Chapter 5.

MANGANESE SEED COATING AS A FERTILISER STRATEGY FOR BARLEY AND WHEAT

5.1 Introduction

In high pH calcareous soils, manganese (Mn) deficiency can be difficult to overcome since soil-applied Mn is rapidly immobilised by soil chemical reactions. In these situations Mn deficiency cannot be completely corrected by soil Mn applications; at least one and sometimes two or three foliar Mn sprays are required to achieve a reasonable grain yield (Reuter and Alston 1975). In these extreme conditions the aim of strategies at sowing is to establish healthy seedlings with enough foliage to intercept foliar applications of Mn effectively.

Manganese is normally drilled at seeding, being either incorporated in the macronutrient fertiliser granule or applied as a physical blend mixed with the macronutrient fertiliser. This close proximity of seed to Mn fertiliser enables the seedling roots to intercept some of the applied Mn before it has been immobilised to unavailable forms (Reuter *et al.* 1988). Soaking seeds in solutions of manganese sulphate or chloride has been shown to increase seedling vigour of wheat, barley and oats (as reviewed in Chapter 2, Section 2.3.2) and to reduce the incidence of *Gaeumannomyces graminis* var. *tritici* (take all) in wheat in Mn deficient soils (Wilhelm *et al.* 1988). Seed soaking however, is not practical in commercial farming systems since imbibed seeds are more prone to damage during storage and sowing operations (Roberts 1948).

Seed coating with Mn provides an opportunity to place the Mn in an available form in close proximity with each seed. Seed coating with Mn has been shown to alleviate Mn deficiency of sugarbeet (Farley and Draycott 1978, Farley 1980); oats (Berkenkamp and McBeath 1966) and barley (McEvoy *et al.* 1988).

The aims of this chapter are: (1) to investigate the effectiveness of various fertilisers for coating Mn seeds and (2) to compare the effectiveness of Mn seed-coating with conventional methods of Mn fertiliser application.

5.2 Sources of Mn and additives for seed coating

5.2.1 Introduction

Manganous sulphate is the most commonly used compound for soil-applied fertilisers, and has been shown to be equal or superior to other Mn sources. However $MnSO_4$ applied as a band has been shown to reduce the establishment of legumes on sandy soils (Alley *et al.* 1978, Boswell *et al.* 1981, Hallock 1979). Manganous oxide (MnO), if applied as finely divided particles, can be effective (Knezek and Davis 1971, Mortvedt and Giordano 1975). It is, however, only slightly soluble in water and is less effective than $MnSO_4$ in correcting Mn deficiency. MnO incorporated in a pelleting compound used with sugarbeet seed has been shown to prevent early symptoms of Mn deficiency in seedlings without risk to seedling establishment. $MnSO_4$ is a more soluble source of Mn, and its incorporation into the coating material is more effective per unit of Mn than MnO, although it has in some circumstances reduced plant establishment (Farley and Draycott 1978; Farley 1980). Mn deficiency in oats was alleviated by coating seeds with $MnSO_4$ and ethyl mercury *p*-toluene sulfonanilide an antimicrobial organomercurial agent (Ceresan M) (Berkenkamp and McBeath 1966).

Microbial activity in the soil affects the availability of Mn (Leeper 1947, Ghiorse 1988). Oxidising bacteria have been shown to be primarily responsible for the oxidation of Mn^{2+} (Uren and Leeper 1978). Two approaches for keeping the Mn in an available form in the immediate vicinity of the seed have been tested. Working with oats, Berkenkamp and McBeath (1966) incorporated the antimicrobial agent, Ceresan M, into the manganese ammonium phosphate pellet to minimise the oxidation of Mn^{2+} to Mn^{4+}. They found that the early advantages of seed coating were carried through to grain yield only when the antimicrobial agent was included. Taking the opposite approach, Marschner *et al.* (1991) isolated strains of Mn reducing microorganisms from the rhizospheres of cereal plants and showed by coating wheat seeds with bacteria either in the presence or absence of Mn seed coating, that one of the roles of rhizosphere bacteria could be to increase the Mn uptake of wheat.

Three experiments, designed to investigate materials that may maintain the applied Mn in a plant available form, are described. Various sources of Mn were investigated as potential coating materials and compared in a field trial with conventional Mn fertiliser techniques.

5.2.2 Materials and Methods

General: Experiments were conducted over 3 years in a farmer's field at Marion Bay on the Yorke Peninsula, South Australia on a calcareous sand (pH 7.9, 77% calcium carbonate; see Appendix 1 for full soil description).

Seed coating was carried out as previously described. Mn sources were finely ground to <150 micron. Seeds were sprayed in short bursts with adhesive, interspersed with additions of Mn, until the total amount had been added, and finally the coating was dried at 45°C whilst tumbling in the coating pan. In the first three experiments methyl cellulose (Celecol HPM 450 0.5g/100 ml of water) was used whereas in 1991 and 1992, a polyvinyl adhesive (Gelvetol 40-10: Air Products Inc., Pennsylvania) was used at 12.5 g/ 100 ml of water. Field plots were 4.5m x 0.8m (4 rows) sown using a cone seeder described by Graham *et al.* (1992). A basal fertiliser of mono-ammonium phosphate (MAP), urea and trace elements was applied at sowing to deliver 23 kg N, 20 kg P, 1 kg Cu and 3 kg Zn ha^{-1}. Galleon barley was sown at 55 kg ha^{-1} whilst the wheat was sown at 60 kg ha^{-1}. Plots were visually assessed for symptoms of Mn deficiency on a scale of 1 to 5. The scale used was; 1 = small chlorotic plants, growing points dying; 2 = small, pale green, limp plants, necrotic and chlorotic; 3 = pale green plants showing some interveinal chlorosis; 4 = no effect of Mn deficiency in height of plant, young leaves pale in colour and flaccid; and 5 = healthy dark green, turgid plants. Vegetative samples were collected by sampling 0.5 m of each of the two inside rows. Grain harvest was by Wintersteiger small plot harvester. 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 inductively coupled plasma emission spectrometer (ICP) after digesting in nitric acid using the method described by Zarcinas (1984). Data were statistically analysed using standard analysis of variance procedures.

Details of each experiment:

Experiment 1 (1989): To investigate some possible additives that may suppress Mn-oxidising bacteria and hence keep the Mn in a more plant available form a preliminary field trial was conducted using three commercial broad-spectrum fungicide seed dressings and the urease inhibitor, in combination with Mn seed coating. The three fungicidal seed dressings and a urease inhibitor were compared to a nil control treatment as described below (Table 5.1). Seed treatments were applied to seeds of

Table 5.1. Treatment description and application rates for seed dressings used in Experiment 1, Marion Bay, 1989.

Treatment	Product	Rate (kg product ha^{-1})
Nil		0.00
Mancozeb	$[-SCS.NHCH_2CH_2NHCS.S.Mn-]_x(Zn)_y$	0.53
Lesan	Fenaminosulf 420g and Lindane 50 g kg^{-1}	0.10
Baytan	Triadimenol 150g kg^{-1}	0.10
PPD	Phenyl phosphorodiamidate, a urease inhibitor	0.60

Bayonet wheat that had either not been treated or was coated at 0.8 kg Mn ha^{-1} in a factorial design with 4 replicates. Plots were sown on the 22nd of June, and sampled

40 and 75 DAS. After this second sampling the Mn deficiency was severe because no foliar Mn sprays were used and the experiment was terminated.

Experiment 2 (1990): Of the materials tested in Experiment 1, Mancozeb had the largest positive effect on dry matter production and Mn uptake. This 2nd field experiment was designed to investigate further the effects of including Mancozeb in the seed coating. Mancozeb (~20% Mn, 2% Zn) and Zineb (~25% Zn) seed dressings were compared as two commercial fungicides with the same active ingredient but different elemental composition to ascertain whether the Mn content of Mancozeb conferred any benefit to the seedling. In addition seeds were coated with Zn alone or Mn and Zn at rates comparable to that present in the fungicide coating. The treatments and rates are described in Table 5.2. The experiment used a split-plot design to allow a foliar application of Mn (1.3 kg ha^{-1} as $MnSO_4$) applied at mid-tillering (86 DAS) to one half of each block. Thus, the foliar treatment corresponds to main plots, whilst the combinations of seed coating were applied to the subplots within each main plot. The experiment was replicated 4 times. Plots were sown on the 10th July and sampled 63 DAS.

Table 5.2. Treatment description and application rates of coating materials used in Experiment 2, Marion Bay 1990.

Treatment	Product	Rate ($kgha^{-1}$)
Nil Mn control		0.0
Coated seed control	$MnSO_4H_2O$	0.8 Mn
Soil Mn control	Micromate 280 granular Mn 28% Mn 11%S (50% MnO + 50% $MnSO_4H_2O$)	6.0 Mn
Zn coated	$ZnSO_47H_2O$	0.13 Zn
Mn+Zn coated	$MnSO_4H_2O$+$ZnSO_47H_2O$	0.1 Mn+0.01Zn
Zineb coated	[-SCS.$NHCH_2CH_2NHCS$.S.Zn-]	0.53 product
Mancozeb coated	[-SCS.$NHCH_2CH_2NHCS$.S.Mn-$]_x(Zn)_y$	0.53 product
Zineb+ Mn coated seed		0.53 product+0.8Mn
Mancozeb+Mn coated seed		0.53 product+0.8Mn

Experiment 3 (1991) : A field experiment was conducted with Galleon barley to investigate which of the components of Mancozeb might be associated with the main benefit (demonstrated in Experiments 1 and 2). The experiment included 2 controls, nil coating and 6 kg Mn ha^{-1} applied to the soil; seed coating with Mn, Zn or Mn+Zn at the same amounts present in the commercial fungicides; seed coating with three fungicides; Maneb, Zineb and Mancozeb (same active ingredient but different mineral composition) at commercial rates with or without additional Mn coated on the seed (0.8 kg Mn ha^{-1}). Details of the coating materials and rates of application are given in Table 5.3. The design was randomised block with 8 replicates. Plots were sown on 26th June and sampled 66 DAS. After sampling a foliar application of Mn (1.3 kg ha^{-1}) was applied to all plots.

Table 5.3. Treatment description and application rates of coating materials used in Experiment 3, Marion Bay 1991.

