Lime and gypsum interactions towards managing subsoil (field trials - IDs: 2017WH08 and 2017WH09)

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BACKGROUND

Subsurface soil acidity (pH_{Ca} <4.8) is a widespread phenomenon in many parts of Western Australia (Gazey et al 2014). At low soil pH the concentration of toxic forms of aluminium in the soil solution increases, significantly reducing root growth and function, and hence crop yield. Incorporation of agricultural lime to an acidic soil can increase soil pH which reduces the level of toxic forms of Al. However, lime applied to the surface soil can take several years to increase subsurface soil pH. Therefore, the physical incorporation of lime is the most recent recommended method.

Surface application of gypsum has also been suggested for managing subsoil acidity. If surface applied gypsum alone or in combination with lime can remediate subsoil acidity faster than the surface applied lime only, this would be an alternative approach to the more aggressive tillage oriented lime incorporation. The combined application of lime and gypsum has the potential to reduce the cost involved in tillage and get a quick return on investment. It is, however, unclear how these ameliorants interact to affect the amelioration of subsoil acidity and Al toxicity and hence crop growth and yield.

OBJECTIVES

To evaluate how the application of lime and gypsum under tillage and no tillage affects soil pH, Al toxicity and crop yield at research plot and farmer scales.

METHODS

Small scale trial at Kalannie, WA

This is an on-going field trial established in a continuously cropped paddock of Bob and Amanda Nixon in Kalannie, Western Australia (35°42'S, 117°29'E). Soil in the paddock is classified as a yellow-orthic acidic tenosol in the Australian Soil Classification. Soil in this region, known as Wodjil soil, was naturally acidic before being cleared for use in agriculture. Both surface and subsurface soils were strongly acidic and, particularly the subsoil, extremely aluminium toxic. The soil had low levels of organic carbon. N, P and K contents were in average level in the topsoil, however, subsoil had very limited level of Colwell P which also had very very low phosphorus buffering index (Table 1).

The trial was established in March 2017. At the beginning, the whole site was ripped to 500 mm depth, to remove soil compaction as a covariate. The trial plots were set at 15° angle to the ripping line. The trial consisted of small plots of 1.8 x 20 m. The trial had a complete factorial design replicated three times. There were three factors: tillage, lime rate and gypsum rate. Four lime rates were used: 0(L0), 2(L1), 4(L2) and 6(L3) t/ha lime (neutralising value of 91.9%, 99.2% particles < 0.5 mm, Table 2). Four gypsum rates were also used: 0(G0), 1(G1), 2(G2), 3(G3) t/ha (gypsum purity 96%, Table 3). Lime and gypsum were applied on the surface of the soil before tillage treatments were applied as blocks. The two tillage treatments were (i) no cultivation and (ii) deep incorporation of lime and gypsum using DPIRD's one-way plough (200 mm depth).

Table 1. Properties of surface- and subsurface soil used in the experiments

Parameters	Surface soil	Subsurface soil
Sampling depth (cm)	0-10	20-40
Texture	Sandy loam	Sandy loam
Bulk density (g/cm^3)	1.34	1.52
pH_{Ca}	4.35	3.95
Al_{Ca} ($mg\ kg^{-1}$)	2.47	22.2
Total N ($mg\ kg^{-1}$)	19	9
Colwell P ($mg\ kg^{-1}$)	31.3	4.33
PBI	24.2	63.1
Colwell K ($mg\ kg^{-1}$)	53.3	32.3
OC (%)	0.85	0.32
S ($mg\ kg^{-1}$)	7.4	28.6
CEC ($meq\ 100\ g^{-1}$)	1.51	1.09

Table 2: The particle size distribution and neutralising value of lime used in two trials at Kalannie.

Sieve range (mm)	%weight	Neutralising value
0-0.125	2.9	92.7
0.125-0.250	61.1	91.2
0.250-0.50	35.2	93.6
0.50-1.00	0.8	75.2
>1.00	0	N/A
Overall	--	91.9

Table 2: The physical and chemical properties of gypsum used in two trials at Kalannie.

Parameters	***Per cent (w/w)***
Moisture	2.95
Calcium	22.4
Sulphate	53.3
Sulfur	0.03
Sodium	17.8
Calcium sulphate – $CaSO_4$	75.5
Gypsum – $CaSO_4x2H_2O$	96

Trial Details

Plot size & replication	20m x 1.8m x 3 replications
Soil type	Acidic (Wadjil) sand
Soil pH ($CaCl_2$)	0-10cm: 4.4 10-20cm: 3.9 20-30cm: 3.9
Paddock rotation:	e.g. 2017 wheat, 2018 wheat, 2019 canola
Sowing date	23/05/2017, 04/06/2018, 02/05/2019
Sowing rate	60 kg/ha Mace wheat, 2.4 kg/ha Bonito canola
Fertiliser	2017 seeding: (MAP 37 kg/ha, SOP 100 kg/ha; Urea 57 kg) 2018 seeding: (MAP 37 kg/ha, Urea 57 kg) 2019 seeding: (MAP 37 kg/ha, Urea 57 kg)
Herbicides, Insecticides & Fungicides	23/05/2017 (Pre-sowing: Triflur 2 L/ha, Sprayseed 250 2 L/ha, Sakura 118 g/ha); 01/08/2017 (Post-emergence: Velocity 670 ml/ha, MSO 1%) 04/06/2018 (Pre-sowing: Triflur 2 L/ha, Sprayseed 250 2 L/ha, Sakura 118 g/ha); 15/08/2018 (Post-emergence: Velocity 670 ml/ha, MSO 1%) 01/05/2019 (Pre-sowing: Atrazine 1.1 kg/ha, Triflurex 1.5 L/ha, Chlorpyrofos 200 ml/ha and Alfa Scud 200 ml/ha; 01/07/2019 (Post-emergence: Atrazine (1.1 kg/ha), MSO 1%)


