Understanding the effects of spading uniformity and lime application to manage subsoil acidity

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Key findings

- In the fourth trial season lentil grain yield benefits were observed from spading and lime treatments. Addition of lime (2200 kg/ha or 6600 kg/ha) and mixing with low, medium or high uniformity were the highest yielding treatments ranging from 3.36 to 3.69 t/ha.
- Lime rate and spading have had variable response on NDVI across four years.
- In the first three years of the trial plant establishment has generally not been affected by lime rate, spading uniformity or deep ripping.
- Lentil tissue tests in year four revealed increased Mo levels (>0.3 mg/kg) in treatments where lime was applied.
- Soil samples taken in 2022 showed both the high and low uniformity treatments plus lime have increased soil pH compared to the control. The high uniformity has had the greatest impact on soil pH across the 5 to 30 cm sampling depths.

Why do the trial?

Acidic layers of soil are increasingly being identified in the subsurface (5-10 cm) and subsoil (>10 cm) of no-till farming systems. Stratified low pH soil layers need appropriate lime treatment to maintain and prevent the decline of soil pH further. Surface application of lime alone is unlikely to raise the pH in subsurface layers quickly. Recent work has reported lime movement as little as 1 cm – 2.5 cm per year (Fleming et al. 2020, Burns et al 2017). For example, if the acidic soil band extends to a depth of 25 cm, the time for surface applied lime to become effective at this depth could be between 10 and 25 years. Given the slow movement of lime, incorporation and mixing of surface applied lime to depth is expected to accelerate the movement of lime.

There are a range of machinery options that can provide different levels of lime incorporation such as spading. However, research to date on rotary spaders has shown soil/amendment mixing is not uniform due to the cyclical process, and the mixing quality reduces significantly at faster speed (Ucgul et al. 2019). This trial aimed to understand how the uniformity of soil-lime mixing by spading affected crop response and soil pH.

How was it done?

Site selection and soil properties

A long-term spading uniformity trial was established at Bute, SA (-33.78001, 138.08717) in 2019. The site was selected based on historical crop performance and soil test results (Table 1). The wheat stubble load was estimated at 4 t/ha going into the 2019 season.

Soil cores were sampled on 21st May 2019 after the trial was sown in buffer areas. Four deep soil cores were taken, bulked and segmented into 10-30 cm, 30-100 cm. The 0-10 cm depth was sampled using a foot probe. The Bute soil is a red sand over red sandy clay, transitioning at a depth of around 30 cm. In general soil nitrogen, phosphorus, potassium and sulphur were present in adequate to high levels (Table 1). The site had moderate levels of organic carbon (0.5%), low cation exchange capacity and low salinity.

Table 1. Starting soil chemical properties in the spading uniformity trial Bute, SA 2019.

Depth	**cm**	**0-10**	**10-30**	**30-100**
Ammonium Nitrogen	**mg/kg**	4	1	1
Nitrate Nitrogen	**mg/kg**	15	6	2
Available Nitrogen	**kg/ha**	25	18	27
Phosphorus Colwell	**mg/kg**	33	27	
PBI		21	22	
DGTP	**ug/L**	89	85	
Potassium Colwell	**mg/kg**	147	190	
Sulfur	**mg/kg**	26	13	5
Available Sulfur	**kg/ha**	34	34	43
Organic Carbon	**%**	0.48	0.27	
Conductivity	**dS/m**	0.09	0.06	0.09
	ECe	1.2 (Low)	0.8 (Low)	0.9 (Low)
CEC		3.1 (Low)	4.1 (Low)	
ESP		2.0 (Low sodicity)	1.0 (Low sodicity)	

Soil pH was analysed in 5 cm depth increments from 0- 30 cm (Figure 1). Soil pH in the top 0 -5 cm was 5.60 (Figure 1) and just outside the 6- 8.5 pH range preferred for crop production (Hughes 2020). The pH in the 5 – 25 cm depths were moderately high to strongly acidic ranging from 4.38 to 5.35. In the 25-30 cm depth pH increased to 5.89.

