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Manganese deficiency - plant nutrition.

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Experimental Summary

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Summary of Conclusions from Results

As reported last year, in 1984, 5 substantial field experiments in the Dale area were planted, sampled either twice or three times during the growing period, ear samples taken, and then harvested for grain yield. Grain yield results were reported. Unfortunately the analyses of the twelve hundred plant tissue samples submitted to the Government Chemical Laboratories were not received until late January and early February this year, delaying the analysis and interpretation of results, and the compilation of this report and submission.

In the 1985 season a total of ten field experiments were planted and sampled, eight in the Dale area and two south of Newdegate. Eight of these were new experiments and two were recropped 1984 experiments.

We now report on conclusions derived from the chemical analyses on samples from the first year experiments and the grain yield results obtained in 1985. Chemical analyses of material from the 1985 programme are not yet to hand.

1. Effectiveness of Different Fertilizers for Correcting Manganese Deficiency in Wheat.

On the pallid zone and gravelly soils of the Great Southern and South-East wheatbelt that produce manganese deficient wheat crops it had previously been (i) shown that 3.8 kg Mn ha^{-1} as manganese sulphate mixed dry with superphosphate and drilled with the seed is often, but not always, sufficient to fully correct the deficiency. (ii) shown that ammonium sulphate mixed dry with superphosphate and drilled with the seed markedly increases the availability of native manganese present in the soils, alleviating and sometimes fully correcting Mn deficiency without additional Mn fertiliser. Combinations of ammonium sulphate and Mn fertiliser were fully effective in the only two experiments in which they were tried. (iii) observed in farmers' paddocks that Agras appeared to markedly relieve the severity of Mn deficiency but had not been experimentally compared with ammonium sulphate. (iv) shown that urea topdressed after seeding was clearly inferior to ammonium sulphate in the correction of Mn deficiency in two experiments. (v) shown in experiments in the early 1950s that in dry mixes manganese sulphate was technically superior in correcting Mn deficiency compared with the finely ground manganous oxides then tested, while manganic oxides had very low effectiveness. Adelaide-Wallaroo fertilisers in the 1970s began producing a form of manganous oxide which compared favourably in price to manganese sulphate, and which when incorporated into moist superphosphate before granulation, satisfactorily corrected manganese deficiency in cereals under South Australian conditions.

Little objective data is available on the comparative efficiency of the various combinations of Mn form, nitrogen fertiliser form, and method of incorporation into mixtures with superphosphate in increasing Mn uptake by wheat. A major thrust of this project is to ascertain the relative technical effectiveness of various combinations of these on W.A. soils as a basis for the development of new fertilisers with superior cost-effectiveness in the correction of manganese deficiency in wheat.

Results available to date from the first eighteen months of this project on these aspects are summarised:

(i) <u>Form of Manganese in Fertiliser</u>

(a) Effects on Mn concentration in wheat tissues

In the absence of ammonium sulphate the manganous oxide was inferior to manganese sulphate in raising Mn concentration in wheat tissues. However, with ammonium sulphate both forms were equally effective. Incorporation of the oxide into the superphosphate pellet had little effect without ammonium sulphate, whereas incorporation appeared to increase the effectiveness of the oxide with ammonium sulphate. For manganese sulphate, incorporation appeared to increase effectiveness slightly both without and with ammonium sulphate. (Tables 1, 2, 4, 10, 11).

(b) Effects on Mn uptake into whole tops, second sampling (Tables 5 and 6)

The variability in dry matter yields was large relative to the differences in effects on uptake of the different manganese form treatments, obscuring any small differences. Without ammonium sulphate, manganese sulphate increased Mn uptake by 47%, and the oxide by 38%. With ammonium sulphate, manganese sulphate increased Mn uptake by 80%, and the oxide by 69%.

It is interesting to note that correcting manganese deficiency by applying manganese fertilisers increased nitrogen uptake into the tops at the time of the second sampling (Table 8) by about 7% without ammonium sulphate and about 15% with ammonium sulphate.

(c) Effects on grain yield (Table 12), and profitability (Table 13).

Without ammonium sulphate, manganese sulphate increased grain yield by 0.34 t/ha^{-1} (30%) and the oxide by 0.29 t/ha^{-1} (26%). With ammonium sulphate manganese sulphate increased grain yield by 0.21 t/ha^{-1} (18%), and the oxide by 0.09 t/ha^{-1} (8%).

If wheat is valued at \$120 t^{-1}, without ammonium sulphate, manganese sulphate increased net returns by \$29.40 ha^{-1}, and the oxide by \$24.50 ha^{-1}. With ammonium sulphate, manganese sulphate increased net returns by \$16.50 ha^{-1} and the oxide by \$4.30. Were wheat priced at \$160 t^{-1} the figures are \$42.80, \$36.90, \$24.70 and \$7.60 respectively.

(ii) <u>Method of Incorporation of Mn Fertilisers into Mixtures</u>

Generally the differences between methods of incorporation in correcting Mn deficiency were small and inconsistent. However the "wet" mixed Agras with manganese sulphate consistently increased Mn concentration and uptake more than the "dry" mix and usually more than any other treatment. e.g. Table 6 shows the "wet" mixing of Agras and manganese sulphate increased Mn uptake into tops at the second sampling by 86% compared with the "dry" mix and 236% compared with the plain superphosphate treatment. It should be noted that the method of

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preparing the "wet" Agras-manganese sulphate mix differed from other "wet" mixes in that a slurry of manganese sulphate was added to the Agras and tumbled in a concrete mixer giving a coating of manganese sulphate on the outside of the Agras granuales. All the other "wet" mixed were made by incorporating the manganese material with or without ammonium sulphate into warm, moist fresh superphosphate and then tumbling to form granules which more of less incorporated all the materials.