Treatment	Product	Rate (kg ha^{-1})
Nil Mn control		0.0
Coated seed control	$MnSO_4H_2O$	0.8 Mn
Soil Mn control	Micromate 280 (as in Table 5.2)	6.0 Mn
Zn coated	$ZnSO_47H_2O$	0.13 Zn
Mn coated	$MnSO_4H_2O$	0.1 Mn
Mn+Zn coated	$MnSO_4H_2O+ZnSO_47H_2O$	0.1 Mn+0.01Zn
Zineb coated	[-SCS.$NHCH_2CH_2$NHCS.S.Zn-]	0.53 product
Maneb coated	[-SCS.$NHCH_2CH_2$NHCS.S.-Mn-$]_x$	0.53 product
Mancozeb coated	[-SCS.$NHCH_2CH_2$NHCS.S.Mn-$]_x(Zn)_y$	0.53 product
Zineb+ Mn coated seed		0.53 product+0.8Mn
Maneb+ Mn coated seed		0.53 product+0.8Mn
Mancozeb+Mn coated seed		0.53 product+0.8Mn

Experiment 4 (1991): A comparison of sources of Mn for seed coating was conducted in a field trial with Galleon barley. Six potential seed coating materials were each applied at two rates of Mn, and with two controls (nil Mn and soil applied Mn at 6 kg Mn ha^{-1}). The application rates were not the same for each source since the less soluble sources were expected to be both less injurious and less available to the seedlings, and were therefore applied at higher rates. Plots were sown on 26th June. Details of the coating materials and rates of application are given in Table 5.4. The experiment was randomised in blocks and replicated 12 times. At early tillering (65 DAS) the plots were visually assessed for symptoms of deficiency as described previously, two sections of 0.5m of row were sampled from the inside rows of each plot for 8 replications only. After this first sampling a foliar Mn application 1.3 kg Mn ha^{-1} was applied to all plots. At maturity, 20 plants were sampled per plot, and grain yield was determined by machine harvest.

Table 5.4. Treatment description and application rates used in Experiment 4.

Treatment	Method	Product	Solubility ($g\ l^{-1}$)	Rate (kg Mn ha^{-1})
Nil Mn Control				0.0
Soil Mn Control	Drilled	Micromate 280 granular Mn (50% MnO + 50% $MnSO_4H_2O$)	n.a.+	6.0
Sulphate	Coated	manganese sulphate $MnSO_4H_2O$	850	0.4, 0.8
Oxysulphate	Coated	finely ground micromate granules	n.a.	0.8, 2.4
Oxide	Coated	manganous oxide MnO	slightly	0.8, 2.4
Dioxide	Coated	manganese dioxide MnO_2	insoluble	0.8, 2.4
Dextrolac	Coated	Manganese Dextro-Lac *	liquid	0.4, 0.8
Gly Mn	Coated	glycerolatomanganese $C_3H_6O_3Mn$	insoluble	0.4, 0.8

* Spray Systems Australia. n.a.+ = not available

5.2.3.Results

Experiment 1 (1989): In the absence of Mn seed coating, seed treatment with Mancozeb increased both dry matter production and Mn uptake of seedlings at both sampling times; Baytan had a small but positive influence on dry matter production and Mn uptake of shoots at the 1st sampling but the effect was no longer significant by the 2nd sampling (Figure 5.1, Table 5.5). Both PPD and Lesan decreased dry matter production and consequently Mn uptake for the first sampling but this was no longer significant by the 2nd sampling. Fungicide treatments, except Mancozeb, increased the concentration of B and decreased the concentration of P in whole shoots for both sampling times (Table 5.5). Seed coating with Mn further increased dry matter and Mn uptake for all additives except Mancozeb for both times of sampling. Manganese seed coating decreased the concentration of B, Zn, Ca and P in the shoots (40 DAS) and this was still apparent at 75 DAS (Table 5.5) but was no longer significant for Zn. In the absence of Mn seed coating Mancozeb produced the highest dry matter yields and Mn uptake at both sampling times.

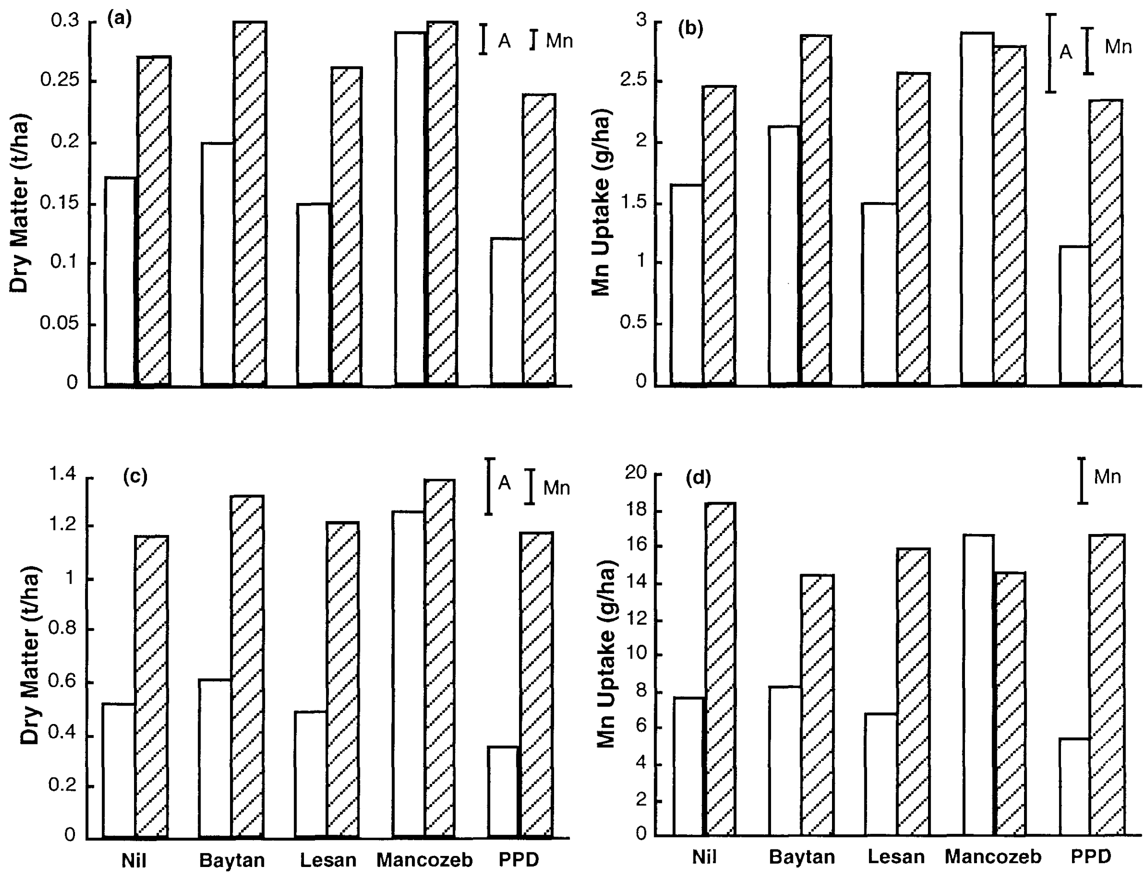

Figure 5.1 The effect of seed coating treatments on (a) dry matter production and (b) Mn uptake at early tillering 40 DAS; and (c) dry matter production and (d) Mn uptake at mid tillering 75 DAS. Experiment 1, Marion Bay 1989. Open columns represent Nil Mn treatments and hatched columns Mn coated seed. Vertical bars indicate lsd (P<0.05) for A = additives and Mn treatments.

Table 5.5. Effect of seed treatment on nutrient content of whole shoots 40 and 75 DAS, and visual assesment of plants 75 DAS. Experiment 1, Marion Bay 1989.

Additive	Mn	1st sampling 40 DAS						2nd sampling 75 DAS						
		Fe	B	Zn	Ca	K	P	Visual Score*	Fe	B	Zn	Ca	Mg	P
			mg kg^{-1}			g kg^{-1}				mg kg^{-1}			g kg^{-1}	
Nil	0	185	7.5	81	20	42	5.8	2.3	267	9.4	36	21	2.6	5.7
Nil	C0.8	149	6.6	65	16	45	5.4	4.0	264	8.6	33	22	2.8	5.2
Baytan	0	222	7.9	79	24	44	5.6	2.5	305	9.5	33	24	2.5	5.5
Baytan	C0.8	154	6.3	66	17	49	5.4	4.3	215	8.6	33	19	2.9	5.5
Lesan	0	200	8.0	83	23	41	5.6	2.0	313	10.0	32	23	2.6	5.5
Lesan	C0.8	163	7.0	70	18	47	5.5	4.0	263	8.4	32	21	2.8	5.3
Mancozeb	0	170	7.0	66	21	48	5.2	4.3	289	8.9	33	24	2.8	5.2
Mancozeb	C0.8	164	6.3	60	17	46	5.1	4.8	202	8.0	30	17	2.8	5.1
PPD	0	149	8.1	101	20	42	5.8	1.5	295	9.6	40	23	2.4	5.7
PPD	C0.8	165	6.7	66	18	48	5.5	4.0	288	9.2	34	24	2.8	5.4
LSD ($P<0.05$)	Additive	NS	0.44	NS	NS	NS	0.2	0.7	47	0.75	NS	NS	NS	0.1
	Mn	NS	0.28	8.6	2	2	0.1	0.4	30	0.48	NS	2	0.07	0.08

* A lower visual score indicates more severe Mn deficiency

Experiment 2 (1990): All treatments increased dry matter production and consequently uptake of Mn (and all other nutrients) at the first sampling in comparison with the nil Mn control treatment (Table 5.6, Figure 5.2). Zineb was beneficial in increasing dry matter production and Mn uptake at 63 DAS in the absence of Mn; however, when Mn was coated on the seed the addition of Zineb had no effect. As in Experiment 1, including Mancozeb in the coating was advantageous both with or without Mn seed coating. The Mn+Zn applied at equivalent rates as that present in the fungicide application was equally effective (within one lsd) as Mancozeb or Zineb applied without additional Mn seed coating, in increasing dry matter yield and Mn uptake. The

Table 5.6 Dry matter yield and nutrient concentration in whole shoots at early tillering and grain yield at maturity of Galleon barley coated with nutrient and fungicide treatments. Experiment 2, Marion Bay 1990.

