Chapter 6.

ENHANCED MANGANESE CONTENT OF BARLEY SEED

6.1 Introduction

Reserves of nutrients in the seed must be sufficient to sustain growth until the root system has developed sufficiently to supply adequate nutrients from the growth medium. During plant establishment nutrients are supplied partly from the seed reserves and partly from the soil. Obviously, high levels of seed nutrients are more important in soils of low nutrient availability as a larger root system is required before the soil can supply the needs of the crop. Low nutritional status of seeds has been reported to reduce plant growth under conditions of low nutrient availability (Asher 1987).

The effect of the nutrient status of seed on both seed viability and seedling vigour was reviewed in Chapter 2; Table 2.1 in that chapter reports the currently available literature on minimum seed concentrations below which seedlings will not grow normally. In addition to being important for subsequent plant growth, seed nutrient levels may also be an important consideration in quality for end-product use (Welch and House 1984, Welch 1993), especially in areas where a high dependency on grain food may result in nutrient deficiencies (notably iron and zinc) in susceptible human populations. Seedling nutrition has also been shown to be an important factor in plant susceptibility to pathogens (as reviewed by Graham 1983, Graham and Webb 1991); seed nutrient levels which fail to maintain adequate nutritional status of seedlings in infertile soils may result in a decrease in plant resistance to some seedling diseases.

For South Australian farmers on soil types low in Mn, seed Mn concentration may be an important consideration for the successful establishment of cereal crops (Marcar and Graham 1986; Longnecker *et al.* 1991). Whilst soil applications of Mn at sowing have been shown to increase levels of Mn in the grain (Graham *et al.* 1985) in conditions of severe Mn deficiency (highly calcareous soils of high pH), the increases are not large. This is because Mn applied at sowing is quickly rendered unavailable (Reuter and Alston 1975) and inadequate to supply the full Mn requirement of cereals. Applications must be followed by at least one and sometimes two or three foliar applications of Mn during tillering for optimal grain yield. Even then, in spite of large increases in yield, this will still result in low levels of Mn in the seed (as low as 5 mg Mn kg^{-1} of seed or on average 0.17 μg of Mn $seed^{-1}$ for barley). This is at the lower end of the range of seed Mn levels reported by White *et al.* (1981) in a survey involving 15 sites in Western Australia, in which wheat seed concentrations ranged from 6 to 118 mg Mn kg^{-1}. Longnecker and Uren (1990) reported that seasonal effects had a small influence on the Mn content of seed, whereas site variations (soil type, pH, Mn availability) had a large effect. Artificially enhancing seed Mn by soaking seeds in $MnSO_4$ prior to sowing was effective in supplementing internal seed Mn (Longnecker *et al.* 1991). However, this technique may not be easily adapted to broad-acre farming, since seed that has imbibed nutrients and water may be prone to mechanical damage during storage and sowing. Growers who retain their own seed therefore may benefit from other strategies to ensure that grain being kept for seed has adequate Mn content. Seed coating with Mn has been suggested as a method of ensuring adequate Mn during the establishment phase and has resulted in increased grain yield of Galleon barley (McEvoy *et al.* 1988, Chapter 5).

This chapter concerns the Mn status of seed itself which may be manipulated by fertiliser strategies during the management of the seed mother-crop. The experiments reported here develop a strategy for farmers on soil types low in Mn to ensure improved Mn status of barley seed. A comparison is then possible between the relative performance of high

Mn content seed and Mn coated seed as potential techniques of ensuring adequate seedling nutrition of the subsequent crop and hence maximum productivity.

6.2 Fertiliser strategies to enhance manganese content of barley seeds.

6.2.1 Materials and methods

A field experiment was conducted to investigate whether post-anthesis foliar applications of Mn could increase the Mn concentration and content of seeds. The experiment used a randomised block design with three replicates and was continued over three years. In 1989, the barley cultivar used was Schooner whereas 1990 and 1991 the cultivar was Skiff. The experiments were conducted in a farmer's field at Marion Bay on the Yorke Peninsula, South Australia, on a calcareous sand (pH (1:5, soil:water) 7.9, 77% calcium carbonate). The crop was sown by the farmer (on the 3rd June 1989, 22nd June 1990 and 11th June 1991) in his usual way using seed coated with $MnSO_4.H_2O$ (0.8 kg Mn ha^{-1}), followed with an early foliar spray of Mn (0.5 kg ha^{-1}) 6 to 8 weeks after sowing, a further foliar Mn application (0.25 kg ha^{-1}) combined with a weed spray at 10 weeks, and a third application at 14 weeks (0.5 kg ha^{-1}). These farmer treatments were uniformly applied to all plots. Plots 0.75 x 6m were superimposed on the farmer's field by applying foliar sprays of 1.3 kg Mn ha^{-1} as $MnSO_4$ using a small hand held boom. The number and timing of foliar sprays varied with the season (listed in Table 6.1); experiments were randomised complete block designs with three replications. After harvest, grain samples were analysed in triplicate by ICP after digestion in nitric acid (Zarcinas 1984). Grain numbers and weight were recorded for each digest.

6.2.2 Results

Manganese content of seed was increased by application of foliar sprays during grain filling (Table 6.1). For the 1991 experiment, without a late foliar application of Mn, the seed Mn content was 0.25 μg Mn $seed^{-1}$. One foliar spray at the water ripe stage

increased seed Mn content to 0.43 μg Mn seed^{-1} and a second spray 4 weeks later further increased seed content to 0.95 μg Mn seed^{-1} (Table 6.1). A single foliar application at hard dough increased seed content to 0.79 μg Mn seed^{-1}. For the other seasons the results were similar, the later spray being more effective in increasing seed Mn content than the early application and two sprays being more effective than one (Table 6.1). Foliar application of Mn during grain filling, did not affect seed size or the concentration of any other element measured including Cu, Zn and P (data not presented; see for comparison however, some data included in Table 6.2).

Table 6.1 The effect of foliar Mn applications during grain filling on the Mn concentration and content of barley grain produced at Marion Bay.

Foliar Mn application Growth stage	DAS*	Mn concentration (mg/kg)	Mn content (μg/seed)
1989 Schooner barley			
Nil		6.9	n.a.+
Early dough	147	12.5	n.a.
Late dough	164	13.2	n.a.
lsd (P<0.05)		2.0	
1990 Skiff barley			
Nil		4.7	0.17
Week 1 Early dough	140	11.9	0.43
Week 2	149	12.5	0.45
Week 3 Hard dough	156	11.1	0.42
Week 1+3	140+156	20.7	0.76
lsd (P<0.05)		1.4	0.06
1991 Skiff barley			
Nil		7.0	0.25
Week 1 Caryopsis water ripe	122	12.3	0.43
Week 2	133	16.7	0.58
Week 3 Early Dough	136	15.7	0.56
Week 5 Caryopsis hard	152	22.1	0.79
Week 1+3	122+136	19.1	0.70
Week 1+5	122+152	27.2	0.95
lsd (P<0.05)		2.6	0.11

+n.a. not available. *DAS = days after sowing

6.3 Comparison of seed Mn content and Mn seed coating for barley

6.3.1 Materials and methods

General: Four experiments were conducted over four years to examine the relative advantages of seeds with a higher Mn content compared to seeds that were coated with $MnSO_4.H_2O$ or sown using the more conventional technique of applying Mn fertiliser to the soil. The experiments were conducted in the farmer's field at Marion Bay described earlier (Chapter 5 and Section 6.2). In the first two years, seeds were collected from different sites to give a range of different Mn seed contents; in the second phase of this program seeds were collected from plots that had received post-anthesis foliar Mn applications (Section 6.2) and were used for experiments on the same soil. By varying seed Mn content in this way, rather than selecting seed from various sites, other factors which affect seedling vigour, for example the status of other nutrients or environmental effects during grain filling, were minimised. Seed sources used in these experiments are listed in Table 6.2.