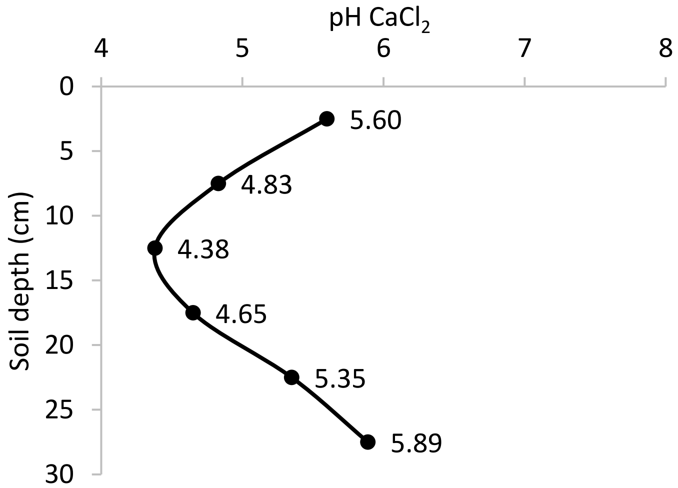

Figure 1. Starting soil pH ($CaCl_2$) measured in 5 cm increments down to 30 cm in spading uniformity trial Bute, SA.

Soil compaction was measured using a handheld penetrometer on the 23rd July 2021. The penetrometer was inserted into the soil and the force required to penetrate the soil at a given depth was reported on a gauge in kilopascals (KPa). Soil compaction was present at this site, with the untreated control exceeding 2500 kPa (root growth is impeded above this value) around 15 cm and returning under this level around 40 cm (Figure 2). This is generally characterised as a "hard pan" on a sandhill.

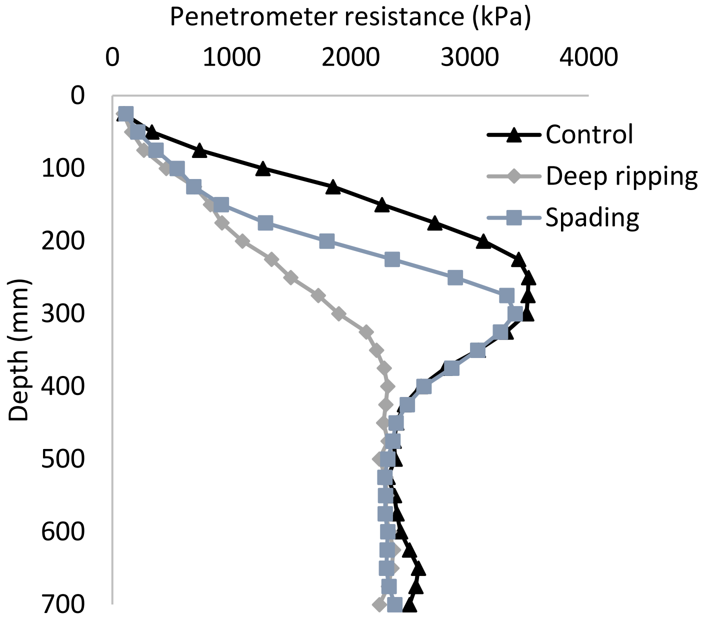

Figure 2. Penetrometer soil resistance measurements for the untreated control, deep ripping and medium uniformity spading treatments in the spading uniformity trial Bute, SA 2019.

Trial design and treatments

Lime rates were calculated using the Lime Cheque calculator based on a sandy soil, low org C% and raising the soil pH to 6.0 (Table 2). Two lime rates were used, 2200 kg/ha (farmer practice enough lime to treat 0-10 cm) and 6600 kg/ha (enough lime to treat 0-30 cm). The product used in this trial was Angaston PenLime Plus with an effective neutralising value (ENV) of 93%.

