PLANT AND SOIL

TITLE: Deep placement of Mn fertiliser on sandy soil increased grain yield and reduced split seed in *Lupinus angustifolius*.

The following manuscript contains 11 pages of text, 3 tables and a suggested short running title could be "Deep placed Mn increased lupin yields".   The author's addresses are:

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Abstract

Experiments were conducted over two years with *Lupinus angustifolius* L. on a site with acid sandy soil near Esperance, Western Australia to determine if deep placed manganese fertilizer increases lupin grain yield. Manganese at 4 and 8 kg ha^{-1} was placed below the surface immediately before sowing at 4, 20 and 30 cm and 4, 8, 12, 16 and 20 cm in 1987 and 1988 respectively. Foliar Mn applied at 1 kg ha^{-1} when the first order laterals were in mid-flowering stage, was also compared.

Increasing the depth of Mn placement increased grain yield in both years. The deepest placed Mn increased grain yields by 255 kg ha^{-1} (10%) and 430 kg ha^{-1} (106%) in year 1 and year 2 over the shallow (4 cm) placed Mn. The higher responses to deep placed Mn occurred in year 2, the year with the driest spring and most intense aphid infestations. Foliar applied Mn was as effective as most deep placed Mn treatments, except for the highest rate (8 kg ha^{-1}) at the greatest depth (20 cm) in year 2. The higher rate of applied Mn gave the best grain yields.

Introduction

Mn deficiency, or split seed, in sweet white-lupins (*Lupinus angustifolius*) has been common prior to the use of Mn fertilisers. The sweet, white lupins have a greater Mn requirement than many other crops (Gartrell and Walton 1984). On acid sandplain soils in Western Australia, 4 kg ha^{-1} of Mn drilled with the seed usually gives adequate control of split seed (Gartrell and Walton 1984). On soils with a higher pH, drilled Mn becomes unavailable to lupins, so foliar applied Mn is commonly used (Hannam et al., 1984).

On the Esperance sandplain in Western Australia, granular Mn sulphate is usually drilled with the seed at 2-6 cm depth. However, despite 8 kg ha^{-1} of Mn being applied, split seed still occurs in some lupin crops, in some years. Lupins are unable to mobilise Mn once deposited in leaf tissue and lupins need a constant Mn supply to meet pod fill requirements. If the surface soil dries during pod filling, much of the soil Mn becomes unavailable (Harter and McLean 1965, Gartrell and Walton 1984). Thus fertiliser granules, located in water repellent topsoil, which remains dry, may not provide Mn to the roots.

The hypothesis tested here is that deep placement of Mn into the wettable subsoil below drying of water repellent topsoils will increase the effectiveness of Mn fertilisers for lupins. We conducted two experiments in consecutive seasons (1987-88) to examine deep placement of Mn on lupin dry matter and grain yield and seed quality.

Materials and methods

Climate and Soils

The two experiments were conducted on the Esperance Downs Research Station, 30 km north of Esperance, Western Australia. The annual average rainfall is 494 mm, with an average of 335 mm falling in the May-October growing season.

Both experiments were on the same soil type at sites 200 m apart but in consecutive years. The soil was uniform white sand, with organic staining in the surface 10 cm, over ironstone gravel which ranged in depth from 25-40 cm over clay which started at 55-70 cm depth (duplex; Dy 4.56, Northcote 1979). For both sites the topsoil (top 10 cm) had 1-1.2% organic carbon, 1% clay, had a severe water repellence value of 2.6 using the molarity of ethanol drop test (MED; King, 1981) and a pH of 5.0 (1:5 0.01 M $CaCl_2$).

The experimental sites were cleared of native vegetation in 1951 and had not previously been sown to lupins or received Mn fertilisers. The sites had been cropped 6-7 times with cereals in rotation with annual pastures. In the previous 4 years, pasture was grown and was composed mainly of subterranean clover (*Trifolium subterraneum*), annual ryegrass (*Lolium rigidum*) and capeweed (*Arctotheca calendula*).