Pic 1: Lime application by hand in small plots


Pic 2: Small plot sowing

Large scale trial at Kalannie, WA

At the start of the trial, the whole site was ripped to 500 mm depth. The plot size was large, i.e., 18 x 50 m and hence lime and gypsum were spread by farmer's scale spreader (Pic 3). Half the plots were cultivate to incorporate lime and gypsum to approximate depth of 200 mm using an one-way plough (Pic 4). Sowing and other site management was carried out by the grower. This trial was sown dry in 2017. The crop was harvested using DPIRD'S plot harvester. The trial used a randomised complete block design replicated four times. There were three factors: tillage, lime rates and gypsum rates. The treatment details are as follows:

Tillage: 1. Surface application of lime and gypsum

2. Deep incorporation using DPIRD's one-way plough (200-300 mm depth)

Lime rate: Two rates: 0 and 4 t ha^{-1} (Lime rate was selected based on a pH buffering capacity of Kalannie soil. It was estimated 4 t per ha lime would change pH_{Ca} of 0-10cm soil from initial 4.7 (Figure 1) to at least 5.5 and 10-40 cm soil from initial pH_{Ca} 4.2 to 4.8).

Gypsum rate: Four rates: 0 and 2 t ha^{-1} (Gypsum rate was similar to that of Kalannie farmer Bob Nixon).

Pic 3: Lime application using multi-spreader

Pic 4: Ploughed (left) and unploughed plots

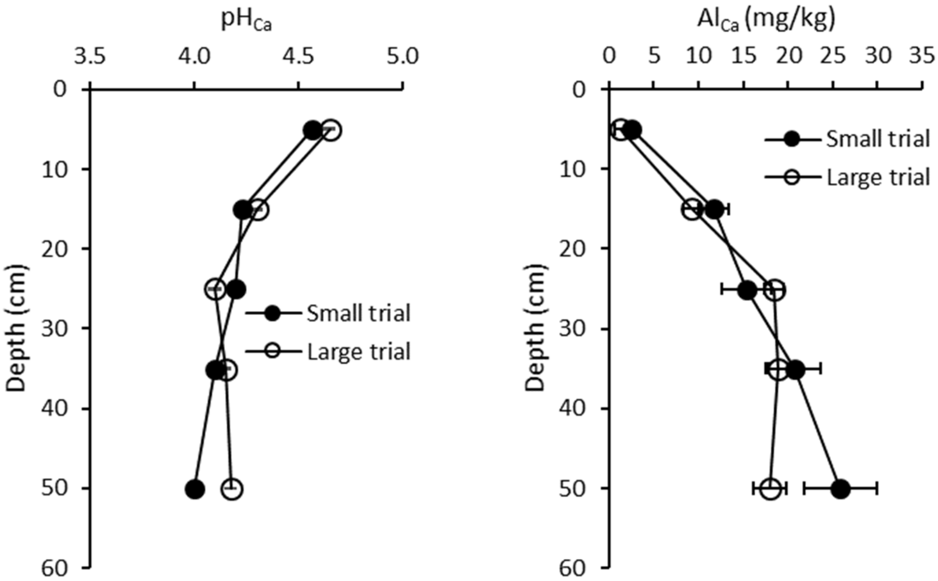


Figure 1: Initial soil pH and aluminium profiles of the two trial sites at Kalannie.

LOCATION

	Latitude (decimal degrees)	Longitude (decimal degrees)
Trial Site #1	-30.415561	117.292964
Nearest Town	Kalannie	
Trial Site #2	-30.403662	117.299069
Nearest Town	Kalannie	

Research	Benefiting GRDC Region (can select up to three regions)	Benefiting GRDC Agro-Ecological Zone (see link: http://www.grdc.com.au/About-Us/GRDC-Agroecological-Zones) for guidance about AE-Zone locations	
Experiment Title	Western RegionWestern RegionWestern Region Choose an item. Choose an item.	☐ Qld Central ☐ NSW NE/Qld SE ☐ NSW Vic Slopes ☐ Tas Grain ☐ SA Midnorth-Lower Yorke Eyre ☒ WA Northern ☒ WA Eastern ☒ WA Mallee	☐ NSW Central ☐ NSW NW/Qld SW ☐ Vic High Rainfall ☐ SA Vic Mallee ☐ SA Vic Bordertown-Wimmera ☒ WA Central ☒ WA Sandplain

RESULTS

On-site weather during 2017-2019

Crop establishment in 2017 was poor due dry conditions at the beginning of the season (around 15 plant/m^2). There was only 10 mm rain in May followed by 1.2 mm in June (Fig. 2a).

Season 2018 began with average rainfall but the rainfall in spring, especially September, was well below average (7 mm, Fig. 2a). The total rainfall for the shortened growing season (May-September) was 187 mm. There were only two days with negative air temperature and these were not low enough to cause crop damage.

Season 2019 had a perfect start with nearly 90 mm rainfall in June, but the crop growing months (July and August) had less than average rainfall and were followed by nil rain in September and October (Fig. 2a). This resulted in a growing season rainfall of 163 mm, almost 60% of which occurred in June. In 2019, there were no incidences of negative air temperature that could cause crop damage (Fig. 2b). The maximum air temperature during grain filling stage did not cause any heat stress.