Mechanical incorporation methods (Table 2) were chosen based on their ability to distribute lime throughout the acidic subsoil layers. Three levels of spading uniformity were included; high mixing uniformity (dual-pass, same direction and low speed, 2.4 km/h), medium mixing uniformity (one pass, at a 5 km/h speed commonly used by farmers) and low mixing uniformity (one pass, at a high speed of 9 km/h). A deep ripping (Williamson ripper equipped with curved 'Michel' shanks) treatment was included and provided a non-compacted benchmark.

Table 2. Incorporation, lime rate and spading speed treatment list for the spading uniformity trial Bute, SA.

Treatment	Incorporation	Lime rate (kg/ha)	Spading speed
1	Control	0	No spading
2	Control	2200	No spading
3	Control	6600	No spading
4	High uniformity	0	2 km/h (multipass)
5	Medium uniformity	0	5 km/h
6	Low uniformity	0	9 km/h
7	High uniformity	6600	2 km/h (multipass)
8	Medium uniformity	2200	5 km/h
9	Medium uniformity	6600	5 km/h
10	Low uniformity	6600	9 km/h
11	Ripping	0	No spading

Lime treatments and incorporation were implemented on 11th May 2019 in a randomised complete block design with four replicates. Lime treatments were applied to the soil surface and then followed by either no incorporation or incorporation by spading. The spading depth was targeted at 300 mm whilst the deep ripping was targeted at 500 mm. The high-rate of lime was evaluated at all three spading uniformities, while the farmer practice rate was only evaluated at medium spading uniformity (which is the recommended spading speed). Soil pit profiles showing the difference in mixing for the low and high uniformity treatments can be seen in Figure 3.

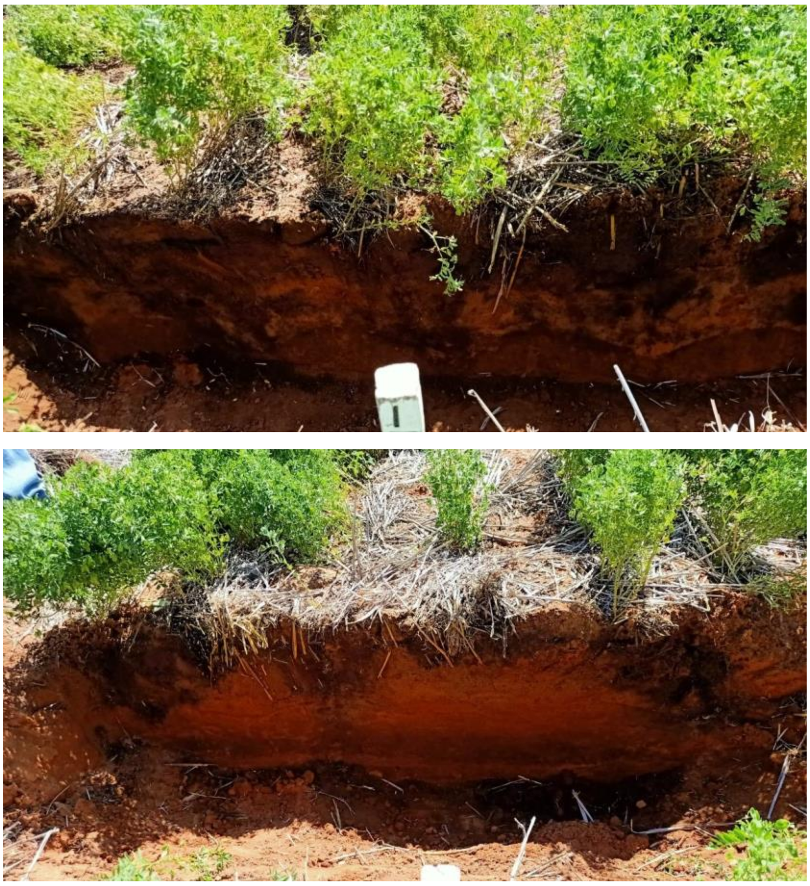

Figure 3. Visual effect of a pH dye indicator applied to a vertical soil profile pit (top) high uniformity 3 km/h double spading of 6600 kg/ha lime and (bottom) low uniformity 9 km/h single pass spading of 6600 kg/ha lime. Dark spots indicate higher pH correlating with the presence of lime.