Experimental procedures

Both experiments were complete randomised blocks with 4 and 3 replicates for experiment 1 and 2 respectively. Plots were 38 m by 1.44 m (8 rows) wide with buffers. Paraquat (100 g L^{-1}) and diquat (100 g L^{-1} plus surfactant) were sprayed at 2.0 and 0.75 L ha^{-1} across the sites on 20 May 1987 and 18 May 1988. Glyphosate (360 g L^{-1}) was applied at 1.5 L ha^{-1} on 26 May 1987 to control capeweed.

The 1987 experiment was complicated by the occurence of the disease rhizoctonia bare patch. Consequently, in the 1988 experiment, all plots were ripped to 30 cm with an Agrowplow® immediately before sowing. Deep ripping on these soils is known to decrease rhizoctonia bare patch in wheat and lupins (Jarvis and Brennan 1986, Brennan and Crabtree 1989). Experiment 2 was ripped again to 20 cm before sowing with a modified cultivator at 18 cm spacings. All plots were sown with a standard combine drill.

Danja and Gungurru lupins (*Lupinus angustifolius*) were inoculated with commercial rhizobium culture and sown at 75 kg ha^{-1} of viable seed on 2 June 1987 and 26 May 1988 into moist soil. Post emergent grasses were controlled with 1.25 L ha^{-1} of Hoegrass® (375 g L^{-1} diclofop-methyl) and 0.5 L ha^{-1} of Fusilade® (212 g L^{-1} Fluazifop plus surfactant) in July 1987 and 30 June 1988. High aphid numbers in 1988 were treated with two misted applications of 300 and 750 g ha^{-1} of Pirimor® (500 g L^{-1} Pirimicarb) and one misted application of 1.0 L ha^{-1} dimethoate (400 g L^{-1}) on 23 August, 6 September and 14 September, all these treatments were mixed with 0.2% light spraying oil before spraying. However, crop damage from aphids still occurred.

Superphosphate (9.1% P) was drilled with the lupin seed at 120 kg ha^{-1}. Soil applied Mn was applied as either granular $MnSO_4$ (27% Mn) or liquid Mangasol® (17.3% Mn) at 4 or 8 kg Mn ha^{-1}. The soil applied Mangasol® was sprayed into tubes mounted behind the tines of an Agrowplow at 33 cm intervals in 1987 and behind the modified cultivator at 18 cm intervals in 1988. Manganese was placed at 4, 20 and 30 cm depths for the 1987 experiment and at 4, 8, 12, 16 and 20 cm depths for the 1988 experiment. For some treatments foliar Mn was misted at 1 kg ha^{-1} as Mangasol® when the flowers on the first order laterals were in mid-flowering.

Measurements

Six plant counts were taken from 1 m of rows 14 days after sowing. Dry matter (DM) production was measured and youngest open leaflets (YOLS) were taken 67 and 106, and 87 and 113 days after sowing in 1987 and 1988 respectively by randomly selecting 20 plants per plot from areas not affected by Rhizoctonia. Plant samples were oven dried at 70°C for at least 48 hours, crushed and digested and analysed for Mn using atomic absorption spectrophotometry. Grain yield was measured by harvesting a 1.3 m strip from the centre of each plot on 18 and 23 November in 1987 and 1988, respectively.

Split seed and seed numbers were measured by randomly selecting (except from Rhizoctonia patches in 1987) 20 plants per plot prior to harvest. The pods from these lupins were divided into main stems and laterals. The pods were then thrashed and the seeds were divided into 5 categories; normal seeds, normal seeds but split, normal seeds incipiently split, shrivelled seeds and shrivelled split seeds, as used by Walton (1976). Each category of seed was weighed, counted and then digested and analysed for Mn content. Some of these categories have been subsequently grouped.

Results

Emergence was not affected by any treatment in either experiment with an average of 40 and 38 plants m^{-2} for experiments 1 and 2, respectively. These densities were considered adequate for optimal plant growth (Walton 1982), although recent work with modern varieties shows that a higher grain yield occurs with higher plant densities (W. Cowling *pers comm*).

Spring rainfall (1 September to 6 November) was 67% more for experiment 1 (1987, see Table 1) than for experiment 2 (1988). Pan evaporation readings, for the adjacent Esperance town site (35 km south) during spring, were 4.4 and 4.8 mm day^{-1} for 1987 and 1988. Both factors making 1988 a drier spring than 1987.