(iii) Form of Nitrogen Fertiliser

Ammonium sulphate and Agras No.1 were drilled with the seed, whereas urea was topdressed immediately after seeding. For Agras and urea these are the methods of application normally used in common practice. If drilled with the seed, urea usually kills the germinating plant. Two earlier experiments showed that urea topdressed was much less effective in increasing manganese uptake than ammonium sulphate drilled. However the urea topdressed treatments were included because urea, by virtue of its lower price per unit of N, is a popular fertiliser and farmers want to see the comparison with the alternatives. An earlier experiment showed that ammonium sulphate topdressed was markedly inferior to drilled but superior to urea topdressed in correcting manganese deficiency. Therefore there was no need to include ammonium sulphate topdressed treatments in these experiments.

(a) Effects on Mn concentration in wheat tissues (Tables 1,2,4, 10, 11)

In the absence of Mn application and in dry mixes with Mn sulphate, ammonium sulphate and Agras produced similar increases in Mn concentration in wheat plant tissues. As noted earlier the "wet" coating of Mn sulphate on Agras produced superior effects. Urea topdressed also increased Mn concentration but effects were small and barely reflected in final grain Mn concentrations.

Compared with corresponding nil nitrogen treatments at the 2nd sampling ammonium sulphate and Agras alone both increased Mn concentration in whole tops by 30%, the increase with urea alone was 7%; in dry mixes with Mn sulphate the increase with ammonium sulphate and Agras was 37%, urea 8% and the "wet" Mn sulphate-Agras was up 67% (Table 4).

(b) Effects on Mn uptake into whole tops, 2nd sampling (Tables 5 and 6).

The nitrogen fertilisers increased plant growth by decreasing the degree of nitrogen deficiency (as well as the degree of Mn deficiency in some treatments). As noted above, the increase in Mn uptake was relatively greater than the increase in dry matter yield as reflected by the higher Mn concentrations where nitrogen fertiliser was applied.

In the absence of Mn fertiliser, and in dry mixes with Mn sulphate, ammonium sulphate increased dry matter yields more than Agras apparently due to a slightly superior nitrogen supply (Mn concentrations were almost identical) (Tables 3 and 9), although the possibility remains that it was due to alleviation of Mn deficiency.

Compared with corresponding nil nitrogen treatments at the 2nd sampling, ammonium sulphate increased Mn uptake by 112%, 125% and 164% with nil Mn sulphate, Mn sulphate mixed dry and Mn sulphate mixed "wet" respectively. For Agras the increases were 81%, 110% and 182% respectively, and for urea topdressed 48%, 64% and 53% (Table 6).

Nitrogen concentrations in whole tops at the 2nd sampling show a strong Piper-Steinjberg effect in that the higher the dry matter yield (Table 3) the lower the N concentration (Table 8) even where the yield response appeared to be solely due to the alleviation of nitrogen stress. Mn fertiliser application also tended to increase N uptake.

(c) Effects on grain yield (Table 12) and profitability (Table 13)

Without Mn fertiliser, ammonium sulphate increased grain yield by 0.50 t/ha^{-1} (44%), Agras No. 1 by 0.37 t/ha^{-1} (33%) and urea by 0.30 t/ha^{-1} (27%). With dry mixes of Mn sulphate the grain yield increases were 0.44 t/ha^{-1} (38%), 0.25 t/ha^{-1} (21%) and 0.24 t/ha^{-1} (21%) respectively.

With wheat valued at $120 t^{-1}, without Mn fertiliser the net return to ammonium sulphate was $24.60, to Agras $12.40 and to urea $8.90. With Mn sulphate the extra net return to ammonium sulphate above Mn sulphate alone, was $11.70 but was slightly negative for Agras No. 1 or urea.

With wheat valued at $160 t^{-1}, without Mn fertiliser the net return to ammonium sulphate was $44.60 to Agras $27.20 and to urea $20.90. With Mn sulphate, the extra net return to ammonium sulphate above Mn sulphate alone was $26.50, to Agras $8.30 and to urea $3.50.

Thus the value of the alternative fertilisers is highly sensitive to cost price ratios. Despite the marked improvements in Mn and N uptakes and grain yields, where nitrogen fertilisers were applied, at current cost price ratios the only treatments where the application of nitrogen fertiliser in addition to Mn sulphate was profitable was where ammonium sulphate was applied. Combinations of Agras or urea with Mn sulphate were not profitable. However were wheat $160 t^{-1} (and at current N fertiliser prices or proportional decrease in cost price ratio) a wet slurried Agras manganese mix would be highly attractive particularly as it can be applied at a lower rate than comparable ammonium sulphate mixes (eg 195 vs 315 kg/ha^{-1}). The return varied markedly between experiments. On the more severely nitrogen deficient site (84NO4, which unlike 84NO5 was not accidentally grazed bare early by sheep) that had good yield potential very worthwhile returns were obtained to ammonium sulphate or Agras even with Mn sulphate.

As a direct result of the interest stimulated by these experiments CSBP have produced a formulation of Agras and Mn and have prepared 1.5 million dollars worth for application to about 33,000 ha this year. This may produce an extra 9,000 t of wheat which may earn W.A. an extra $1.5 m export revenue, but no increase in net profit to farmers if they applied it across the range of Mn deficient situations in the same proportion as encountered in our experiments.

Thus with current cost price ratios the farmer must choose his fertilisers very carefully in relation to the paddock to be cropped taking into account the nitrogen status and pattern of distribution of Mn deficiency in each paddock to be cropped.

As a guide:

(i) N status moderate or higher, Mn deficiency in small patches which cannot be conveniently drilled separately to Mn adequate areas - use phosphate only and apply two Mn sprays three weeks apart to larger Mn deficient patches.

(ii) N status moderate or higher, Mn deficiency in patches that can be conveniently drilled separately - use Mn superphosphate on Mn deficient areas and phosphate-only on remainder.