Crop assessments

Over the past four seasons the trial has followed a barley, lentil, wheat rotation. Various in season assessments have occurred and are summarised below (Table 3) for each trial year.

Table 3. Summary of seeding details and crop measurements in spading uniformity trial Bute, SA 2019-2023.

Year	**Rainfall**	**Crop, seeding date and fertiliser**	**Crop assessments**
2019	Annual: 240 mm GSR: 213 mm	RGT Planet barley at 70 kg/ha 15th May 2019 32N + 10P nutrition applied	Crop establishment GreenSeeker NDVI 24/07/2019 Grain yield and grain quality
2020	Annual: 390 mm GSR: 301 mm	PBA Hallmark XT lentil at 50kg/ha 12th May 2020 MAP at 60kg/ha	Crop establishment Greenseeker NDVI 31/07/2020 Grain yield
2021	Annual: 346 mm GSR: 234 mm	Chief CL Plus wheat 27th of May 2021 DAP at 100kg/ha	Crop establishment GreenSeeker NDVI 23/07/2021 Grain yield and grain quality
2022	Annual: 451 mm GSR: 314 mm	PBA Highland XT lentil at 45 kg/ha 26th May 2022 MAP Zn at 80 kg/ha	Soil pH pit face samples 18/05/2022 GreenSeeker NDVI 11/08/2022 Tissue test 11/08/2022 YEB (top few cm) at 12 node Dry matter and N fixation Grain yield
2023			Pre-seeding Predict rNod

Results and discussion

Soil compaction

Both spading and deep ripping were able to reduce compaction in the hard pan at Bute (Figure 2). The maximum spading depth was 300 mm and compaction was reduced to this depth when compared with the control. However, soil resistance still exceeded 2500 kPa by 250 mm. The deep ripping treatment reduced soil resistance to less than 2500 kPa to a depth of 700 mm.

Crop establishment

There was no difference in plant establishment in the first year after spading, lime and ripping treatments were imposed. Barley crop establishment ranged from 140-173 plant/m^2 across all treatments (Table 4). Similarly in the other cereal phase (year three wheat), crop establishment was not affected by any treatment ranging from 200- 225 plants/m^2.

In year two lentil plant establishment was improved in some of the incorporation treatments (Table 4). The highest lentil establishment was measured in the high and medium uniformity with 6600 kg/ha lime applied, increasing lentil establishment by 23% and 21%, respectively compared to the control. However, while there were minor differences among the remaining treatments, there was no clear outcome for lime rate, uniformity or ripping. Overall, from three years of assessment plant establishment has not been affected by lime rate, uniformity (spading) or ripping treatment.

Table 4. Plant establishment (plants/m^2) or emergence in spading uniformity trial Bute, SA 2019-2021.

Incorporation	Lime rate (kg/ha)	Spading speed	2019 Barley	2020 Lentil	2021 Wheat
			Plants/m^2		
Control	0	No spading	141	86 c	200
Control	2200	No spading	143	86 c	206
Control	6600	No spading	156	96 abc	204
High uniformity	0	2km/h (multipass)	160	95 abc	206
Medium uniformity	0	5km/h	155	95 abc	212
Low uniformity	0	9km/h	140	89 c	201
High uniformity	6600	2km/h (multipass)	159	105 a	204
Medium uniformity	2200	5km/h	160	92 bc	225
Medium uniformity	6600	5km/h	173	103 ab	216
Low uniformity	6600	9km/h	157	98 abc	222
Ripping	0	No spading	148	89 c	203
		LSD (P≤0.05)	ns	12.3	ns

Greenseeker NDVI

Lime rate and spading have had a variable response on NDVI across four years. In the first season after treatments were implemented, barley NDVI ranged from 0.65 to 0.76 (Table 5). While there were minor differences among the treatments there was no consistent trend for spading uniformity, lime rate or ripping. In the other cereal phase (wheat 2021) there was no NDVI response.

