Chapter 5. Field studies: Determining optimum application dose rate and adjuvants for late post-emergence applications of selective herbicides

5.1. *Introduction*

The apparent optimum wild oat growth stage for application of herbicides to achieve maximum reduction in seed production was determined in pot and field studies as when one in five tillers has begun to elongate (approximately Zadoks DC = 31) (Chapters Three and Four). It is possible further efficiencies could be gained by optimising herbicide rates at this growth stage. Medd and Pandey (1993) claimed that wild oat seed production needs to be reduced by at least 70% to realise economical and long term reductions of wild oat seed banks. If this level of reduction is to be achieved consistently, herbicide dose rates need to be determined that minimise the risk of failure.

The addition of adjuvants could assist in both improving the reliability of herbicide efficacy and reducing the dose rate of herbicides over a range of environmental conditions. Adjuvants are defined as substances that improve the efficacy of the active ingredient by changing at least one physical or chemical property of the spray solution (Behrens 1964), and improve uptake. Surfactants (wetters), penetrants, inorganic salts and oils are all categorised as adjuvants and may be used to improve spray retention (Wynen and Combellack 1992).

Surfactants are used to improve surface contact between oily (lipophilic) and water based (hydrophilic) surfaces. The lipophilic parts of the surfactant will be attracted to the waxy cuticle layer of weed leaves. This encourages better droplet spread on weeds, thus increasing contact with spray solutions (Behrens 1964). Evidence in the literature also suggests that surfactants can selectively alter the nature of the cell plasmalemma, resulting in increased cell membrane permeability (St. John *et al.* 1974). The primary role of oils is to increase retention of spray thereby enhancing herbicide uptake through leaf surfaces (McWhorter 1982). Inorganic salts used as adjuvants, such as ammonium sulfate, significantly increased herbicide absorption within the first hour after application (Smith and Vanden Born 1992).

The wide array of literature indicating the benefits of adjuvant technology imply that there is much scope for improvement with regard to augmenting wild oat control (Sharma *et al.* 1976; Taylor *et al.* 1982; Turner and Ayres 1985; Chow 1988; Harker 1992; Holloway and Edgerton 1992; Smith and Vanden Born 1992; Ryan 1993). Hulme (1991), Grayson *et al.* (1995) and Stevens *et al.* (1995) found beneficial effects of adjuvants on non-reproductive wild oat parameters when combined with either fenoxaprop-p-ethyl or flamprop. Wynen and Combellack (1992) stated that adjuvants had a non-significant, variable effect on flamprop-methyl potency, whereas diclofop-methyl potency was improved significantly using the same adjuvants. Few studies have investigated specifically the role of adjuvants to reduce weed seed production. One such report by Jones *et al.* (1984) investigated the use of adjuvants with glyphosate for pasture topping annual grasses such as annual ryegrass, *Bromus* spp. (brome grass), *Hordeum leporinum* Link (barley grass) and *Vulpia* spp. (silver grass). It was concluded that adjuvants did not enhance the efficacy of glyphosate in reducing seed production. This small quantity of evidence indicates that there may or may not be scope for improving reductions in wild oat seed production using late post-emergence selective herbicides. On the negative side, there is the possibility of increased crop phytotoxicity or uncertain wild oat control, and it is would be an expensive exercise to test all herbicide / adjuvant / cultivar / growth stage combinations (A. Hill, pers. comm.).

Current label mixing instructions for Mataven®100 (flamprop-methyl) and Puma®S (fenoxaprop-p-ethyl) state that the addition of adjuvants is not required. However, because there is not likely to be an immediate economic return from applying herbicides at the defined apparent optimum time, it is prudent to explore the use of adjuvants with a view to finding if they offer any beneficial effects.

5.2. *Aims*

The primary objective of the work reported in this chapter was to determine whether quarter, half or full RDRs of flamprop-M-methyl and fenoxaprop-p-ethyl, applied near the apparent optimum growth stage, consistently reduced wild oat seed production by at least 70%. Another objective was to investigate if efficacy of low dose rates of the herbicides could be improved by the addition of one of six different categories of adjuvant. A subsidiary objective was to analyse, investigate and interpret any interactions (rate by herbicide and rate by adjuvant) and to determine which wild oat growth parameters were the main factors contributing to low seed production.

5.3. *Materials and methods*

The work reported in this chapter emanates from three field experiments undertaken in commercial wheat crops coded CR93ADJ, CR94ADJ, and SM94ADJ; in addition, further results regarding herbicide dose rates from the experiments outlined in Chapter Four (IN92RXT, CR92RXT, IN93RXT and SM94RXT) are included. Site selection, method of herbicide application, assessment techniques, variables measured for each experiment and statistical analyses, is described in Chapter Two. Supplementary information describing methodology of experiments IN92RXT, CR92RXT, IN93RXT and SM94RXT are outlined in Chapter 4.2. Additional details of the three adjuvant experiments (suffixed ADJ), including historical / present paddock details, harvesting dates (Table 5.1), growth stage, date and time of application and weather conditions (Table 5.2), are presented below.

Table 5.1. Paddock details relating to experiments CR93ADJ, CR94ADJ and SM94ADJ.

Paddock record	Experimental code		
	CR93ADJ	CR94ADJ	SM94ADJ
Paddock history	2nd year of wheat	2nd year of wheat after long fallow	2nd year of wheat
Wheat cultivar	'Hartog'	'Sunstate'	'Suneca'
Sowing date	13.5.93	7.5.94	3.6.94
Sowing rate (kg/ha)	45	42	40
Harvest date for wheat	24.11.93	15.11.94	16.11.94
Seed indexing date	18.11.93	24.10.94	17.10.94
Hand harvest date for wild oat	18.11.93	24.10.94	16.11.94
Fertilisers (kg/ha)		Urea = 100 (N[a] = 46)	
Wild oat densities prior to spraying (plants/m^2)	16 to 32	35 to 67	34 to 71

[a] Equivalent units of nitrogen.

Table 5.2. Herbicide application details including growth stage of wild oats and wheat, and the spraying conditions at the time of application for experiments CR93ADJ, CR94ADJ and SM94ADJ.

