Nitrogen fertility drives the crop response to subsoil manuring in the high rainfall zone of south western Victoria

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Abstract
Subsoil manuring – the incorporation of organic amendments into dense clay subsoil by deep ripping – can improve crop yields on hostile subsoils. Adoption of the technique is limited in part due to a lack of understanding regarding what is driving the yield response and which amendment type and incorporation method are most effective for improving plant growth. In order to address these research gaps, two long-term experiments were established at Westmere in the high rainfall zone of south-western Victoria in 2012 and 2014. Both experiments were set up as two-way factorial designs testing type of amendment (nil, poultry litter, synthetic fertiliser) and method of incorporation (no till, deep rip, mouldboard plough). The 2012 experiment also included an additional incorporation treatment of surface application plus deep ripping. The nutrient content of the synthetic fertiliser treatment was balanced so that it matched that of the poultry litter. Fertiliser was applied each year so that nitrogen was non-limiting. Over eight (site)x(year) combinations, crop yields were not improved by application of amendments and there was never a significant positive interaction between amendment and incorporation treatments. Additionally, poultry litter and synthetic fertiliser performed similarly. This indicates that (1) deep placement of amendment had no advantage over surface application of the same amendment; (2) there was no benefit of using an organic amendment over an synthetic source of equivalent nutrition; and (3) subsoil manuring did not increase yields via amelioration of subsoil constraints. Nitrogen was the key driver of crop yield and grain quality after subsoil manuring.

Keywords
Subsoil manuring, subsoil constraints, nitrogen fertility, grain yield, high rainfall zone.

Introduction
Subsoil manuring is a technique that has been developed in the high rainfall zone of south-eastern Australia with the aim of increasing the yields of dryland crops grown on hostile clay subsoils. The practice involves the incorporation of high rates of nutrient-rich organic matter such as poultry litter into the subsoil by deep ripping. Previous research has shown that subsoil manuring can improve soil physical, chemical and biological properties and significantly increase crop yields as a result of increased subsoil water use, plant biomass and grain protein (see e.g. Gill et al. 2012; Sale et al. 2013).

Despite promising trial results, adoption of subsoil manuring has been limited due to the cost of the operation, access to suitable machinery and availability of suitable amendments (Nicholson et al. 2015). In addition, the most effective amendment and method of placement have yet to be determined and there is still a poor understanding of the mechanisms leading to the soil and plant response. Specifically, it is not known whether the yield increases are due to the nutrition of the amendment or the amelioration of subsoil constraints. Ongoing research by Southern Farming Systems aims to address these research gaps.

Methods
Two long-term experiments investigating subsoil manuring were established at the Southern Farming Systems' Westmere trial site in the high rainfall zone of south-western Victoria. The soil at this site was a sodosol (Isbell 2002) with gilgai microrelief, an A2 buckshot horizon of variable thickness and variable depth to B horizon (Table 1).

A large-scale experiment was established in 2014 with experimental plots applied in strips 6 m wide and 200 m long. The treatments were the same as the small-scale experiment except surface application followed by ripping was omitted. Crop management details are shown in Table 3. Growing season rainfall for the large-scale experiment is as per the small-scale experiment in Table 2.

Table 1. General soil chemical and physical properties at Westmere trial site in Victoria.
EC, electrical conductivity; CEC, cation exchange capacity; ESP, exchangeable sodium percentage; BD, bulk density.

Depth (cm)	pH_{CaCl2}	EC (dS/m)	CEC (meq/100g)	ESP (%)	Organic C (%)	Colwell P (mg/kg)	Available N (kg/ha)	BD (g/cm3)	Sand (%)	Silt (%)	Clay
0-10	5.5	0.139	10.2	3.1	2.43	59	49	1.2	60	30	9
10-20	5.1	0.078	5.0	3.8	1.19	30	38	1.3	65	27	9
20-30	6.0	0.085	8.2	15.1	0.44	13	6.5	1.3	69	23	9
30-40	6.0	0.078	17.3	14.9	0.36	6	5.6	1.4	55	18	28
40-60	6.2	0.122	23.7	19.8	0.49	3	5.6	1.4	38	15	48
60-80	7.3	0.168	27.7	23.8	0.41	2	9.0	1.5	22	10	68
80-100	7.8	0.298	28.9	26.4	0.18	< 2	6.0	1.5	28	10	64

A small-scale experiment (1.6 m x 12 m plots) was established in 2012. There were 12 treatments comprising three amendments (no amendment, poultry litter 15 t/ha, fertiliser) in factorial combination with four incorporation methods (no till, surface application followed by deep rip, deep rip, surface application followed by mouldboard plough). Crop management details are shown in Table 2.

Table 2. Crop management details for the small-scale subsoil manuring experiment at Westmere. GSR = growing season rainfall (April to November).

Year	Crop	Sowing date	In-season N (kg/ha)	GSR (mm)
2012	Wheat (Revenue)	18 May	150	350
2013	Barley (Oxford)	12 June	75	420
2014	Canola (Hyola 525 RT)	7 May	125	300
2015	Wheat (Derrimut)	20 May	70	250
2016	Faba bean (Rana)	22 April	-	560

Table 3. Crop management details for the large-scale subsoil manuring experiment at Westmere.

Year	Crop	Sowing date	In-season N (kg/ha)
2014	Canola (Stingray)	6 May	210
2015	Wheat (Trojan)	20 May	150
2016	Barley (Westminster)	13 May	150

The manure used in each experiment was analysed for nutrient content (Table 4). In both experiments the synthetic fertiliser treatment was a custom granular blend with nutrition balanced to match the poultry litter. All treatments were carried out once prior to sowing in the year of establishment except for nitrogen in the large-scale experiment: half was applied prior to sowing as 645 kg/ha urea and half was applied during growth of the canola crop as liquid urea and ammonium nitrate (UAN) in two separate applications of 220 L/ha at start of stem extension and 520 L/ha at yellow bud.