Table 1. Esperance Downs Research Station monthly and weekly rainfall (mm).

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1987	19	2	24	49	94	53	41	53	49	20	44	13	463
1988	20	2	25	38	97	77	61	46	31	16	24	27	465
Avg†	21	2	25	38	55	61	63	63	53	40	32	19	494
	Spring rainfall (mm) September				October				November		Total		
Date	1	2	3	4	1	2	3	4	1	2	-		
1987	15	0	5	29	0	7	13	0	16	2	87		
1988	2	7	4	7	15	5	0	8	0	8	52		

† Long term average (35 years)

Experiment 1

Applying Mn doubled average grain yield, doubled seed size, greatly increased the percentage of normal seeds, and decreased the area of rhizoctonia by 10% for all depths of Mn placement (Table 2). Applied Mn at 0, 4 and 8 kg ha^{-1} gave grain yields of 1362, 2647 and 2819 kg ha^{-1}, seed size of 85, 146 and 165 mg, the amount of healthy seeds were 7, 89 and 92 % and rhizoctonia was decreased from 10.6 to 9.7 and 9.5 %.

Shallow (4 cm deep placed) Mn, either as a liquid drilled at 33 cm spacings or as granules at 18 cm spacings gave equal plant responses.

Ripping to 30 cm decreased rhizoctonia bare patch, and increased early and late DM, grain yield, number of seeds and percent of normal seeds. Increasing ripping depth through 5, 20 and 30 cm increased yields with early DM values of 2339, 2732 and 3120 kg ha^{-1}, late DM of 4466, 5325 and 5749 kg ha^{-1}, grain yield of 2000, 2334 and 2493 kg ha^{-1}, the number of seeds being 829, 845 and 930 per 0.5 m^2 and the percentage of normal seed being 58, 65 and 64 %.

Increasing ripping depth decreased the area of rhizoctonia patch from 21 % without ripping to 7 to 2 % for ripping at 20 and 30 cm depth. Higher rates of applied Mn (8 versus 4 kg ha^{-1}) decreased the area of rhizoctonia patch by 30 % ($P < 0.10$) for 20 cm ripping and by 39 % (ns) for 30 cm ripping. For a detailed discussion on the effects of ripping on rhizoctonia at this site see Brennan and Crabtree (1989).

Foliar applied Mn gave similar grain yields to surface applied Mn, although it can not be directly compared to deeper placed Mn due to an additional response to cultivation which accompanied the deep placement of Mn.

Table 2. Effects of Mn placement and soil ripping in 1987 on lupin DM production, grain yield, grain quality and area of rhizoctonia.

Treat-ment No.	Mn applied (kg ha^{-1}) as			Rip depth (cm)	Dry matter (kg ha^{-1})		Grain Yield (kg ha^{-1})	Area of Rhizo-ctonia (%)	Seed size (mg)	Seed number per ½ m^2	Percentage of seeds that are		
	granules†	foliar‡	liquid§		28 Aug	23 Sep					normal	split + shrivel#	split-filled
1	0	0	0	5	2390	4472	1251	23	88	711	7	21	50
2	0	0	4	5	2362	4427	2310	20	115	100	83	6	6
3	0	0	8	5	2265	4499	2439	22	159	768	85	3	9
4	0	0	0	20	2631	5301	1295	7	68	948	6	19	56
5	0	0	4	20	2778	5343	2697	8	188	719	94	1	4
6	0	0	8	20	2788	5332	3011	5	173	869	96	1	3
7	0	0	0	30	3078	5814	1540	2	98	784	7	18	57

8	0	0	4	30	3056	5659	2933	2	136	1080	90	3	4
9	0	0	8	30	3227	5774	3007	1	162	928	96	0	3
10	4	0	0	30	3117	5694	2678	3	144	930	88	4	3
11	4	0	8	30	3103	5780	3060	2	191	801	98	0	2
12	0	1	0	5	2305	4423	2492	17	135	923	92	2	4
13	4	1	0	5	2420	4590	2544	19	159	801	95	1	3
14	4	0	0	5	2410	4523	2421	22	108	1124	86	3	7
15	8	0	0	5	2422	4624	2509	22	133	944	93	2	4
LSD (0.05)					234	446	212	3.3	27	166	2.5	2.6	2.6

†, ‡ and § = Mn applied as granules, foliar or liquid (drilled at the rip depth, at 36 cm spacings).