	Experimental code		
	CR93ADJ	CR94ADJ[a]	SM94ADJ[ab]
Spraying conditions:			
Herbicide application date	3.9.93	30.8.94	5.9.94
Days after sowing	113	115	94
Time	4:05 pm	2:50 pm	2:00 pm
Temp. Wet bulb (°C)	12.5	14.0	14.5
Temp. Dry bulb (°C)	16.0	25.0	24.0
Relative humidity (%)	67	26	32
Cloud cover (%)	Nil	15 increasing to 50	30 increasing to 60
Wind direction	SW/S	N/NE	N/NW
Wind speed (m/s)	1.9 to 5.6	0.0 to 0.5	2.4 to 4.9
Average wind speed (m/s)	3.2	0.1	3.5
Growing conditions	Excellent, growing actively	Moderate levels of moisture stress	Previously stressed, plant recovery revived by recent rainfall
Wild oat growth stages[c] (averaged for both flamprop-M-methyl and fenoxaprop-p-ethyl treatments):			
Zadoks DC for main stem only	12 to 37	12 to 49	12 to 45
Vegetative (%)	77	50	63
Elongating (%)	23	46	29
Booting (%)	0	4	8
Inflorescence (%)	0	0	0
Wheat growth stages[c] (averaged for both flamprop-M-methyl and fenoxaprop-p-ethyl treatments):			
Zadoks DC for main stem only	12 to 39	12 to 32	12 to 32
Vegetative (%)	43	45	78
Elongating (%)	57	55	22
Booting (%)	0	0	0
Inflorescence (%)	0	0	0

[a] These experiments were designed with four treatment replications whereas experiment CR93ADJ had three replications.
[b] A brief rain shower fell on the experiment approximately 2½ hours after the application of the last treatment. A further 3 mm of rainfall occurred during the night following application.
[c] See Chapter 2.1.1 for method of determining growth stages.

Half and quarter RDRs of flamprop-M-methyl and fenoxaprop-p-ethyl (indicated in Chapter Two) were applied in combination with Liase® at 2% v/v (ammonium sulfate 417 g/L), BS-1000® at 0.2% v/v (non-ionic organic surfactant 1,000 g/L), Ethokem® at 0.2% v/v (polyethanoxy alkyl amine 870 g/L - a cationic wetter), Pulse® at 0.25% v/v (polydimethyl siloxane 1,000 g/L - a penetrant), Synertrol oil® at 250 mL/ha (emulsifiable vegetable oil 83.2 g/L) and Uptake® at 0.5% v/v (emulsifiable paraffinic oil 647 g/L + non-ionic surfactant 228 g/L) for experiment CR93ADJ. For experiments SM94ADJ and CR94ADJ, BS-1000®, Pulse® and Uptake® were mixed with half and quarter RDRs of flamprop-M-methyl and fenoxaprop-p-ethyl. Within all adjuvant experiments, all herbicide by rate combinations were also applied without addition of an adjuvant and untreated control plots were included. A randomised complete block design was used for the layout of experiment CR93ADJ and consisted of three replications. Experiments CR94ADJ and SM94ADJ had split block designs with herbicide as the main plot and rate / adjuvant combinations as the sub-plots and consisted of four replications.

5.4. *Results*

5.4.1. Optimising herbicide rates.

Reductions in seed production relative to the untreated control, for full RDRs (average of both herbicides) at application time two that corresponded approximately to the apparent optimum growth stage of wild oats, were 98.8 and 99.6% for experiments IN92RXT (calculated from data presented in Figure 4.1(b)) and CR92RXT (calculated from data presented in Figure 4.3(b)), respectively. The corresponding reductions in seed production for half RDRs were 89.2 and 94.7%. Similar reductions were exhibited by the rates by timing seed production data for wild oat panicle density for experiments IN92RXT and CR92RXT (calculated from data presented in Figures 4.2(a) and 4.4(b), respectively). However, the reductions in panicle density for the respective half and full RDRs were 75.2 and 96.7% (experiment IN92RXT) and 89.2 and 98.2% (experiment CR92RXT). Therefore, relative reductions in panicle densities were lower than those of the respective seed production values.

In experiment IN92RXT, average transformed panicle seed set for half and full RDRs were 3.215 and 3.106 ln seeds/panicle, with the s.e.d. equal to 0.052. Thus, the increase in rate from half to full RDR resulted in lower panicle seed set values ($P<0.05$). The untreated control plants had 3.994 ln seeds/panicle, significantly higher than both half and full RDRs. Consequently, the combination of the reduced panicle seed set and panicle densities resulted in much greater reductions in seed production for both rates of herbicide.

Herbicide by rate interactions ($P<0.01$) were common to wild oat seed production, fecundity and panicle seed set parameters, for experiment CR93ADJ (Figures 5.1(a), (b), (c) and Table A.9). The extent of these interactions were such that an increase in rate from quarter to half RDR had more effect on all three wild oat reproductive parameters, using flamprop-M-methyl compared with fenoxaprop-p-ethyl. Both rates of flamprop-M-methyl and fenoxaprop-p-ethyl significantly ($P<0.001$) reduced seed production (Figure 5.1(a)). Furthermore, seed production resulting from the application of half RDRs of either herbicide was significantly ($P<0.01$) less than quarter RDR. The reductions in seed production for quarter RDRs of flamprop-M-methyl and fenoxaprop-p-ethyl, relative to the untreated control, were 42.0 and 54.9% respectively. With respect to half RDRs, the reductions in seed production were 79.1 (flamprop-M-methyl) and 71.2% (fenoxaprop-p-ethyl). These data are averaged across seven adjuvant combinations.

Quarter and half RDRs in experiment CR93ADJ also resulted in significant ($P<0.05$) reductions in wild oat fecundity (Figure 5.1(b)) and panicle seed set (Figure 5.1(c)). Flamprop-M-methyl was superior ($P<0.01$) to fenoxaprop-p-ethyl in relation to reducing panicle seed set at half RDRs (Figure 5.1(c)) and was superior ($P<0.001$) to half RDRs of fenoxaprop-p-ethyl for reducing wild oat fecundity (Figure 5.1(b)).