Seed coating was carried out in an inclined pharmaceutical tablet coating pan (30 cm diameter) rotating at approximately 30 rpm. $MnSO_4.H_2O$ was finely ground to <150 micron with 1% w/w of Hexacol Amarynth Lake (a water insoluble dye). Seeds were sprayed in short bursts with adhesive interspersed with additions of $MnSO_4.H_2O$ + dye until the total amount had been added, and finally the coating was dried at 45^{0}C whilst tumbling in the pan. In the first three experiments, methyl cellulose (Celecol HPM 450 0.5g/100 ml of water) was used as the adhesive whereas in 1992 a polyvinyl alcohol adhesive (Gelvatol 40-10: Air Products Inc., Pennsylvania) was used at 12.5 g/ 100 ml of water .

A basal fertiliser of mono-ammonium phosphate (MAP) and urea was applied to deliver 23 kg N, 20 kg P, 1 kg Cu and 3 kg Zn ha^{-1}. Soil Mn (6 kg ha^{-1}) was applied where required as granules of manganese oxysulphate mixed in with the seed using the

magazine system and cone seeder described by Graham *et al.* (1992). Plots were 4 rows (0.8 m) x 4.5 m. Vegetative samples were collected at early and late tillering and maturity (where possible) by sampling 0.5 m of each of the two inside rows. Plant samples were dried at 80°C, weighed and ground using a stainless steel grinding mill to pass through a 0.5 mm sieve. Tissue analysis was conducted by ICP spectrometer after digestion in nitric acid using the method described by Zarcinas (1984). Since no grain was produced in the first year, due to severe Mn deficiency, a foliar application of Mn at tillering was applied (1.3 kg ha^{-1} Mn as $MnSO_4$) in subsequent experiments to ensure grain production. Plants were assessed visually for severity of Mn deficiency at tillering on a scale of 1 to 5 (as described in Chapter 5). Data were statistically analysed using standard analysis of variance procedures.

Table 6.2. Seed source, nutrient concentration and seed weight for barley seeds used in Experiments 1 to 4. Values in parentheses are standard errors of 3 replicates.

Experiment	Source	Nutrient concentration				Seed weight
		Mn	Zn	Cu	P	
		mg kg^{-1}				mg $seed^{-1}$
1. 1989 Galleon	Wangary	3 (0.3)	32 (0.3)	3.4 (0.03)	2100 (60)	38.0 (2.6)
	Karoonda	8 (0.1)	27 (1.1)	3.0 (0.01)	2900 (40)	38.2 (1.4)
	Turretfield	14 (0.1)	39 (1.5)	5.2 (0.20)	2500 (27)	41.8 (0.0)
	Brentwood	21 (4.0)	19 (0.7)	4.8 (0.01)	1900 (35)	41.0 (1.8)
2. 1990 Schooner	Warooka	3 (0.1)	27 (1.0)	5.0 (0.20)	3700 (160)	n.a*
	Marion Bay	6 (0.2)	12 (0.0)	2.2 (0.04)	1700 (20)	n.a
	Bute	8 (0.3)	13 (0.6)	3.0 (0.10)	3200 (160)	n.a
	Cooke Plains:	10 (0.1)	12 (0.1)	3.0 (0.10)	2900 (115)	n.a
	Marion Bay	12 (0.3)	11 (0.1)	2.3 (0.03)	1700 (30)	n.a
	Borrika	14 (0.2)	19 (0.7)	4.0 (0.10)	2800 (43)	n.a
3. 1991 Skiff	Marion Bay	5 (0.03)	19 (0.3)	3.2 (0.10)	2600 (1)	37.7 (0.9)
	Marion Bay	14 (0.6)	21 (1.0)	3.8 (0.10)	2700 (2)	36.4 (0.5)
	Marion Bay	21 (0.6)	20 (0.4)	3.4 (0.03)	2500 (5)	37.6 (1.6)
4. 1992 Skiff	Marion Bay	7 (0.2)	21 (0.2)	3.1 (0.04)	3000 (10)	34.1 (0.6)
	Marion Bay	12 (0.3)	20 (0.7)	3.3 (0.07)	2900 (10)	35.2 (0.6)
	Marion Bay	15 (0.8)	22 (0.4)	3.5 (0.05)	3000 (4)	32.7 (0.6)
	Marion Bay	17 (0.5)	19 (0.6)	3.0 (0.10)	2700 (4)	35.0 (0.3)
	Marion Bay	21 (0.7)	19 (0.3)	2.6 (0.04)	2700 (3)	36.5 (0.7)
	Marion Bay	26 (1.7)	21 (0.5)	2.7 (0.04)	3000 (4)	33.3 (0.7)

*n.a. not available

Details of each experiment

Experiment 1 (1989): Galleon barley seed was selected from 4 locations resulting in a range of seed Mn contents (Table 6.2). Seeds were sown (on 22nd June) with or without Mn coated at 0.8 kg Mn ha^{-1}. The experimental design was a randomised complete block with 4 replications. Vegetative sampling was conducted by sampling 2 x 0.5 m sections of two inside rows at 74 DAS. In 1989 the Mn deficiency was so severe that plants died after the first sampling even where Mn had been applied as seed coatings: no further measurements were possible.

Experiment 2 (1990): Six sources of Schooner barley were selected from 5 locations with varying Mn content as shown in Table 6.2, and one source where the Mn seed content had been increased by treatment of the mother crop at the same site (Marion Bay). Seeds were sown (on the 10th July) without Mn or coated at 0.8 kg Mn ha^{-1}. The experimental design used was a split-plot to allow a foliar application of Mn (1.3 kg ha^{-1} as $MnSO_4$) applied at mid-tillering to one half of each block. Thus, the foliar Mn treatment corresponds to the main plots, whilst the factorial combinations of seed source and coating were randomly allocated to the subplots within each main plot. Four replicates were used. Plots were sampled at early tillering, 69 DAS (nil foliar spray plots only), late tillering, 84 DAS, and maturity by sampling 0.5 m of row in each of the 2 adjacent inside rows.

Experiment 3 (1991): Three levels of seed Mn in Skiff barley were selected from plots that had received post-anthesis foliar applications of Mn in 1990 (as described in Section 6.2 above). Seeds were sown (on 26th June) without added Mn, coated at 0.8 kg Mn ha^{-1}, or with drilled granules of Mn fertiliser (Micromate 280 containing 28% Mn, 11% S, approximately 50% as MnO and 50% as $MnSO_4.H_2O$, Stoller Chemical Company Houston, Texas) at 6 kg Mn ha^{-1}. Foliar Mn was applied at early tillering (1.3 kg ha^{-1} as $MnSO_4$, 35 DAS) to half of each block in a split plot design as for Experiment 2.

There were 5 replicates. Plots were sampled at early tillering (nil foliar spray plots only, 35 DAS) and again at maturity by sampling 0.5 m of row in each of the 2 adjacent inside rows.

Experiment 4 (1992): Six levels of seed Mn in Skiff barley were selected from plots that had received post-anthesis foliar applications of Mn in 1991 (as described in Section 6.2 above). Seeds were sown (on 18th June) either without added Mn, coated at 0.8 kg Mn ha^{-1} or with soil-applied Mn (6 kg Mn ha^{-1}, Micromate 280 as described for Experiment 3). Foliar Mn was applied at mid and late tillering (1.3 kg ha^{-1} as $MnSO_4$, 49 and 104 DAS) to half of each block in a split-plot design as for Experiments 2 and 3. The experiment consisted of 5 replicates. Plots were sampled at early tillering at 45 DAS (nil foliar spray plots only) and ear peep (115 DAS) by sampling 0.5 m of each of the 2 adjacent centre rows. Grain yield was measured by Wintersteiger small plot harvester.

