Correcting iron deficiency in broad beans growing on highly calcareous clay loams

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Abstract
Highly calcareous soils are common in some areas of south-eastern Australia and can challenge crop production due to a range of constraints. Severe yellowing and stunting are common in broad bean crops grown on highly calcareous clay soils in the south-east of South Australia. The cause of yellowing is thought, by local growers and advisers, to be due to a combination of iron (Fe) and manganese (Mn) deficiencies brought on by cold and wet conditions during winter. Current corrective practices have little impact on remediating the issue. Two seasons of field trials and a pot experiment in controlled conditions suggest that the primary cause of the disorder in beans was Fe deficiency, that Fe ethylenediamine-N,N′-bis(2-hydroxyphenylacetic acid) (Fe-EDDHA) was an effective source for correcting the issue but that multiple applications in the field gave the best outcomes in terms of grain yield. Grain yield increases of up to 5 t/ha in the field were recorded with effective strategies. However, the rates of Fe-EDDHA required to correct the disorder are very expensive and the best timing for applications is not yet clear. Further work is required to fine tune rates and timings of applications for the most cost-effective outcomes for bean growers. Other crops grown in the area also suffer this issue suggesting Fe-EDDHA based strategies may also have a role in other crops. This paper summarises the field trial undertaken in the second year of activities.

Keywords
Iron deficiency, dryland cropping, Fe-EDDHA.

Introduction
Highly calcareous soils are common in some areas of south-eastern Australia and can challenge crop production due to a range of constraints. Severe yellowing and stunting are common in crops grown on highly calcareous clay soils in the south-east of South Australia (Reuter 2007). The cause of yellowing is believed by local growers and advisers to be a combination of iron (Fe) and manganese (Mn) deficiencies brought on by cold and wet conditions during winter. The trial reported here was established through a 3 year project jointly funded by the CRC for High Performance Soils and GRDC. After discussions with local farmers and advisers in late 2020, it was clear that yellowing in broad beans was a major issue on highly calcareous loamy clays.

A trial was conducted in 2021 on a calcareous grey clay to investigate the problem. Many approaches with Fe and/or Mn to correct yellowing, stunting and to improve yields were included in that trial. However, none of the strategies prevented yellowing and stunting in winter but for those in which multiple applications of Fe had been included. They yielded approximately 1 t/ha better than the typical practice of 2 foliar sprays of Fe and Mn sulphates.

A new trial was conducted in 2022 on a site close to the previous trial to further investigate the problem, but with treatments adjusted after the experiences of 2021. The 2022 trial is reported in this paper.

Methods
The field site was on a shallow black vertosol over limestone in a paddock frequently cropped near Robe, in the south-east region of South Australia. Key soil properties in the top 10 cm were pH (water): 8.0, carbonate: 47 %, W&B carbon: 7.4 %, Colwell P: 70 mg/kg, DTPA-Fe: 8.0 mg/kg, DTPA Mn: 4.5 mg/kg. Thirteen treatments, with a range of Fe and Mn strategies, were implemented (see Table 1 for details), some of which also investigated the effectiveness of fluid P and extra N on boosting bean performance.

Aquadulce broad beans were sown at 277 kg/ha after inoculating with peat-based rhizobia on 12 May, 2022. All plots received 100 kg/ha of MAP or a fluid equivalent under each seed row except the no nutrient control. The paddock grew wheat in 2021 and stubbles were burnt prior to seeding. Weed, pest and disease control were typical for the district. Plots were 24 m long × 6 rows @ 21 cm spacing × four replicates. Annual rainfall in 2022 was 558 mm.

Foliar sprays of Mn and/or Fe were applied on 27 June, 8 August (first flowers) or 29 September (mid flowering). Establishment, early crop vigour and colour, Fe concentration in youngest fully open leaves (YOLs) at flowering, nodulation and grain yields were assessed.

Table 1. Mn and Fe strategies applied to broad beans on a shallow vertosol in the south-east of South Australia in 2022.

Treatment	Coated on seed	Banded under seed rows as a fluid	Early foliar	2 x foliar, first flowers and mid flowering
No P, N or TEs				
NP only				
Fluid P				Mn + Fe sulphate
Typical Practice				Mn + Fe sulphate
Extra N				
Extra N + Fe		Fe EDDHA		Mn + Fe sulphate
Triple Treat Mn	Mn EDTA	Mn EDTA		Mn EDTA
Triple Treat Fe	Fe EDDHA	Fe EDDHA		Fe EDTA
Triple Treat Combo	Mn EDTA + Fe EDDHA	Mn EDTA + Fe EDDHA		Mn + FE EDTA
Triple Treat Combo + Fluid P	Mn EDTA + Fe EDDHA	Mn EDTA + Fe EDDHA		Mn + FE EDTA
Chelated TEs 2 ways		Mn EDTA + Fe EDDHA		Mn + FE EDTA
Early Fe EDDHA			Fe EDDHA	Fe EDTA
Fe EDDHA foliar				Fe EDDHA

Notes. All treatments received granular P as MAP except Fluid P which was ammonium polyphosphate. Fe and Mn were coated at 2 kg/tonne of seed each; banded at 2 or 3 kg/ha at seeding (respectively), and 0.5 kg/ha each as foliar sprays.
Extra N received 50 kg N/ha as urea banded at seeding in addition to the standard MAP rate.

Results

The crop emerged and established well, averaging 19 plants per sq m regardless of treatments, except for very stunted plants with Mn only coated seeds. Coating seed with chelated Fe and/or Mn did not affect establishment or vigour but testing of the seed after seeding revealed that most of the trace element products may have fallen off the seeds prior to seeding.