Considering herbicide by rate interactions for half and full RDRs, seed production was significantly ($P<0.01$) affected in experiments CR92RXT and IN92RXT (Table A.8 and Figures 5.2(a) and (b)). Seed production (as transformed data), was lowered more by an increase from half to full RDR using fenoxaprop-p-ethyl than flamprop-methyl for both rates by timing experiments in 1992 (Figures 5.2 (a) and (b)). This was the basis of the herbicide by rate interaction. However, this interaction was different with flamprop-M-methyl rate increases, from quarter to half RDRs, resulting in greater reductions in seed production than fenoxaprop-p-ethyl (Figure 5.1(a)), as discussed previously. At half RDRs, 92.0 and 81.7% reductions in seed production, relative to the untreated control, were attributed to fenoxaprop-p-ethyl and flamprop-methyl, respectively (calculated from data presented in Figure 5.2(a)). Similarly, for experiment IN92RXT, these corresponding values were 72.8 (fenoxaprop-p-ethyl) and 70.6% (flamprop-methyl). The use of full RDRs for both experiments and herbicides that are represented in Figures 5.2 (a) and (b), resulted in at least a 90.5% (flamprop-methyl - experiment IN92RXT) reduction in seed production relative to the untreated control.

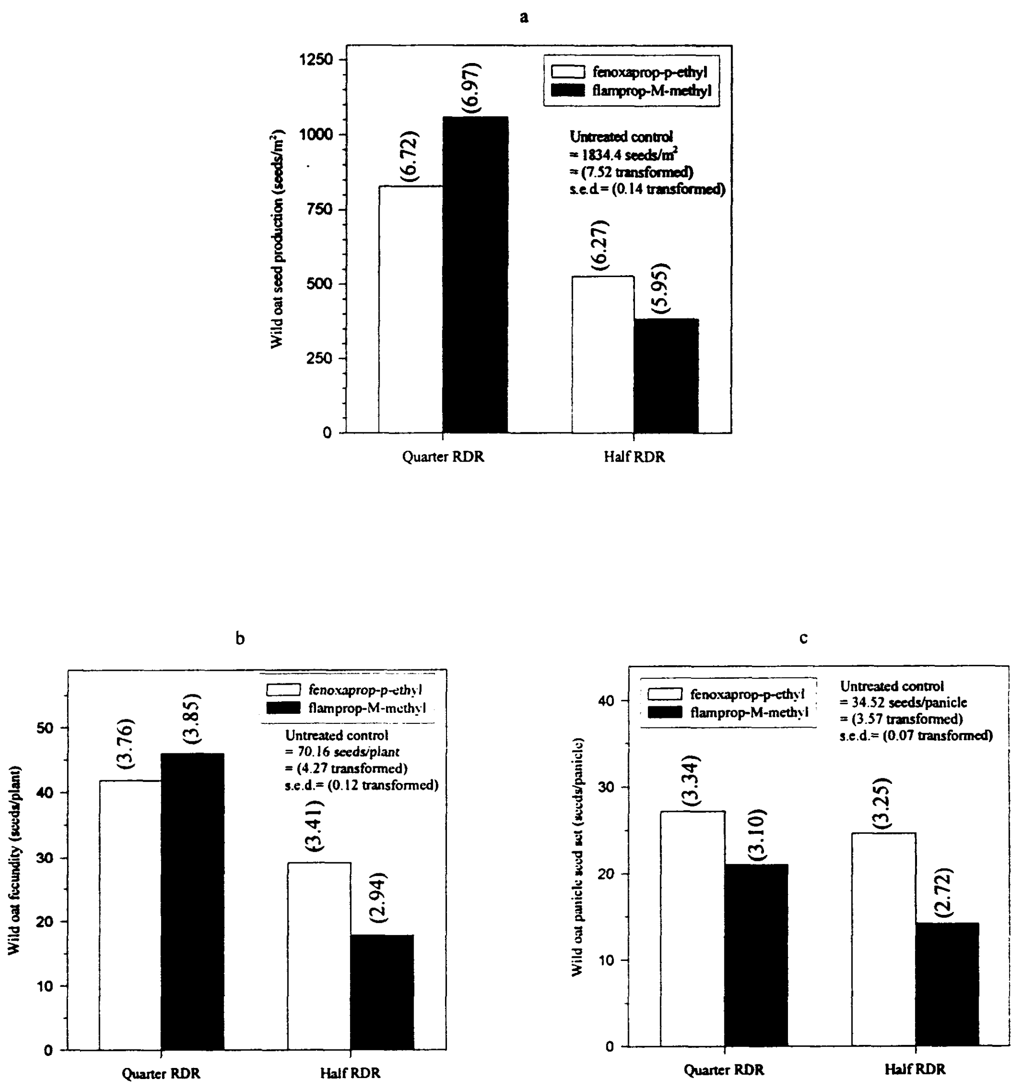


Figure 5.1. Experiment CR93ADJ: Effect of fenoxaprop-p-ethyl and flamprop-M-methyl rate, averaged across all adjuvant combinations, on (a) wild oat seed production (seeds/m^2), (b) fecundity (seeds/plant) and (c) panicle seed set (seeds/panicle). Data presented were covariate adjusted. Logarithmic transformed data presented in parentheses.