6.3.2 Results

Experiment 1 (1989): In the initial experiment in 1989, where seed was chosen from different locations, the effect of seed Mn content on early vegetative production and consequently Mn uptake was large. Plants grown from seeds low in Mn were smaller than those from seeds with higher Mn concentrations from different locations (Figure 6.1). The yield advantage from higher seed Mn concentration appears to be about 3 fold in the absence of applied Mn. The effect of seed coating was complex, there being an increase in dry matter due to coating at all levels of seed Mn; however for Mn uptake there was no effect of seed coating at the highest level of seed Mn. At low levels of seed Mn (3 and 8 mg kg^{1}) the effect of Mn seed coating on dry matter and Mn uptake was large; however, at higher concentrations of Mn in the seed, the effect of seed coating on both dry matter and Mn uptake by shoots decreased. The largest dry matter production was attained by coating seed with Mn concentration 8 mg kg^{1} with Mn.

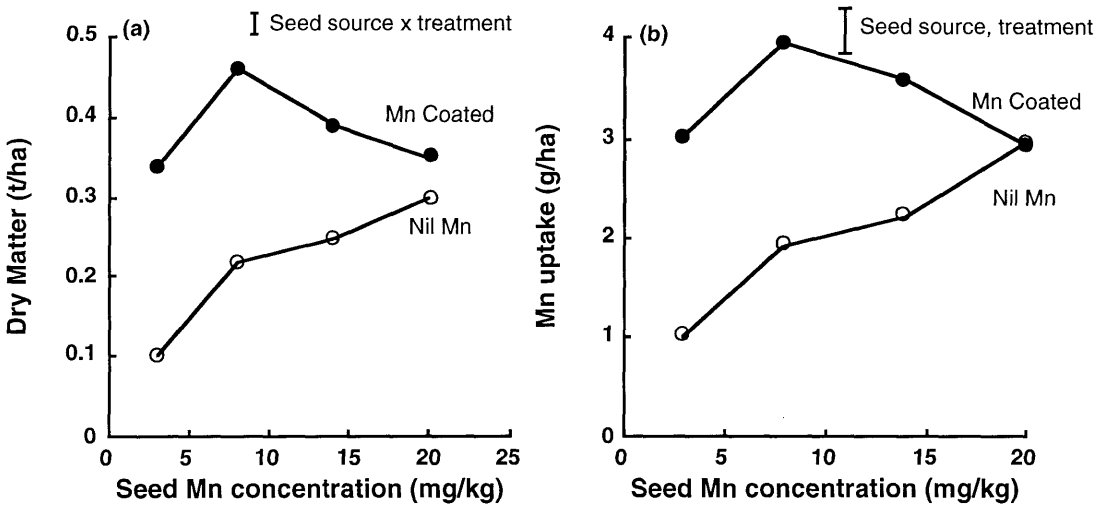

Figure 6.1. (a) Vegetative yield and (b) Mn uptake at tillering of Galleon barley grown from seed with different Mn concentrations selected from various sites and grown at Marion Bay in 1989 (Experiment 1). Vertical bars indicate the lsd (P = 0.05).

Experiment 2 (1990): In the absence of foliar Mn, the effect of seed Mn content was small or negative and this result was carried through to grain yield; plants in all treatments were Mn deficient and grain yield was significantly reduced compared to plants that were treated with foliar Mn (Table 6.3). By the second sampling, plants in the Mn coated treatments were Mn deficient (shoot Mn concentration approximately 7 mg kg^{-1}) and consequently treatment effects were no longer significant (Table 6.3). Where Mn had been applied as a foliar spray there was a significant effect of seed content on grain yield in the nil coating treatments, but not where seeds had been coated with Mn and plants given a foliar Mn spray; seed coating with Mn compensated fully for the low seed Mn content and there was no effect of seed source on grain yield (Table 6.3, Figure 6.2). The reduced yield, where the seed came from Marion Bay, may be due to the fact that this seed had poor general nutrient status (P: 0.17%, Zn: 11 mg kg^{-1}) compared with seed from the other sites (P: 0.2-0.3%, Zn 17-28 mg kg^{-1}); moreover, within this pair also the Mn content was no advantage. Omitting these Marion Bay treatments and looking at data for seed from the other four locations (Figure 6.2), the trends have some similarity to Experiment 1 (Fig 6.1). The effect of seed coating, whilst still advantageous, decreased at seed Mn concentrations of 10 mg kg^{-1} and above.

Table 6.3. Effect of seed source on dry matter yield, Mn uptake and grain yield of Schooner barley grown with and without seed-coated Mn. Experiment 2. Marion Bay 1990.

Seed Source	Seed Mn mg/kg seed	1st Sampling Dry Matter Yield (t ha-1)		2nd Sampling Dry Matter Yield (t ha-1)		2nd Sampling Mn Uptake (g ha-1)		Grain Yield (t/ha) No Foliar Mn		Grain Yield (t/ha) + Foliar Mn	
	Mn	Nil	Coat	Nil	Coat	Nil	Coat	Nil	Coat	Nil	Coat
Marion Bay	6	0.42	0.43	4.33	4.65	29.2	32.4	1.8	1.8	2.4	2.4
Marion Bay	12	0.53	0.52	5.05	4.42	34.4	30.3	1.7	2.3	1.9	2.4
Warooka	3	0.66	0.73	5.16	5.03	38.5	32.0	2.1	2.3	2.3	2.7
Bute	8	0.58	0.73	6.65	5.44	32.1	41.4	1.9	2.2	2.5	2.6
Cooke Plains	10	0.53	0.64	4.55	4.72	25.5	30.4	1.9	2.0	2.6	2.7
Borrika	14	0.55	0.58	5.04	4.66	39.1	31.8	2.0	2.0	2.5	2.7
LSD (P<0.05) Mn treatment		0.13		N.S.		N.S.		0.29			

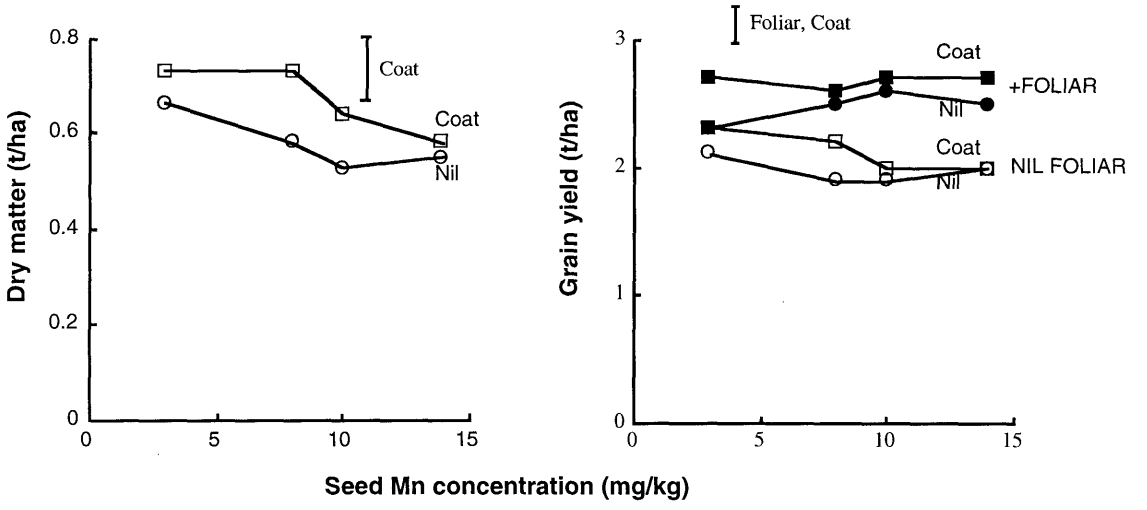

Figure 6.2 (a) Dry matter yield 69 DAS and (b) grain yield of Schooner barley sown from seed from different locations and with different Mn concentrations at Marion Bay in 1990 (Experiment 2). The two seed lots collected from Marion Bay (Table 6.4) have been omitted from this graph. Vertical bars indicate the lsd (P =0.05).