Treatment	1st Sampling DM ($t\ ha^{-1}$)	Fe	Mn	B	Cu	Zn ($mg\ kg^{-1}$)	P	S ($g\ kg^{-1}$)	Maturity Grain Yield ($t\ ha^{-1}$) Nil Foliar	+Foliar Mn
Nil	2.96	42	7.2	4.5	3.6	12.8	2.0	1.8	1.42	1.76
Seed Mn	3.67	41	9.0	4.5	4.0	13.5	2.1	1.8	1.56	1.75
Soil Mn	3.45	47	8.8	4.7	3.7	13.7	2.1	1.9	1.55	1.93
Mn+Zn	3.64	41	8.8	5.1	3.9	14.3	2.1	1.8	1.60	1.66
Zn	3.82	45	10.2	5.4	4.0	14.1	2.0	1.9	1.69	1.76
Zineb	3.37	47	8.1	4.2	3.4	11.8	1.8	1.8	1.54	1.62
Zineb+SeedMn	3.65	42	10.2	3.9	3.6	12.8	2.0	1.8	1.63	1.88
Mancozeb	3.60	47	9.9	4.9	3.8	13.1	2.0	1.8	1.60	1.70
Mancozeb+SeedMn	4.61	44	9.8	4.4	3.9	12.5	1.9	1.7	1.53	1.81
LSD ($P<0.05$)										
Treatment	0.06	N.S.	1.6	N.S.	N.S.	N.S.	N.S.	N.S.	significant at 10%	
Foliar									0.15	

greatest dry matter yield was produced by coating seeds at 0.8 kg Mn ha^{-1} and including Mancozeb in the coating. Soil applied Mn fertiliser at 6 kg Mn ha^{-1} was ineffective, compared to Mn seed coating, in producing dry matter at the first sampling however when a foliar Mn spray was applied this treatment resulted in the greatest grain yield. By maturity the Mn deficiency was so severe that all treatments yielded poorly being 80-85% of +foliar in the sub-plots where Mn had not been applied as a foliar spray and the treatment effects were no longer significant. The foliar Mn application was applied to the + foliar subplots after the first sampling by which time the plants in all treatments were deficient in Mn and Zn (Mn concentration whole shoots ranging from 7 to 10 mg kg^{-1}, and Zn concentration 13 mg kg^{-1} Table 5.6). Consequently, the effects on grain yield of both the treatments applied at sowing and the foliar Mn application were smaller than would be expected from the response measured at the first sampling. Zinc deficiency may also have confounded the response to Mn.

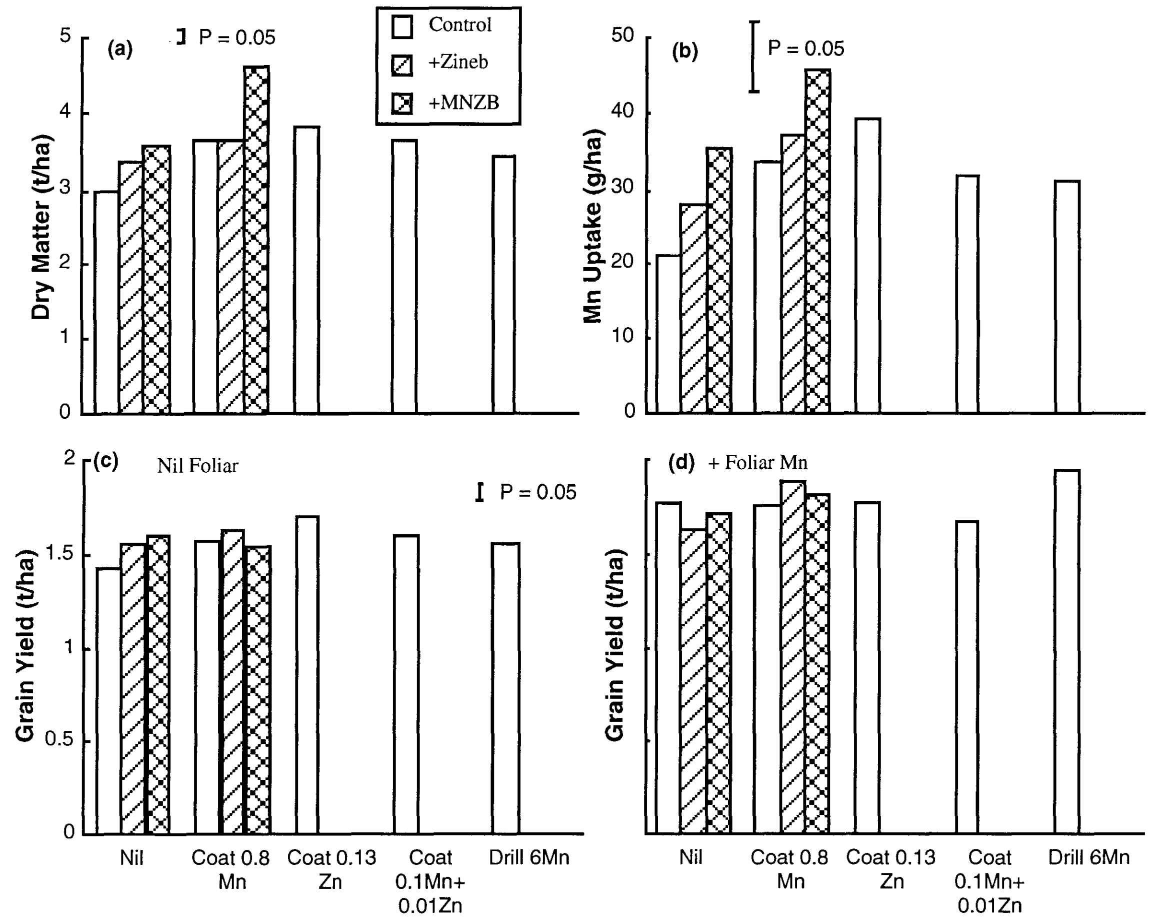

Figure 5.2 Effect of nutrient fungicide combinations on (a) dry matter yield, (b) Mn uptake of whole shoots 63 DAS, (c) grain yield at maturity without a foliar Mn application and (d) grain yield with foliar applied Mn. Experiment 2, Marion Bay 1990. Vertical bars represent lsd (P = 0.05). MNZB = Mancozeb, Control = no fungicide.

Experiment 3 (1991): In this experiment, as in Experiments 1 and 2, the fungicide treatments which contained Mn (i.e. Maneb and Mancozeb), improved dry matter production in the absence of applied Mn; this effect was still evident when Mn coating was applied, and was carried through to grain yield (Table 5.7, Fig 5.3). Maneb or Mancozeb applied in combination with seed Mn coating produced the greatest grain yield. Again the Mn component of the fungicide was equally effective in increasing dry matter production as the fungicide 66 DAS however, by maturity, the Maneb and Mancozeb treatments, were superior to the corresponding nutrient treatment. In this trial dry matter production at early tillering was similar for Mn coated at 0.8 kg ha^{-1} plus Maneb or Mancozeb, or Mn drilled at 6 kg ha^{-1}, however by maturity the Maneb or Mancozeb fungicide plus Mn coating combination produced more grain than the application of 6 kg Mn ha^{-1} drilled with the seed. Coating with fungicide and Mn together resulted in a greater dry matter production at early tillering (Figure 5.3) than Mn coating alone. Grain yield was greatest where both Mn and fungicide were coated onto the seed.

Treatments had no effect on seedling establishment, but had a large effect on plant development by 66 DAS (Table 5.7). Where a small amount of Mn (0.1 kg ha^{-1}) or a Mn containing fungicide was applied to the seed, plants had more tillers and when either Maneb or Mancozeb were included or a higher rate of Mn (0.8) the plants were also taller (Table 5.7).

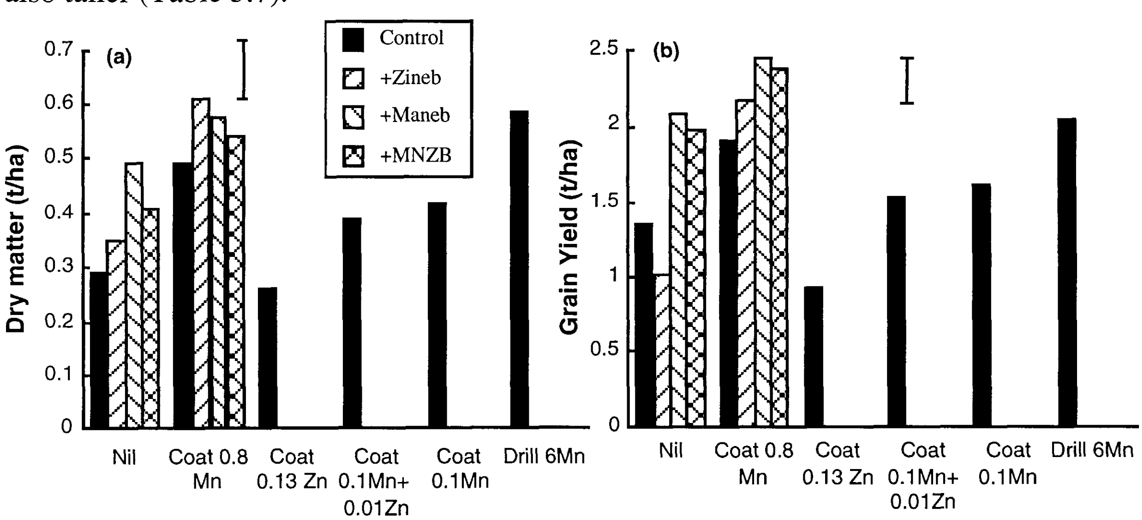

Figure 5.3. Dry matter production at (a) early tillering 66 DAS and (b) grain yield of Galleon barley coated with combinations of nutrients and fungicides. Experiment 3, Marion Bay in 1991. Vertical bars represent lsd (P = 0.05). MNZB = Mancozeb, Control = no fungicide.

Table 5.7 Plant establishment, vegetative yield, Mn concentration and Mn uptake at early tillering 66 DAS and grain yield at maturity of Galleon barley coated with different combinations of nutrients and fungicides. Experiment 3, Marion Bay 1991.