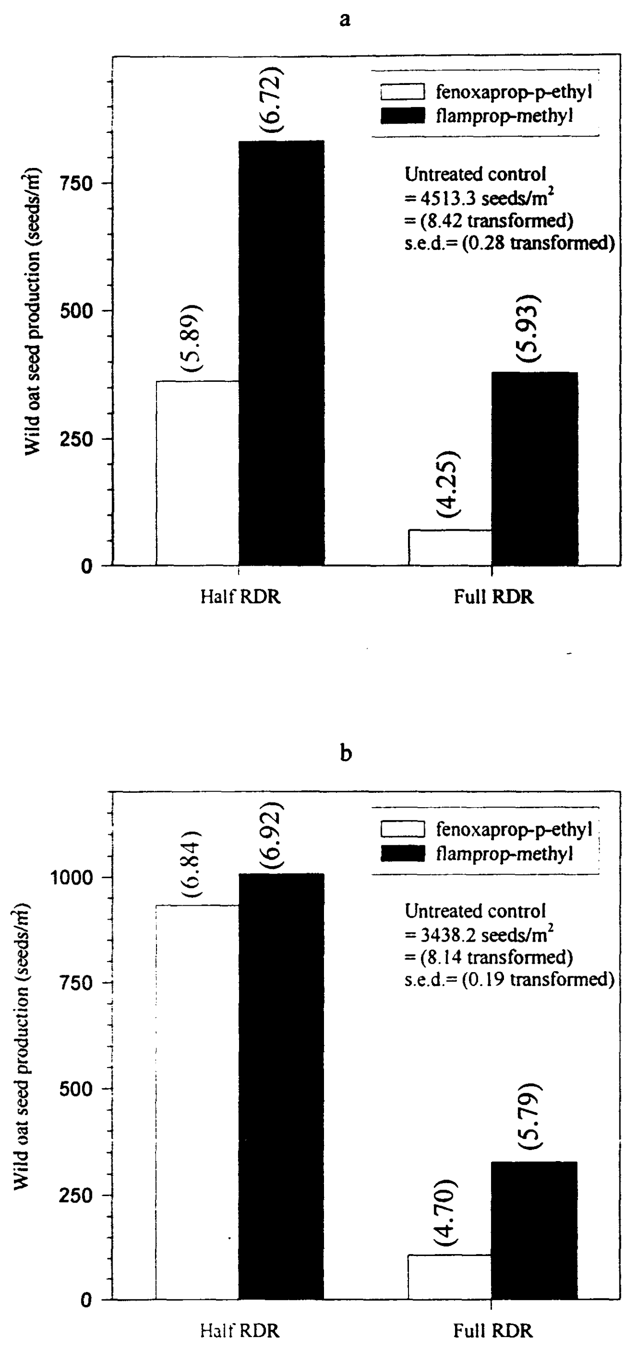


Figure 5.2. Effect of fenoxaprop-p-ethyl and flamprop-methyl rate, averaged for all application times, from experiments CR92RXT (a) and IN92RXT (b) on wild oat seed production (seeds/m^{-2}). Data presented were covariate adjusted. Logarithmic transformed data presented in parentheses.

Seed production and percent reduction in seed production data for individual treatments near the apparent optimum growth stage are listed in Table 5.3. Applications of half RDRs reduced seed production from 55.3 to 96.8% (fenoxaprop-p-ethyl) and 46.0 to 91.0% (flamprop). The application of full RDRs at the same time of application reduced seed production by 88.4 to 99.9% (fenoxaprop-p-ethyl) and 73.2 to 98.8% (flamprop).

Table 5.3. Reductions in seed production (%) and transformed data for applications of half and full RDRs of fenoxaprop-p-ethyl and flamprop, without the addition of adjuvants, applied near the apparent optimum growth wild oat growth stage. Data presented were sourced from experiments IN92RXT, CR92RXT, IN93RXT and CR93ADJ. Data in parentheses were logarithmic transformed and data in bold print represent reductions in seed production (%) relative to the untreated control treatment, based on back transformed data.

	Experimental code				
	IN92RXT	CR92RXT	IN93RXT	IN93RXT	CR93ADJ
Application time	Time 2	Time 2	Time 1	Time 2	Time 1
Tillers elongating (%)	21	17	2	31	23
Zadoks DC for main stem - range of values	14 to 32	13 to 32	14 to 32	13 to 32	12 to 37
	Reduction in seed production (%) *and (seed production):*				
Fenoxaprop-p-ethyl at half RDR	**93.3** (5.44)	**96.8** (4.98)	**88.2** (4.98)	**59.2** (6.22)	**55.3** (6.71)
Fenoxaprop-p-ethyl at full RDR	**99.4** (3.04)	**99.9** (1.84)	**88.4** (4.97)	**94.8** (4.17)	N/A
Flamprop at half RDR	**82.3** (6.41)	**91.0** (6.01)	**64.2** (6.09)	**46.0** (6.50)	**68.2** (6.37)
Flamprop at full RDR	**97.7** (4.39)	**98.8** (4.00)	**91.3** (4.68)	**73.2** (5.80)	N/A
Untreated control	(8.14)	(8.42)	(7.12)	(7.12)	(7.52)
s.e.d.	(0.31)	(0.62)	(0.57)	(0.57)	(0.38)

Examining experiments with significant rate by herbicide interactions, such as experiment CR93ADJ, flamprop-M-methyl had lower seed production values than fenoxaprop-p-ethyl at half RDRs (Figure 5.1(a)). In contrast, this situation was reversed in experiment CR92RXT (Figure 5.2(a)) and there was no significant difference in experiment IN92RXT (Figure

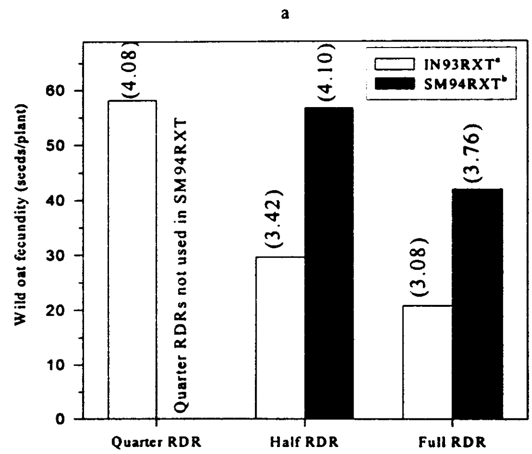
5.2(b)). For individual treatments (half RDRs) made near the apparent optimum growth stage, fenoxaprop-p-ethyl significantly reduced ($P<0.05$) seed production more than flamprop on one occasion (experiment IN92RXT) and was not significantly different ($P<0.05$) to flamprop on the remaining four occasions (Table 5.3). At full RDRs, fenoxaprop-p-ethyl exhibited better reductions in seed production compared with flamprop-methyl (Figures 5.2 (a) and (b)). Additionally, for individual treatments made near the apparent optimum growth stage, fenoxaprop-p-ethyl consistently reduced seed production more effectively than flamprop at full RDRs, on three out of four applications for near optimal wild oat growth stages (Table 5.3).