Incipient (or nearly) split.

Experiment 2

Applying 8 kg ha^{-1} of granular Mn fertiliser, at 4 cm depth, increased grain yield three-fold, seed size two-fold and the percentage of normal seeds eleven-fold (Table 3). Increasing the rate of applied Mn from 0 to 4 and 8 kg ha^{-1} increased grain yield from 182 to 396 and 567 kg ha^{-1}, average seed size from 34 to 48 and 68 mg (being half of typical seed size - perhaps due to the bad aphid infestation) and the amount of healthy seeds from 3 to 13 and 34 %, respectively. Foliar applied Mn gave less grain yield, a lower incidence of normal seeds and a smaller seed size than did the deep placed (20 cm) Mn treatment.

These improvements were further increased by deeper placement. Increasing Mn placement depth from 4 to 20 cm doubled grain yield and percent normal seeds, increased seed size by 50%, and decreased shrivelled seeds to one-seventh. Increasing depth of Mn placement from 4 to 20 cm increased grain yield from 466 to 945 kg ha^{-1}, amount of normal seeds from 29 to 71% and seed size from 60 to 92 mg, while shrivelled seeds were reduced from 36 to 7%.

The formulation of Mn drilled at seeding as granules or liquid had no effect on any plant measurement at either 4 or 8 kg ha^{-1} of Mn. Foliar applied Mn gave better grain yields, more normal seeds and larger seed size than surface applied Mn (P<0.001), but 8 kg ha^{-1} Mn placed at 20 cm depth was even better than foliar applied Mn (P<0.001). Foliar applied Mn plus drilled Mn granules gave a similar, but slightly better grain yield and other seed effects compared to foliar applied Mn alone.

Table 3. Manganese placement effects in 1988 on lupin DM production and grain yield and quality.

Treat-ment No.	Mn applied (kg ha^{-1}) as			Mn depth (cm)	Dry matter (kg ha^{-1}) taken		Grain Yield (kg ha^{-1})	Seed size (mg)	Seed number per ½ m^2	Percentage of seeds that are			Main stem seeds (%)
	gran-ules†	fol-iar‡	liq-uid§		1 Aug	9 Sep				nor-mal	split+ split#	shriv-illed	
1	0	0	4	4	1177	7230	330	58	728	30	30	40	34
2	0	0	8	4	1177	7187	587	63	608	29	40	31	63
3	0	0	4	8	1184	7128	461	51	535	25	36	39	21
4	0	0	8	8	1239	7153	574	66	526	32	37	31	46
5	0	0	4	12	1176	7112	601	55	560	16	49	35	47
6	0	0	8	12	1223	7239	802	81	506	50	36	14	74
7	0	0	4	16	1178	7159	766	76	649	47	42	11	39
8	0	0	8	16	1186	7011	967	76	622	61	32	7	60

9	0	0	4	20	1256	7203	844	83	581	66	29	6	42
10	0	0	8	20	1229	7245	1045	101	542	77	15	8	67
11	0	0	0	-	1094	6814	182	34	568	3	24	73	63
12	0	1	0	-	-	-	797	71	594	29	29	41	21
13	4	0	0	4	1274	7178	410	48	411	14	38	49	65
14	4	1	0	4	-	-	876	75	505	48	31	21	45
15	8	0	0	4	1206	6879	567	68	623	42	30	28	42
LSD (0.05)					ns	ns	144	27	ns	29	14	12	ns

†, ‡ and § = Mn applied as granules, foliar or liquid (drilled at the rip depth, at 36 cm spacings).

Incipient (nearly) split.