Coating	Plants (/m row)	Tillers (/plant)	Plant Ht (cm)	Dry Matter (t/ha)	Mn Concn (mg/kg)	Mn Uptake (g/ha)	Grain Yield (t/ha)
Nil	32	4.3	23.8	0.29	15.02	4.43	1.35
Zn (0.13)	29	4.7	23.0	0.26	14.48	3.83	0.93
Mn (0.1)	30	5.3	25.3	0.42	15.72	6.51	1.63
Mn (0.1),Zn (0.01)	26	6.1	27.8	0.39	14.72	5.81	1.53
Mn (0.8)	28	6.2	31.0	0.49	14.05	6.93	1.89
Zineb	34	4.5	24.8	0.35	15.76	5.49	1.02
Zineb +0.8 Mn	30	6.5	30.3	0.61	15.22	9.28	2.17
Maneb	27	7.0	29.4	0.49	14.76	7.31	2.08
Maneb+0.8 Mn	26	7.7	31.8	0.58	15.48	9.07	2.45
Mancozeb	25	6.6	26.5	0.41	14.33	5.91	1.96
Mancozeb+0.8 Mn	26	6.7	31.4	0.54	16.25	9.39	2.37
Soil Appln 6 Mn	31	6.5	30.1	0.59	15.52	9.28	2.05
lsd ($P<0.05$)	NS	1.0	3.0	0.11	NS	2.9	0.38

Experiment 4 (1991): In this experiment all seed coating materials improved vegetative yield over that of the nil Mn control (Figure 5.4a, Table 5.8). Responses to treatments are shown in Plate 3. Mn oxide at the low rate of coating, however, had no effect. Gly Mn was tested in this experiment since all metalo glycerates hydrolyse rapidly, hence the Mn contained in Gly Mn should be readily available to the seedling (R. Taylor pers comm). Gly Mn was not as effective as expected, this is attributed to the instability of the material, which converts on crystallisation to MnO_2. At the first sampling (65 DAS) the plants in treatments that had been coated with Mn dextrolac at 0.8 kg Mn ha^{-1} appeared darker green and more vigorous as indicated by the visual score in Table 5.8. However, by this time plants in all treatments were severely Mn deficient (Mn concentration whole shoots 10 mg kg^{-1}, Table 5.8) so that treatment effects were smaller than if plants had been sampled before plants in the more effective treatments became deficient. Seed coating with Mn dextrolac, sulphate or oxysulphate resulted in the largest vegetative yields. This early advantage was sustained throughout the season

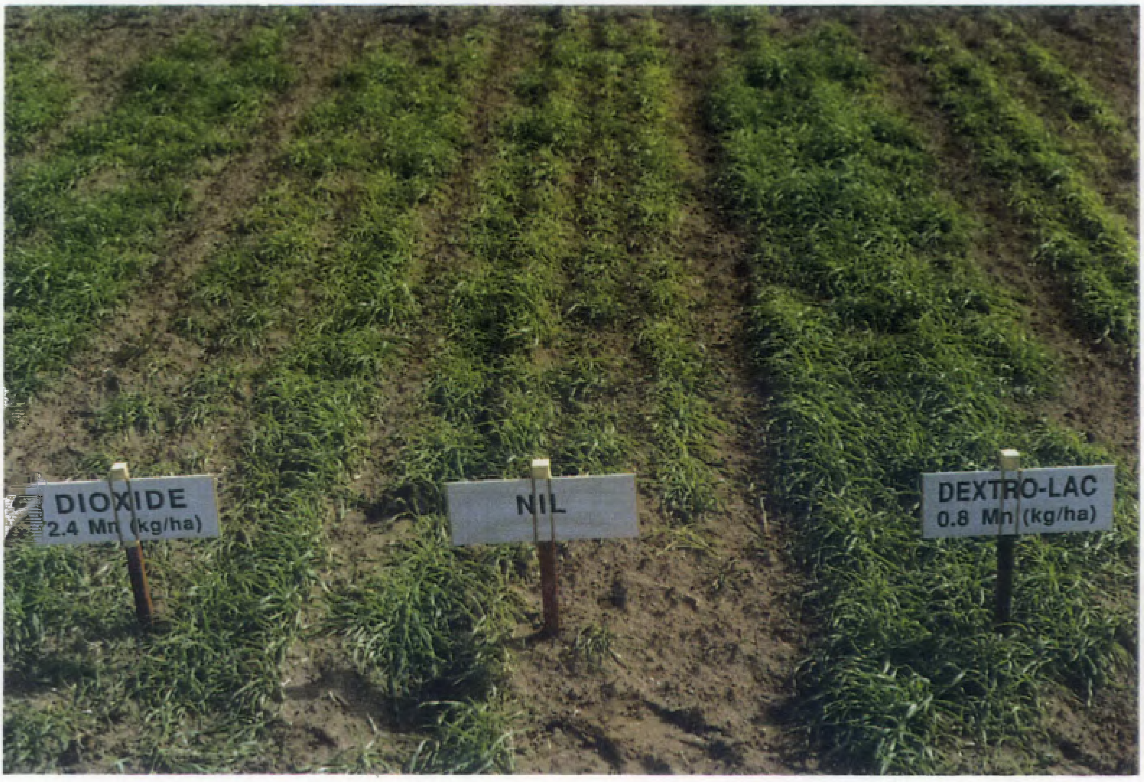

Plate 3. Response of Galleon barley to Mn fertilisers applied as seed coating materials in Experiment 4 at Marion Bay 1991.

and Mn dextrolac coated at 0.8 kg Mn yielded equally (within one lsd) with 6 kg Mn drilled with the seed (Figure 5.4c). For grain yield, oxysulphate applied at 2.4 kg Mn ha^{-1} was equivalent to the sulphate applied at 0.8 kg Mn ha^{-1}. The oxide at 2.4 kg Mn ha^{-1} was equivalent to sulphate at 0.4 kg Mn ha^{-1}. Dioxide at 0.8 kg Mn ha^{-1} was not comparable to any rates of sulphate. Dextrolac at 0.4 kg Mn ha^{-1} was equivalent to oxysulphate at 0.8 kg Mn ha^{-1} and at 0.8 kg Mn ha^{-1} dextrolac out performed the oxysulphate, oxide and dioxide applied at 2.4 kg Mn ha^{-1} and equalled the sulphate at 0.8 kg Mn ha^{-1}. Both the sulphate and dextrolac applied at 0.8 kg Mn ha^{-1} were equivalent for grain yield to the soil application of 6.0 kg Mn ha^{-1} (Figure 5.4c).

Table 5.8 Visual assessment, vegetative yield, Mn concentration, Mn uptake at early tillering and grain yield at maturity of Galleon barley coated with different Mn sources grown at Marion Bay S.A. 1991 (Experiment 4).

Coating (kg Mn/ha)	Visual score*	Dry Matter (t/ha)	Mn Concn (mg/kg)	Mn Uptake (g/ha)	Grain Yield (t/ha)
Nil	1.0	0.50	11.34	5.68	1.37
Sulphate 0.4	3.0	0.89	10.83	9.71	2.01
Sulphate 0.8	3.5	0.86	10.80	9.71	2.36
Oxysulphate 0.8	3.0	0.86	10.56	9.14	2.17
Oxysulphate 2.4	3.9	0.80	10.56	9.14	2.40
Oxide 0.8	2.5	0.64	11.89	7.74	1.86
Oxide 2.4	2.9	0.83	10.80	9.03	2.07
Dioxide 0.8	2.0	0.75	11.39	8.59	1.73
Dioxide 2.4	2.2	0.75	11.01	8.24	1.84
GlyMn 0.4	2.8	0.72	10.72	7.69	1.80
GlyMn 0.8	3.1	0.75	11.56	8.71	1.96
Dextrolac 0.4	3.6	1.01	10.81	10.95	2.16
Dextrolac 0.8	4.1	1.03	10.40	10.86	2.55
Soil Appl 6.0	2.9	0.78	11.43	8.90	2.78
lsd ($P<0.05$)	0.3	0.17	NS	2.23	0.29

*A lower visual score indicates more severe Mn deficiency.

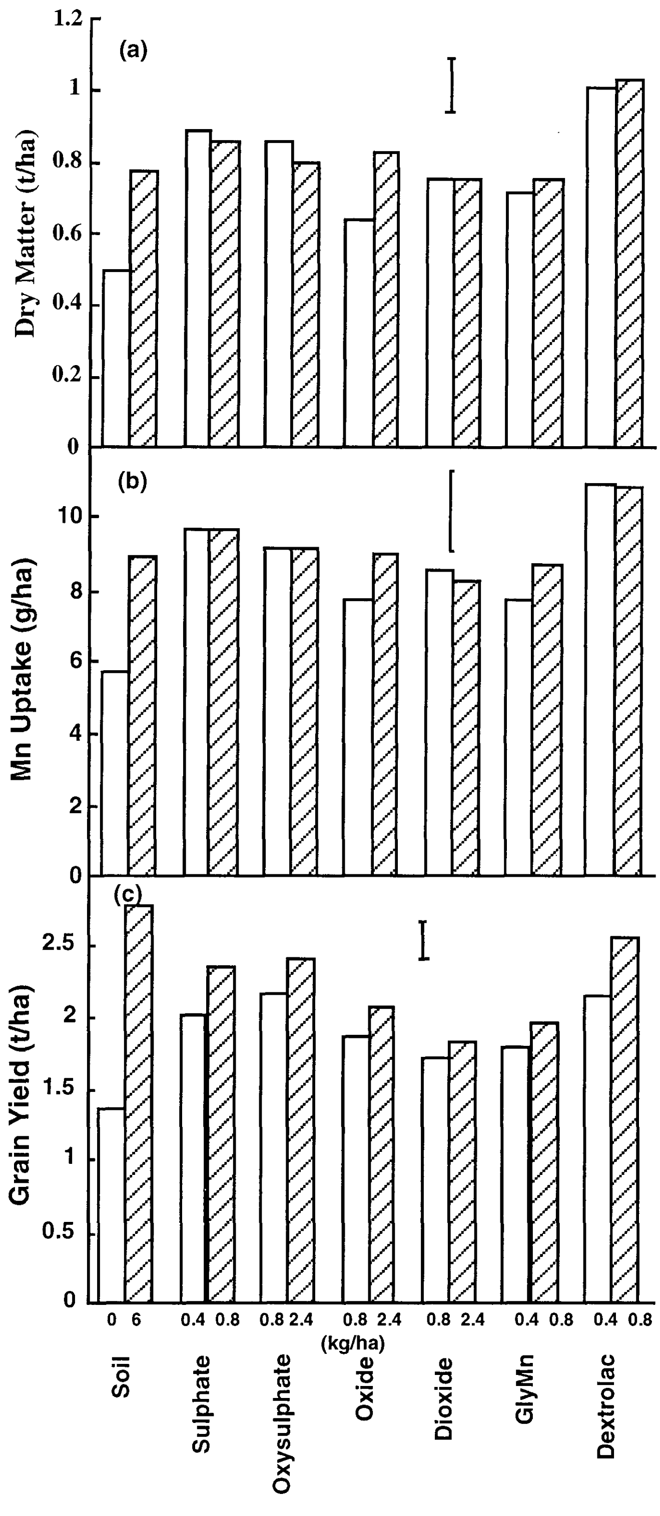

Figure 5.4. (a) Dry matter production and (b) Mn uptake of whole shoots at tillering (65 DAS) and (c) grain yield of Galleon barley coated with six potential seed coating materials applied at two rates. Open columns are the low rates of application (nil for soil, 0.4 for sulphate, GlyMn and dextrolac and 0.8 for others) whereas the hatched columns are for the higher rates of application (6.0 for soil, 0.8 for sulphate, GlyMn and dextrolac and 2.4 for the other materials). Experiment 4 at Marion Bay in 1991. Vertical bars indicate lsd ($P<0.05$) for comparison of treatments.

