Shifting investment from nutrients to lime and cultivation on acid soils: is an immediate payback possible?

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Key messages

- One way ploughing changed soil pH_{Ca} in the 0-20 cm soil zone, while rotary spading changed soil pH in the 0-30 cm soil zone.
- An immediate payback from lime incorporation is possible though profit is driven by the cultivation effect on nutrient availability.

Aims

- Determine whether cultivation and lime incorporation cause an immediate change in grain yield response to fertiliser.
- Assess the short term profitability of cultivation, lime incorporation and reducing fertiliser rates.

Method

Field trials

Two field trials were conducted in 2013 to quantify the effect of cultivation and incorporating lime with cultivation on soil nutrient availability. The trials were located at Dalwallinu and Dandaragan and had the same trial design, although different randomisations. A strip-plot design was used and the main treatments were: 1. Control (no deep cultivation or lime); 2. Deep Cultivation, and 3. Lime + Deep Cultivation. The method used for cultivation differed between the two sites. A deep ripper followed by a one-way plough fitted with 65 cm diameter discs that achieved cultivation depths of 30 cm and 20 cm respectively were used at Dalwallinu. An Imants 37SX rotary spader was used at Dandaragan, which achieved a cultivation depth of 35 cm. At both sites, 3 t/ha of lime sand (94% neutralising value) was applied to the lime + cultivation treatments prior to cultivation. The sub treatments were applied as nutrient omission treatments and were; All, All-K, All-N, All-P, All-S, Nil. See Table 1 for details of nutrient omission treatments.

Table 1 Nutrients applied in the nutrient omission treatments. All nitrogen (N) treatments were applied as urea (46% N), all phosphorus treatments were applied as double superphosphate (18% P), all potassium (K) treatments applied as muriate of potash (50% K) and all sulphur treatments applied as gypsum (17% S). Bracket show where different rates were applied at Dandaragan.

	Drilled at sowing		Topdressed at sowing			Topdressed 4 WAS
Sub-treatment	N (kg/ha)	P (kg/ha)	N (kg/ha[1])	K (kg/ha)	S (kg/ha)	N (kg/ha)
All	10	20	10 [20]	100	20	20
All-K	10	20	10 [20]		20	20
All-N		20		100	20	
All-P	10		10 [20]	100	20	20
All-S	10	20	10 [20]	100		20
Nil						

* WAS = weeks after sowing.

Soil description

The soil type at both sites was deep yellow sand (Orthic-Tenosol, Australian Soil Classification) with moderate soil fertility (Table 2). Soil pH_{Ca} at Dalwallinu was slightly below the recommended levels of 5.5 and 4.8 (Gazey and Davies 2009) for the 0 to 10 and 10 to 20 cm soil layers respectively, while soil pH at Dandaragan was slightly above recommended levels. At Dalwallinu, Colwell phosphorus was adequate for approximately 80 to 90% of maximum production while it is above the level required for 95% of maximum production at Dandaragan (Bell *et al.* 2013). Colwell potassium is slightly below the level required for 90% of maximum production at 2 to 3 t/ha grain yield (42 mg/kg) at Dalwallinu while it is at the level required for 90% of maximum production for > 3 t/ha (54 mg/kg) at Dandaragan (Brennan and Bell 2013). Sulphur in the 0 to 30 cm soil depth was 4.1 mg/kg at Dalwallinu and 4.3 mg/kg at Dandaragan, and exceeded the level required for 90% of maximum production on these soils (2.5 to 3.1 mg/kg) (Anderson *et al.* 2013).

Table 2 Soil chemical profiles measured May 2013. Analysis was completed by CSBP Plant and Soil laboratories using standard methods.

	Organic Carbon (%)	Ammonium Nitrogen (mg/kg)	Nitrate Nitrogen (mg/kg)	Colwell Phosphorus (mg/kg)	PBI	Colwell Potassium (mg/kg)	Sulphur (mg/kg)	pH ($CaCl_2$)	Extractable Aluminium ($CaCl_2$)
	Dalwallinu								
0-10	0.6	3.7	17	18	8.7	37	5.3	5.2	0.5
10-20	0.2	3.0	5.3	19	9.5	30	3.3	4.4	4.2
20-30	0.1	2.0	2.7	20	12	29	3.7	4.3	6.4
30-40	0.1	2.0	2.3	9.7	11	31	4.8	4.5	4.2
40-60	0.1	1.0	1.7	<2	11	40	6.2	4.8	0.6
60-80	0.1	1.3	1.0	<2	12	42	6.4	5.5	<0.2
80-100	0.2	1.3	1.0	7.0	12	39	6.6	5.7	<0.2
	Dandaragan								
0-10	1.5	4.7	18	28	17	56	6.0	6.1	0.4
10-20	0.4	2.7	6.3	18	14	40	3.8	4.9	1.6
20-30	0.2	1.7	3.0	10	13	41	3.2	4.7	2.3
30-40	0.2	2.0	3.0	4.7	17	52	3.9	4.9	1.2
40-60	0.1	2.0	2.7	2.0	23	60	4.4	5.4	-
60-80	0.1	1.7	1.7	2.0	26	50	5.9	5.9	-
80-100	0.1	2.0	1.0	<2	32	53	6.7	6.0	-