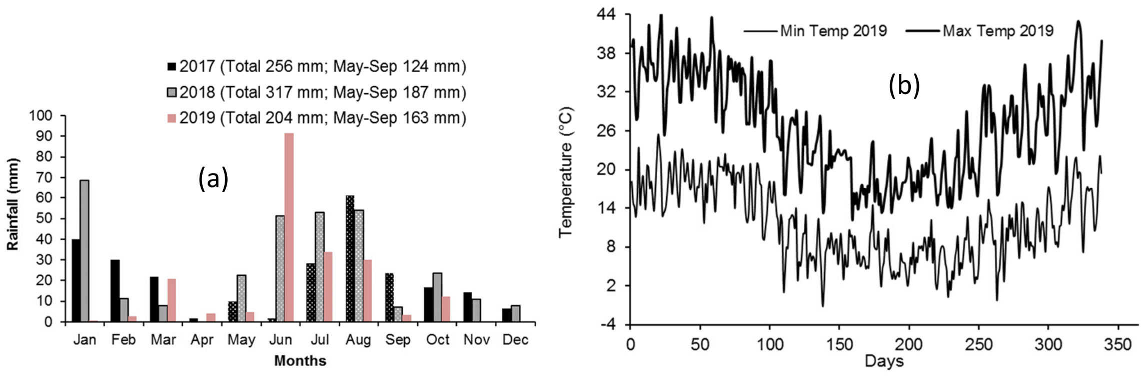


Figure 2: (a) Monthly total rainfall in 2017, 2018 and 2019 seasons, and (b) daily minimum and maximum temperatures at the trial site in 2019.

Grain yield in small plot trial

There were no significant interactions between tillage, lime rate and gypsum rate in any growing season (Table 3). The main effects of tillage and of gypsum rate were not significant in any season, but the main effect of lime rate was highly significant in all seasons ($P \leq 0.001$). When the effect of gypsum was re-analysed as 'without' or 'with' gypsum there was a significant effect of plus gypsum on grain yield (Table 3).

Overall there was a 13% increase in wheat grain yield from lime treated plots over the control (ripping only) in 2017 (Fig. 3a and 3b). Gypsum did not increase crop yield as much (average 5% increase in yield). In general, combined application of lime and gypsum increased yield more than either ameliorant alone. For example, application of 6 t/ha of lime with 3 t/ha of gypsum without incorporation produced 30% more grain (1.04 t/ha) than the control (0.79 t/ha). Whereas 6 t/ha lime alone increased yield to 0.99 t/ha and 3 t/ha gypsum increased yield to 0.85 t/ha.

Similarly to 2017, there was an average 12% increase in wheat grain yield from lime treated plots over the control (ripping only) in 2018 (Fig. 3c and 3d). Overall application of gypsum had an 11% yield benefit over the control. As with 2017, the combined application of lime and gypsum increased yield by more than the application of lime or gypsum individually. Incorporation of 6 t/ha lime plus 3 t/ha gypsum produced 23% more grain (2.05 t/ha) than the control (1.66 t/ha). Whereas 6 t/ha lime alone increased yield to 1.86 t/ha and 3 t/ha gypsum increased yield to 1.82 t/ha.

As for wheat in 2018, the yield of canola in 2019 was higher where lime and gypsum had been applied, either separately or in combination. There was an average 48% increase in canola grain yield from lime treated plots over the control (Fig. 3e). Overall application of gypsum had a 19% yield benefit over the control (Fig. 3f).

The treatment effects were not significant for plant emergence, NDVI readings, number of wheat heads per unit area, the size of the wheat heads in 2017 and 2018 season (data not presented).

Lime and gypsum treatments did not affect any grain quality parameters, i.e., protein content or canola oil content (data not presented).

Table 3: Summary of the ANOVA test for grain yield during 2017-2019

Year	Crop	Interactions	Incorporation	Lime rate	Gypsum rate	Gypsum (+/-)
2017	Wheat	NS	NS	***	NS	*
2018	Wheat	NS	NS	***	NS	*
2019	Canola	NS	NS	***	NS	***