5.3 Efficacy of Mn seed coating compared with current Mn fertiliser strategies.

5.3.1 Introduction

The experiments described in this section tested the efficacy of Mn seed coating compared with soil-applied Mn-coated fertilisers for wheat and barley. The comparison was conducted against a background of two basal fertilisers commonly used by farmers in South Australia; these are monoammonium phosphate combined with urea (MAP+Urea 18:20) and diammonium phosphate (DAP 18:20).

5.3.2 Materials and Methods

General:

Experiments were conducted over 4 years in the same field at Marion Bay described previously. Seeds were coated using the method described in Section 5.2. Fertiliser was prepared by coating granules of either DAP or MAP+Urea mixtures with trace elements using the technique described by Walter (1990). Basal fertiliser was applied to supply 27 kg N, 30 kg P, 1 kg Cu, 1 kg Zn, 150 g Mo and 150 g Co ha^{-1} in 1989 and 1990; and to supply 18 kg N, 20 kg P, 1 kg Cu, 1 kg Zn, 150 g Mo and 150 g Co ha^{-1} in 1991, 1992 an 1993. The Mn was coated onto this basal fertiliser granule so that each granule was a carrier of Mn. Experiment details are listed in Table 5.9. All plots were 10 rows (1.5m) sown with a cone seeder. Where a split plot design was used each plot was split into 2 sub-plots one of which received a foliar Mn spray (1.3 kg Mn ha^{-1}).

Results of previous field trials (Section 5.2) had indicated that the best yields were obtained when a combination of $MnSO_4$ and Mancozeb were coated on the seed. Additionally, Mn dextrolac was under investigation as a potential coating material. The final experiment in this chapter (Experiment 9), was designed to extend the results from Section 5.2 and compare seed coating with $MnSO_4$ or Mn dextrolac at three rates of Mn sown either with or without an additional dressing of Mancozeb and contrast these treatments against a response curve for drilled Mn fertiliser.

Plots were assessed visually throughout the season using the scale described in Section 5.2. Plots were sampled as required by sampling 4 m of row for 10 m plots or 2 m of row for 5m plots in a grid pattern, avoiding outside rows or previously sampled neighbouring rows. Plant samples were dried, weighed, ground and nutrient content analysed by Inductively Coupled Plasma Spectrometer as described previously. Mitscherlich curves were fitted to the yield data; all data were analysed using standard statistical packages.

Table 5.9. Rates of application of Mn to the soil (kg ha^{-1}) in each of the 5 field experiments, Marion Bay, S.A.

Expt details and design

No	Year	Sowing date	Crop	Plot size	Design	No. Reps	Foliar Mn (DAS)*	Sampling dates (DAS)
5	1989	22nd June	Galleon	5m	split plot	4	75	74 and 140
6	1990	11th July	Galleon	5m	split plot	4	86	69
7	1990	11th July	Spear	5m	split plot	4	86	69 and 130
8	1991	26th June	Galleon	10m	complete block	5	77	65
9	1992	18th June	Galleon	10m	complete block	4	49	45 +YEB's only

Mn fertiliser treatments

Expt 5 1989	8 drilled Mn rates with DAP as basal: 0, 0.75, 1.5, 2.5, 5, 10, 15, 20 kg Mn ha^{-1} 2 Mn seed coated 0.4 and 0.8 kg Mn ha^{-1} and 1 combination C0.4+D5
Expts 6 & 7 1990	5 drilled Mn rates with DAP as basal: 0, 0.75, 1.5, 2.5, 5 kg Mn ha^{-1} 4 drilled Mn rates with MAP+urea as basal: 0, 0.75, 5, 20 kg Mn ha^{-1} 3 Mn seed coated 0, 0.4 and 0.8 kg Mn ha^{-1} and 1 combination C0.4+D5 sown with either MAP or DAP as basal
Expt 8 1991	8 drilled Mn rates with DAP as basal: 0, 0.8, 1.6, 2.7, 5.7, 12.7, 21, 32 kg Mn ha^{-1} 8 drilled Mn rates with MAP+urea as basal: 0, 0.9, 1.8, 3.0, 6.3, 13.9, 23, 34 kg Mn ha^{-1} 3 Mn seed coated 0, 0.4 and 0.8 kg Mn ha^{-1} and 1 combination C0.4 sown with either D6.7 MAP or D6.1 DAP as basal
Expt 9 1992	6 drilled Mn rates with DAP as basal: 0, 0.4, 0.8, 1.2, 6.25, 13.9 kg Mn ha^{-1} 4 coated Mn rates as MnSO4 0, 0.4 and 0.8 and 1.2 kg Mn ha^{-1} 4 coated Mn rates as Mn dextrolac 0, 0.4 and 0.8 and 1.2 kg Mn ha^{-1} All treatments were applied with or without a seed dressing of Mancozeb (0.53 kg ha^{-1}) 1 combination treatment Mn dextrolac coated at 0.4 +Mn drilled at 5 + seed dressing of Mancozeb.

*DAS = days after sowing, +YEB's=Youngest expanded leaf blade with ligule.

5.3.3 Results

Experiment 5 (1989): In this trial the response to Mn at the first sampling was small as demonstrated by dry matter yield (74 DAS, Figure 5.5a). Concentrations of Mn in whole shoots ranged from 19 to 64 mg kg^{-1} (Table 5.10). However, by the second sampling (140 DAS) there was a marked response to soil applied Mn in terms of dry matter produced. The response to foliar Mn, although apparent visually, was not supported by an increase in weight of dry matter produced at this second sampling, except at Mn treatments below 5 kg ha^{-1} at sowing. Analysis of whole shoots indicated that all treatments including the foliar Mn treatments were deficient in Mn (Table 5.10). Critical level for Mn in barley being 11-17 mg kg^{-1} (Reuter and Robinson 1986).

Table 5.10. The effect of Mn fertiliser treatments on Mn concentration and uptake of Galleon barley grown in Experiment 5 at Marion Bay 1989.

Mn applied (kg/ha)	1st sampling 74 DAS Mn Concentration (mg kg^{-1})	1st sampling 74 DAS Mn Uptake (g ha^{-1})	2nd sampling 140 DAS Mn Concentration (mg kg^{-1}) -Foliar	2nd sampling 140 DAS Mn Concentration (mg kg^{-1}) +Foliar	2nd sampling 140 DAS Mn Uptake (g ha^{-1}) -Foliar	2nd sampling 140 DAS Mn Uptake (g ha^{-1}) +Foliar
Drilled						
0	20.98	4.84	2.78	3.02	2.02	3.43
0.75	21.62	5.53	2.58	3.40	2.23	4.24
1.5	20.70	5.44	3.49	3.79	3.30	4.02
2.5	21.47	6.19	3.49	4.73	3.45	5.01
5	28.11	9.86	5.66	4.97	7.26	6.94
10	40.00	13.67	6.23	7.25	9.88	10.86
15	55.34	18.38	7.39	7.66	9.41	11.77
20	63.91	23.31	8.76	8.16	13.64	12.18
Coated						
0.4	18.76	4.57	2.57	2.81	1.94	2.84
0.8	19.36	5.03	2.38	3.42	1.68	3.45
Combination C+D						
5.4	24.48	7.75	5.01	4.99	5.62	6.22
lsd(P<0.05) Mn	3.9	2.78	0.47		0.19	
Foliar			0.07		1.03	
Mn x Foliar			0.63		N.S.	

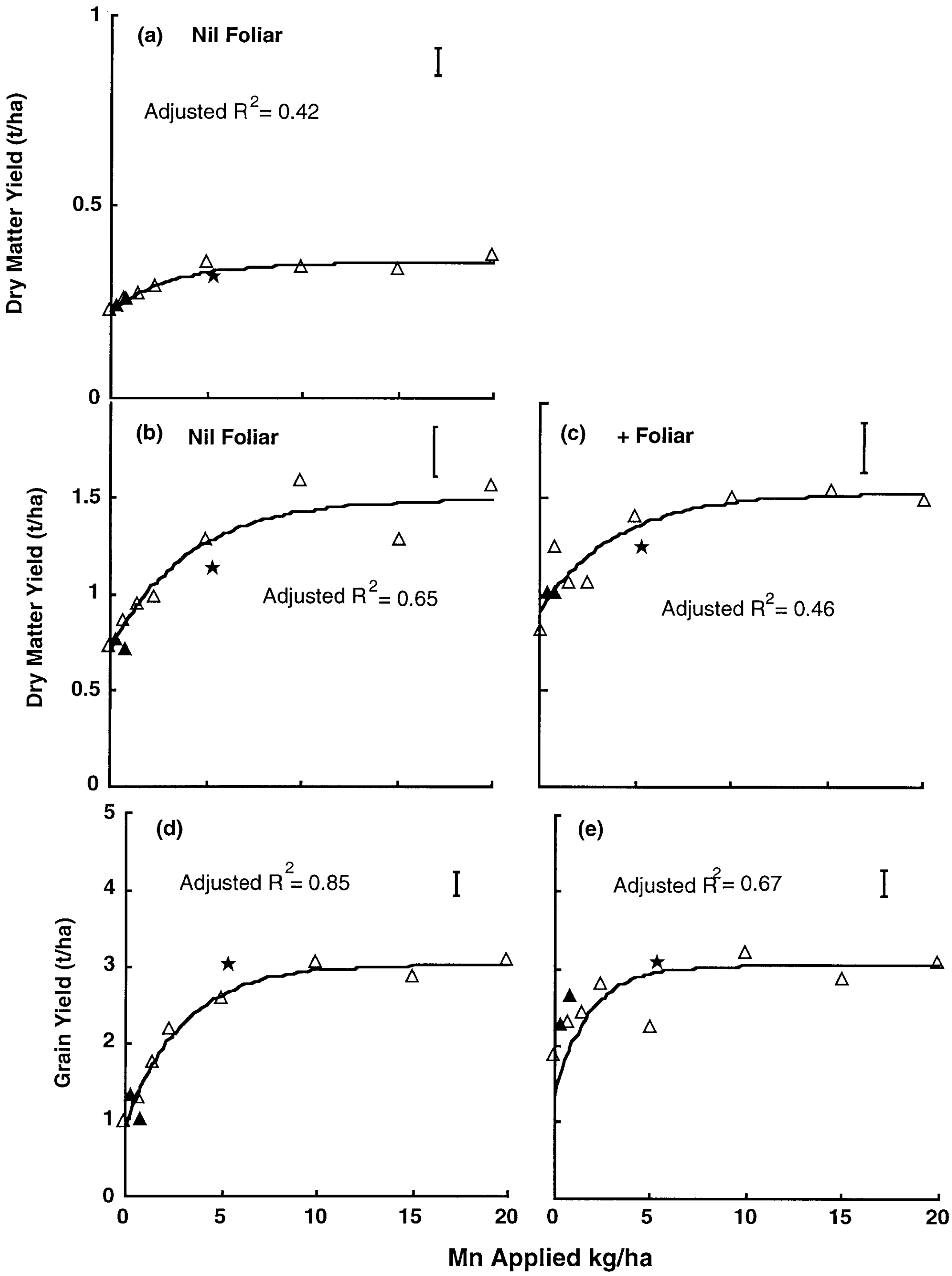

Figure 5.5. Effect of method and rate of Mn application on shoot dry matter yield of Galleon barley (a) sampled 74 DAS, (b) sampled 140 DAS without foliar applied Mn, (c) sampled 140 DAS with foliar applied Mn, (d) grain yield without foliar Mn, and (e) grain yield with foliar Mn. Experiment 5, Marion Bay 1989. The adjusted R^2 applies to the response curve $y=A(1-e^{(-kMn_{rate}-Mn_0)})$ fitted to the drilled applications. Application method was not significant. Drilled Mn (Δ), seed coated Mn (▲), combination coat +drill (★). lsd's (P = 0.05) were calculated for the drilled response curves only since there was no significant difference between coated and drilled treatments, and are indicated by vertical bars.