(iii) N status low, Mn deficiency in patches which cannot be conveniently drilled separately - use Agras No. 1 over whole paddock. If necessary spray any Mn deficient patches as in (i).

(iv) N status low, Mn deficiency in patches that can be conveniently drilled separately - use Agras manganese on deficient patches and Agras No. 1 on remainder.

Table 1 Manganese concentration in whole tops. 1st sampling
Mn (µg g^{-1})

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1} Nil	$MnSO_4$ 15 Dry	Wet	MnO = 15 Dry	Wet
	84NO3 7.8.84				
Super 150 (13.7 P)	16.0	21.0	24.0	18.7	22.3
Super 150 + S/A (31.5 N)	18.7	27.3	34.0	30.3	34.7
Agras 180 (= P & N)	18.7	27.7	34.3		
Super 150 + Urea (31.5 N)	16.0	23.2	26.3		
	84NO4 31.7.84				
Super 150 (13.7 P)	12.7	38	32	25	25
Super 150 + S/A (31.5 N)	32	54	41	48	54
Agras 180 (= P & N)	21	40	69		
Super 150 + Urea (31.5 N)	23	38	56		
	84NO5 (Not Done)				
Super 150 (13.7 P)					
Super 150 + S/A (31.5 N)					
Agras 180 (= P & N)					
Super 150 + Urea (31.5 N)					

Table 2 Manganese concentrations in Youngest Expanded Blades, 1st sampling

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1} Nil	$MnSO_4$ 15 Dry	Wet	MnO = 15 Dry	Wet
	84NO3 7.8.84				
Super 150 (13.7 P)	11.6	15.7	17.0	14.0	14.3
Super 150 + S/A (31.5 N)	16.3	20.7	22.0	21.3	24.3
Agras 180 (= P & N)	16.3	19.0	19.6		
Super 150 + Urea (31.5 N)	13.7	17.0	19.0		
	84NO4 31.7.84				
Super 150 (13.7 P)	12.3	26.3	32.0	20.0	18.7
Super 150 + S/A (31.5 N)	25.3	48.3	53.3	44.7	52.7
Agras 180 (= P & N)	23.3	44.0	68.3		
Super 150 + Urea (31.5 N)	18.7	35.0	36.7		
	84NO5 15.8.84				
Super 150 (13.7 P)	7.4	13.9	16.7	10.9	14.0
Super 150 + S/A (31.5 N)	16.7	27.3	32.7	31.7	34.3
Agras 180 (= P & N)	16.7	22.3	41.3		
Super 150 + Urea (31.5 N)	12.0	18.0	21.0		

Table 3 Whole tops, dry matter (t ha^{-1}) at 2nd sampling

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1}				
	Nil	$MnSO_4$ 15		MnO = 15	
		Dry	Wet	Dry	Wet
	84NO3	18.9.84			
Super 150 (13.7 P)	2.23	2.69	2.31	2.46	2.37
Super 150 + S/A (31.5 N)	2.89	3.00	2.74	3.12	2.74
Agras 180 (= P & N)	2.44	2.53	3.10		
Super 150 + Urea (31.5 N)	2.48	3.08	2.86		
	84NO4	19.9.84			
Super 150 (13.7 P)	0.94	1.03	1.13	1.37	1.06
Super 150 + S/A (31.5 N)	1.56	1.70	2.04	1.77	1.60
Agras 180 (= P & N)	1.43	1.66	1.74		
Super 150 + Urea (31.5 N)	1.32	1.64	1.32		
	84NO5	21.9.84			
Super 150 (13.7 P)	0.53	0.64	0.70	0.74	0.60
Super 150 + S/A (31.5 N)	1.05	1.06	1.13	1.15	1.03
Agras 180 (= P & N)	0.88	0.99	1.04		
Super 150 + Urea (31.5 N)	0.71	1.15	0.87		

Table 4 Manganese concentration in whole tops, 2nd sampling

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1} Nil	$MnSO_4$ 15 Dry	Wet	MnO = 15 Dry	Wet
	84NO3 18.9.84				
Super 150 (13.7 P)	6.4	7.5	8.0	7.0	7.3
Super 150 + S/A (31.5 N)	7.7	8.9	10.3	9.3	8.2
Agras 180 (= P & N)	7.9	8.7	12.3		
Super 150 + Urea (31.5 N)	6.3	7.6	9.5		
	84NO4 19.9.84				
Super 150 (13.7 P)	7.6	9.6	10.6	9.3	9.3
Super 150 + S/A (31.5 N)	10.0	12.3	12.1	11.3	12.7
Agras 180 (= P & N)	10.7	13.3	15.3		
Super 150 + Urea (31.5 N)	8.0	8.4	9.3		
	84NO5 21.9.84				
Super 150 (13.7 P)	6.1	7.3	7.6	7.4	7.1
Super 150 + S/A (31.5 N)	8.4	10.2	12.3	10.4	11.0
Agras 180 (= P & N)	7.4	9.6	11.9		
Super 150 + Urea (31.5 N)	7.3	7.6	9.4		
	Mean of 3 experiments				
Super 150	6.7	8.1	8.7	7.9	7.9
Super 150 + S/A (31.5 N)	8.7	10.5	11.6	10.3	10.6
Agras 180 (= P & N)	8.7	10.5	13.2		
Super 150 + Urea (31.5 N)	7.2	7.9	9.4		
	Mean of 3 experiments as % of Nil Mn - Nil N				
Super 150	100	121	130	118	118
Super 150 + S/A (31.5 N)	130	157	173	154	158
Agras 180 (= P & N)	130	157	197		
Super 150 + Urea (31.5 N)	107	118	140		

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Table 5 Manganese uptakes (g ha^{-1}) in whole tops, 2nd sampling