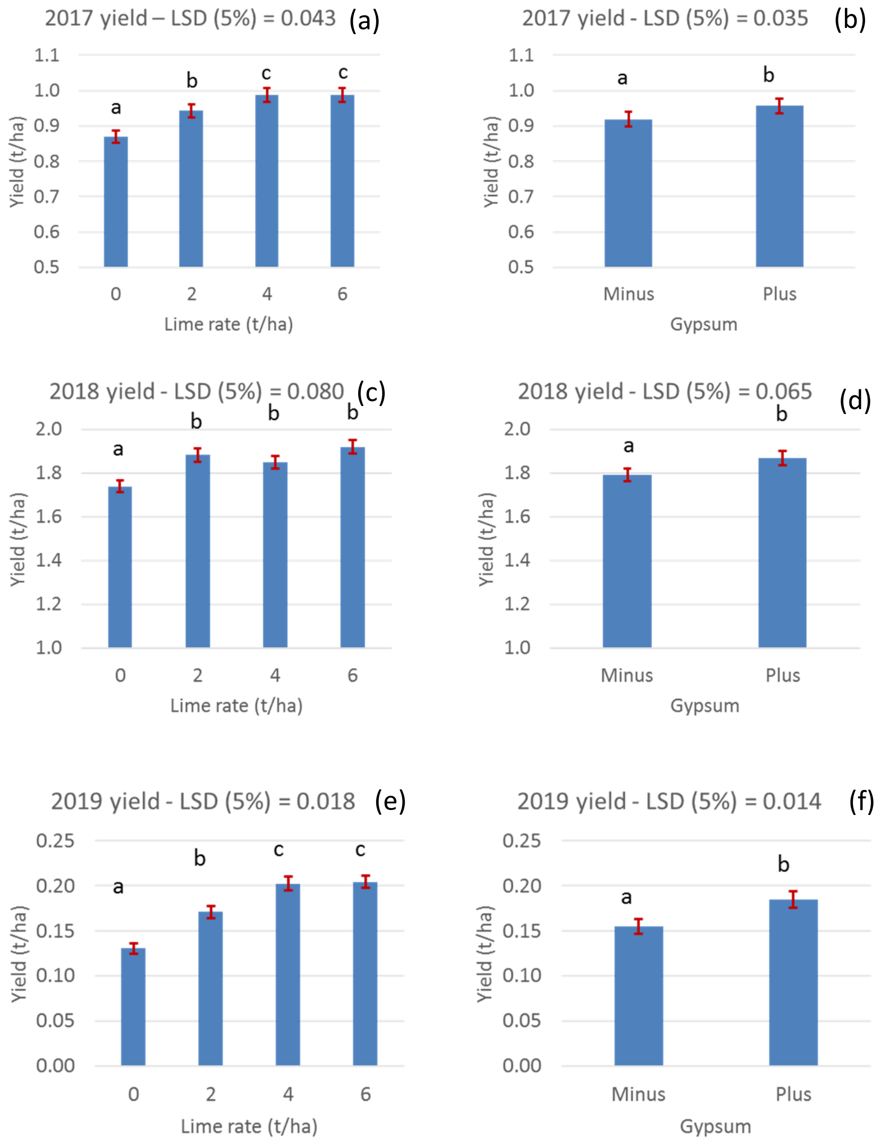


Figure 3: Grain yield from small scale trial at Kalannie, WA. Wheat crops were grown in 2017 (a and b) and 2018 (c and d), while canola was grown as a break crop in 2019 (e and f). Effects of lime rate on grain yield are presented in a, c and e while effects of gypsum are in b, d and f. Vertical error bars show the standard error of the mean grain yield. LSD(5%) is also presented on the respective figure.

Amelioration of acidity and Al toxicity

Surface soil (annual measurements)

A three-way interaction between tillage x lime rate x gypsum rate had significant effect on the surface soil (0-10 cm) pH, soils those were collected after first two cropping seasons. After third cropping season the significant interaction was found only between tillage and lime (Table 4). In these interactions of lime rates had positive influence on the surface soil pH, whereas both tillage (due to dilution of lime to the deeper depths and decrease soil pH) and gypsum rate (probably by quick release of Ca from gypsum that releases hydrogen ions in the solution and decreases soil pH) had negative influence on surface soil pH.

Table 4: Surface soil pH (0.01M $CaCl_2$) for each treatment. Twenty samples of soil were collected from each plot in March following each cropping season and bulked before chemical analysis. LSD (5%) 2018: 0.32 for plough x lime rate x gypsum rate; 2019: 0.31 for plough x lime rate x gypsum rate and 2020: 0.22 for plough x lime rate.

	Pre-seeding 2018				Pre-seeding 2019				Pre-seeding 2020			
	Gypsum rate (t/ha)				Gypsum rate (t/ha)				Gypsum rate (t/ha)			
Tillage and lime rate (t/ha)	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
No ploughing												
0	4.67	4.50	4.57	4.43	4.77	4.93	4.80	4.67	4.53	4.57	4.67	4.73
2	4.87	5.07	4.87	4.87	5.53	5.63	5.43	6.03	5.67	5.33	5.23	5.30
4	4.90	5.00	4.90	4.70	5.83	5.87	5.93	5.77	5.80	5.53	5.57	5.53
6	5.17	4.97	5.17	4.80	6.20	6.03	5.70	5.83	6.03	5.83	6.00	5.53
One-way plough												
0	4.60	4.50	4.57	4.40	4.70	4.63	4.70	4.60	4.67	4.53	4.77	4.53
2	4.83	4.50	4.83	4.60	5.10	4.93	5.00	4.97	4.83	5.03	4.80	4.93
4	5.00	5.00	4.57	4.67	5.40	5.20	5.07	4.97	5.33	5.23	4.77	4.93
6	4.67	5.10	4.87	5.00	5.07	5.27	5.33	5.27	5.30	5.40	4.87	5.37

A two-way interaction between tillage x gypsum rate had a significant effect on the surface soil S content and EC after the second cropping season, but the main effects of tillage and gypsum alone were significant in all seasons (Table 5 and 6). Tillage had a negative effect (due to dilution gypsum and sulphur of potash to the deeper depths) while gypsum had a positive effect on the surface soil S content and EC.

Table 5: Sulfur content (mg/kg) in 0–10 cm soil. Twenty samples were collected from each plot in March following each cropping season and bulked before chemical analysis. LSD (5%) 2018: 35.2 for plough and 49.8 for gypsum rate; 2019: 70.0 for plough x gypsum rate; 2020: 35.2 for plough, 65.0 for gypsum rate.

	Pre-seeding 2018				Pre-seeding 2019				Pre-seeding 2020			
	Gypsum rate (t/ha)				Gypsum rate (t/ha)				Gypsum rate (t/ha)			
Tillage treatments	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
No ploughing	22.5	166.3	220.2	280.5	14.9	113.9	193.5	381.6	22.3	97.2	189.7	257.5
One-way plough	22.8	90.7	118.8	163.1	20.2	70.3	113.6	100.7	25.3	93.0	139.7	140.9

Table 6: Soil EC (mS/cm) in 0–10 cm soil. Twenty samples were collected from each plot and bulked before chemical analysis. Soil samples were collected in March following each cropping season. 2018: LSD(5%) for plough = 0.03 and for gypsum rate = 0.04: LSD(5%) for plough x gypsum rate = 0.04; 2020: LSD(5%) for plough = 0.03, for gypsum rate = 0.04.

	Pre-seeding 2018				Pre-seeding 2019				Pre-seeding 2020			
	Gypsum rate (t/ha)				Gypsum rate (t/ha)				Gypsum rate (t/ha)			
Tillage treatments	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
No ploughing	0.17	0.28	0.31	0.35	0.09	0.18	0.26	0.36	0.11	0.18	0.25	0.29
One-way plough	0.13	0.20	0.20	0.28	0.09	0.14	0.18	0.17	0.11	0.16	0.20	0.20

Soil Profile analysis in 2018 (2 years after amelioration)

Soil profile samples were collected in July 2018 and the next round of sampling will occur in July/August 2020.

The interaction of lime rate and tillage as well as the individual effects of these two factors significantly increased soil pH in the top 20 cm (Fig. 4a and 4b). There was some negative effect of gypsum on soil solution pH (Fig. 5) but it was not significant.