Experiment 3 (1991): The effect of seed Mn content and method of Mn application on dry matter production and the appearance of visual symptoms of Mn deficiency at tillering are shown in Plate 6. Seed selected from the same site with varying levels of seed Mn from 5 to 21 mg Mn kg^{-1} had no uniform effect on dry matter production or Mn uptake at early tillering or on grain yield (Table 6.4, Figure 6.3). At the first sampling Mn deficiency symptoms were apparent at all levels of seed Mn in the nil and drill treatments but not in any of the coated treatments (Table 6.5). Plant establishment was not affected by any treatment; however plants in the coated treatments had more tillers (Table 6.5). There was an increase in dry matter, Mn uptake and grain yield due to applications of Mn at sowing (Figure 6.3). Drilled applications of 6 kg Mn ha^{-1} increased all these parameters, seed coating applications of 0.8 kg ha^{-1} resulted in even greater increases in yield and Mn uptake. The effect of seed coating again decreased with increasing concentrations of Mn in the seed. The foliar application at mid-tillering was effective in increasing grain yield in all cases, but not successful in alleviating Mn deficiency, as indicated by the low grain yields. The benefit of a small addition of Mn by seed coating was carried through to maturity and resulted in the greatest grain yield (Figure 6.3).

Plate 6. Skiff barley with varying content of seed Mn sown at Marion Bay Experiment 3, 1991.

Table 6.4. Vegetative yield and Mn uptake (35 DAS) of Galleon barley seedlings grown from seed with varying levels of seed Mn with and without Mn fertiliser applied to the seed or soil at sowing at Marion Bay 1991.

Source	Seed Mn conc mg kg^{-1}	Veg yield (kg ha-1)			Mn Uptake (g ha-1)		
		Nil	Coat	Drill	Nil	Coat	Drill
Marion Bay	5	46	109	70	0.48	2.35	1.07
Marion Bay	14	54	101	65	0.56	2.27	1.09
Marion Bay	21	59	91	74	0.64	2.01	1.03
LSD (P<0.05)							
Mn treatment			10			0.23	

Table 6.5. Visual score, number of plants established/metre of row, number of tillers per plant and plant height of barley seedlings, 35 DAS, grown from varying levels of seed Mn with and without Mn fertiliser applied to the seed or soil at sowing at Marion Bay 1991.

Seed Mn conc mg kg^{-1}	Visual Score*			Plants/m			Tillers/plant			Plant height cm/plant		
	Nil	Coat	Drill	Nil	Coat	Drill	Nil	Coat	Drill	Nil	Coat	Drill
5	2	5	3	29	29	32	1.3	2.7	1.6	12.8	13.7	13.0
14	3	5	4	31	29	26	1.3	2.6	1.8	12.6	13.5	12.7
21	3	5	3	30	28	28	1.6	2.5	2.0	12.9	13.5	13.3
LSD (P<0.05)												
seed Mn		0.4			NS			NS			NS	
Mn treatment		0.4			NS			0.75			0.5	
Seed Mn x Mn treatment		0.7			NS			NS			NS	

* A lower visual score indicates more severe Mn deficiency

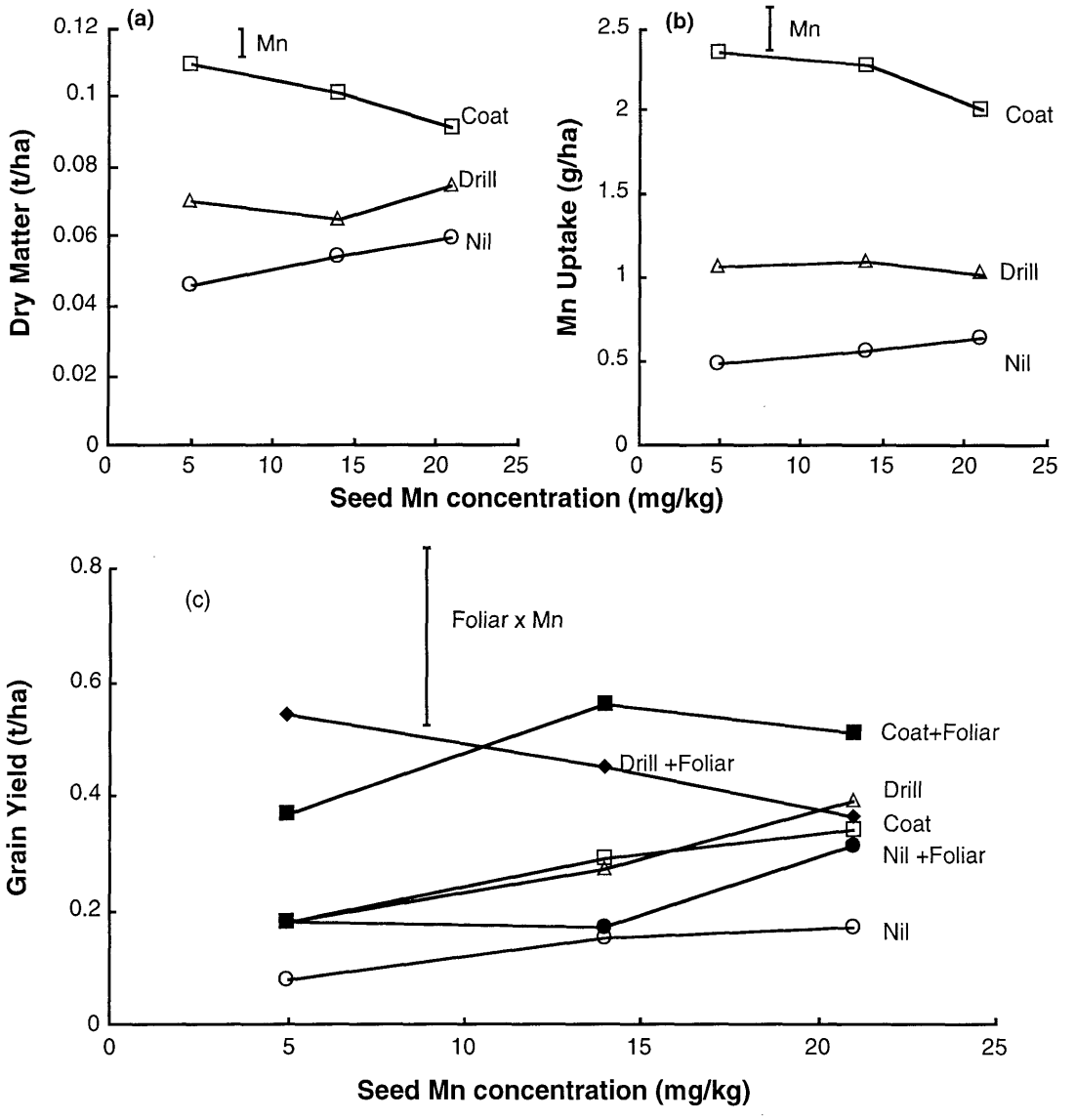

Figure 6.3 Effect of seed Mn content and Mn application on (a) Dry matter production at 35 DAS, (b) Mn uptake at 35 DAS and (c) Grain yield of Skiff barley grown from seed with different Mn concentrations at Marion Bay 1991 (Experiment 3). Vertical bars indicate the lsd (P = 0.05)

Experiment 4: (1992): In this experiment, as in Experiment 3, there was no effect of Mn seed content on vegetative yield at early tillering (49 DAS), ear peep (115 DAS) or maturity (Table 6.6, only ear peep data provided). Seed coating with Mn produced greater yield than applying eight times as much Mn to the soil when a foliar application of Mn was also applied (Table 6.6, Figure 6.4) but was not always more effective without

foliar Mn. Seed coating was generally advantageous, compared with nil Mn, for all levels of seed Mn (Figure 6.4).