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1}				
	Nil	$MnSO_4$ 15		MnO = 15	
		Dry	Wet	Dry	Wet
	84NO3 18.9.84				
Super 150 (13.7 P)	15.3	21.3	18.8	16.8	17.6
Super 150 + S/A (31.5 N)	22.4	27.1	28.3	29.1	22.5
Agras 180 (= P & N)	19.5	22.4	38.2		
Super 150 + Urea (31.5 N)	15.6	23.2	28.0		
	84NO4 19.9.84				
Super 150 (13.7 P)	7.1	9.9	12.3	12.8	9.5
Super 150 + S/A (31.5 N)	15.7	20.7	24.5	20.3	20.2
Agras 180 (= P & N)	15.4	22.3	27.2		
Super 150 + Urea (31.5 N)	10.6	13.7	13.4		
	84NO5 21.9.84				
Super 150 (13.7 P)	3.3	4.7	5.5	5.4	4.2
Super 150 + S/A (31.5 N)	8.9	10.8	14.0	11.9	11.4
Agras 180 (= P & N)	6.6	9.5	12.4		
Super 150 + Urea (31.5 N)	6.4	8.8	8.2		

Table 6 Manganese uptakes in whole tops, 2nd sampling expressed as percentage of the Superphosphate only treatment

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1}				
	Nil	$MnSO_4$ 15		MnO = 15	
		Dry	Wet	Dry	Wet
		84NO3	18.9.84		
Super 150 (13.7 P)	100	139	123	110	115
Super 150 + S/A (31.5 N)	146	177	185	190	147
Agras 180 (= P & N)	127	146	250		
Super 150 + Urea (31.5 N)	102	152	183		
		84NO4	19.9.84		
Super 150 (13.7 P)	100	139	173	180	134
Super 150 + S/A (31.5 N)	221	292	345	286	285
Agras 180 (= P & N)	217	314	383		
Super 150 + Urea (31.5 N)	149	193	189		
		84NO5	21.9.84		
Super 150 (13.7 P)	100	142	167	164	127
Super 150 + S/A (31.5 N)	270	327	424	361	345
Agras 180 (= P & N)	200	289	376		
Super 150 + Urea (31.5 N)	194	267	248		
	Mean of 3 experiments				
Super 150	100	140	154	151	125
Super 150 + S/A (31.5 N)	212	265	318	279	259
Agras 180 (= P & N)	181	250	336		
Super 150 + Urea (31.5 N)	148	204	207		

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Table 7 Nitrogen Uptakes (kg ha^{-1}) in whole tops, 2nd sampling

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1}				
	Nil	$MnSO_4$ 15		MnO = 15	
		Dry	Wet	Dry	Wet
	84NO3 18.9.84				
Super 150 (13.7 P)	46.7	54.9	43.5	49.0	47.7
Super 150 + S/A (31.5 N)	51.6	60.4	48.1	60.0	49.7
Agras 180 (= P & N)	48.8	51.9	62.5		
Super 150 + Urea (31.5 N)	53.6	53.0	53.3		
	84NO4 19.9.84				
Super 150 (13.7 P)	22.4	22.7	23.1	28.8	24.4
Super 150 + S/A (31.5 N)	32.4	35.4	41.1	44.9	33.4
Agras 180 (= P & N)	31.6	34.0	33.4		
Super 150 + Urea (31.5 N)	28.7	32.8	27.6		
	84NO5 21.9.84				
Super 150 (13.7 P)	12.9	12.3	13.4	14.3	12.2
Super 150 + S/A (31.5 N)	19.2	18.4	20.4	20.8	18.7
Agras 180 (= P & N)	17.1	18.9	19.4		
Super 150 + Urea (31.5 N)	15.6	21.7	18.3		
	Mean of 3 experiments				
Super 150	27.3	30.0	26.7	30.7	28.1
Super 150 + S/A (31.5 N)	34.4	38.1	36.5	41.9	33.9
Agras 180 (= P & N)	32.5	34.9	38.4		
Super 150 + Urea (31.5 N)	32.6	35.8	33.1		

Table 8 Nitrogen concentrations in whole tops, 2nd sampling (%N)

P & N Fertilizer	Nil	Mn (3.8 kg Mn ha^{-1}) $MnSO_4$ Dry	Wet	Mn oxide Dry	Wet
	84NO3	18.9.84			
Super 150	2.11	2.02	1.88	1.84	2.05
Super 150 + S/A	1.80	2.03	1.76	1.93	1.82
Agras No. 1 180	2.01	2.04	2.02		
Super 150 + Urea	2.23	1.72	1.87		
	84NO4	19.9.84			
Super 150	2.38	2.23	2.09	2.12	2.28
Super 150 + S/A	2.09	2.10	2.01	1.99	2.11
Agras No. 180	2.23	2.06	1.94		
Super 150 + Urea	2.17	2.01	2.14		
	84NO5	21.9.84			
Super 150	2.52	1.94	1.92	1.94	1.95
Super 150 + S/A	1.81	1.73	1.79	1.82	1.73
Agras No. 1 180	1.94	1.90	1.87		
Super 150 + Urea	2.24	1.91	2.14		
	Mean of 3 experiments				
Super 150	2.34	2.06	1.96	1.97	2.09
Super 150 + S/A	1.90	1.95	1.85	1.91	1.89
Agras No. 1	2.06	2.00	1.94		
Super 150 + Urea	2.21	1.88	2.05		

Table 9 Nitrogen Uptakes in whole tops, 2nd sampling expressed as percentage of the Superphosphate only treatment