Wild oat fecundity and panicle seed set were consistently affected by herbicide rates, without any other associated interaction (Table A.8 and Figures 5.3(a) and (b)). Wild oat fecundity represented in Figure 5.3(a), was not significantly ($P>0.05$) affected by quarter RDRs and significantly ($P<0.05$) lower for half RDRs in experiment IN93RXT, and significantly lower for experiments IN93RXT and SM94RXT with full RDRs. By referring to the same figure, there were significant ($P<0.05$) differences in fecundity between half and full RDRs, in experiments IN93RXT and SM94RXT, with full RDRs having the lowest fecundity.

Panicle seed set was also unaffected by quarter RDRs but was lowered using half or full RDRs (Figure 5.3(a)). A change from half to full RDRs, for all experiments in Figure 5.3, resulted in a significant reductions in panicle seed set.

The effects on spikelet seed set when herbicides were applied near the apparent optimum growth stage is best seen for times of application one and two in experiment IN93RXT. A significant ($P<0.01$) rate by timing interaction was found for this experiment (Tables A.8 and 4.5). Although herbicide rates had no effect on spikelet seed set for times of application one and three, full RDRs at time of application two reduced spikelet seed set (Table 4.5).

Spikelet seed set was not significantly ($P>0.05$) affected by any factorial treatment effects in experiments CR94ADJ and SM94RXT and a significant ($P<0.05$) rate by adjuvant interaction occurred in experiment CR93ADJ (Table A.9). The rate by adjuvant interaction, although significant, did not reveal any important trends. For instance, an increase in rates from quarter to half RDRs did not change spikelet seed set for Synertrol oil®, Liase®, Pulse®, Ethokem® and nil adjuvant but reduced spikelet seed set for BS-1000® and increased spikelet seed set for Uptake® (results not presented).



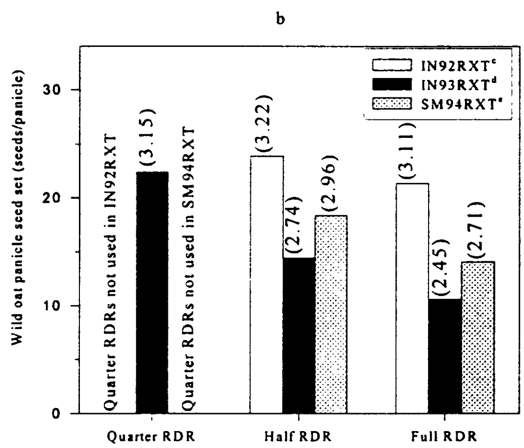


Figure 5.3. Experiments IN92RXT, IN93RXT and SM94RXT: Effect of herbicide rate, averaged for all application times and herbicides, on (a) wild oat fecundity (seeds/plant) and (b) panicle seed set (seeds/panicle). Logarithmic transformed data presented in parentheses. Wild oat fecundity data were covariate adjusted for experiment SM94RXT. Figure (b) represents experiments IN93RXT and SM94RXT only.

[a] Experiment IN93RXT: s.e.d. = (0.16 transformed), untreated = 56.9 seeds/plant (4.06 transformed).
[b] Experiment SM94RXT: s.e.d. = (0.07 transformed), untreated = 66.3 seeds/plant (4.21 transformed).
[c] Experiment IN92RXT: s.e.d. = (0.05 transformed), untreated = 53.3 seeds/panicle (3.99 transformed).
[d] Experiment IN93RXT: s.e.d. = (0.09 transformed), untreated = 24.9 seeds/panicle (3.26 transformed).
[e] Experiment SM94RXT: s.e.d. = (0.05 transformed), untreated = 24.1 seeds/panicle (3.22 transformed).

5.4.2. Improving herbicide efficacy using adjuvants

The use of adjuvants caused highly significant ($P<0.001$) effects on seed production in experiments CR93ADJ and SM94ADJ and significant ($P<0.05$) effects in experiment CR94ADJ (Table A.9 and Figure 5.4). This is typified by significant ($P<0.05$) reductions in seed production for both herbicides and rates (quarter and half RDRs), compared with applying herbicides without adjuvants, when mixed with either Uptake® (all experiments), Pulse® (all experiments) and BS-1000® (experiments CR93ADJ and CR94ADJ) (Figure 5.4). Synertrol oil®, Ethokem® and Liase® did not enhance herbicide activity significantly by further reducing seed production and were consequently not used in 1994 adjuvant experiments. Uptake® was significantly ($P<0.05$) more effective than all the other adjuvant combinations in experiment CR93ADJ and was better ($P<0.05$) than BS-1000® in experiment SM94ADJ.

Reduction in seed production, relative to the untreated control and averaged for herbicides and rates, from wild oats treated with either Uptake®, BS-1000® or Pulse® ranged from 71.6 to 82.5% in 1993 and from 14 and 38.2% for both experiments in 1994 (calculated from data presented in Figure 5.4). In experiment CR93ADJ, Uptake®, BS-1000® and Pulse® further reduced seed production by 66.4, 50.4 and 45.2% respectively, compared with herbicides applied without any adjuvants. These three adjuvants also reduced seed production by an additional 17.9 to 36.1% in the 1994 experiments.

Linkages between two experiments CR93ADJ and CR93MVM (Appendix Three), were established since both experiments were implemented on the same day, paddock and were adjacent to each other. Experiment CR93MVM contained two flamprop treatments applied at full RDRs and therefore comparisons of these treatments with the most effective flamprop / half RDR / adjuvant combinations could be made. Seed production was reduced by 94.4 (flamprop-M-methyl) and 96.6% (flamprop-methyl) for full RDRs in experiment CR93MVM, which is marginally better than 89.9 (BS-1000®) and 85.9% (Uptake®) for half RDRs of flamprop-M-methyl used in experiment CR93ADJ.