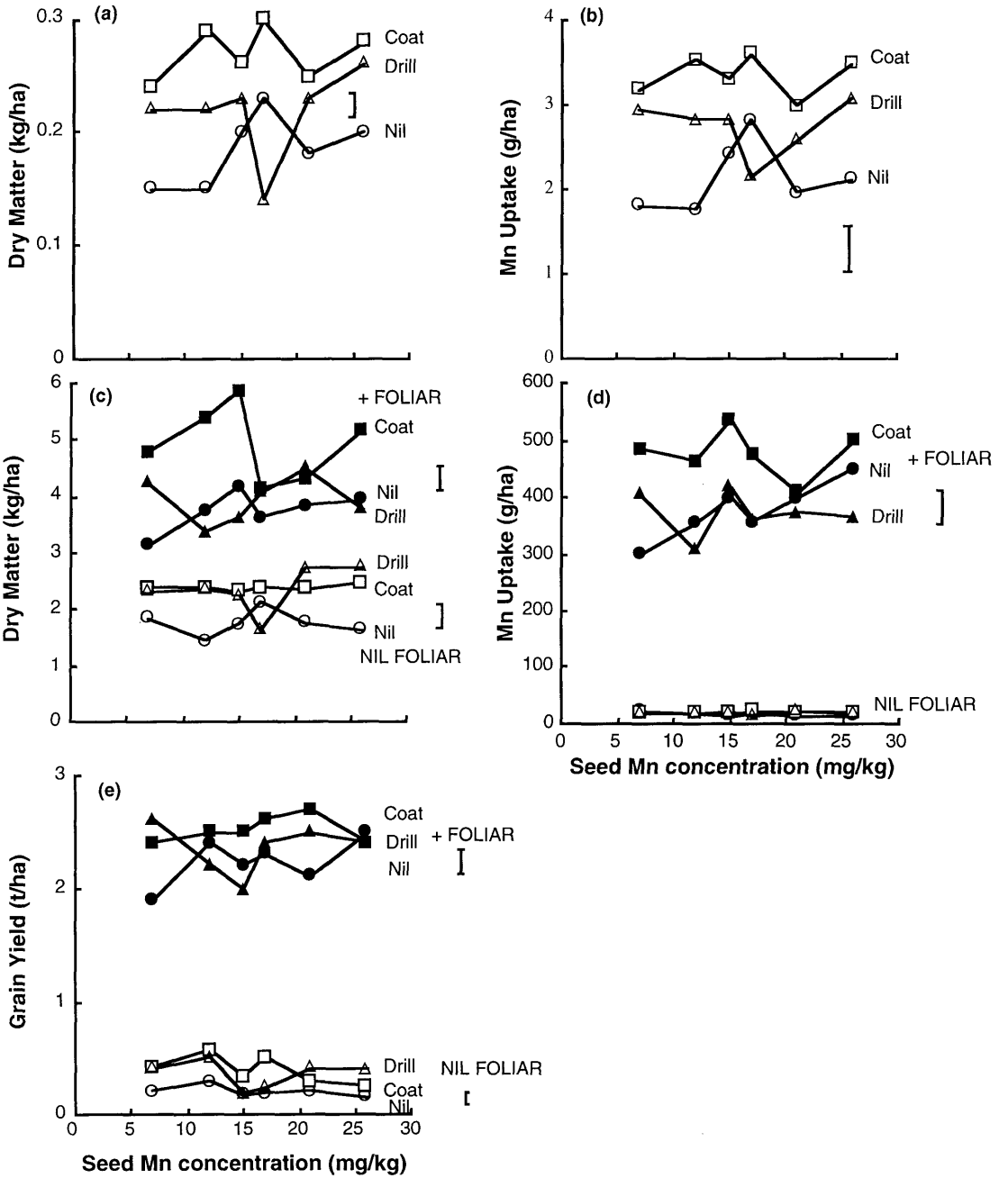

Figure 6.4 Yield and Mn uptake of Skiff barley grown from seed with different Mn concentrations and treated with nil, seed coated or drilled applications of Mn at Marion Bay 1992. (a) Dry matter production 45 DAS (b) Mn uptake of shoots 45 DAS, (c) dry matter production 115 DAS, (d) Mn uptake of shoots 115 DAS and (e) grain yield at maturity. Vertical bars indicate lsd (P = 0.05).

Table 6.6 Effect of Seed Mn content and Mn application on dry matter production and Mn uptake at ear peep (115 DAS) of Skiff barley. Experiment 4, 1992.

Source	Seed Mn conc mg kg^{-1}	Veg yield (t ha-1)			Mn Uptake (g ha-1)		
		Nil	Coat	Drill	Nil	Coat	Drill
Nil foliar							
Marion Bay	7	1.84	2.37	2.32	22	19	16
Marion Bay	12	1.43	2.38	2.36	15	17	17
Marion Bay	15	1.75	2.32	2.23	14	16	18
Marion Bay	17	2.12	2.91	1.64	16	21	14
Marion Bay	21	1.76	2.35	2.72	13	18	23
Marion Bay	26	1.63	2.44	2.77	13	17	20
LSD (P<0.05) Mn treatment			0.035			N.S.	
+Mn Foliar Applied							
Marion Bay	7	3.12	4.77	4.24	298	484	405
Marion Bay	12	3.74	5.39	3.34	355	464	307
Marion Bay	15	4.19	5.83	3.63	400	534	419
Marion Bay	17	3.63	4.14	4.07	357	475	361
Marion Bay	21	3.82	4.29	3.49	399	410	375
Marion Bay	26	3.94	5.15	7.78	450	498	367
LSD (P<0.05) Mn treatment			0.36			49	
Seed Source x Mn treatment			0.89			N.S.	

6.4 Discussion

Post anthesis foliar applications have been effective in increasing the Mn concentration (content) of barley seed without affecting the concentration or content of other elements. The timing of these applications was not critical, but, since the farmer's final foliar spray (at 14 weeks after sowing, by which time the flag leaf had unfolded), still resulted in low seed Mn it appears this late application must be after grain development commences.

Manganese seed coating compensated completely for low seed Mn content; and greatest productivity resulted from treatments with Mn seed coating plus foliar Mn at tillering. This is consistent in field work conducted over 4 years. Seed coating with Mn was generally, more effective, per unit of applied Mn, in increasing yield and reducing Mn

deficiency, than soil applied Mn fertiliser. Seed coating with 0.8 kg Mn ha^{-1} produced greater yields than 6 kg Mn ha^{-1} drilled with the seed. In the absence of a foliar Mn application plants in all treatments became acutely deficient in Mn and subsequently treatment differences were smaller.

Manganese seed content had a significant effect on dry matter and grain yield only when seed was selected from different locations and no foliar spray was applied. When seed from the same site but with different concentrations of Mn was sown, seed Mn concentration did not influence dry matter or grain yield significantly although it is possible that where seed had been selected from different locations some other factor (factors) correlated with seed Mn could be affecting seed performance (for example embryo size, other nutrients, protein levels). The Marion Bay site is highly alkaline with a high $CaCO_3$ content, so that the availability of Mn, P and Zn is low. At this site, seed sources with high contents of P and Zn as well as Mn may be beneficial in conferring a starter effect. The Marion Bay seed used in Experiment 2 was lower in P, Zn and Cu than the other seed sources selected; consequently, tissue concentrations of these nutrients were marginal at early tillering and deficient by late tillering. Seed selected from other sites may be conferring benefits in terms of these nutrients as well as Mn. Ayers *et al.* (1976) demonstrated that seedling vigour is related to the protein content of the whole seed and the endosperm, and to the salt soluble and insoluble fractions of the endosperm. Manganese applied by late foliar sprays may be deposited in tissue other than the provascular material in the base and mid-region of the radicle (Lott and Spitzer (1980); Mazzolini *et al.* (1985)) and hence may be less available to the developing seedling.