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1}				
	Nil	$MnSO_4$ 15		MnO = 15	
		Dry	Wet	Dry	Wet
	84NO3 18.9.84				
Super 150 (13.7 P)	100	118	93	105	102
Super 150 + S/A (31.5 N)	110	129	103	128	106
Agras 180 (= P & N)	104	111	134		
Super 150 + Urea (31.5 N)	115	113	114		
	84NO4 19.9.84				
Super 150 (13.7 P)	100	101	103	129	109
Super 150 + S/A (31.5 N)	145	158	183	200	149
Agras 180 (= P & N)	141	152	149		
Super 150 + Urea (31.5 N)	128	146	123		
	84NO5 21.9.84				
Super 150 (13.7 P)	100	110	98	112	103
Super 150 + S/A (31.5 N)	126	140	134	153	124
Agras 180 (= P & N)	119	128	141		
Super 150 + Urea (31.5 N)	119	131	121		
	Mean of 3 experiments				
Super 150	100	110	98	115	105
Super 150 + S/A (31.5 N)	127	142	140	160	126
Agras 180 (= P & N)	121	130	141		
Super 150 + Urea (31.5 N)	121	130	119		
	Δ N c.f. Super only. Mean 3 experiments				
Super 150	0	4		10	
Super 150 + S/A (31.5 N)	27	41		43	
Agras 180 (= P & N)	21	36			
Super 150 + Urea (31.5 N)	21	25			

Table 10 Manganese concentrations in Youngest Expanded Blades, 2nd sampling

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1} Nil	$MnSO_4$ 15 Dry	$MnSO_4$ 15 Wet	MnO = 15 Dry	MnO = 15 Wet
	84NO3 18.9.84				
Super 150 (13.7 P)	9.6	10.9	10.9	10.3	10.2
Super 150 + S/A (31.5 N)	11.3	11.7	14.0	10.9	12.3
Agras 180 (= P & N)	11.2	12.0	13.0		
Super 150 + Urea (31.5 N)	9.9	10.7	10.7		
	84NO4 19.9.84				
Super 150 (13.7 P)	8.8	11.2	12.3	10.5	10.5
Super 150 + S/A (31.5 N)	12.0	13.3	13.7	13.7	15.0
Agras 180 (= P & N)	10.9	13.0	18.0		
Super 150 + Urea (31.5 N)	10.2	11.7	11.5		
	84NO5 21.9.84				
Super 150 (13.7 P)	9.3	9.4	11.5	10.2	8.8
Super 150 + S/A (31.5 N)	11.3	16.0	17.0	13.0	15.7
Agras 180 (= P & N)	12.3	14.0	17.7		
Super 150 + Urea (31.5 N)	9.9	13.3	12.7		
	Mean of 3 experiments				
Super 150	9.2	10.5	11.6	10.3	9.8
Super 150 + S/A (31.5 N)	11.5	13.7	14.9	12.5	14.3
Agras 180 (= P & N)	11.1	13.0	16.2		
Super 150 + Urea (31.5 N)	10.0	11.9	11.6		

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Table 11 Manganese concentration in grain ($\mu g\ g^{-1}$)

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1}				
	Nil	$MnSO_4$ 15		MnO = 15	
		Dry	Wet	Dry	Wet
		84NO3			
Super 150 (13.7 P)	5.5	5.7	6.0	6.1	5.1
Super 150 + S/A (31.5 N)	6.0	7.1	6.7	8.4	6.5
Agras 180 (= P & N)	5.6	6.3	7.8		
Super 150 + Urea (31.5 N)	5.4	6.3	6.7		
		84NO4			
Super 150 (13.7 P)	4.9	7.3	8.7	7.4	6.2
Super 150 + S/A (31.5 N)	7.9	9.3	8.4	9.5	8.4
Agras 180 (= P & N)	6.7	8.0	9.8		
Super 150 + Urea (31.5 N)	6.1	7.4	6.6		
		84NO5			
Super 150 (13.7 P)	5.0	5.6	5.8	4.9	6.8
Super 150 + S/A (31.5 N)	7.0	7.7	9.5	8.8	8.6
Agras 180 (= P & N)	5.3	7.4	8.7		
Super 150 + Urea (31.5 N)	4.7	6.5	6.9		
	Mean of 3 experiments				
Super 150	5.1	6.2	6.8	6.1	6.0
Super 150 + S/A (31.5 N)	7.0	8.0	8.2	8.9	7.8
Agras 180 (= P & N)	5.9	7.2	8.8		
Super 150 + Urea (31.5 N)	5.4	6.7	6.7		

Table 12 Effects of acidifying nitrogen fertilizers on the uptake of manganese by wheat from native soil supplies and fertilizer manganese supplied as sulphate as an oxide, either dry mixed or incorporated into the fertilizer granule. Wheat grain yields t ha^{-1}

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg/ha^{-1} Nil	$MnSO_4$ 15 Dry	$MnSO_4$ 15 Wet	MnO = 15 Dry	MnO = 15 Wet
84NO3, Rep 1, B. Schillings					
Super 150 (13.7 P)	1.5	2.2	1.9	2.0	2.1
Super 150 + S/A (31.5 N)	1.7	2.4	2.4	2.4	2.4
Agras 180 (= P & N)	2.0	2.0	2.2		
Super 150 + Urea (31.5 N)	1.7	2.2	2.3		
84NO3, Mean of 3 reps					
Super 150 (13.7 P)	1.9	2.2	2.2	2.1	2.1
Super 150 + S/A (31.5 N)	2.3	2.5	2.5	2.4	2.4
Agras 180 (= P & N)	2.2	2.2	2.4		
Super 150 + Urea (31.5 N)	2.1	2.5	2.5		
84NO4, E. Crisps					
Super 150 (13.7 P)	0.9	1.4	1.5	1.6	1.2
Super 150 + S/A (31.5 N)	1.7	2.0	1.9	1.8	1.7
Agras 180 (= P & N)	1.5	1.9	1.9		
Super 150 + Urea (31.5 N)	1.5	1.6	1.5		
84NO5, R. Huddleston					
Super 150	0.6	0.7	0.8	0.8	0.7
Super 150 + S/A (31.5 N)	0.9	1.1	1.0	1.0	1.0
Agras 180 (= P & N)	0.8	0.9	1.0		
Super 150 + Urea (31.5 N)	0.7	0.9	0.9		
Mean of 3 experiments					
Super 150	1.13	1.43	1.50	1.50	1.33
Super 150 + S/A (31.5 N)	1.63	1.87	1.80	1.73	1.70
Agras 180	1.50	1.67	1.77		
Super 150 + Urea (31.5 N)	1.43	1.67	1.63		
Mean of 3 experiments as % of Nil Mn - Nil N					
Super 150	100	127	133	133	118
Super 150 + S/A (31.5 N)	144	165	159	153	150
Agras 180	133	148	157		
Super 150 + Urea (31.5 N)	127	148	144		