Agronomic management

The field trials were managed following district practice. At Dalwallinu, wheat *cv.* Mace was sown at 80 kg/ha at 3 cm depth on 22nd May and was harvested 19th November. At Dandaragan, wheat *cv.* Magenta was sown 28th May. Following extensive damage to the cultivation treatments by birds the trial was re-sown with wheat *cv*. Mace at 80 kg/ha on 13th June. The trial at Dandaragan was harvested 13th November.

Results

Soil pH at tillering

Cultivation with or without lime led to significant changes in soil pH in the surface 20 cm at Dalwallinu and the surface 30 cm at Dandaragan (Table 3). Cultivation at Dalwallinu caused a significant reduction in soil pH 0-10 cm due to acidic subsoil being bought to the surface by the one-way plough. The lime + cultivation treatment at Dalwallinu also led to a significant decrease in soil pH 0-10 cm, although at the same time a significant increase in soil pH 10-20 cm occurred. A similar trend occurred at Dandaragan where the cultivation treatment led to a significant decrease in soil pH 0-10 cm and a significant increase in soil pH 10-20 cm. In the lime + cultivation treatment, no statistically-significant change in soil pH 0-10 cm was observed though a significant increase was observed in soil pH 10-20 cm and 20-30 cm. The mixing depth and efficiency of the implements used at these sites explains the observed changes in soil pH. Staining of pit-faces at both sites using universal pH indicator (not shown here) revealed that the spader used at Dandaragan caused a patchy mixing of lime to approximately 30 cm, while the one way plough used at Dalwallinu tended to invert the 0-20 cm layer, leaving most of the lime in concentrated layers.

Soil nitrate increased at the Dandaragan trial site depending upon the cultivation treatment, and the increase was significant in respect to total N supply. The total soil nitrate in 0-40 cm was 48, 53 and 80 kg ha^{-1} for the control, cultivation and lime + cultivation treatments respectively. The difference in total soil nitrate between the control and lime + cultivation treatments was 32 kg/ha which is enough soil nitrogen for approximately 0.7 /ha wheat grain. No statistically significant increases in soil nitrate were observed at Dalwallinu, which is most likely due to the small organic pool of nitrogen available for mineralisation and nitrification at this site.

Table 3 Soil pH_{Ca} profiles measured 8th August (17 weeks after lime application and cultivation). Data shown are for Nil sub-treatment only and are the mean of 30 samples (10 profiles per plot, 3 replicates).

	Dalwallinu			Dandaragan		
Soil depth (cm)	Control	Cultivation	Lime + cultivation	Control	Cultivation	Lime + cultivation
0-10	5.8	4.9	5.4	6.4	5.8	6.2
10-20	4.8	5.0	5.1	5.3	5.7	6.2
20-30	4.6	4.6	4.6	4.9	5.0	5.7
30-40	4.4	4.5	4.4	4.7	4.7	4.9
LSD (5%)		0.3			0.3	

Soil strength

Cone penetrometer measurements showed that deep ripping reduced soil strength at Dalwallinu (not shown here). The control treatment exceeded 3 MPa between 20 and 50 cm while soil strength in the cultivation treatment was always below 3 MPa. At the Dandaragan, the rotary spader did not change soil strength.

Grain yield

There was a yield response to cultivation at both sites, though the addition of lime did not result in additional grain yield. At Dalwallinu, the mean yield for main treatments (average of all 6 nutrients treatments including Nil; Table 4) for the cultivation and lime + cultivation treatments were 2168 and 2101 kg/ha respectively, significantly higher than the control 1759 kg/ha [LSD (5%) = 169 kg/ha]. Similarly, at Dandaragan the mean yield for the cultivation and lime + cultivation treatments were 3142 and 3169 kg/ha respectively, significantly higher than control at 2543 kg/ha.

Cultivation had an effect on the yield lost by omitting P fertilizer at Dalwallinu. The yield loss of 619 kg/ha from omitting P fertilizer (All compared to All-P) in the control was significantly different (LSD = 386 kg/ha), while the yield losses due to omitting P fertilizer of 355 kg/ha in the cultivation and 132 kg/ha in the lime + cultivation were not significantly different. The yield losses from omitting N fertilizer were not statistically significant; 258 kg/ha in the control, 372 kg/ha in the cultivation and 342 kg/ha in the lime +cultivation.

The yield for the Nil nutrient treatments were significantly lower than the All treatments for all main treatments at Dalwallinu and in the control main treatment at Dandaragan (Table 4). For each main treatment at both sites, the Nil treatment was always the lowest yield though not significantly lower than an omission treatment within the same main treatment (e.g. All-P). This suggests that an interaction between availability of N, P, K and S has occurred though the effect is subtle.