There was no advantage of Mn seed coating over drilled Mn treatments. By maturity however, the grain yield of coated treatments, where a foliar Mn treatment had been applied, was slightly (but not significantly) above the drilled response curve (Figure 5.5). Seed coating at 0.4 or 0.8 kg Mn ha^{-1} produced the same dry matter and Mn uptake at both times of sampling as soil applied Mn at 0.75 kg ha^{-1} and even with a foliar application of Mn was insufficient to attain maximum yield (Figure 5.5). The combination treatment C0.4+D5 did not perform better than the corresponding drilled Mn fertiliser. The combination treatment C0.4+D5 equalled the corresponding drilled Mn fertiliser and was sufficient to maintain within 95% of maximum yield.

Experiment 6 (1990): Plants sown with a basal dressing of DAP produced more dry matter and grain yield than those sown with MAP + urea at the same rates of basal nutrients (Figure 5.6) Coated treatments were equivalent to drilled treatments where DAP was the background fertiliser but were slightly above the drilled response curve where MAP had been used and foliar Mn applied. Coating at 0.8 kg Mn ha^{-1} and sowing with DAP basal resulted in a slight (but not significant) depression in both vegetative and grain yield. However, in the 1990 season the overall yields were higher where DAP had been the basal fertiliser. Where MAP had been used the response to applied Mn was smaller.

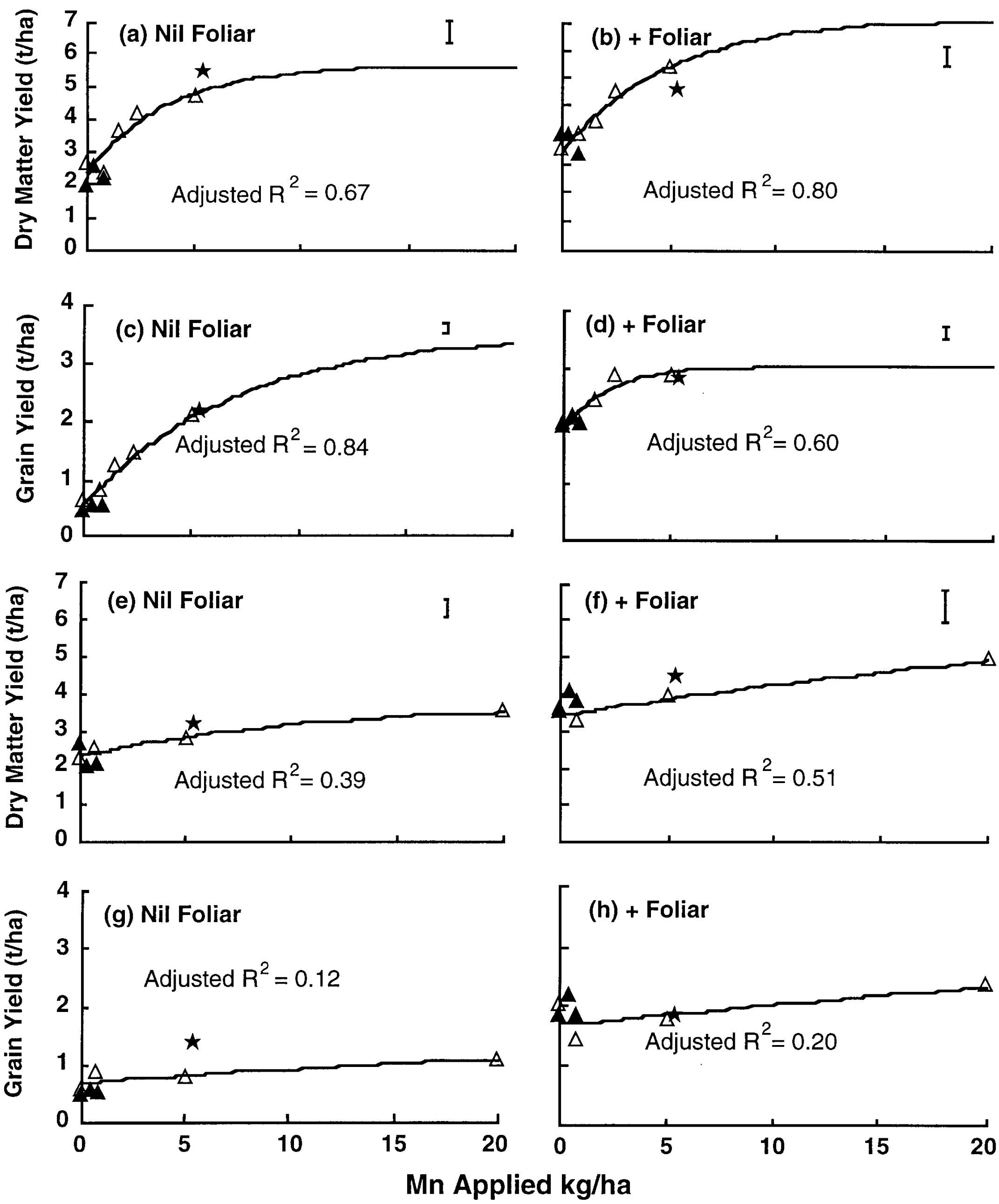

Figure 5.6 Effect of method and rate of Mn application on shoot dry matter and grain yield of Galleon barley grown in Experiment 6 Marion Bay 1990. Figures (a) to (d) are for treatments sown with DAP basal fertiliser; (a) first sampling (69 DAS), no foliar Mn; (b) first sampling foliar Mn applied; (c) grain yield, no foliar Mn; (d) grain yield foliar Mn applied. Figures (e) to (h) are for treatments sown with MAP basal fertiliser; (e) first sampling (69 DAS), no foliar Mn; (f) first sampling foliar Mn applied; (g) grain yield, no foliar Mn; (h) grain yield foliar Mn applied.

The adjusted R^2 applies to the response curve $y=A(1-e^{(-kMn_{rate}-Mn_0)})$ fitted to the drilled applications. Application method was not significant. Drilled Mn (Δ), seed coated Mn (▲), combination coat + drill (★). Vertical bars indicate lsd (P = 0.05) where significant; and were calculated for the drilled response curves only since there was no significant difference between coated and drilled treatments.

Experiment 7 (1990): In this experiment with wheat, as in Experiment 5.5 for barley, there was little response to Mn applied at seeding for the first sampling (69 DAS), regardless of background fertiliser (Figure 5.7). Analysis of youngest expanded leaf blades (YEBs) indicated that all plants were acutely deficient in Mn at this stage (YEB concentrations ranging from 5 to 12 mg kg^{-1}) and marginally deficient in Zn (ranging from 18 to 24 mg kg^{-1}). When the basal fertiliser was DAP, seed coating depressed dry matter production and grain yield for both rates of coating; however, the combination coat + drill treatment plus a foliar application of Mn enhanced both vegetative and grain yield above the drilled response curve (Figure 5.7). When the basal fertiliser was MAP+urea, although overall yields were lower, coating was less damaging and coated treatments were on or above the drilled response curve. As with the barley (Experiment 6, Figure 5.6), the combination treatment did not confer a yield benefit in either background fertiliser. Again, as found in Experiment 6 (Galleon barley) the overall yields were higher where DAP was the basal fertiliser; the response to applied Mn was much smaller where MAP+urea was used.