Table 13 Additional cost* of Manganese and Nitrogen fertilisers above plain superphosphate at 150 kg ha^{-1} and Gross Margin Returns.

P & N Fertiliser	Mn rates in $MnSO_4$ equivalent kg ha^{-1} Nil	$MnSO_4$ 15 Dry	$MnSO_4$ 15 Wet	MnO = 15 Dry	MnO = 15 Wet
Extra cost of N & Mn ($) Mean of 3 experiments					
Super 150	0	10.8	10.8	8.7	8.7
Super 150 + S/A (150 kg ha^{-1})	35.4	43.5	43.5	41.4	41.4
Agras 180 (= P & N)	32.0	43.3	43.3		
Super 150 + Urea 68.5 kg ha^{-1}	27.1	37.9	37.9		
With wheat @ $120/t, Gross Margin to extra Mn & N - 3 experiments					
Super 150	0	25.2	33.6	35.7	13.3
Super 150 + S/A 150	24.6	45.3	36.9	30.8	27.0
Agras 180	12.4	21.5	33.5		
Super 150 + Urea 68.5	8.9	26.9	22.1		
With wheat @ $160/t, Gross Margins to extra Mn & N - 3 experiments					
Super 150	0	37.2	48.4	50.5	23.3
Super 150 + S/A 150	44.6	74.9	63.7	54.6	49.8
Agras 180	27.2	43.1	59.1		
Super 150 + urea 68.5	20.9	48.5	42.1		

P & N Fertiliser	Nil	$MnSO_4$ 15	MnO = 15
With wheat @ $120/t, Gross Margins to extra Mn & N - 3 experiments			
Super 150	0	29.4	24.5
Super 150 + S/A 150	24.6	41.1	28.9
Agras 180	12.4	27.5	
Super 150 + Urea 68.5	8.9	24.5	
With wheat @ $160/t, Gross Margin to extra Mn & N - 3 experiments			
Super 150	0	42.8	36.9
Super 150 + S/A 150	44.6	69.3	52.2
Agras 180	27.2	51.1	
Super 150 + Urea 68.5	20.9	45.3	

* Basis of calculations:
Super $132/t
Ammonium Sulphate $200/t
Agras No. 1 $288/t
Urea $322/t + $5/ha topdressing cost
Manganese sulphate (25%) $520/t
Manganous Oxide 75% of price of Mn sulphate per unit of Mn
Mixing fee of all mixes $18/t of final mix
Wheat $120/t or $160/t.

2. Apparent Critical Levels in Field Experiments

Table 14 summarises the apparent critical levels for 35 comparisons between manganese concentrations in a tissue and the dry matter yield of that or another tissue at that or another time.

It should be borne in mind that samples were taken at random along plots with no attempt to select uniform plants showing a particular level of deficiency or otherwise. Therefore some samples contained a mixture of deficient and adequate plants in which cases the apparent critical level will be higher than the actual concentration in the deficient plants even at the time of sampling. This may have particularly applied to the 84NO4 first sampling as the occurrence of Mn deficiency symptoms appeared patchier in this experiment than in the others.

An encouraging feature of these results is that for diagnosis (ie. for differentiating between healthy plants and those suffering growth limitation due to Mn deficiency at the time of sampling) the concentration in youngest expanded blades (YEBS) was acceptably constant (except for 84NO4, T1) ranging from 10.5 to 12.5 µg Mn g^{-1} in the YEBS T2 [Mn] x WT D.M. T2 and was < 12 µg Mn g^{-1} in 84NO3 YEBS T1 [Mn] x WT D.M. T1. It is also worth noting that the apparent critical levels based on YEBS T2 [Mn] were little different for WT T2 compared with grain yields. In glasshouse studies with minimal within sample variation in Mn status Loneragan (unpublished) has found critical levels for YEBS of 10 µg Mn g^{-1}.

The relationships between grain Mn concentration and grain yield are also of considerable interest and despite the variation between experiments of some 1.5 µg Mn g^{-1} in critical level between experiments the data suggest that a level of < 6.5 µg Mn g^{-1} indicates deficiency and above 8.0 µg Mn g^{-1} indicates that Mn deficiency probably did not limit grain yield. The results are promising enough to warrant further investigation.

The differences in critical levels based on the [Mn] WT T2 in diagnosing growth limitations due to Mn deficiency at T2 or grain yield restriction appeared greater both between experiments and between yield parameters (for WT D.M. T2 diagnosis, the range of uncertainty in C.L. was 7.2 to 10.5 µg Mn g^{-1} and for grain yield prediction, 7.3 to 10.8 µg Mn g^{-1}).

The difficulties in predicting Mn status of plants at later stages of growth from those taken earlier are illustrated in the change in apparent C.L.s for WT T1 [Mn] and YEBS [Mn] T1 through WT T2 and grain yield.

Table 14 *Apparent Field Critical Level Relationships Between Mn concentrations of tissues taken at different times versus Plant or Grain Yield at different times. (Range shown in parenthesis).