Without incorporation, all lime treated plots had higher soil pH_{Ca} in 0-5 and 5-10 cm depths compared to the unlimed control plots. The minimum target for the top soil pH_{Ca} (>5.50) was achieved but only in 0-5 cm depth. No significant increase in soil pH was recorded in soil below 10 cm. On the other hand, with incorporation liming had significantly higher pH to the depth of cultivation (20 cm) compared to the untreated control. There was no significant effect of lime rates on pH in either of the tillage treatments.

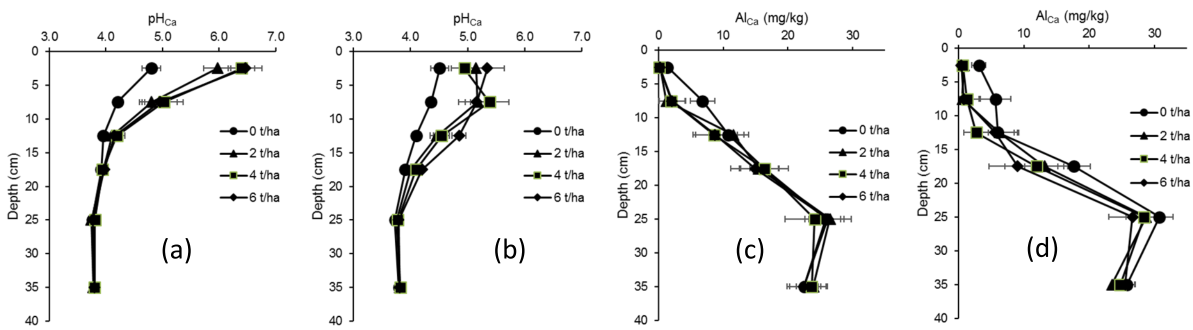


Figure 4: Changes in soil pH in 0.01M $CaCl_2$ (a and b) and $CaCl_2$ extractable total Al concentration (c and d) due to application of lime with incorporation (a and c) and without incorporation (b and d). Horizontal bars represent ± standard error of the mean pH and Al concentration.

The changes in soil pH were reflected in a significant effect of lime rate and tillage to decrease soil Al (Fig. 4d and 6a). Without incorporation, all lime rates decreased Al concentration but only in 0-10 cm depth (Fig. 4c and 6a). Whereas with incorporation lime decreased Al in 0-20 cm depth (Fig. 4d). Application of gypsum, especially when incorporated in the subsurface soil, significantly increased Al concentration in the soil solution (Fig. 6).

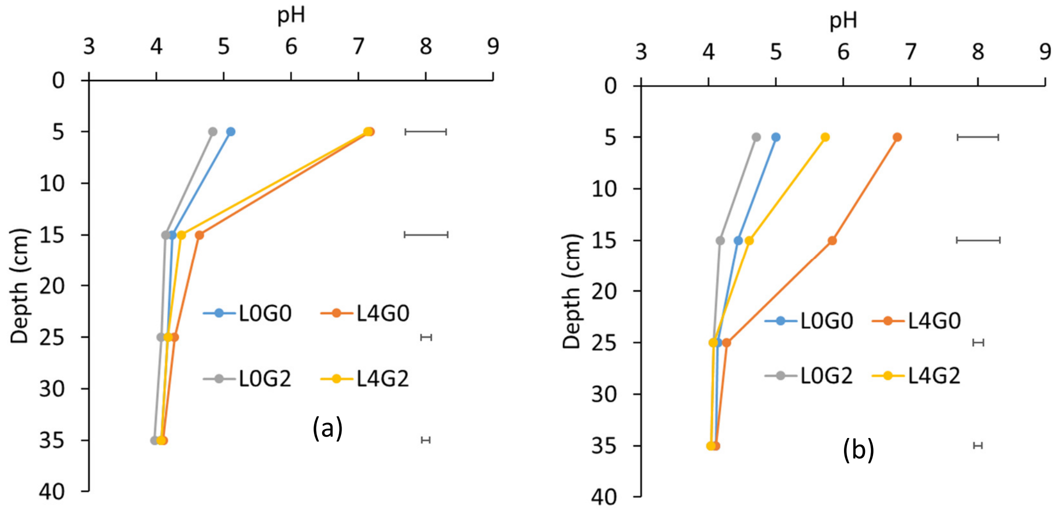
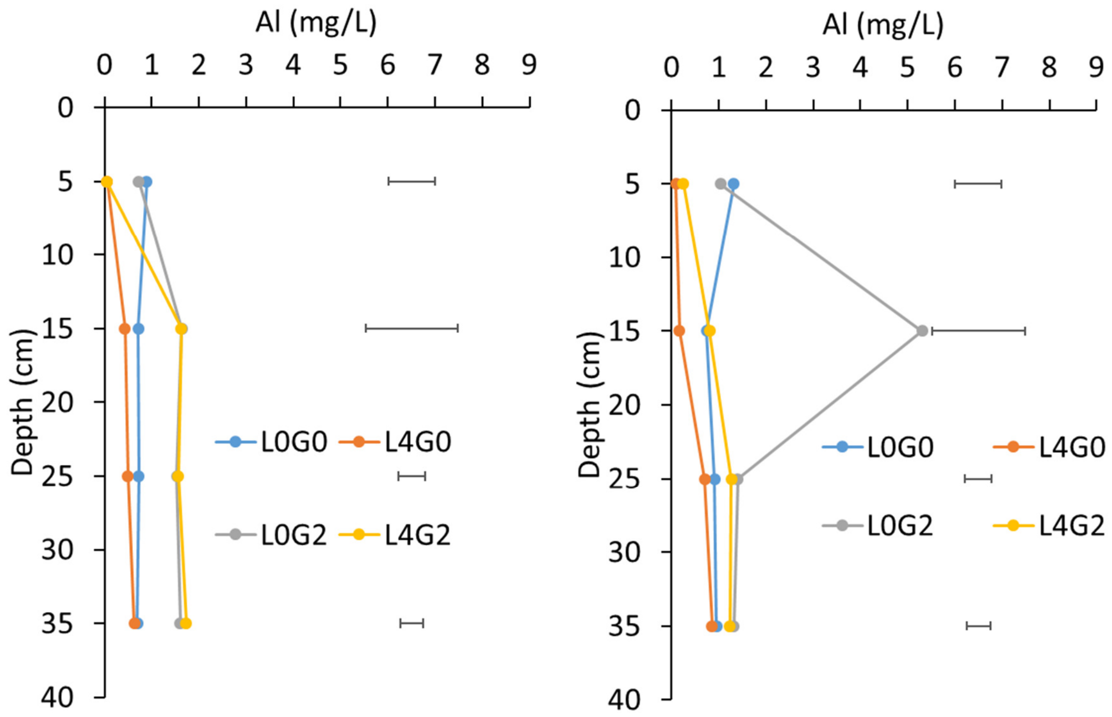