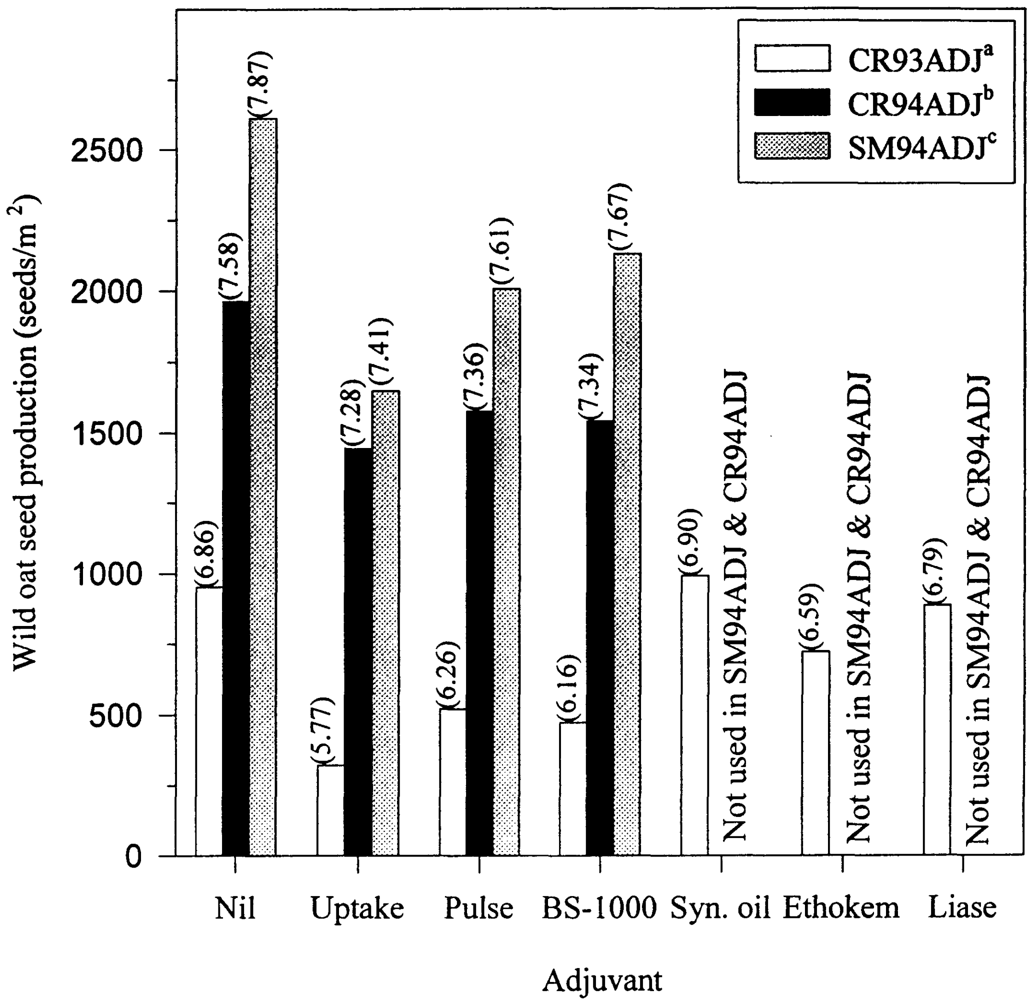


Figure 5.4. Experiments CR93ADJ, CR94ADJ and SM94ADJ: Effect of adjuvants on wild oat seed production (seeds/m^2). Data presented are the average of both herbicides and RDRs. Logarithmic transformed data presented in parentheses.

[a] Experiment CR93ADJ: s.e.d. = (0.19 transformed), untreated = 1834.4 seeds/m^2 (7.52 transformed).
[b] Experiment CR94ADJ: s.e.d. = (0.10 transformed), untreated = 1832.5 seeds/m^2 (7.51 transformed).
[c] Experiment SM94ADJ: s.e.d. = (0.11 transformed), untreated = 2666.8 seeds/m^2 (7.89 transformed).

A similar comparison was possible between treatments within experiments SM94RXT and SM94ADJ. In this comparison, application time two for experiment SM94RXT corresponded closely with the application of herbicides in experiment SM94ADJ, each having similar growth stages (Tables 4.4 and 5.2). Furthermore, comparisons can be made for both herbicides since experiment SM94RXT contained two treatments, fenoxaprop-p-ethyl and flamprop-M-methyl applied at full RDRs without addition of adjuvants. These treatments reduced seed production by 25.3 and 65.4% respectively. This compared with reductions in seed production from fenoxaprop-p-ethyl (half RDR) plus BS-1000® (27.4% reduction) or Uptake® (38.3% reduction) and flamprop-M-methyl at half RDR plus Uptake® (67.9%) for experiment SM94ADJ.

The greatest reduction in seed production for an individual treatment in experiment CR94ADJ was 48.0% (flamprop-M-methyl at half RDR + Uptake®), in experiment SM94ADJ was 67.9% (flamprop-M-methyl at half RDR + Uptake®) and 91.2% (fenoxaprop-p-ethyl at half RDR + Uptake®) for experiment CR93ADJ.

Experiment CR93ADJ, involved seven treatments which markedly reduced seed production, namely; flamprop-M-methyl at half RDR mixed with either Ethokem® (80.2%), Pulse® (80.8%), Liase® (73.6%), BS-1000® (89.9%) and Uptake® (85.9%) also including fenoxaprop-p-ethyl + Uptake® at quarter RDR (82.0%) and half RDR (91.2%). The most common adjuvant in this list of treatments was Uptake®, providing enhanced control with both herbicides.

Addition of Uptake®, BS-1000® and Pulse® to the herbicides, irrespective of herbicide or rate, significantly ($P<0.05$) reduced wild oat fecundity in all adjuvant experiments, except for BS-1000® in experiment CR94ADJ (Figure 5.5). These herbicide / adjuvants combinations also significantly ($P<0.01$) lowered panicle seed set relative to the untreated control (Figure 5.6). The adjuvant, Uptake®, analysed as a factorial effect in experiments CR93ADJ and CR94ADJ, irrespective of herbicide or rate, was significantly ($P<0.05$) better than the other adjuvants, reducing wild oat fecundity and panicle seed set (Figures 5.5 and 5.6).