Sampled Tissue	Expt No.	Date Sampled	Apparent Critical Level (μg Mn g^{-1}) in Tissue in Relationship to Dry Matter Yield of		
			WT T1	WT T2	Grain Yield
			D		
WT T1	84NO3	7.8.84	< 16	18.5 (18.5-19.0)	21 (20-23)
	84NO4	31.7.84	25	30 (25-35)	35 (35-55)
			D		
YEBS T1	84NO3	7.8.84	< 12	16.0 (15.0-16.5)	17.5 (17.0-17.5)
	84NO4	31.7.84	24	25 (25-37)	35 (30-40)
	84NO5	15.8.84		17 (15-20)	23 (18-23)
	84NO7	31.7.84			27.5
				D	
WT T2	84NO3	18.9.84		7.5 (7.2-7.8)	9.0 (7.3-9.0)
	84NO4	19.9.84		10.0 (9.5-10.5)	10.8 (9.5-10.8)
	84NO5	21.9.84		7.4 (7.3-7.5)	9.0 (7.5-9.8)
	84NO7	21.9.84		7.5?	8.5
				D	
YEBS T2	84NO3	18.9.84		11.0 (10.6-11.4)	11.3 (10.3-11.4)
	84NO4	19.9.84		12.0 (10.5-12.5)	12.0 (11.5-12.5)
	84NO5	21.9.84		10.5 (10.5-12.3)	12.5 (12.5-14.0)
	84NO7 (a)	21.9.84			12.0 (10.7-12.7)
	(b)	17.9.84			11.0
					D
Grain	84NO3				6.5 (6.0-6.5)
	84NO4				8.0 (7.5-8.0)
	84NO5				7.2 (6.0-7.2)
	84NO7				6.5

(a) by W.A.D.A.

(b) By Murdoch University

D: Relationships with best chance of constancy and therefore most likely to be of value for diagnostic purposes. Remainder are expected to vary but may provide some basis for prediction.

* Apparent Field Critical Level, bearing in mind that due to the patchy occurrence of Mn deficiency in the study conditions, and that in the comparisons other than indicated by "D", time has elapsed between when the samples were taken and the growth or yield measurement.

3. Differences between Wheat Varieties in Ability to Absorb and Utilize Soil and Fertiliser Manganese under Deficiency and Near-Deficiency Conditions in the Great Southern.

In the 1984 experiment (84NO6 - Tables 15-20) there appeared to be substantial differences between varieties in their abilities to absorb either or both soil and fertiliser manganese. However, variability within the experimental site was, unfortunately high. Thus it is too early at this stage to talk about these results with much certainty. It does appear that Eradu had low ability to absorb soil Mn in the 1984 and in both 1984 and 1985 its yields appeared to suffer more than varieties like Canna or Aroona.

Eradu is a recommended variety in many of the areas affected by Mn deficiency. There may prove to be a need to change these recommendations. (See also Table 21, 85NO68).

4. Results 1985

Grain yield results of 1985 experiments are shown in Tables 22 onwards but not discussed due to lack of required chemical analyses data.

5. Publicaions Arising

Johnston, T.C., Gartrell, J.W. and Riley, M.M. The effectiveness of manganese and nitrogen fertilisers on manganese uptake and correction of manganese deficiency in wheat in south-western Western Australia (In preparation).

Table 15   84NO6 YEBS T1 [Mn]

Variety	LSD .05 = 10.64 0 Mn		15 $MnSO_4$		
Jacup	27.67	7	46.33	1	***
Eradu	26.67	10	43.67	5	**
Bokal	30.00	4	36.33	13	ns
Gamenya	26.67	10	42.00	7	**
Bodallin	37.67	1	44.33	4	ns
Egret	32.00	3	43.00	6	*
Canna	27.33	8	39.67	10	*
Lance	28.00	6	38.33	12	ns
Miling	26.67	10	45.67	2	***
Madden	23.33	14	35.67	14	*
Tincurrin	34.00	2	39.00	11	ns
Millewa	25.00	13	40.33	9	**
Gutha	29.33	5	40.67	8	*
Aroona	27.00	9	45.00	3	**

Table 16   84NO6 Mn Uptakes T1

Variety	LSD .05 = 4.32 0 Mn		15 $MnSO_4$		
Jacup	7.60	14	17.40	6	***
Eradu	9.17	11	14.73	13	*
Bokal	9.17	11	15.73	11	**
Gamenya	11.73	5	20.77	1	***
Bodallin	15.60	1	16.97	8	ns
Egret	10.73	8	16.20	10	*
Canna	12.70	3	14.93	12	ns
Lance	9.23	10	14.57	14	*
Miling	11.60	6	16.87	8	*
Madden	10.70	9	19.93	3	***
Tincurrin	12.33	4	20.73	2	***
Millewa	13.57	2	17.07	7	ns
Gutha	8.67	13	18.33	5	***
Aroona	11.07	7	18.73	4	***

Table 17 84NO6 YEBS T2 [Mn]

Variety	LSD .05 = 3.66 O Mn	15 $MnSO_4$	
Jacup	13.67	17.67	*
Eradu	13.33	15.67	ns
Bokal	12.67	15.67	ns
Gamenya	14.00	16.67	ns
Bodallin	18.67	22.33	*
Egret	17.67	21.33	*
Canna	17.67	19.00	ns
Lance	14.33	13.67	ns
Miling	14.00	14.67	ns
Madden	13.67	16.67	ns
Tincurrin	13.67	16.00	ns
Millewa	14.67	16.33	ns
Gutha	13.00	15.33	ns
Aroona	15.67	20.00	*