Economic analysis

The net margin for the nil nutrient treatments at these two sites show that a positive net margin was achieved when shifting investment from fertilisers to cultivation with or without lime (Table 5).The net margin for lime + cultivation with nil nutrients applied was 203 and 400 $/ha at Dalwallinu and Dandaragan respectively. The All-K treatments were always higher than the All treatments because there were small, if any yield deficits from omitting K fertiliser and the cost of K was significant ($139/ha).

Table 4 Mean grain yields for the two trial sites. Data are the mean of three replicates.

Main treatment	Nutrient treatment					
	All	All-K	All-N	All-P	All-S	Nil
Dalwallinu						
1. Control	2050	1942	1792	1431	2243	1094
2. Cultivation	2417	2201	2044	2062	2495	1786
3. Lime + cultivation	2243	2249	1900	2110	2435	1671
LSD (5%)	386					
Dandaragan						
1. Control	2886	2772	2285	2585	2796	1936
2. Cultivation	3289	3373	2688	3236	3662	2603
3.Lime + cultivation	3301	3127	2964	3493	3217	2910
LSD (5%)	862					

It should be noted that the economic analysis may not be realistic because fertiliser rates were higher than used in practice. The fertiliser rates used in this trial were designed to examine the effect of the main treatments on soil nutrient supply, and consequently high fertiliser rates were required to meet the trial aims.

Table 5 Mean net margin for all treatments. Net margin is grain income minus cultivation, lime and fertiliser costs.

	All	All-K	All-N	All-P	All-S	Nil
Dalwallinu						
Control	209	324	178	148	254	241
Cultivation	230	321	174	227	250	333
Lime + cultivation	86	227	37	132	132	203
Dandaragan						
Control	355	469	287	364	339	426
Cultivation	279	436	210	299	365	408
Lime + cultivation	206	307	196	324	192	400

Discussion and conclusion

Our results suggest shifting investment from nutrients to lime and cultivation to maintain profit in the first year for our 2 sites is a feasible proposition. However, this is dependent on the soil constraints and existing soil fertility. In the work described here, it appears that the cultivation response at Dalwallinu was driven by a removal of a soil physical constraint, while at Dandaragan it was driven by an increase in the mineralisation rate of organic matter. The incorporation of lime did not provide any yield benefit; at Dalwallinu this is most likely because only a small proportion of soil was ameliorated by the one-way plough, while at Dandaragan the rotary spader achieved much better mixing of the lime though this had no impact on growth because soil pH was already above target levels. At both sites, the yield benefit from cultivation was enough to offset the cost of the cultivation and some of the lime application, and the net margin in the year of application could be improved by reducing fertiliser rates. There is likely to be a future benefit from the lime incorporation at Dalwallinu because extractable aluminium is near toxic levels at 20-40 cm soil depth and the lime has been placed at about 10 to 20 cm depth by the one-way plough. While there was no economic gain from the lime this year, with time the acidic subsoil will be ameliorated 2 to 3 years faster than if the lime was top dressed and not cultivated.

Our results from the Dalwallinu site contrasts with our previous work at Darkan, and despite using a similar plough design at both trial sites. At Darkan incorporating 3 t/ha lime sand increased soil pH_{Ca} 0-10 cm from 4.4 to 5.2 and soil pH_{ca} 10-20 cm from 4.6 to 5.1. At Darkan, soil pH_{Ca} in both the 0-10 and 10-20 cm would have been constraining growth, especially for barley that was grown at this site.

Based upon work to date, we propose the following checklist to assess whether cultivating to incorporate lime will bring significant economic benefit over topdressing lime only. Firstly, soil pH_{Ca} in the 0-10 and 10-20 cm soil layer needs to be well below the recommended levels of 5.5 and 4.8 respectively. While we don’t have sufficient data to provide an estimate of yield response from lime application as a function of soil pH_{Ca}, our knowledge of the relationship between exchangeable Al and soil pH for WA soils suggests an immediate response to lime incorporation is almost certain where soil pH_{Ca} falls below 4.5. Secondly, soil fertility needs to be adequate. For example, a boost in mineralisation rate did not occur at Dalwallinu where organic carbon 0-10 cm was 0.6% but it did occur at Dandaragan where organic carbon was 1.5%. Colwell P levels need to be at sufficient levels were expenditure on P fertiliser is being reduced. Finally, the implement used to achieve the incorporation is an important factor. If the implement can mix to the depth where the soil pH constraint occurs then an immediate payback on lime and cultivation is possible. If the implement cannot mix to the depth where the soil constraint occurs the benefits from incorporating lime need to be balanced against the cost of the cultivation and the risks to crop emergence and soil erosion posed by cultivation.

Key words

Soil pH, acidity, liming, cultivation, phosphorus, nitrogen, potassium, sulphur

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