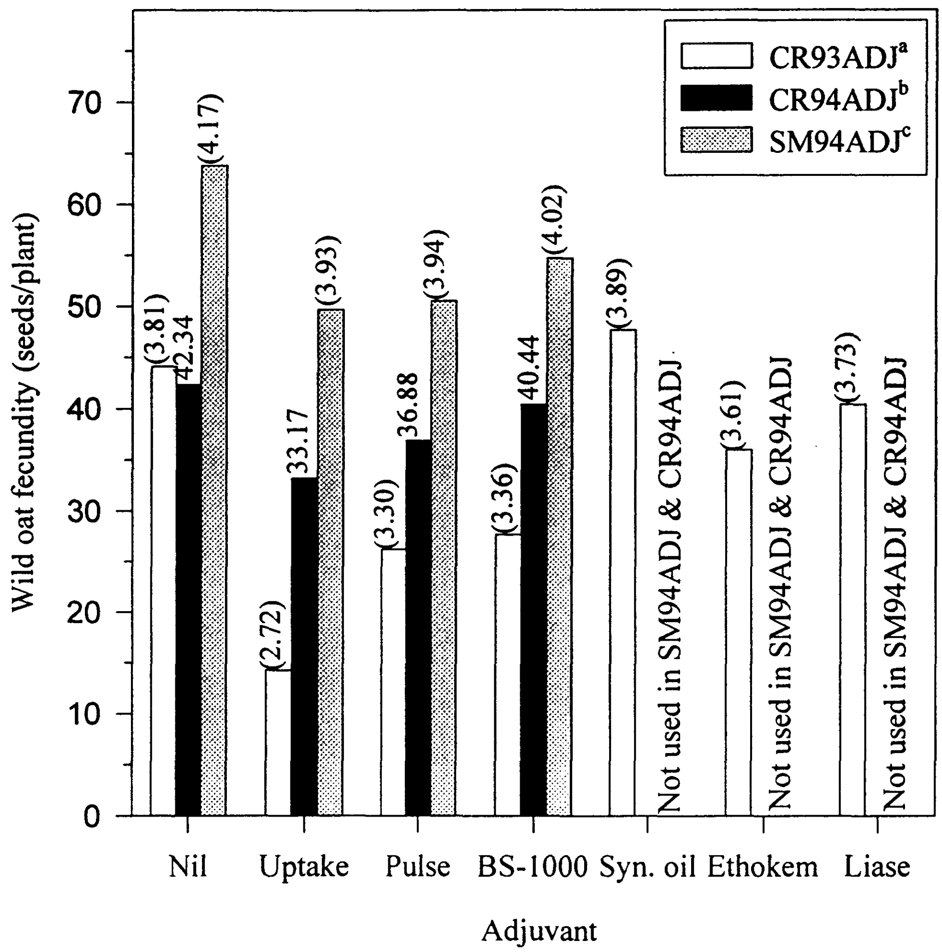


Figure 5.5. Experiments CR93ADJ, CR94ADJ and SM94ADJ: Effect of adjuvants on wild oat fecundity (seeds/plant). Data presented are averaged across herbicides and RDRs (quarter and half). Logarithmic transformed data presented in parentheses, except for experiment CR94ADJ. Data for experiment SM94ADJ were covariate adjusted.

[a] Experiment CR93ADJ: s.e.d. = (0.16 transformed), untreated = 70.2 seeds/plant (4.27 transformed).
[b] Experiment CR94ADJ: s.e.d. = 1.721 seeds/plant, untreated = 37.6 seeds/plant.
[c] Experiment SM94ADJ: s.e.d. = (0.07 transformed), untreated = 66.2 seeds/plant (4.21 transformed).