Figure 5: Soil solution pH measured by Chem Center of WA shows gypsum (with or without lime) can reduce soil solution pH, especially in the subsurface soil (L0G0 = control; L0G2 = 2 t/ha gypsum; L4G0 = 4 t/ha lime; L4G2 = 4 t/ha lime and 2 t/ha gypsum) under both (a) surface application and (b) incorporation. Horizontal error bars represent standard error of the mean pH.



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Gypsum application significantly increased soil EC (Table 7) throughout the profile (0-40 cm) and hence the ionic strength (I_s) of the soil (Table 8). In general, the I_s of gypsum treated soil was at least doubled compared to the control. The effect of lime rates on EC and I_s was inconsistent and not as great as gypsum. Tillage had no effect on either soil EC or I_s.

Table 7: Effect of lime and gypsum (with and without incorporation by one-way plough) on soil EC (µS/cm) measured in September 2018.

Lime (t/ha) →	0				2				4				6			
Gypsum (t/ha) →	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
Depth (cm) ↓	Without incorporation															
0-5	37	59	59	78	63	55	73	51	36	40	42	48	20	40	64	53
5-10	29	33	41	48	36	30	47	41	26	33	44	39	20	33	38	43
10-15	29	37	38	48	27	32	47	56	30	32	60	46	28	48	47	40
15-20	33	37	41	46	31	32	49	50	29	35	64	45	29	44	49	47
20-30	51	59	62	73	51	57	68	68	45	55	73	77	37	55	66	63
30-40	47	51	59	70	43	60	62	64	49	61	75	64	42	57	77	60
	With incorporation															
0-5	37	34	71	32	28	36	47	32	33	42	37	221	23	28	66	33
5-10	39	32	59	50	45	59	35	65	30	68	299	359	20	31	107	46
10-15	35	111	178	70	27	59	37	62	27	63	259	74	22	45	75	98
15-20	31	62	43	36	27	42	32	50	31	33	53	44	28	47	42	47
20-30	55	53	64	66	49	53	47	61	46	56	73	79	42	54	59	65
30-40	46	53	60	60	46	56	44	54	43	49	67	67	45	49	60	63

Table 8: Effect of lime and gypsum (with and without incorporation by one-way plough) on soil I_s (mM) measured in September 2018.

Lime (t/ha) →	0				2				4				6			
Gypsum (t/ha) →	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
Depth (cm) ↓	Without incorporation															
0-5	0.0015	0.0025	0.0024	0.0033	0.0026	0.0023	0.0031	0.0021	0.0014	0.0016	0.0017	0.0020	0.0007	0.0016	0.0027	0.0022
5-10	0.0011	0.0013	0.0017	0.0020	0.0014	0.0012	0.0019	0.0016	0.0010	0.0013	0.0018	0.0016	0.0007	0.0013	0.0015	0.0018
10-15	0.0011	0.0015	0.0015	0.0020	0.0010	0.0012	0.0019	0.0023	0.0012	0.0013	0.0025	0.0019	0.0011	0.0020	0.0019	0.0016
15-20	0.0013	0.0015	0.0017	0.0019	0.0012	0.0013	0.0020	0.0021	0.0011	0.0014	0.0027	0.0018	0.0011	0.0018	0.0020	0.0019
20-30	0.0021	0.0024	0.0026	0.0031	0.0021	0.0024	0.0029	0.0029	0.0018	0.0023	0.0031	0.0033	0.0015	0.0023	0.0028	0.0027
30-40	0.0019	0.0021	0.0025	0.0029	0.0017	0.0025	0.0026	0.0027	0.0020	0.0025	0.0032	0.0027	0.0017	0.0024	0.0032	0.0025
	With incorporation															
0-5	0.0015	0.0014	0.0030	0.0013	0.0011	0.0014	0.0019	0.0013	0.0013	0.0017	0.0015	0.0097	0.0009	0.0011	0.0028	0.0013
5-10	0.0016	0.0013	0.0024	0.0021	0.0018	0.0025	0.0014	0.0027	0.0012	0.0029	0.0132	0.0158	0.0007	0.0012	0.0046	0.0019
10-15	0.0014	0.0048	0.0078	0.0029	0.0010	0.0025	0.0015	0.0026	0.0010	0.0026	0.0114	0.0031	0.0008	0.0018	0.0032	0.0042
15-20	0.0012	0.0026	0.0017	0.0014	0.0010	0.0017	0.0013	0.0021	0.0012	0.0013	0.0022	0.0018	0.0011	0.0019	0.0017	0.0019
20-30	0.0023	0.0022	0.0027	0.0028	0.0020	0.0022	0.0019	0.0026	0.0019	0.0023	0.0031	0.0033	0.0017	0.0023	0.0025	0.0027
30-40	0.0019	0.0022	0.0025	0.0025	0.0019	0.0023	0.0018	0.0022	0.0017	0.0020	0.0028	0.0028	0.0018	0.0020	0.0025	0.0027

Nutrient concentration in wheat tissue

Tissue nutrient concentrations were measured only for wheat crop in 2018 season. The wheat crop in 2017 and the canola crop in 2019 had poor and non-uniform growth hence no tissue tests were conducted. We expect to analyse nutrient uptake by the barley crop in 2020.