Both lentil seasons (2020 and 2022) have resulted in differences in NDVI among the incorporation and lime treatments (Table 5). Where lime had been applied at 2200 kg/ha and 6600 kg/ha in the high, medium, and low uniformity treatments resulted in the higher NDVI (Table 5). In general lime rates (no spading), and ripping produced NDVI values similar to the control. In 2020 high and medium uniformity without lime resulted in improved NDVI compared to the control. This was not observed in 2022. These results suggest in the short-term incorporation of lime is consistently having an impact on lentil growth.

Table 5. Greenseeker NDVI taken in July or August for all treatments in lime uniformity trial Bute, SA 2019-2022.

Incorporation	Lime rate (kg/ha)	Spading speed	24 July 2019	31 July 2020	23 July 2021	11 Aug 2022
Control	0	No spading	0.70 bcd	0.24 f	0.69	0.25 cd
Control	2200	No spading	0.69 de	0.26 f	0.71	0.28 bc
Control	6600	No spading	0.70 bcd	0.24 f	0.70	0.25 cd
High uniformity	0	2km/h (multipass)	0.65 e	0.31 c	0.68	0.24 d
Medium uniformity	0	5km/h	0.72 abcd	0.30 cd	0.68	0.24 d
Low uniformity	0	9km/h	0.73 ab	0.28 e	0.71	0.25 cd
High uniformity	6600	2km/h (multipass)	0.69 cd	0.36 a	0.65	0.32 a
Medium uniformity	2200	5km/h	0.70 bcd	0.31 c	0.71	0.28 ab
Medium uniformity	6600	5km/h	0.74 a	0.33 b	0.69	0.29 ab
Low uniformity	6600	9km/h	0.73 abc	0.31 c	0.71	0.30 ab
Ripping	0	No spading	0.76 a	0.29 de	0.66	0.24 cd
		LSD (P≤0.05)	0.04	0.02	ns	0.03

Grain yield

Barley grain yield in year one ranged from 3.96 t/ha – 4.61 t/ha. There was no difference in grain yield among the incorporation and lime rates. Similarly in year two and three lentil and wheat grain yields were generally high and unaffected by lime rate, spading speed (uniformity) or deep ripping compared to the control (Table 6). These results suggest the lime had not moved into acidic layers and spading or ripping were yet to provide crop benefits.

In the fourth trial season lentil grain yield benefits were observed from spading and lime treatments. Addition of lime (2200 kg/ha or 6600 kg/ha) and mixing with low, medium or high uniformity were the highest yielding treatments ranging from 3.36 to 3.69 t/ha. This is also consistent with higher NDVI readings in these treatments. These responses in crop growth indicates the Bute soil profile required both lime and spading to address the subsoil acidity in the short-term. It also shows the higher speed 9 km/hr (low uniformity) was able to achieve results similar to the medium and high uniformity this season. This suggests the low level of incorporation has created enough pathways for the crop roots to overcome the constraint at the Bute site.

The high and medium uniformity treatments alone (no lime) were also higher yielding compared to the control (2.33 t/ha). Similarly, deep ripping improved lentil grain yields at 3.06 t/ha. Yield benefits from spading and deep ripping alone in other research has been linked to improved root growth (more efficient nitrogen and water capture) and increased nitrogen mineralisation from the incorporation of organic matter at depth.

Table 6. Grain yield (t/ha) for lime uniformity trial Bute, SA 2019 to 2022.