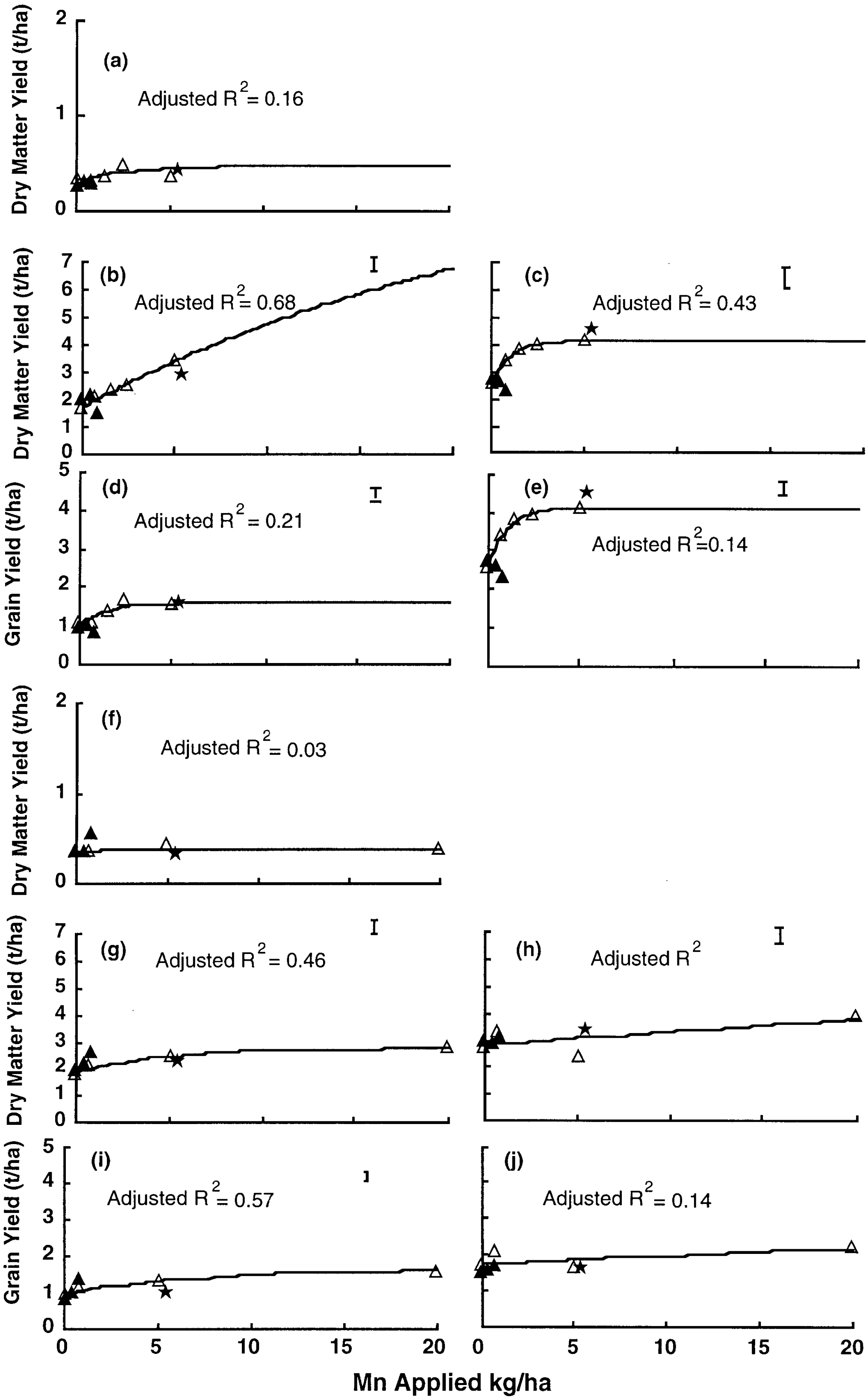
(a)
Adjusted R^2 = 0.16
(b)
Adjusted R^2 = 0.68
(c)
Adjusted R^2 = 0.43
(d)
Adjusted R^2 = 0.21
(e)
Adjusted R^2=0.14
(f)
Adjusted R^2 = 0.03
(g)
Adjusted R^2 = 0.46
(h)
Adjusted R^2
(i)
Adjusted R^2 = 0.57
(j)
Adjusted R^2 = 0.14
Dry Matter Yield (t/ha)
Grain Yield (t/ha)
Mn Applied kg/ha

Plate 4. Layout of Experiment 8 at Marion Bay in 1991 showing treatment responses at tillering.

Experiment 8 (1991): The experimental layout and magnitude of the response to Mn treatment are shown in Plate 4 and 5. In contrast to experiments 6 and 7, in the 1991 season, there was a larger response to applied Mn and a larger overall yield where MAP+urea was the basal fertiliser compared to where DAP had been applied at equivalent rates of nutrients (Figure 5.8). Seed coating had no effect on plant establishment regardless of whether MAP/urea or DAP were used (Table 5.11). In the

Table 5.11 Effect of rate and method of application of Mn fertiliser on establishment, development and yield of Galleon barley grown in Experiment 8 at Marion Bay in 1991.

Fertiliser /Rate	Plants (/m row)	Tillers (/m row)	Plant Ht (cm/plant)	Dry Matter (g/m of row)	Grain Yield (kg/plot)
DAP					
Drill0	20	103`	21	2.94	0.30
Drill0.8	23	158	22	5.03	1.10
Drill1.6	18	140	23	4.61	1.06
Drill2.7	22	179	24	5.92	1.54
Drill5.7	21	166	23	5.92	1.55
Drill12.7	19	161	23	5.90	1.62
Drill21	20	153	24	4.86	1.38
Drill32	20	155	22	4.97	1.36
Coat0	20	98	19	2.80	0.19
Coat0.4	22	150	23	4.71	0.69
Coat0.8	23	156	24	5.42	1.01
C+D6.1	20	173	24	6.82	2.17
lsd(P<0.05)	NS	24	2.1	1.07	0.33
MAP/urea					
Drill0	22	96	20	2.63	0.15
Drill0.9	19	129	21	4.34	1.11
Drill1.8	20	145	23	5.03	1.11
Drill3.0	20	165	25	6.21	1.71
Drill6.3	22	174	25	6.82	2.16
Drill13.9	21	192	25	7.63	2.50
Drill23	19	199	25	8.57	3.06
Drill34	20	183	25	7.58	2.82
Coat0	23	105	20	2.97	0.35
Coat0.4	23	138	22	4.67	0.71
Coat0.8	23	151	23	5.56	1.09
C+D6.7	20	180	25	7.62	2.25
lsd(P<0.05)	NS	26	2.3	1.44	0.31

Plate 5. Response of Galleon barley to coated and drilled applications of Mn at Marion Bay in Experiment 8, 1991.

presence of DAP, coating some Mn on the seed and drilling some with the fertiliser produced the greatest dry matter at early tillering and the greatest grain yield. In the presence of MAP/urea the coating treatments were more productive than the drilled fertiliser treatments at early tillering but this effect was not sustained through to grain yield. (Figure 5.8, Table 5.11). Both vegetative and grain yields were greatest when MAP+urea was used.

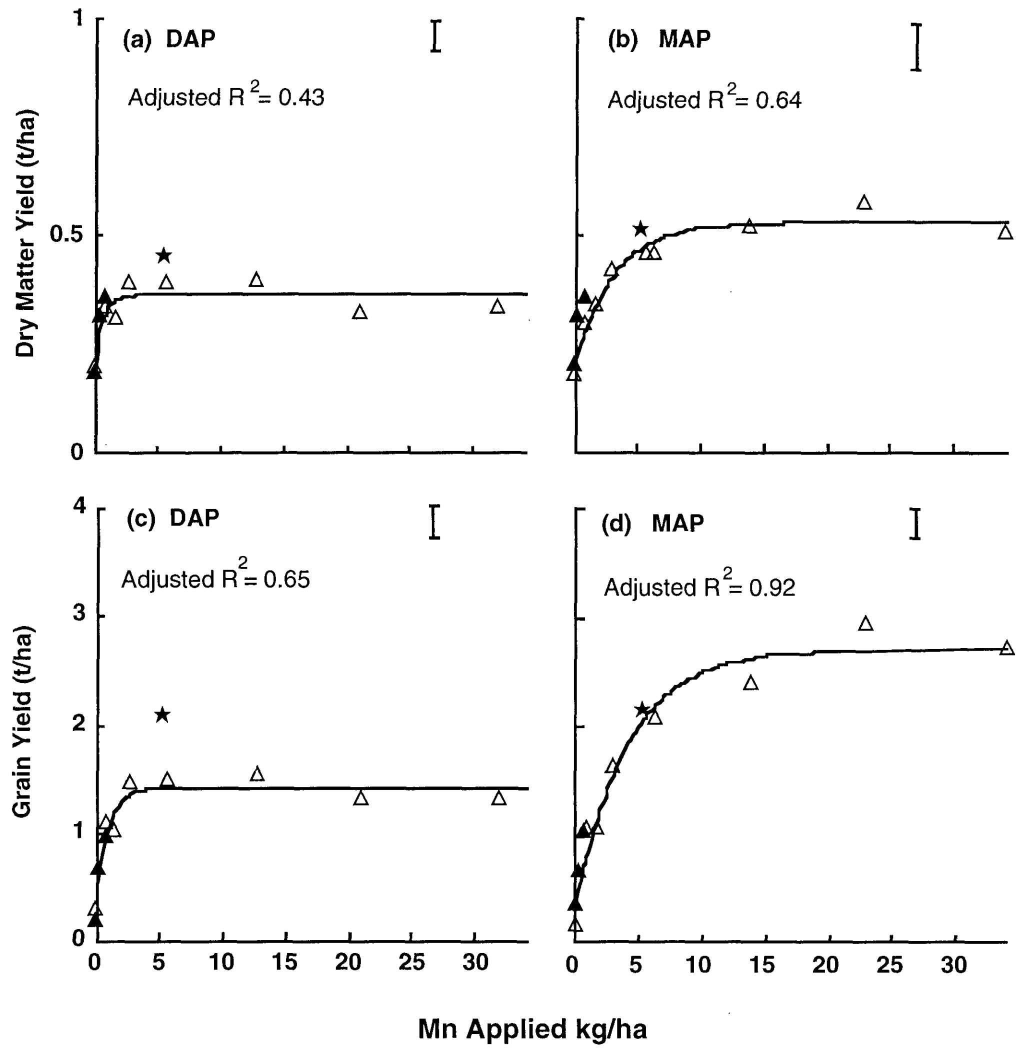

Figure 5.8 Efficacy of Mn seed coating in the presence of two background fertilisers DAP (a & c) and MAP+urea (b & d). Marion Bay 1991 Experiment 8. The adjusted R^2 applies to the response curve $y=A(1-e^{(-kMn_{rate}-Mn_0)})$ fitted to the drilled applications. Drilled Mn (Δ), seed coated Mn (▲), combination coat + drill (★). Vertical bars represent lsd's (P<0.05) and were calculated for the drilled response curves only since there was no significant difference between coated and drilled treatments.

Experiment 9 (1992): In this experiment Mn sulphate was superior to the Mn dextrolac as a coating material when Mancozeb was added (Figure 5.9). Omitting the Drill 6.25, Drill 13.9 and the combination treatment, statistical analyses indicated increasing the rate of Mn applied increased the tissue concentration of Mn, and grain yield but decreased the tissue concentration of Zn and P (Table 5.12). The addition of Mancozeb

Table 5.12 Effect of Mn treatments on concentration of nutrients in YEBs (45 DAS) and on grain yield of Galleon barley Marion Bay 1992 (Experiment 9). MNZB*=Mancozeb.