Discussion

Grain yield increased progressively with increasing depth of Mn placement over two seasons. This is the first recorded study, we know of, where a deep-placed micronutrient has increased grain yield relative to a shallow placed micronutrient. (Nable and Web 1993 (Plant and Soil), Halloway 1997 (Thesis))

Benefits have been shown with many plant species from deep placement of macro-nutrients, in particular, deep placed phosphorus in Mediterranean climates. The increased grain yield in this study is considered mostly due to better Mn availability during spring. Surface soil drying has often been shown to restrict root uptake of surface applied nutrients. This has been found for phosphorus in wheat (Piper and de Vries, 1964), lucerne (Simpson and Lipsett, 1973), annual medic (Scott, 1973) and lupins (Jarvis and Bolland, 1991).

Crabtree et al. (1996) showed in a pot experiment that Mn uptake by lupins was reduced as the surface soil containing the Mn dried. This probably also occurred in this study as larger responses occurred with the deep placed Mn in the drier of the two seasons (1988).

Laboratory studies often show that an increase in Mn extractability occurs as soils dry (Ritchie, 1989). However, this is not always the case, and is influenced by several factors including pH, the ability of Mn to complex with organic, sesquioxide and clay mineral particles, and the biological activity of the soil. Despite this complex set of possible interactions Mn uptake by lupins is probably more dependent on survival of the plant root cortex, as a soil dries, than on the solubility of Mn (Crabtree et al., 1996).

Deeper placed Mn requires increasing ripping depth, which involves increased cost, and may prohibit deep (>15 cm) placement of Mn. It is likely therefore, that farmers on these soils, may benefit from placing Mn at a 10-14 cm depth. Farmers may also want to cultivate to these depths to control rhizoctonia (Brennan and Crabtree, 1989), avoid fertiliser toxicity (especially with wider row spacings), increase early root growth by providing softer soil below the seed, and providing deep placement of phosphorus.

The deep placement of Mn with phosphorus should be investigated. Plant roots proliferate where phosphorus is placed (Baeumer and Bakermans 1973, Drew and Saker 1978) and if Mn was placed with phosphorus, the plant may have greater access to Mn, with the potential to further improve grain yield.

In this study twice the recommended rate of applied Mn increased grain yield for all placement depths over yields obtained for the recommended rate (4 kg ha^{-1}). Thus recommended rates of Mn fertilisers may be too low and more than 4 kg ha^{-1} of Mn should be applied where Mn has not previously been applied. However, a combination of drilling 4 kg ha^{-1} of Mn, then doing a tissue test at early pod set, followed by a foliar spray if neccessary, may be a cheaper option, as this research has shown that foliar applications are successful.

Foliar applied Mn gave equal or better grain yields than all soil placement techniques except the 8 kg ha^{-1} rate at 16 and 20 cm depths. However, foliar applied Mn has little residual value for subsequent crops, can cause crop damage (when applied from the ground) and the crop has to be monitored for correct timing of spraying.

The wide row spacing (33 cm) of the applied Mn in the 1987 experiment did not decrease lupin grain yield compared to the 18 cm row spacing. This is perhaps a consequence of lupins having a high requirement for Mn during pod fill (Gartrell and Walton, 1984) which occurs when lupins have had the opportunity to grow roots into the deep subsoil where the Mn was placed. Manganese is more available in acid soils and the Esperance sandplain is acidic with the subsoil (100-150 mm depth) being about 0.3 pH units lower than the topsoil. In this more acidic subsoil Mn might remain more available.

Farmers are therefore encouraged to adopt an integrated approach to Mn application on acidic sandplain soils, using deep placed (~12 cm) Mn, monitoring Mn in foliage in spring and using foliar sprays if needed. More long-term field experiments would be beneficial to better define situations that will respond to deep placed Mn. However, enough benefits currently exist to make deep placement of Mn a desirable practice. Rhizoctonia is greatly reduced by deep working (10 cm) which is often a useful benefit for Western Australian farmers who adopt no-tillage sowing techniques.

Wider rows also enable farmers to seed through thick cereal stubbles and farmers may need to deep band their fertilisers to consistently avoid fertiliser toxicity (Jarvis and Bolland, 1991). There is a potential yield advantage to deep banding both Mn and phosphorus and farmers may benefit by modifying their seeders to deep band a proportion of both these nutrients. Also, there is more moisture available at depth during spring when Mn uptake is essential to plant development. This work indicates that deep placing other micronutrients in environments where topsoils are dry during part of the growing season may be advantagous.

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