Incorporation	Lime rate	Spading speed	2019	2020	2021	2022
	(kg/ha)		Barley	Lentil	Wheat	Lentil
Control	0	No spading	4.25	2.41	4.41	2.33 f
Control	2200	No spading	4.30	2.46	4.47	2.58 def
Control	6600	No spading	4.35	2.47	4.49	2.55 ef
High uniformity	0	2 km/h (multipass)	4.26	2.25	4.39	2.79 cde
Medium uniformity	0	5 km/h	4.27	2.59	4.56	2.95 cd
Low uniformity	0	9 km/h	3.96	2.37	4.35	2.72 cdef
High uniformity	6600	2 km/h (multipass)	4.61	2.10	4.47	3.69 a
Medium uniformity	2200	5 km/h	4.22	2.36	4.53	3.38 ab
Medium uniformity	6600	5 km/h	4.19	2.68	4.48	3.67 a
Low uniformity	6600	9 km/h	4.15	2.46	4.41	3.36 ab
Ripping	0	No spading	4.32	2.64	4.61	3.06 bc
LSD (P≤0.05)			ns	ns	ns	0.40

Grain quality

In the cereal years lime and spading uniformity has had little impact on grain test weight (Table 7). In the first year after spading test weights in barley ranged from 61.7 kg/hL to 64.6 kg/hL. While there were small differences among the treatments, they had little consequence on overall grain receival standard. None of the treatments met test weights for malt classification (>65 kg/hL) and generally all treatments were in the BAR1 classification range (>62.5 kg/hL). For wheat there were small differences measured when analysed for uniformity alone (higher uniformity = lower test weight). However, these differences had no impact on receival standard with all treatments >76 kg/hL, minimum required for maximum grade (H1 or H2).

For grain protein in 2019 there were few differences across the trial (Table 7). In general grain protein in barley was low, ranging from 8.4% to 9.5% (range required for malt classification is 9-12%). Wheat grain protein was not affected by lime application but increased with the intensity of incorporation. The control, ripping and low uniformity treatment averaged 10.4 % protein and increased to 10.9 % and 11.3 % for the medium and high uniformity treatments, respectively. This increase in protein means an additional 4.7 and 5.8 kg N/ha was removed from the medium and high uniformity treatments compared to the other treatments. The additional nitrogen in the grain is likely to have come from nitrogen mineralised from organic matter that was buried during the spading process. With increasing mixing uniformity, the amount of organic matter that is buried in the profile is also increased which leads to increased mineralisation.

Table 7. Grain protein (%) and test weight (kg/hL) for incorporation treatments in the spading uniformity trial 2019 and 2021.

Incorporation	Lime rate (kg/ha)	Spading speed	2019 Barley		2021 Wheat	
			Test weight (kg/hL)	Protein (%)	Test weight (kg/hL)	Protein (%)
Control	0	No spading	63.4 abc	9.2 ab	79.5	10.4
Control	2200	No spading	62.2 bc	9.0 ab	79.6	10.4
Control	6600	No spading	61.7 c	8.8 ab	79.6	10.3
High uniformity	0	2 km/h (multipass)	64.3 a	8.4 b	78.9	11.2
Medium uniformity	0	5 km/h	64.6 a	8.9 ab	79.3	10.6
Low uniformity	0	9 km/h	62.5 bc	8.8 ab	79.4	10.4
High uniformity	6600	2 km/h (multipass)	63.7 ab	8.7 ab	78.8	11.4
Medium uniformity	2200	5 km/h	63.8 ab	8.6 ab	79.2	10.9
Medium uniformity	6600	5 km/h	63.6 ab	9.5 a	79.3	11.1
Low uniformity	6600	9 km/h	62.3 bc	8.9 ab	79.5	10.5
Ripping	0	No spading	63.6 ab	9.0 ab	79.5	10.4
		LSD (P≤0.05)	1.6	0.95	ns	ns

Lentil tissue test - season four

The critical limits for micronutrients in lentil tissue tests are not well established. In 2022 youngest emerged blades (top few cm of lentils) were sampled in select treatments at the 12-node growth stage. Of particular interest in low pH soils were manganese (Mn) and molybdenum (Mo). Manganese toxicity can occur in lentils grown on soils with low pH. In the treatments tissue tested, Mn concentrations were highest where lime had not been applied (Table 8). Application of lime in the control (surface) or incorporated by low and high uniformity all reduce the Mn concentration.