Longnecker *et al.* (1991) reported that high amounts of seed Mn increased dry weight of roots and shoots, Mn content of roots and shoots, number of early tillers, plant survival and number of grains per plant. These workers used seed of Galleon barley that had been grown at different sites with a range of Mn concentrations (3 to 27 mg kg^{-1}) and

content (0.14 to 1.2 μg seed^{-1}). The ranges of seed Mn content/concentration are similar to the present study and compare with the results of Experiment 1, but contrast with results of the other three experiments. In addition Longnecker *et al* included seed that had been soaked in 0.25 M $MnSO_4$ for 6 h; this treatment had the effect of enhancing seed Mn concentration from 27 to 1151 mg kg^{-1} and Mn content from 1.2 to 53 μg Mn seed^{-1}. They reported increased grain yield from plants grown from a high seed Mn source irrespective of whether these plants were fertilised with additional Mn, although the effect was smaller where Mn fertiliser was applied to the soil.

Three main differences exist between the present study and that of Longnecker *et al.*: (1) the severity of the deficiency; the experiments reported by Longnecker *et al.* were conducted at Wangary on the Eyre Peninsula, which is a site more deficient in Mn than the Marion Bay site used in the present study In addition, the Marion Bay site is also marginally deficient in Cu and Zn so that early seedling vigour may also be dependent on the Cu and Zn content of seeds. (2) choice of varieties; Longnecker *et al.* used the cultivar Galleon which is more sensitive to manganese deficiency, exhibiting symptoms in the field much earlier than either Schooner or Skiff used in this study. Seed of Galleon barley selected from plants grown at different locations was used in Experiment 1 and the results from this experiment agree with those of Longnecker *et al.* 1991 but, contrast with Experiments 2, 3 and 4. (3) Apart from the seed that had been soaked in Mn solution to increase the seed Mn content, Longnecker *et al.* used seed collected from different sites, so that factors other than Mn content, for example concentrations of other nutrients, protein content, embryo size, may have influenced their results. Manganese contained in the seed as a result of soaking seeds in $MnSO_4$ was approximately 50 times greater than the highest seed Mn content used in the present study. In addition, Mn transported to the seed via the stem or by soaking the seed in $MnSO_4$ may be in a more available form than that applied by a late foliar application of Mn and therefore more readily available to the emerging seedling.

Further research is required to explain the phenomenon that seed collected from plants grown at other locations performs better than seed from the same paddock. Enhanced seed concentrations of Cu, Mn, Zn and P may confer added benefits in situations where more than one element is limiting. Post-anthesis foliar applications enable manipulation of the Mn concentration (content) of barley seed without affecting the concentration or content of other elements. This technique may enable identification of the importance of Mn seed content on seedling vigour. Preliminary results with Zn are encouraging, post-anthesis foliar applications of Zn have increased seed Zn concentration. Enhancing seed levels of Zn, Cu, Mn, P or combinations of these nutrients by applying late foliar treatments may avoid confounding factors involved in selecting seed from other locations. Using seed prepared in this way to investigate the effect of seed nutrient status on seedling vigour and crop performance may clarify the relative importance of these nutrients in the seed for seedling performance at the Marion Bay site. More understanding is required of the effect that seed nutrition has on seedling vigour, disease resistance and grain quality.

Chapter 7.

GENERAL DISCUSSION

Strategies that enable the applied fertiliser to remain in plant available forms rather than being immobilised by soil chemical and microbial processes lead to better efficiency of fertiliser usage. For the soil immobile (diffusion limited in soil) nutrients these strategies require that the elements are placed so that they can be readily taken up by the growing plant.

The experiments conducted in this thesis have concentrated on techniques of application of P (a soil immobile macro-element) and Mn (a soil immobile micro-element). Whilst the demand for P by cereals is generally (although not always) greater during the first eight weeks of growth, (Brenchley, 1929; Sutton *et al.*, 1983; Jones *et al.,* 1992), the demand for Mn is throughout the whole growing season. The challenge is to supply each nutrient in a plant available form to meet this demand. For P then, the requirement is to supply P in a plant available form placed close to the seed for easy access of seedlings. For Mn, the required strategy involves placement of a small amount of Mn in close proximity to the seed, followed with foliar applications when symptoms of Mn deficiency first appear. This discussion attempts to integrate the results of the experiments conducted and to review the relevance of the findings for agriculturalists in Australia.

The potential for coating seeds with P or Mn as a method of delivering small, precise quantities of nutrient close to the seed was investigated. The studies with P seed coatings demonstrated that whilst seed coating may improve the availability of applied P and hence the efficiency of fertiliser usage, it can result in severe injury during germination and emergence. In the emergence study comparing tolerance of species to P seed coating, it was demonstrated that in general the legumes were intolerant of P placed close to the seed

whereas the cereals were most tolerant and hence were good candidates for P seed coating. Of the cereals tested barley and oats were more tolerant to seed coating than wheat. Scott *et al.* (1987) reported that whilst oats could tolerate seed coatings of 10 kg P ha^{-1} (as MCP) without reduction in emergence this rate reduced the emergence of wheat. The tolerance of oats to fertiliser injury by superphosphate was explained by Guttay (1957) as due to the protection provided by the lemma and palea compared to the naked seed of wheat. This argument that seed structure can protect the seed from fertiliser injury was suggested for pasture seed by McWilliam and Phillips (1971) and Silcock and Smith (1982) and was further developed by Scott (1986) and Garotte *et al.* (1987 and 1989a).

The injury during germination/emergence due to P coatings was shown to be more severe where soil moisture was limiting and on coarse textured sandy soils. The time to first emergence was the most sensitive parameter for assessing the injury during emergence. The rate of emergence was also severely affected.

The pot experiments with wheat to investigate the efficacy of P seed coating compared to conventional drilled applications of P indicate the importance of environmental conditions on the availability of applied P. Under conditions of low light intensity and wetter soil conditions seed coating was more effective than drilled applications of P. However, under high light intensity and drier soil conditions this efficacy was reduced (in terms of yield per unit of applied P). Choice of variety also appears to be an important factor in the efficacy of seed coating. Although only two varieties of wheat were studied, it appears that the variety which is more responsive to P applications may obtain greater benefit from the closer placement of P than the variety with smaller response to P applications.

Under field conditions, fertiliser injury was exacerbated by coarse sandy soil texture and lower soil moisture so that coatings of 3.5 kg P ha^{-1} to wheat reduced emergence

(compared to previous applications of 7.5 kg P ha^{-1} with no apparent injury in the pot experiments).

The experiments described in this thesis have demonstrated that where moisture is not limiting during germination and on fine textured soils P seed coating can confer benefits in terms of increased fertiliser efficiency; it has also highlighted the need to understand mechanisms of fertiliser injury in order to reduce injury and improve the effectiveness of seed coatings. Whilst such mechanistic work was originally planned as part of this thesis it was not possible owing to the already heavy work load.

This study has highlighted the need for the development of 'safe coatings'. Before P seed coating can be adopted for broad scale farming systems, reliable coatings that are safe on seeds over a wide range of soil texture and moisture need to be developed. Polymer coatings have been investigated to reduce the injury during germination, (Smid and Bates, 1971; Scott, 1986). These coatings may act by delaying imbibition and hence allowing changes in availability of applied P rather than excluding P uptake (Scott and O'Donnell, 1987); and hence these polymer coatings may in turn be less effective in supplying P.