The interaction of lime and gypsum application significantly increased total N concentration in wheat tissue at Z65 growth stage, but no such effect was noticed in P and K concentrations (data not presented). The concentrations of total N (data not presented), P (Fig. 5a) and K (data not presented) increased with lime alone. Liming also increased Ca (Fig. 5c) and Mg (data not presented) as indicated by higher concentration in wheat tissue collected from limed plots. The main effect of gypsum was not significant for N, P and K but, as expected, gypsum application significantly improved S and Ca concentration in wheat tissue (Fig. 5b and 5c). Tillage did not affect the concentration of macronutrients in plant tissue.

Gypsum application increased the concentration of B (data not presented), Mn (Fig. 5d) and Zn (data not presented) in wheat tissue collected at Z65 stage. In contrast, lime decreased the concentration of Mn (Fig. 5d) and Zn in wheat tissue (data not presented). Neither lime nor gypsum application affected the concentration of Cu, Mo and Fe (data not presented). None of the treatments decreased nutrient level below critical levels.

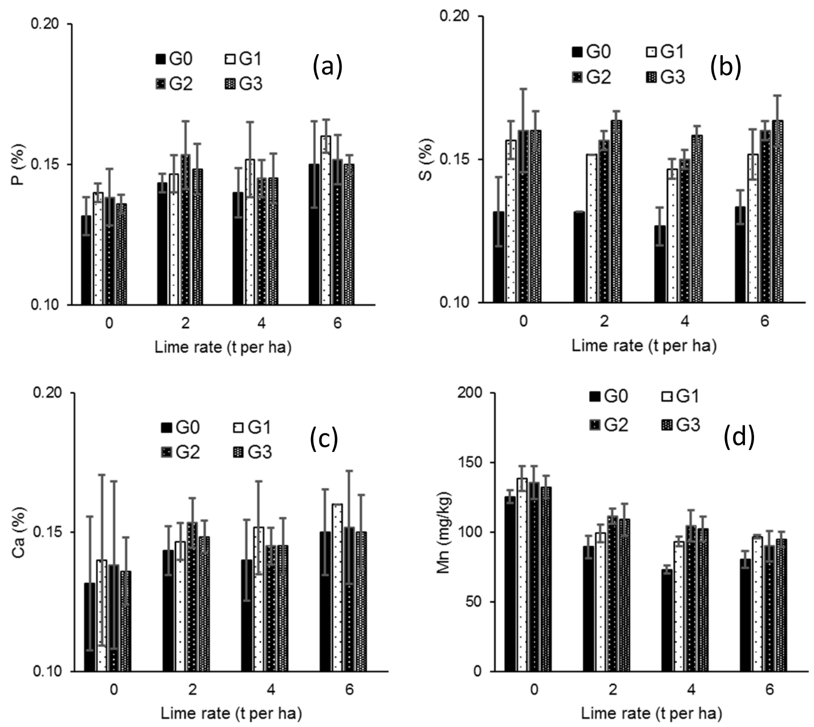

Figure 5: Concentration of (a) P, (b) S, (c) Ca and (d) Mn in wheat tissue at Z65 growth stage in 2018 growing season due interactive application of lime and gypsum. It should be noted that measurements on some of the nutrients are not presented here. Vertical bars represent ± standard error of the mean nutrient concentration.

Nutrient concentration in wheat tissue

Tissue nutrient concentrations were measured only for wheat crop in 2018 season. The wheat crop in 2017 and the canola crop in 2019 had poor and non-uniform growth hence no tissue tests were conducted. We expect to analyse nutrient uptake by the barley crop in 2020.

The interaction of lime and gypsum application significantly increased total N concentration in wheat tissue at Z65 growth stage, but no such effect was noticed in P and K concentrations (data not presented). The concentrations of total N (data not presented), P (Fig. 5a) and K (data not presented) increased with lime alone. Liming also increased Ca (Fig. 5c) and Mg (data not presented) as indicated by higher concentration in wheat tissue collected from limed plots. The main effect of gypsum was not significant for N, P and K but, as expected, gypsum application significantly improved S and Ca concentration in wheat tissue (Fig. 5b and 5c). Tillage did not affect the concentration of macronutrients in plant tissue.

Gypsum application increased the concentration of B (data not presented), Mn (Fig. 5d) and Zn (data not presented) in wheat tissue collected at Z65 stage. In contrast, lime decreased the concentration of Mn (Fig. 5d) and Zn in wheat tissue (data not presented). Neither lime nor gypsum application affected the concentration of Cu, Mo and Fe (data not presented). None of the treatments decreased nutrient level below critical levels.