It is well known that the soil availability of Mo declines with acidification. Preliminary research trials conducted by Trengove et al. (2021) have shown Mo levels in lentil of <0.1 mg/kg are low, <0.2 mg/kg is marginal and >0.2 mg/kg is adequate. The control and high uniformity without lime had Mo concentrations below 0.1 mg/kg indicating Mo levels were low. Where lime was applied, Mo levels increased above 0.3 mg/kg (adequate) regardless if the lime was surface applied (control) or low or high uniformity.

Table 8. Concentration of Mn (mg/kg) and Mo (mg/kg) in lentil tissue test sampled 11th August 2022 from incorporation treatments in the spading uniformity trial.

Incorporation	**Lime rate (kg/ha)**	**Manganese (mg/kg)**	**Molybdenum (mg/kg)**
Control	0	218 b	0.14 c
Control	6600	165 c	0.58 a
High uniformity	0	343 a	0.14 c
High uniformity	6600	92 d	0.31 b
Low uniformity	6600	133 cd	0.50 a
Pr(>F)		<0.001	<0.001
LSD (0.05)		45.8	0.167

Lentil dry matter and nitrogen fixation – season four

In season four lentil dry matter and nitrogen fixation showed positive responses to lime incorporation. The high uniformity plus lime treatment resulted in the highest dry matter production at 7.4 t/ha (Table 9). The next highest treatment was the low uniformity plus lime however, it was also no different to the remaining treatments or controls. Both the high and low uniformity plus lime had the highest amount of nitrogen fixed in the shoots at 126 and 166 kg N/ha, respectively. On average these treatments contained 30 kg N/ha more compared to the controls and high uniformity alone (no lime). These results suggest incorporation of lime has increased the rate of raising the soil pH, which may have improved nodulation, N fixation and produced a larger lentil crop.

Table 9. Lentil dry matter and N fixation in lentil sampled at early-mid pod fill in selected treatments from spading uniformity trial October, 2022.

Incorporation	**Lime rate (kg/ha)**	**Dry matter (t/ha)**	**N fixed (kg N/ha)**
Control	0	5.0 b	92 b
Control	6600	5.2 b	90 b
High uniformity	0	5.8 b	88 b
High uniformity	6600	7.4 a	126 a
Low uniformity	6600	6.5 ab	116 a
Pr(>F)		0.029	0.002
LSD (0.05)		1.5	19

Soil pH – three years after trial establishment

Soil samples were taken from a selection of treatments pre-seeding in 2022 and analysed (lime x incorporation) for soil pH (Figure 4 and Table 10). While no changes in the 0-5 cm layer were detected, the remaining depths (5-10 cm, 10-20 cm and 20-30 cm) were all effected by lime and incorporation. When analysed alone (average of all incorporation treatments), lime application did increase pH in the 0-5 cm layer (data not shown). The high uniformity with lime consistently increased pH compared to the control (Figure 4). The pH in this treatment was greater than 5.85 across all sampling depths. The low uniformity with lime had elevated the pH in both 5-10 cm and 10-20 cm layer. However, beyond 20 cm the low uniformity was unable to increase pH compared to the control. Both the high uniformity with no lime and surface applied lime did not increase soil pH compared to the control (no lime). This suggests spading alone is not influencing soil pH. The control plus lime results confirms the moment of surface applied lime is slow and in three years after application has not increase pH at the surface or at depth.