Table 4. Total nutrition supplied (kg/ha) by 15 t/ha poultry litter (dry weight) in the two long-term subsoil manuring experiments at Westmere.

	2012 batch Small-scale experiment	2014 batch Large-scale experiment
Nitrogen	20	594
Phosphorous	76	130
Potassium	131	266
Sulfur	18	80
Calcium	90	220
Magnesium	-	71

Results and Discussion

In the small-scale subsoil manuring experiment (Table 5), there have been no consistent effects of amendment choice or method of incorporation on grain yield or quality. Subsoil manuring with poultry litter only increased yield relative to no amendment and synthetic fertiliser treatments in one of four years (canola in 2014), and in that case by only 0.3 t/ha. However, the poultry litter treatment had higher grain protein (and lower canola oil) indicating a sustained nitrogen effect from the organic amendment on grain quality. There was no yield advantage of any tillage treatment over and above standard district practice (i.e. no tillage with surface applied nitrogen). There was no significant positive interaction between amendment and incorporation treatments which demonstrates that deep placement of amendment (subsoil manuring) has no advantage over surface application of the same amendment.

Table 5. **Grain yield and quality for the small-scale subsoil manuring experiment established in 2012 at Westmere. Means followed by the same letter do not differ significantly at *p*=0.05, ns = not significant.**

	2012 Wheat		2013 Barley		2014 Canola		2015 Wheat		2016 Faba bean
	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Oil (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)
No amendment	7.79 a	9.7 b	7.99	10.8 b	2.22 b	44.9 a	2.81	13.4 b	5.24
Synthetic fertiliser	7.94 a	10.1 b	7.94	10.8 b	2.26 b	45.3 a	2.90	13.6 b	5.16
Poultry litter	7.18 b	12.7 a	8.22	12.5 a	2.56 a	43.0 b	2.65	15.2 a	5.03
p-value	*0.041*	*<0.001*	*ns*	*0.003*	*0.020*	*0.003*	*ns*	*0.011*	*ns*
No till	7.57	10.4 b	8.24	11.3	2.32	44.9	2.62	14.0	5.43 a
Surface rip	7.51	10.8 ab	7.69	11.2	2.45	44.7	2.80	13.6	5.47 a
Deep rip	7.58	11.0 b	8.05	11.2	2.20	44.7	2.79	14.6	4.99 ab
Mouldboard plough	7.89	11.2 a	8.22	11.9	2.40	44.2	2.93	14.1	4.70 b
p-value	*ns*	*0.036*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*0.046*

As with the small plot experiment, the large-scale experiment established in 2014 showed no consistent, significant effects of amendment type or method of incorporation on grain yield or quality (Table 6). In this experiment, poultry litter and synthetic fertiliser performed equally and did not provide a statistically significant yield advantage over the unamended treatment. Both the poultry litter and synthetic fertiliser treatment yielded significantly less than the no amendment treatment in the dry, hot season of 2015. Grain protein and oil responses, together with the yield reduction in the dry 2015 season, again suggest a strong nitrogen effect of both of these amendments on the crop. In terms of method of incorporation, in 2016 there was a yield advantage of deep ripping, but in all other years standard district practice of no till and no amendments was just as effective. As with the small plot experiment, there was no significant interaction between amendment and incorporation treatments, indicating there is no advantage to deep placement of amendments relative to surface application.

Table 6. **Grain yield and quality results for the large-scale subsoil manuring experiment established in 2014 at Westmere. Means followed by the same letter do not differ significantly at *p*=0.05, ns = not significant.**

	2014 Canola		2015 Wheat		2016 Barley	
	Yield (t/ha)	Oil (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)
No amendment	2.17	46.2 a	3.55 a	12.5 b	5.82	9.7
Synthetic fertiliser	2.43	41.3 c	2.91 b	16.9 a	5.96	10.8
Poultry litter 15 t/ha	2.38	42.3 b	2.93 b	16.5 a	6.08	11.3
p-value	*ns*	*<0.001*	*0.039*	*<0.001*	*ns*	*ns*
No till	2.35	43.6	3.13	15.0	5.77 b	10.2
Deep rip	2.34	43.1	3.13	15.4	6.14 a	10.8
Mouldboard plough	2.29	43.2	3.12	15.5	5.95 b	10.8
p-value	*ns*	*ns*	*ns*	*ns*	*0.009*	*ns*
Grower bulk paddock yield	2.3		3.6		5.0	

Comparison of these experimental yields with the bulk paddock yields of the grower (Table 6) shows that in 2014-15 there was no difference, but in 2016 the grower's paddock yielded roughly 1 t/ha below the experiment results.

Conclusion

Recent findings from field and controlled environment experiments have validated earlier results published by Southern Farming Systems (Paridaen and Celestina 2012; Creelman and Celestina 2015). The key factor driving the crop response to subsoil manuring at Westmere is nutrition – especially nitrogen – not depth of placement or subsoil amelioration *per se*. At Westmere where plentiful fertiliser N was applied in-crop such that nitrogen did not limit yields, crop yields have not been improved by the application of amendments. Poultry litter did not consistently outperform the synthetic nutrient treatment, indicating that both treatments are similar in terms of their fertiliser effect on the crop. There was never any benefit from deep placement of amendments, either poultry litter or synthetic fertiliser, relative to surface application. Consequently, there is no evidence of subsoil manuring increasing yield through amelioration of subsoil constraints at this site.

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