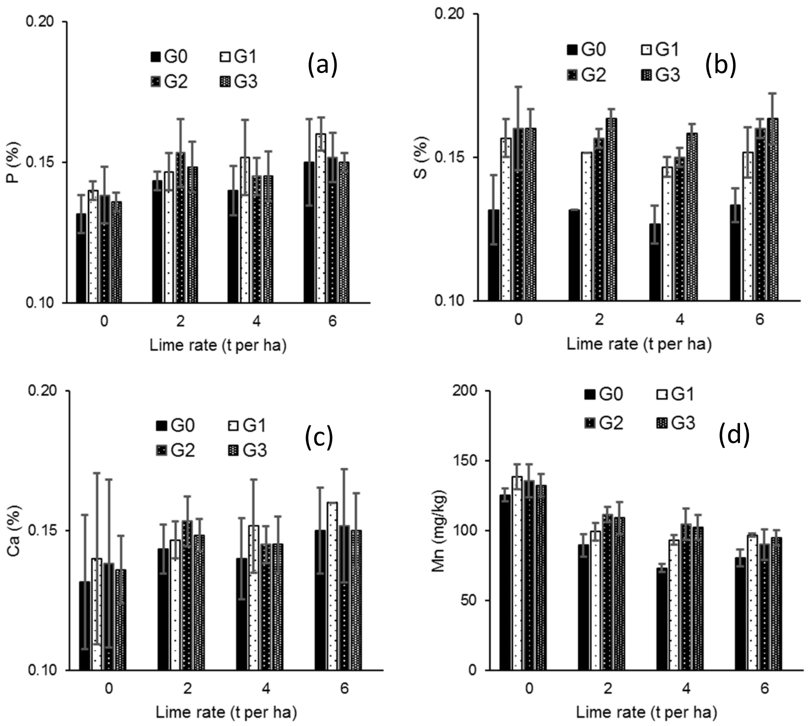

Figure 5: Concentration of (a) P, (b) S, (c) Ca and (d) Mn in wheat tissue at Z65 growth stage in 2018 growing season due interactive application of lime and gypsum. It should be noted that measurements on some of the nutrients are not presented here. Vertical bars represent ± standard error of the mean nutrient concentration.

Grain yield in large plot trial

In the large plot trial, there were no significant differences in yield with any treatment combinations in any of the three growing seasons, despite numerical increases (Table 9).

In 2017, surface application of 4 t/ha lime increased grain yield by only 5% compared to the control (Table 9). Surface application of gypsum increased grain yield by 26% compared to the control but this too was not significant. The combined application of lime and gypsum had no added benefit over the application of a single ameliorant.

In 2018, there was a non-significant trend to increased grain yield with lime and gypsum, especially with surface application of these ameliorants (Table 9). Surface application of 4 t/ha lime increased grain yield by 25% from the control. Surface application of gypsum increased grain yield by 34% compared to the control. The combined application of lime and gypsum without incorporation increased yield by more than the application of lime or gypsum individually where application of 4 t/ha lime plus 2 t/ha gypsum produced 38% more grain (3.33 t/ha) than the control (2.41 t/ha). Whereas 4 t/ha lime alone increased yield to 3.01 t/ha and 2 t/ha gypsum increased yield to 3.24 t/ha. There was no yield response to the incorporation treatment alone.

In 2019, surface application of 4 t/ha lime increased canola grain yield by 42% from the control (Table 9). Surface application of gypsum also increased grain yield by 19% compared to the control. The combined application of lime and gypsum without incorporation increased yield by more than the application of lime or gypsum individually. Application of 4 t/ha lime plus 2 t/ha gypsum produced 45% more grain (0.61 t/ha) than the control (0.42 t/ha). Whereas 4 t/ha lime alone increased yield to 0.60 t/ha and 2 t/ha gypsum increased yield to 0.50 t/ha. Again there was no yield response to the incorporation treatment alone.

Table 9: Grain yield in a farmer scale trail at Kalannie, WA during 2017-2020.

Treatments	2017 (wheat)	2018 (wheat)	2019 (canola)
Surface 0L + 0G	0.80	2.41	0.42
Surface 4L + 0G	0.84	3.01	0.60
Surface 0L + 2G	1.01	3.24	0.50
Surface 4L + 2G	0.95	3.33	0.61
Incorporated 0L + 0G	1.03	3.00	0.49
Incorporated 4L + 0G	0.94	2.79	0.60
Incorporated 0L + 2G	1.19	3.22	0.48
Incorporated 4L + 2G	0.94	2.54	0.51
Stat			
Tillage	NS	NS	NS
Lime	NS	NS	NS
Gypsum	NS	NS	NS

CONCLUSIONS

In the small plot trial, liming, with or without incorporation, significantly increased soil pH and hence decreased aluminium (Al) toxicity, resulting in increased wheat and canola grain yield in three growing seasons. Higher soil pH, due to liming, improved uptake of major macronutrients but decreased Zn and Mn.

Gypsum also improved grain yield; but not by improving soil pH nor reducing total Al concentration. Gypsum rather decrease soil solution pH and increased Al concentration, however, such increase in Al might represent non-toxic forms of AL and hence did not have any negative effect on plant growth and grain yield. Gypsum also greatly increased the ionic strength of soil throughout the profile which might have reduced the relative activity of Al. Gypsum provided an extra amount of S and Ca as well as improved uptake of B, Mn, and Zn by crop plants.

The application of lime and gypsum together had a greater additive effect to improve grain yield than the application of either individually, especially with the surface application of these ameliorants. This can be explained because lime increased soil pH and hence decreased total amount of Al in soil solution. Gypsum likely altered toxic Al into non-toxic forms and leached deeper in the soil. Combined application of lime and gypsum also had an additive effect, improving the uptake of most macronutrients.

In any season, cultivation did not increase wheat or canola grain yield in either of the trials in Kalannie. Although the one-way plough was thought to incorporate lime to 30 cm depth, the effective working depth was around 20 cm. Overall, soil pH was higher in the 0-20 cm soil depths due to incorporation, but surface soil pH was lower in the one-way ploughed plots compared to unploughed plots. Also, ploughing increased the rate of soil water loss through evaporation and diluted soil organic carbon and other nutrients from the top soil affecting the quality of seedbed. Hence, this shallow incorporation of lime had net zero influence on the improvement of grain yield.

Although we saw the benefits of lime and gypsum application in the paddock scale trial, especially under without tillage, the effect was not significant which could be due to large variation in at a paddock scale. In this case an economic analysis will reveal whether these amelioration option are economically viable.

The benefits of higher lime rates were not translated into yield advantage. It will be interesting whether higher rates more suitable for longer term and provide future yield advantage without requiring re-application of lime. It will also be interesting how long the benefits of gypsum last, especially under low rainfall condition in Kalannie.

Acknowledgements

This work was funded by the GRDC under the 'Soil Constraints West' group of projects (Project Code DAW00252). Thanks to Dr James Fisher for reviewing the report. We also thank DPIRD technical staffs from Northam and Wongan Hills in managing the trials.

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