	5.7	6.2	5.3	6.5	5.9	6.3	0.50	0.0015
pH_{Ca}	4.61	5.26	4.62	5.58	4.94	5.44	0.62	0.0205
Organic C %	2.3	2.2	2.0	2.0	2.1	2.2	–	ns
EC (1:5 water) (dS/m)	0.08	0.08	0.17	0.07	0.10	0.08	0.06	0.0286
S (mg/kg)	27	22	88	8	31	20	24.0	0.003
CEC (cmol(+)/kg)	26	25	22	28	26	29	2.90	0.0073
Al (%CEC)	0.4	0.4	0.5	0.4	0.4	0.3	–	ns
Ca (%CEC)	49.3	56.1	51.7	55.2	50.8	55.3	–	ns
Exch. Ca	12.8	14.3	11.6	15.4	13.1	16.1	2.80	0.0365
Mg (%CEC)	46.4	39.6	44.5	40.7	44.0	40.5	–	ns
Exch. Mg	12.0	10.0	10.0	11.4	11.3	11.8	–	ns
Na (%CEC)	2.5	2.0	2.1	1.9	2.7	2.3	–	ns
Exch. Na	0.646	0.491	0.474	0.540	0.688	0.668	–	ns
Ca/Mg ratio	1.07	1.43	1.17	1.37	1.13	1.37	–	ns
Labile C (mg/kg)	367	400	376	413	376	396	–	ns

ns: not significant
Soil chemical analyses were conducted by Dr Bob Aitken, consultant soil scientist

Treatment three, gypsum-only (5 t/ha), significantly increased the electrical conductivity from 0.08 dS/m to 0.17 dS/m in the surface soil layer (Table 5). This, in conjunction with gypsum being a soluble source of Ca, explains the effect of this treatment in reducing the tendency for dispersion (Table 8).

There was no significant effect from the treatments on labile carbon (potassium permanganate oxidisable carbon), but there was a trend for increased labile carbon where lime was applied (Table 5).

Post harvest chemical soil properties – subsoil layer (10–30 cm)

In the 10–30 cm subsoil layer, there were few significant effects from treatments on soil chemical properties (Table 6). This highlights the difficulty in ameliorating subsoils, particularly heavy clay soils. Lime application had no effect on soil pH in the 10–30 cm layer. It is possible that the amendments were only incorporated to a depth of around 10 cm to 15 cm despite the appearance of deeper incorporation during cultivation.

Treatment three, gypsum-only (5 t/ha), significantly lowered the soil pH_{water} value to 5.8 compared with 6.3 in the untreated control. This was likely to be due to a salt effect on the measurement of pH_{water}. The significant increase in sulfate sulfur in the 10–30 cm layer to 102 mg/kg in the gypsum-only treatment compared with 39 mg/kg in the untreated control (Table 6), suggests that sulfate sulfur moved deeper into the soil layer. As gypsum is used to supply sulfur and the mobility of sulfur in soil, this result is not unexpected.

The sub soil layer (10–30 cm) is sodic with an exchangeable Na percentage of 6% (Table 6). This explains the management difficulties the grower encountered with soil physical characteristics at the site.

Table 6. Effect of treatments on subsoil properties (10–30 cm), taken after harvest (August 2018) and eight months after treatment application.

Soil property (10–30 cm)	Treatment						l.s.d.	*P*
	1 Control	2 Gypsum (2.5 t/ha) + lime (5 t/ha)	3 Gypsum (5 t/ha)	4 Lime (5 t/ha) annually	6 Compost (15 t/ha)	7 Compost (15 t/ha) + lime (5 t/ha)		
pH_{water}	6.3	6.0	5.8	6.4	6.1	6.2	0.27	0.0037
pH_{Ca}	5.05	4.84	4.85	5.02	4.92	4.87	ns	ns
EC (1:5 water) (dS/m)	0.09	0.11	0.19	0.08	0.11	0.09	0.04	0.0012
S (mg/kg)	39	48	102	22	51	34	30	0.0022
CEC (cmol(+)/kg)	30.2	26.4	27.3	29.3	27.2	27.3		ns
Al (%CEC)	0.3	0.4	0.4	0.3	0.4	0.4		ns
Ca (%CEC)	42.7	43.2	44.0	42.7	43.2	46.0		ns
Exch. Ca	12.9	11.4	12.0	12.5	11.7	12.5		ns
Mg (%CEC)	50.4	50.0	49.4	50.3	49.9	47.5		ns
Exch. Mg	15.3	13.2	13.5	14.7	13.6	13.0		ns
Na (%CEC)	6.0	6.2	6.0	6.2	6.3	5.9		ns
Exch. Na	1.82	1.62	1.64	1.83	1.73	1.61		ns
Ca/Mg ratio	0.85	0.87	0.89	0.85	0.87	0.96		ns
Labile C (mg/kg)	253	243	283	245	220	256		ns

ns: not significant
Soil chemical analyses were conducted by Dr Bob Aitken, consultant soil scientist.