Treatment		YEB Analyses (mg kg^{-1})					Grain Yield
		Fe	Mn	Zn	Cu	P	(t ha^{-1})
Drill 0		99	11.4	11.6	30.0	5950	0.91
Drill 0	+ MNZB*	96	11.7	11.3	29.9	5390	1.09
Drill 0.4		101	11.3	10.6	28.7	5650	0.81
Drill 0.4	+MNZB	92	13.2	11.1	27.1	4910	1.39
Drill 0.8		99	14.7	10.4	27.7	4860	1.37
Drill 0.8	+ MNZB	101	13.0	10.1	28.2	5050	1.15
Drill 1.2		100	21.7	11.5	26.7	4340	1.86
Drill 1.2	+ MNZB	92	14.7	10.4	24.5	4400	1.83
Mn Dextrolac C0		106	12.3	11.5	32.2	6450	0.57
Mn Dextrolac C0	+ MNZB	104	12.6	10.3	28.9	5660	1.25
Mn Dextrolac 0.4		87	12.4	9.9	26.3	4560	1.21
Mn Dextrolac 0.4	+ MNZB	96	13.3	10.3	29.4	4790	0.81
Mn Dextrolac 0.8		103	13.8	11.5	29.2	5120	1.14
Mn Dextrolac 0.8	+ MNZB	99	16.2	10.8	27.9	4720	1.33
Mn Dextrolac 1.2		96	14.0	11.1	27.3	4670	1.55
Mn Dextrolac 1.2	+ MNZB	108	18.1	11.0	26.3	4616	1.46
Mn Sulphate C0		105	12.5	11.4	31.4	6260	0.40
Mn Sulphate C0	+ MNZB	94	13.1	10.7	26.5	4700	1.12
Mn Sulphate 0.4		93	11.0	11.2	31.4	5290	1.07
Mn Sulphate 0.4	+ MNZB	94	12.3	9.7	26.5	4639	0.95
Mn Sulphate 0.8		85	10.9	9.6	25.5	4590	0.80
Mn Sulphate 0.8	+ MNZB	101	17.7	10.4	27.8	4430	2.30
Mn Sulphate 1.2		93	20.5	10.7	27.7	4550	1.59
Mn Sulphate 1.2	+ MNZB	99	16.5	10.4	29.3	4600	2.13
lsd (P<0.05)	Mn rate	NS*	2.08	1.73	NS	330	0.27
	Method	NS	NS	NS	NS	NS	NS
	Mancozeb	NS	NS	NS	NS	230	0.19

NS *= not significant

increased grain yield and generally decreased the concentration of P in YEB's at the lower rates of Mn application. There was no significant difference between coating and drilled applications of Mn on any of the parameters measured.

However, when the experiment was analysed as an unbalanced design (data not shown), there was no affect of application method, rate or Mn source on Fe, Ca or Na concentration of YEB's (sampled 45 DAS) (Table 5.12). Rate of Mn applied significantly decreased P, Mg, Cu and Zn concentration of YEB's. The application of Mancozeb decreased B and increased Zn and P concentration of YEB's but had no effect on Mn concentration. Mancozeb significantly increased grain yield with $MnSO_4$ coating and Mn drilled but not with Dextrolac. Rate of application and source of Mn both significantly affected Mn concentration of YEB's.

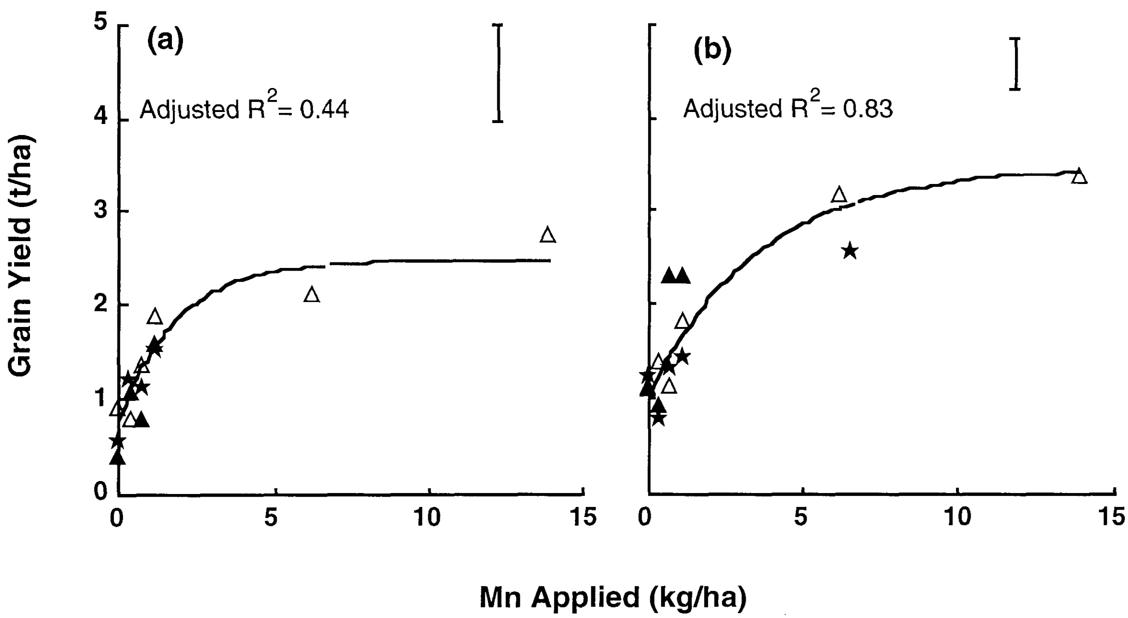

Figure 5.9 Effect of Mn fertiliser treatments on grain yield of Galleon barley grown at Marion Bay 1992 (a) without fungicide and (b) with Mancozeb fungicide (Experiment 10). The adjusted R^2 applies to the response curve $y=A(1-e^{(-kMn_{rate}-Mn_0)})$ fitted to the drilled applications. Drilled Mn (Δ), seed coated with $MnSO_4$ (▲), seed coated with Mn dextrolac (★) combination coat + drill (★).
Vertical bars represent lsd's ($P < 0.05$) calculated for the drilled response curve only since there was no significant difference between coated and drilled treatments.

5.4 Discussion

The experiments in Section 5.2 demonstrated, that of the materials tested, $MnSO_4$ and Mn dextrolac were the most effective seed coating materials. An advantage of using Mn dextrolac over $MnSO_4$ is that it is available in a solution form which already contains natural adhesives so there may be no further need for preparation of glues and no need to handle the dusty, corrosive $MnSO_4.H_2O$ powder.

Addition of the fungicide Mancozeb was effective in increasing the dry matter production and Mn uptake of barley plants. This enhancement of performance due to the presence of the fungicide was shown to be due to the nutritional composition of the fungicide, rather than effects of the fungicide on microbial activity and Mn availability as was suggested by Berkenkamp and McBeath (1966) in their study with Ceresan M and Mn coating of oats. The other fungicides tested (Baytan, Lesan and Zineb) without any Mn constituent were ineffective in increasing the availability of Mn. Combining Mn seed coating with either Mancozeb or Maneb produced more vigorous seedlings and greater uptake of Mn. However, the benefits were not always sustained through to grain yield. It is possible that the Mn in Mancozeb and Maneb is more available than that in mineral salts, judging from the comparison with the equivalent amounts of Mn added.

Seed coating with Mn (0.8 kg ha^{-1}) + Mancozeb (0.53 kg product or 0.1 kg Mn ha^{-1}) plus a foliar application of Mn produced equal or better yields than 6 kg Mn ha^{-1} drilled at seeding into the soil as granules (Micromate 280) plus a foliar application of Mn.

However, in the experiments described in Section 5.3 in which Mn seed coating was compared with drilled applications of Mn coated on macronutrient fertiliser granules, seed coating performed similarly to drilled applications of Mn applied at the same rate. In these experiments the soil applied Mn was in the micro environment of the fertiliser granule rather than the bulk soil and would therefore be more available than in the experiments described in Section 5.2. This Mn would also have been distributed more uniformly throughout the plot being applied at a higher rate of total fertiliser than the more concentrated micromate granules. This may account for the reduced efficiency of Mn seed coating in these experiments relative to the experiments in Section 5.2.

In Experiments 5 and 6 there was a slight depression due to seed coating at 0.8 kg Mn ha^{-1}. However, when the application of N and P was reduced from 27 to 18 and from 30 to 20 kg ha respectively for experiments 7, 8 and 9 there was no longer any evidence of a detrimental effect of coating. The rates of fertiliser used in experiments 7, 8 and 9 were chosen to be similar to that which growers would use, whereas the higher rates used for experiments 5 and 6 were designed to exacerbate Mn deficiency.

Manganese seed coating performed as well as and in some cases marginally better than drilled applications of Mn at equivalent rates. The performance of coated seed in comparison with drilled fertiliser applications appears to interact with season, in particular soil moisture at sowing and during seedling establishment. The relative effectiveness of DAP and MAP also appears dependent on seasonal effects which may be altering the severity of Zn deficiency. The concentrations of Zn in plant tissue at the first sampling in 1990 were marginal (ranging from 17 to 23 mg kg^{-1}) and DAP out performed MAP. In the 1991 season however, the tissue Zn concentrations were adequate (ranging from 20 to 40 mg kg^{-1}) and plants in the MAP treatments yielded higher than those sown with DAP. MAP is more acidic (pH in 1% solution 4.2), than DAP which is neutral (pH in 1% solution 7.3) and is more soluble than MAP. The 1990 season was also wetter (424 mm rainfall May-September) than the 1991 season (316 mm).

Similarly Mn dextrolac out performed Mn sulphate as a coating material in 1991 but not in 1992. In 1992 the tissue concentrations of Zn in YEBs were extremely low (ranging from 9 to 12 mg kg^{-1}); plants were deficient in Zn compared to the adequate levels in 1991. Again the 1992 season was wetter (412 mm rainfall May - September) so that seasonal effects may be influencing the severity of both Mn and Zn deficiency and the performance of seed coating and fertiliser materials.

At the time this study commenced the technology of coating micronutrients onto MAP and DAP granules was only just developing; products available on the market were either 'cold' mixes or coated fertilisers with Mn on one in every three granules.

It is difficult to make general recommendations from the nine experiments conducted over 4 four seasons described in this chapter. Any fertiliser recommendation must consider the costs involved as well as any expected yield increases. Seed coating outperformed drilled applications of Mn where the drilled Mn was applied as granules of Mn oxysulphate. However there was little or no yield advantage where the drilled Mn was applied coated on the macronutrient granule. Mn seed coating allows flexibility of choice of macronutrient fertilisers and may be more economical. At current prices, coating $MnSO_4$ on enough seed for 1 ha costs approximately \$1.75 (excluding labour and hire of a cement mixer; \$3.20 if these are included) whereas, current district practice of applying 6 kg Mn per ha as a coated fertiliser costs \$14 per ha. Applying Mn as a coated fertiliser at the equivalent amount of coated seed costs \$4 per ha. Using Mn dextrolac rather than the sulphate increases the cost to \$36 per ha (\$37.45 including labour and hire of cement mixer). The addition of Mancozeb as a seed coating material enhanced both dry matter and grain yield at an extra cost of approximately \$2.86 per ha. On the basis of costs as well as performance the safest recommendation would be seed coating with $MnSO_4$ plus Mancozeb followed by at least one foliar application of Mn when symptoms of Mn deficiency appear.