In the case of Mn seed coatings, fertiliser injury is much less of a problem since much smaller amounts of nutrient are applied. The experiments described in Chapter 5 investigated sources of Mn for coating. Of the fertiliser sources tested Mn sulphate and Mn dextrolac were most effective in increasing yield. However under the severely deficient conditions of this study, none of the Mn coatings was sufficient to attain maximum yield without an additional foliar application of Mn. Addition of the seed dressing Mancozeb, on top of the Mn coating, further improved yield. This effect is unlikely to be due to its fungicidal properties since, in some experiments, seeds were dressed with Baytan before coating with Mn. Coating Mn and Zn at the same rate as

contained in the fungicide had a similar effect on dry matter production at tillering but a smaller effect on grain yield than the fungicide, suggesting perhaps that the Mn in the dithiocarbamate complex may be in a more plant available form for a longer time. In all of the experiments reported here the Mancozeb dressing was applied after the Mn coating, and was thus not in contact with the seed. Mancozeb dressings resulted in a further increase in grain yield above the Mn coating treatments, ranging from 17 to 45% in the four experiments described. This yield increase warrants further investigation as to whether Mancozeb seed dressings could be recommended for cereals grown on calcareous soils provided farmers were warned against long term storage of treated seed. In fact Mancozeb dressings improved yields even when no Mn was applied either to the soil or as seed coating; in these experiments there was no reduction in emergence due to Mancozeb being in contact with the seed. This result may have important consequences for farmers in marginally Mn deficient soils; seed coating with Mn plus a dressing with Mancozeb may be sufficient to supply the full Mn requirement of cereals avoiding the necessity of a foliar Mn application.

Mn seed coating (0.8 kg Mn ha^{-1}) resulted in greater yields than drilled applications (6 kg Mn ha^{-1}) of Mn as granules of Mn oxysulphate (Micromate 280). However, when Mn seed coating was compared with drilled applications of macronutrient fertilisers coated with Mn the relative effectiveness of seed coating was reduced and plants in seed coated treatments yielded similarly to drilled applications at the same rate of Mn applied.

A further complication was discovered in the experiments described in Chapter 5. In years that were drier (rainfall, May-September, 300 mm) basal fertilisers of MAP + Urea (18:20:0) + Cu, Zn, Mo, Co resulted in higher grain yields and a larger response to applied Mn than basal fertiliser of DAP (18:20:0) + micronutrients at the same rate of application, the levels of all nutrients in plant tissue being adequate. However in wetter seasons, (rainfall, May-September > 400 mm) nutrients applied with DAP resulted in

more grain yield and a larger response to applied Mn; in these years however, analysis of plant tissue indicated that plants were marginally deficient in Zn. This result is difficult to explain in terms of current knowledge of fertiliser chemistry. All nutrients were applied at the same rate. It may however help to explain the observation among growers, agronomists and scientists of South Australia, that in years where Zn deficiency is predominant the severity of Mn deficiency is reduced and in seasons where Mn deficiency is acute reports of Zn deficiency are fewer.

The inherent nutrient content of seeds has recently been addressed as an important consideration for seedling establishment and early plant nutrition (see for example studies on P content of seed by Bolland and co workers and Mn content of seeds: Longnecker *et al.* 1991, Marcar and Graham 1985, 1986, and was the topic of a recent review, Ascher *et al.* 1994). The P content of seed can be manipulated by applying large amounts of P at sowing (Bolland and Baker 1988). Farmers on severely Mn deficient soils however, were unable to enhance the Mn content of cereal seed grown on their poorer soil types. They were faced with the expensive prospect of buying seed from registered growers (grown under more fertile conditions) or the less costly, but more risky alternative of swapping seed with neighbours on better soil types and risking importation of weeds. The experiments in Chapter 6 (Section 6.2) developed a strategy of enhancing the Mn content of barley seeds by applying one or two foliar applications of Mn during grain filling. This technique has been readily adopted by growers on the Eyre and Yorke Peninsulas in South Australia, and in situations of less severe Mn deficiency, may reduce the need for additional Mn through foliar or seed coating techniques.

Mn content of seeds has been shown to be important for the establishment of cereals on soils low in Mn (Marcar and Graham 1986, Longnecker *et al.* 1991); however these researchers used seed collected from other sites. In this case factors other than Mn content of seeds could be confounding their results. The technique of post-anthesis foliar

applications of Mn (described in Section 6.2) allowed material to be collected from the same site so that the content of elements other than Mn and the conditions during grain filling/ripening were the same for all seed-treatments. The experiments described in Section 6.3, were designed to test whether barley seeds with enhanced Mn content improved establishment and to test whether Mn seed coating was as effective as enhanced seed Mn content in improving seedling establishment and nutrition. The results of these experiments may have been confounded by the fact that the Marion Bay site is highly calcareous and consequently P deficient and in some seasons Zn deficient so that the seeds produced were low in both P and Zn. Under these conditions enhanced Mn content of seed was ineffective in improving dry matter yield of seedlings or increasing grain yield. However when seed from other sites were compared, Mn seed content improved dry matter production and Mn uptake of barley seedlings. Seed coating with Mn was able to compensate completely for low seed Mn content. From these experiments farmers on severely Mn deficient soil types would benefit most from seed coating, whereas those on more marginal soil types would benefit from post-anthesis foliar applications of Mn to enhance seed Mn content, providing other elements were not limiting in the seed.

Since fertiliser recommendations must consider cost, productivity and efficiency of the strategy used, seed coating with Mn sulphate in combination with a seed dressing of Mancozeb at sowing followed with a foliar application of Mn would be a general recommendation for farmers on severely Mn deficient soils. For less severe deficiency a combination of seed with Mn concentration greater than 26 mg kg^{-1} coated with Mancozeb in combination with a foliar application of Mn when Mn deficiency symptoms appear, may be adequate to ensure maximum grain yield.

The results of this research have demonstrated that seed coating with P or Mn can be an effective method of supplying these nutrients to cereal crops. Since seed coating has

been demonstrated to improve the efficiency of P and Mn applications further research is warranted to develop safe effective coatings. It may be necessary to formulate slow release coatings that keep the applied nutrient in a plant available form. Possible approaches are polymer coatings, combinations of soluble and partially soluble compounds to enable the release of nutrient over time; incorporating S in the coating to decrease the pH of the coating, thus increasing the availability of the applied P or Mn; incorporation of Mn reducing microorganisms in the coating material to maintain the applied Mn in the reduced form; or the use of anti-microbial or fungicidal agents that may prevent oxidation of Mn to unavailable forms in the immediate vicinity of the seed. In addition problems associated with long term storage of coated seeds need to be identified, it may be necessary to recommend a storage life for coated seeds.

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Appendix 1

DESCRIPTION OF SOILS USED IN EXPERIMENTS

Soil 1 Used in Experiments 3.1, 3.2 and 3.3 and pot experiments 4.1 and 4.2. Note only the A1 horizon was used. (from Godwin D C (1981) M. Rur. Sc. Thesis, U.N.E.)