Post-harvest physical soil properties

Ten cone penetrometer measurements were made in the middle bed of each plot (16 August 2018). These readings measured the maximum pressure (kPa) attained while pushing the cone to a depth of 15 cm. The readings for each plot were averaged to give a mean. Plot means were then used for an ANOVA (analysis of variance) analysis for a randomised complete block experiment design. Although there was no statistically significant treatment effect ($P = 0.05$), there was a trend for the treatments with Ca amendments (treatments two, three, four and five) to have lower values than the untreated control and the compost only treatment (treatments one and six respectively; Table 7). Lower values indicate softer soil due to less resistance.

Table 7. Treatment effects on cone penetrometer readings.

Treatment No.	Treatment	Mean cone penetrometer reading (kPa)
1	Control	2500
2	Gypsum (2.5 t/ha) + lime (5 t/ha)	1600
3	Gypsum (5 t/ha)	1300
4	Lime (5 t/ha) annually (3 years)	1700
5	Gypsum (5 t/ha) annually (3 years)	1700
6	Compost (15 t/ha)	2200
7	Compost (15 t/ha) + lime (5 t/ha)	1800

No significant treatment effect ($P = 0.05$)

Air-dried aggregates (or peds) from the 0–10 cm soil depth from each plot were assessed using the Emerson slaking and dispersion test. All aggregates slaked to some degree, that is, their physical structure slumped and fell apart in water. There was minimal to no dispersion in the water around the peds (Figure 4, left) in the untreated control plots and there were no discernible differences between the treatments. The test was repeated using soil samples remoulded at field capacity moisture to simulate working the soil in a wet condition. The results for remoulded soil are shown in Table 8 and Figure 4, right, showing strong slaking and dispersion.

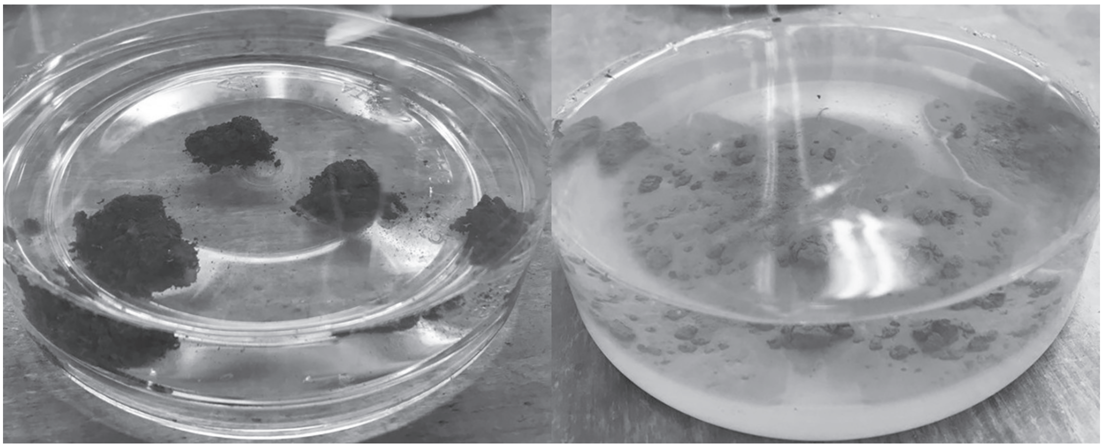

Figure 4. Air-dried soil aggregates (peds) showing a small amount of dispersion and little to no slaking (left) compared with a remoulded sample of the untreated control displaying a high degree of dispersion and slaking of remoulded peds (right).
Photos: N. Moore, NSW DPI.

Table 8. Treatment effects on dispersion score for remoulded soil samples.

Treatment No	Treatment	Remoulded aggregate dispersion score
1	Control	Strong to complete dispersion
2	Gypsum (2.5 t/ha) + lime (5 t/ha)	Moderate dispersion
3	Gypsum (5 t/ha)	Slight dispersion
4	Lime (5 t/ha) annually (3 years)	Strong dispersion
5	Gypsum (5 t/ha) annually (3 years)	–
6	Compost (15 t/ha)	Strong dispersion
7	Compost (15 t/ha) + lime (5 t/ha)	Strong dispersion

Differences between treatments occurred, with only the gypsum treatments showing a lower tendency to disperse after remoulding (Table 8). Relative to lime, gypsum is a more soluble source of Ca and these observations are consistent with the relative solubility of lime and gypsum.

In winter 2018, a cereal crop was intended to be sown over the site, however, due to a change by the grower, a chickpea crop was sown. Grain yield of the chickpea crop and soil chemical and physical properties will be measured before additional amendments are applied and soybean is sown on the site in 2018–19. Treatment effects will continue to be measured over three summer and three winter seasons, along with calculating the cost/benefit of the soil amendments in relation to grain production.

Acknowledgements

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