Bright yellowing and interveinal chlorosis in young leaves, extending to the whole plant in some cases, appeared in the trial within the first two months after seeding but only in plots which had not received Fe-EDDHA by that time (Table 2). This pattern continued throughout the season; the greenest and most vigorous plants were in the triple treat Fe (Figure 1), then there were a group of treatments with Fe-EDDHA and Mn, which were performing well and a third cluster which had not received Fe-EDDHA and were yellow and stunted (Table 2).

Figure 1. Response of broad beans to Fe applications near Robe in 2022. LH plot – typical practice, RH plot – Triple treat Fe.

While the best performing treatment was triple treat Fe, early Fe-EDDHA and foliar sprays of Fe-EDDHA also produced substantial growth improvements (Table 2).

At mid flowering, dry matter of shoots was nearly three times higher with triple treat Fe compared to NP only and typical practice (Table 2). Where Fe and Mn were applied in combination, dry matter was still substantially better than typical practice but not as good as with Fe alone. Extent of nodulation was also assessed at mid flowering for a subset of treatments which represented a wide range of early TE strategies. Treatments that received seed coats of Fe or Fe+Mn had at least 40% more nodules per root system than the no TE control (Table 2). An application of Fe or Fe+Mn at seeding had little impact on nodule numbers.

The trial was harvested at maturity in January 2023 and the pattern of poor and well performing treatments seen during the growing season was also largely present in grain yields (Table 2). Broad beans in treatments without Fe or Mn were very stunted at maturity and the plots were largely overwhelmed by ryegrass; they only yielded between 1,600 and 2,600 kg/ha. Yields with typical practice (two foliar sprays of Fe and Mn sulphate) were also very poor at 2,300 kg/ha. The highest yielding treatment was triple treat Fe, which was more than 5,300 kg/ha better than the no TE control and these beans almost completely outcompeted the background population of ryegrass. All other treatments that received multiple applications of Fe and Mn yielded in the range of 6,200 to 6,500 kg/ha, suggesting that the addition of Mn partly suppressed the benefits of Fe-EDDHA. Beans in the Mn only treatment had an early setback from the Mn seed coat and struggled all season, yielding no better than the no TE treatments.

Applying a foliar spray of Fe-EDDHA very early in crop growth reduced yellowing and promoted crop growth during winter and spring but resulted in a modest grain yield of only 4,500 kg/ha. In contrast two foliar applications of Fe-EDDHA at later timings produced a grain yield of 6,100 kg/ha, similar production to treatments with Fe applications starting at seeding.

The only difference between triple treat combo and chelated TEs 2 ways was that chelated TES 2 ways did not receive a seed coating of Fe and Mn and yet it produced similar grain yields to triple treat combo (Table 2). This suggests that the seed coating had little impact on crop performance apart from improved nodulation in this one season.

Even strategies which eliminated yellowing and resulted in large improvements in crop performance had little impact on Fe concentrations in young leaves and levels in all treatments were in the critical range (Reuter et al. 1997).

Table 2. Effect of Mn and Fe applications on growth of broad beans on a calcareous clay in the south-east of South Australia in 2022.

Treatment	Early crop colour (1: yellow - 5: green)	Mid Flower			Grain yield (kg/ha)
		Dry wt of shoots (kg/ha)	Fe in YOLs* (mg/kg)	Nodules per plant	
No P, N or TEs	3.1	1059	59		1560

NP only	2.6	890	65	55	2267
Fluid P	2.6	990	75		2562
Typical Practice	2.8	944	62		2316
Extra N	3.2	881	63		1609
Extra N + Fe	4.1	1219	70		6306
Triple Treat Mn	1.7	590	84		2056
Triple Treat Fe	4.4	2488	69	95	7595
Triple Treat Combo	4.0	1358	81	79	6414
Triple Treat Combo+Fluid P	4.1	2091	76		6526
Chelated TEs 2 ways	4.0	1244	77	64	6231
Early Fe EDDHA	3.2	1292	59		4491
Fe EDDHA foliar	2.4	1049	93		6137
LSD (P=0.05)	*0.8*	*925*	*15*	*22*	*1125*

* Youngest fully open leaf

Conclusion

Elimination of yellowing and large increases in biomass and grain yield of broad beans growing on a shallow vertosol over limestone occurred with applications of Fe in 2022. These finding suggest that yellowing and stunting of broad beans on calcareous soils of the south-east region of South Australia is due to Fe deficiency and not Fe plus Mn deficiencies. Fe-EDDHA is a formulation of Fe which corrects Fe deficiency in broad beans grown in these situations, which is consistent with its performance in situation overseas (Wiersma 2005) and seems to be due to its stability at high pH (Lucena 2006). The strategies with Fe-EDDHA used so far to correct Fe deficiency require high rates of Fe per ha (either as banding applications at seeding or foliar sprays) which are very expensive to apply. The Fe applications in the Triple treat Fe are currently costed at nearly $1,000/ha. Although farmers have been treating their yellowing bean crops with both Fe and Mn foliar sprays, in this trial, Mn not only did not relieve symptoms but also appeared to have an antagonist effect on the response of broad beans to Fe applications.

The next phase of this research will investigate application strategies of Fe which continue to be effective, but at reduced cost. These opportunities include reduced rates of Fe-EDDHA, different strategies for applying FE-EDDHA to crops e.g. incorporating boomspray applications by seeding, timing and frequency of foliar sprays, seed coat formulations which keep Fe on bean seeds, genotypic variation within popular crops and different formulations of Fe which are stable at high pH and deliver plant-available Fe to crops.

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