Table 18 84NO6 Mn Uptake - Anthesis T2, 3, 4

Variety	LSD .05 = 11.08 O Mn		15 $MnSO_4$		
Jacup	26.30	11	39.87	8	*
Eradu	22.43	14	32.23	12	ns
Bokal	27.13	8	41.27	7	*
Gamenya	37.20	3	47.13	3	ns
Bodallin	32.50	6	41.80	6	ns
Egret	30.63	7	44.40	5	*
Canna	33.60	5	46.93	4	*
Lance	25.87	12	26.30	14	ns
Miling	26.80	9	38.03	9	*
Madden	26.57	10	36.70	10	ns
Tincurrin	42.13	1	64.03	1	***
Millewa	36.97	4	35.33	11	ns
Gutha	23.96	13	31.97	13	ns
Aroona	39.13	2	52.97	2	*

Table 19 84NO6 Grain [Mn]

Variety	LSD .05 = 2.39 O Mn		15 $MnSO_4$		
Jacup	7.90	12	11.67	4	**
Eradu	8.80	10	9.20	11	ns
Bokal	8.90	7	9.20	11	ns
Gamenya	8.83	9	10.73	7	ns
Bodallin	10.00	3	10.80	6	ns
Egret	8.57	11	11.93	3	**
Canna	12.33	1	14.00	1	ns
Lance	9.10	5	9.60	10	ns
Miling	7.87	13	8.63	14	ns
Madden	8.87	8	9.87	8	ns
Tincurrin	9.10	5	9.77	9	ns
Millewa	7.00	14	8.97	13	ns
Gutha	9.83	4	11.00	5	ns
Aroona	10.93	2	12.67	2	ns

Table 20 84NO6 Grain Yield (t/ha)

Variety	LSD .05 = 0.27 O Mn		15 $MnSO_4$		
Jacup	1.58	11	1.73	10	ns
Eradu	1.64	10	1.86	4	ns
Bokal	1.51	13	1.58	13	ns
Gamenya	1.83	4	1.72	11	ns
Bodallin	1.79	5	1.79	8	ns
Egret	1.69	7	1.81	7	ns
Canna	1.78	6	1.84	5	ns
Lance	1.41	14	1.47	14	ns
Miling	1.91	3	2.06	2	ns
Madden	1.66	9	1.79	8	ns
Tincurrin	1.95	2	2.19	1	ns
Millewa	2.03	1	1.84	5	ns
Gutha	1.53	12	1.64	12	ns
Aroona	1.67	8	1.90	3	ns

Table 21 85NO68 - Grain Yields (kg/ha)

	0 Mn	20 Mn
Millewa	885	895
Gamenya	890	1030
Bodallin	1000	1090
Canna	1075	1159
Jacup	850	740
Cranbrook	1005	1235
Eradu	720	870
Aroona	1025	1220
Tincurrin	1150	1217

Table 22 85NO64 Grain Yields

	Rate of $MnSO_4$ (kg/ha) 0	15	22.5
D A P 83 + Double Super 95	1815	1760	1690
D A P 167 kg	1760	1905	1965
S/A 71 + Double Super 190	1810	1840	1835
S/A 143 + Double Super 190	1770	1720	2000
$NaNO_3$ 94 + Double Super 190	1660	1570	1775
$NaNO_3$ 188 + Double Super 190	1550	1660	1950

Table 23 85NO65 Grain Yields

	Mn	Yield kg/ha
Agras No 1 180	0	1409
	15	1435 (1534)
	30	1511
	60	1493
Super 150	0	880
Super 150 + Urea 68.5	0	1200 (1026)

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Table 24 85NO66 - Grain Yields

Rate of S/A (kg/ha)	Rate of $MnSO_4$ (kg/ha) 0	7.5	15
0	825	1125	1070
50	1185	1275	1165
100	1410	1350	1420
150	1455	1480	1490
200	1415	1540	1555

Table 25 85NO67 - Grain Yields (3 reps only)

Rate of S/A (kg/ha)	Rate of $MnSO_4$ (kg/ha) 0	7.5	15
0	1587	1507	1580
50	1827	1753	1707
100	1647	1700	1687
150	1820	1880	1887
200	1827	1880	1847

Table 26 85NO69 Grain Yields (2 reps only)

	Mn Sprays (4 kg/ha) 0	1	2
1. Super 150 + Urea 68.5	480	390	610
2. Super 150 + Urea 68.5 & $MnSO_4$ 15	610	640	580
3. Agras 180	760	660	960
4. Agras 180 + $MnSO_4$ 15	720	800	710

Table 27 85NO5 - 1985 Grain Yields

Treatment	1984	1985	kg/ha
1	P	P	164
2	P S/A	P Mn S/A	347
3	A	A	178
4	P U	P S/A	409
5	P Mn S D	P	138
6	P Mn S W	P	258
7	P S/A Mn S D	P S/A	396
8	P S/A Mn S W	P S/A	298
9	A Mn S D	A	298
10	A Mn S W	A	289
11	P Mn S DU	P S/A	284
12	P Mn S W U	P Mn S/A	342
13	P Mn O D	P Mn	204
14	P Mn O W	P	142
15	P S/A Mn O D	P Mn S/A	369
16	P S/A Mn O W	P S/A	351

Trial badly affected by take-all

Table 28 84NO7 - Grain Yields 1985

		$MnSO_4$		Grain Yield
		1984	1985	1985
Super 150 & Urea 6805	1	0	0	591
	2	15	0	715
	3	30	0	724
	4	60	0	640
	5	0	0	644
	6	0	0	733
Agras No 1 180	7	0	0	769
	8	15	0	942
	9	30	0	769
	10	60	0	942
	11	0	15	858
	12	0	0	858
	13	0	0	893
	14	15	15	827
	15	39	15	818
	16	0	0	871

Substantial take-all damage

Table 29 85LG36 - Grain Yields

	Mn Sprays 0	1	2
S & U	625	642	640
SU & Mn	610	663	610
A	555	555	501
A & Mn	532	602	501

Table 30 85LG37 - Grain Yields - Lupins

	Mn Sprays 0	1	2
SU	463	494	440
SU & Mn	432	409	440