Classification:

Australian*	Bleached Eutropic Grey Chromosol; medium, non-gravelly, loamy/clayey, moderate
Northcote Key	Gleyed podzolic. Dy 4.42
Location:	NE corner 'Kirby' farm University of New England, Armidale, NSW
Topography	Gently undulating terrain, N W facing slope (4°). Profile described at slightly convex mid slope position.
Climate	Armidale. Sub-humid, summer rainfall dominant
Parent material	Mount Duval ademellite
Profile drainage	Imperfect
Vegetation	Cleared, native grasses, *Panicum* spp. dominant
Land use	Sheep and cattle grazing

Morphology

Horizon	Depth (cm)	
A1	0-20	Dark brown (7.5YR 3/2 moist) coarse sandy loam; weak fine subangular blocky; earthy fabric; moist friable, wet slightly sticky, slightly plastic. Abundant roots. Field pH 6.0
A2	20-29	Pale brown (10YR 6/3 moist, 7/3 dry) with yellowish brown (10YR 5/8 moist) common fine distinct mottles; loamy sand; weak fine subangular blocky; earthy fabric; moist friable, wet non-sticky slightly plastic. Few roots. Field pH 6.5
B1 (gleyed)	29-37	Light brownish grey (2.5YR 6/2 moist) with strong brown (7.5YR 5/8 moist) few fine distinct mottles; coarse sandy clay; strong coarse angular blocky (peds 8mm across); smooth ped fabric; moist firm, wet sticky, very plastic. Field pH 6.0
B2	37-80	Brownish yellow (10YR 6/5 moist) with yellowish brown (10YR 5/8) many coarse distinct mottles; coarse sandy clay; strong coarse angular blocky (peds 12 mm across) smooth ped fabric; moist firm, wet sticky very plastic. Field pH 6.0
B3	80-90	As above with 40% of soil volume consisting of soft micaceous saprolite weathered from Mount Duval ademellite; massive, sandy clay loam. Field pH 7.0
C	90-	Soft micaceous saprolite

Chemical Analysis 0-10 cm

pH (1:5 water)	5.4
Organic carbon (% w/v)	0.9
Phosphorus (bicarbonate extract) (mg kg^{-1})	5.0
Potassium (meq 100 g^{-1})	0.21
Calcium (meq 100 g^{-1})	1.45
Magnesium (meq 100 g^{-1})	0.85
Sodium (meq 100 g^{-1})	0.04
Conductivity (millisiemens cm-1)	0.03
Copper (mg kg^{-1})	0.5
Zinc (mg kg^{-1})	0.7
Manganese (mg kg^{-1})	8.0

Soil 2 Used in Experiment 3.3 Note only the A1 horizon was used.

Classification:

Australian*	Epicalcareous Self-Mulching Black Vertosol; non gravelly, medium fine/very fine, moderate.
Northcote key	Black Earth
Location:	Trevenna, University of New England, Armidale
Topography	Gently undulating terrain, W facing slope .
Climate	Armidale. Sub-humid, summer rainfall dominant
Parent material	Basalt
Profile drainage	Imperfect
Vegetation	Semi improved pasture
Land use	Sheep grazing

Morphology

Horizon	Depth (cm)	
A11	0-10	10YR 2/2 medium clay; pH 6.0
A12	10-35	10YR 2/2 medium clay; pH 6.5
AC (gleyed)	35-100	10YR 2/2 heavy clay; pH 7.5-8.0

Chemical Analysis 0-10 cm

pH (1:5 water)	6.1
Phosphorus (bicarbonate extract) (mg kg^{-1})	13
Potassium (mmol (p^+) kg^{-1})	11.6
Calcium (mmol (p^+) kg^{-1})	213.7
Magnesium (mmol (p^+) kg^{-1})	183.3
Sodium (mmol (p^+) kg^{-1})	6.0

Australian* A Classification System for Australian Soils (3rd approximation, Dec 1993 Update), R. F. Isbell CSIRO Soils Divisional Report 2/1993

Soil 3 Used in the Gunnedah field experiment Chapter 4
Described by Ian Holford NSW Agriculture, Agricultural Research Centre, Nemington NSW

Classification:

Australian*	Calcic Eutotrophic Demosol; medium, non-gravelly, clayey/clayey, moderate
Northcote	Brown clay Ug 5.3
Location:	Gunnedah
Topography	Undulating
Climate	Sub-humid, summer rainfall dominant
Profile drainage	Imperfect
Vegetation	Cropping
Land use	Annual cropping

Morphology

Horizon	Depth (cm)	
A1	0-10	Dark red brown (5YR 3/3) loamy clay; friable self mulching. Abundant roots. Field pH 7.6
A2	15-30	Dark red brown (5YR 3/2) clay, friable Field pH 7.6
B1 (gleyed)	30-60	Dark red brown (5YR 3/4) clay, cloddy Field pH 7.7
B2	60-90	Reddish brown (5YR 4/4) clay, cloddy Field pH 7.95
B3	90-120	Yellowish red (5YR 4/6) clay, cloddy Field pH 8.1
C	90-	

Chemical Analysis 0-10 cm

pH (1:5 water)	7.6
Organic carbon (% w/v)	0.86
Total nitrogen (%)	0.09
Nitrate N	6.3
Phosphorus (bicarbonate extract) (mg kg^{-1})	21.0

Australian* A Classification System for Australian Soils (3rd approximation, Dec 1993 Update), R. F. Isbell CSIRO Soils Divisional Report 2/1993

Soil 4 Used in the Monarto field experiment Chapter 4
Described by J Hall Primary Industries South Australia

Classification:

Australian*	Calcic Subnatic Red Sodosol; medium non gravelly, loamy/clayey, moderate
Northcote	Sandy Red Brown Earth
Location:	Monarto, South Australia
Topography	Undulating
Climate	Warm temperate, winter rainfall dominant
Vegetation	Cleared mallee scrub
Land use	Cropping / pasture rotation

Morphology

Horizon	Depth (cm)	
A1	0-10	Dark brown (7.5YR 3/3), non-calcareous, sandy loam; pH6; Massive structure; with abrupt boundary change (over 5-20 mm). Field pH 6.0
B21	10-50	Red (2.5YR 4/6), non-calcareous, medium heavy clay. Weak to massive structure and a strong consistence when dry (unable to break piece between thumb and forefinger). Dispersive in distilled water. 2-10% soft orange siltstone fragments. Gradual boundary change (over 50-100 mm). Field pH 8.0
B22	50-84	Red (2.5YR 4/6), calcareous (high fizz), silty medium clay. Massive structure with 2-10% soft orange siltstone fragments, with a gradual boundary change . Field pH 8.5
BC	84-90	Yellowish -red (5YR 5/8), calcareous (high fizz), silty medium clay, 2-10% soft carbonate segregations. Massive structure with 2-10% soft orange siltstone and 2-10% soft grey schist. Field pH 9.0

Australian* A Classification System for Australian Soils (3rd approximation, Dec 1993 Update), R. F. Isbell CSIRO Soils Divisional Report 2/1993

Soil 5 Used in the Marion Bay field experiments Chapters 5 and 6
Described by J Hall Primary Industries South Australia

Classification:

Australian*	Shelly Calcarosol; thin, non-gravelly, loamy/sandy, moderate
Northcote	Calcareous Sand
Location:	Marion Bay, Yorke Peninsula. South Australia
Topography	Rise in swale.
Climate	Cool temperate, winter rainfall dominant
Parent material	Shell grit
Profile drainage	Rapidly to well drained
Vegetation	Cleared mallee scrub
Land use	Barley /pasture rotation/sheep

Morphology

Horizon	Depth (cm)		
A1	0-6	Sandy loam, 74% $CaCO_3$.	Field pH 7.9
BA1	6-22	Sandy loam, 72% $CaCO_3$.	Field pH 8.1
BA2	22-45	Sandy loam, 86% $CaCO_3$.	Field pH 8.3
B1	45-102	Sandy loam, 81% $CaCO_3$.	Field pH 8.6
B2	102-162	Coarse loamy sand, 80% $CaCO_3$	Field pH 9.0
B3	162-178	Sandy loam, 95% $CaCO_3$.	Field pH 8.8

Chemical Analysis 0-10cm

pH (1:5 water)	7.9
Organic carbon (% w/v)	3.1
Phosphorus (bicarbonate extract) (mg kg^{-1})	50
Potassium (meq 100 g^{-1})	0.34
Calcium (meq 100 g^{-1})	13.6
Magnesium (meq 100 g^{-1})	1.04
Sodium (meq 100 g^{-1})	0.18
Conductivity (millisiemens cm-1)	0.43 dS/m
Copper (mg kg^{-1})	0.4
Zinc (mg kg^{-1})	0.8
Manganese (mg kg^{-1})	2.9

Australian* A Classification System for Australian Soils (3rd approximation, Dec 1993 Update), R. F. Isbell CSIRO Soils Divisional Report 2/1993