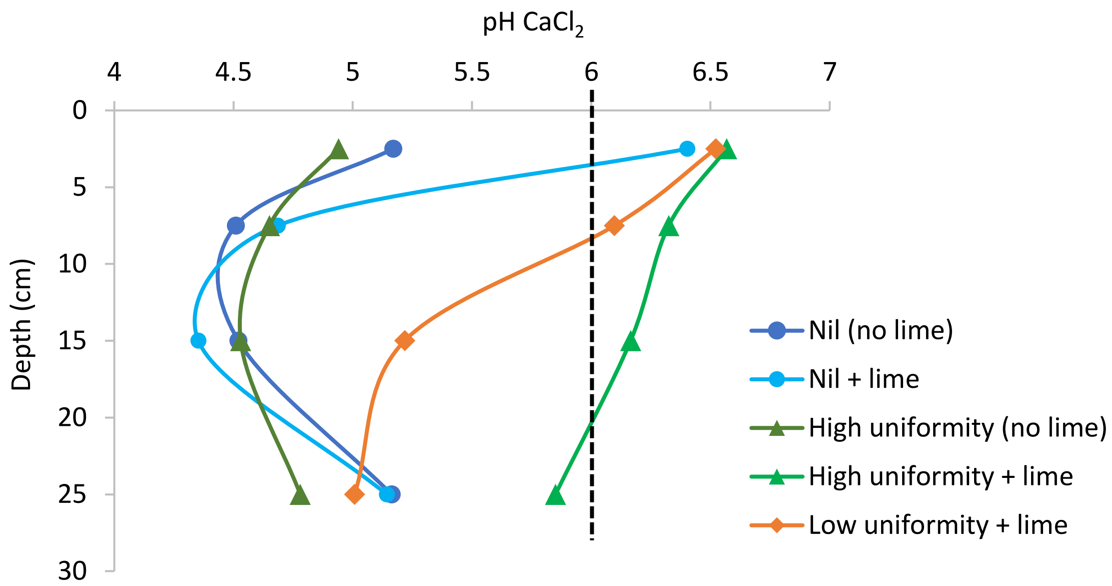

Figure 4. Soil pH sampling for incorporation treatments in the spading uniformity trial 2022. Dashed black line indicates preferred pH 6 – 8.5 for crop production.

Table 10. Soil pH sampling for incorporation treatments in the spading uniformity trial 18/5/2022. Values within a sampling depth row appended by a different letter are significantly different.

Incorporation	**Control**		**High uniformity spading**		**Low uniformity spading**
Lime (kg/ha)	**0**	**6600**	**0**	**6600**	**6600**
0-5 cm	5.17	6.40	4.94	6.57	6.52
5-10 cm	4.51 b	4.69 b	4.65 b	6.33 a	6.10 a
10-20 cm	4.52 c	4.35 c	4.53 c	6.17 a	5.22 b
20-30 cm	5.16 b	5.14 bc	4.78 c	5.85 a	5.01 bc

Soil rhizobia – fours years after trial establishment

Soil chemical properties such as pH affect both the survival of rhizobia in soil and the formation of nodules. Four years after the trial was established (pre-seeding 2023), rhizobia number were assessed using the Predicta rNod test. All samples contained high numbers (greater than 10,000 rhizobia /g soil) of group E/F rhizobia. Generally, 100 – 1,000 rhizobia /g soil are required for adequate nodulation of the target crop species. Values higher than 5,000 rhizobia/g soil suggest a negligible response to inoculation is likely. The high group E/F numbers in all treatments, including the control is due to soil sampling occurring after the lentil crop phase. The only treatment to have E/F rhizobia numbers different to the rest was the surface applied lime treatment. Soil sampling for the rNod test samples the top 0-10 cm. The high concentration of lime at the surface has raised the pH in the 0-10 cm layer (Table 10) and resulted in more favourable conditions for the rhizobia to survive.

In comparison, the group G/S rhizobia were detected in lower numbers. However, they were still adequate for lupin and serradella nodulation to occur.

Table 11. Soil rhizobia concentrations for selected treatments in the spading uniformity trial sampled prior to seeding, 2023.

Incorporation	Lime rate (kg/ha)	Group E/F rhizobia /g soil	Group G/S rhizobia/g soil
Nil	0	26,364 bc	1,183 a
Nil	6600	46,935 a	1,055 a
High Uniformity	0	10,600 c	419 b
High Uniformity	6600	27,468 bc	1,181 a
Low Uniformity	6600	29,239 b	923 a

Group E/F legumes nodulated = Field pea, lentil, vetch and faba bean

Group G/S legumes nodulated = Lupin and serradella

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