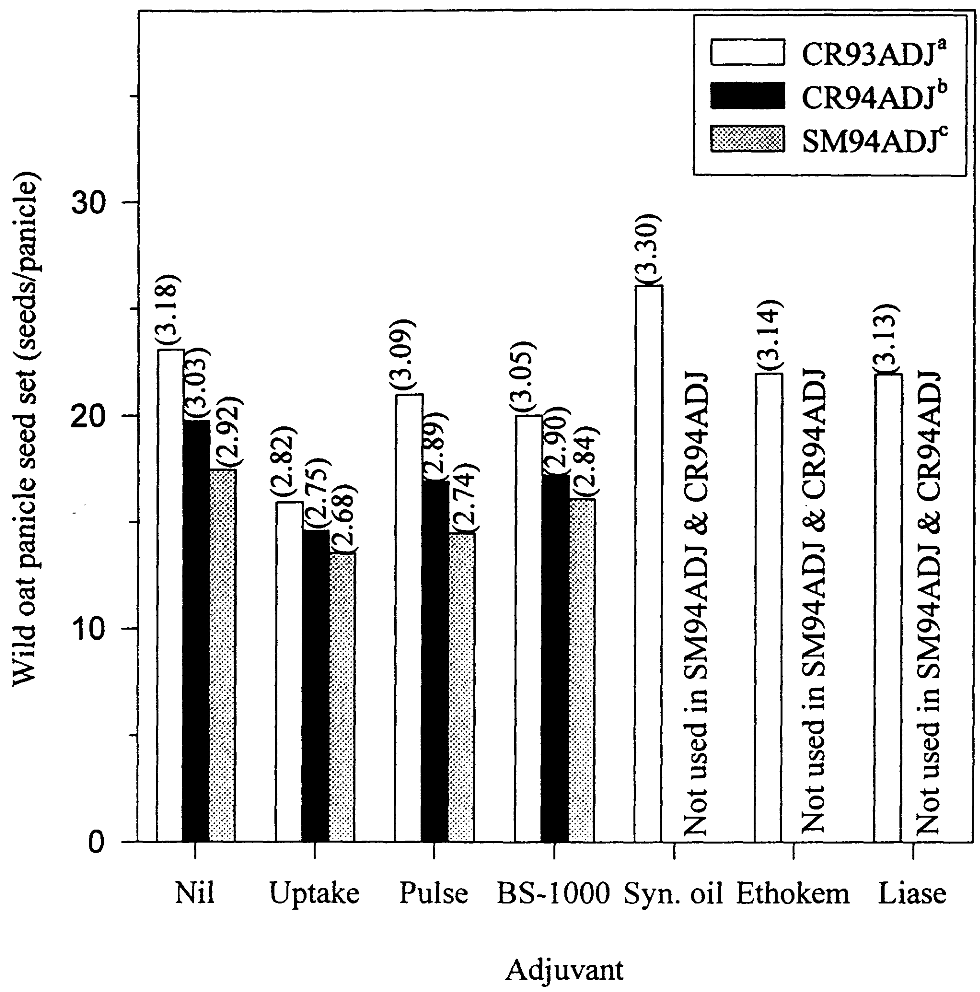


Figure 5.6. Experiments CR93ADJ, CR94ADJ and SM94ADJ: Effect of adjuvants on wild panicle seed set (seeds/panicle). Data presented are the average of both herbicides and RDRs (quarter and half). Logarithmic transformed data presented in parentheses. Data for experiment SM94ADJ were covariate adjusted.

[a] Experiment CR93ADJ: s.e.d. = (0.09 transformed), untreated = 34.5 seeds/panicle (3.57 transformed).

[b] Experiment CR94ADJ: s.e.d. = (0.03 transformed), untreated = 21.5 seeds/panicle (3.11 transformed).

[c] Experiment SM94ADJ: s.e.d. = (0.04 transformed), untreated = 20.1 seeds/panicle (3.05 transformed).

5.5. *Discussion*

Full RDRs of fenoxaprop-p-ethyl and flamprop, applied without adjuvants and near the apparent optimum growth stage, always reduced seed production in excess of 70%, and mostly by more than 88%. In contrast, use of half RDRs of either herbicide without adjuvants, resulted in inconsistent reductions in seed production, as also reported in Appendix Three, applied near the identical growth stage, often falling below the purported critical level of 70%. Quarter RDRs of either herbicide consistently resulted in unacceptable reductions in seed production.

Application of herbicides near the apparent optimum growth stage may not be possible in some seasons due to inappropriate conditions such as moisture stress or prolonged wet periods preventing access to paddocks. Delaying application past the apparent optimum growth stage will incur a penalty of reduced herbicide efficacy, as described in Chapter Four. Furthermore, the benefits of increasing rates to compensate for this loss of efficacy reduces with time.

Medd *et al.* (1992) did not find any significant difference between half and full RDRs of flamprop-methyl in relation to wild oat seed production at two experimental sites. Growing conditions for both experiments were considered near-optimal for satisfactory wild oat control but herbicides were applied to wild oats at the late booting stage, with more than 60% of tillers elongating or being more advanced. This result emphasises the effect seen in this chapter that later application times (post-optimal) diminishes the rate responsiveness of wild oat seed production to herbicides. Similar findings were reported by Wilson (1979b) after the application of flamprop-methyl at 0.5 and 1.0 kg a.i./ha to wild oats in the early or late tillering stage with no significant differences between wild oat panicles above crop after applications made to late tillering wild oats but differences were reported after application to early tillering wild oats. From the same report, Wilson noted that lowest spikelet production (spikelets/m^2) occurred after flamprop-methyl at either 0.45 or 0.90 kg a.i./ha was applied to wild oats at the boot stage.

If an increase to full RDR is justifiable, due to delays in application, the use of fenoxaprop-p-ethyl would result in greater reductions in seed production compared with flamprop-M-methyl. However, near the apparent optimum growth stage, when the use of lower herbicide rates may be envisaged, an increase from quarter to half RDR was more effective with flamprop. At half

RDRs applied near the apparent optimum application wild oat growth stage, reduction in seed production was generally similar for either herbicide with a slight advantage using fenoxaprop-p-ethyl. Seed production was reduced more by fenoxaprop-p-ethyl than flamprop at full RDRs, particularly near the apparent optimum growth stage.

The main wild oat growth parameters affected by herbicide rates were panicle density and panicle seed set. The relationship was such that increases in herbicide rates lead to smaller panicles (low panicle seed set (seeds/panicle)) and reduced panicle density (panicles/m^2), ultimately having a multiplying effect on wild oat seed production (seeds/m^2), as illustrated in Figure 2.2. Lower panicle seed set (seeds/panicle) values also have an effect on wild oat fecundity (seeds/plant), as these parameters are linked by panicle production (panicles/plant).

The screening of six adjuvants resulted in three products appearing to give a synergistic effect. Of the three adjuvants, Uptake® was superior to BS-1000® and Pulse®. Uptake® resulted in greater reductions in wild oat panicle seed set and this accordingly affected wild oat fecundity. Seed production was reduced by an additional 45.2 to 66.4% using Uptake®, BS-1000® and Pulse®, compared to the same herbicide dose rates without adjuvants, in the one experiment completed under favourable environmental conditions. The two experiments (CR94ADJ and SM94ADJ) designed specifically to investigate these three adjuvants in 1994 were severely affected by drought and resulted in much lower herbicide efficacy. The drought conditions affected both crop competitiveness and herbicide efficacy. Moisture stress is a likely cause for poor efficacy since both herbicide label recommendations suggest that herbicides should not be applied to wild oats that are under moisture stress. Other researchers (Xie *et al.* 1994; Lemerle and Verbeek 1995) have also found that fenoxaprop-ethyl efficacy was reduced by drought stress imposed before spraying. Flamprop-methyl was also reported by Lemerle and Verbeek (1995) to produce unsatisfactory control in dry conditions. As well as the poor environmental conditions in 1994, the spraying of herbicides occurred when wild oats had notably passed the apparent optimum timing growth stage within a relatively uncompetitive wheat crop. The technical manual of flamprop-methyl (Anon. 1990) also states that best results with flamprop-methyl occur in association with a competitive crop.

Addition of Uptake® to either herbicide when applied at half RDRs reduced seed production to comparable levels to those achieved using full RDRs applied without adjuvants, even under the drought stressed conditions experienced in 1994. However, reduction in seed production for half RDRs plus Uptake® in 1994 did not reach acceptable levels.

Improved efficacy with the addition of adjuvants is widely reported for herbicides applied for wild oat control (Sharma *et al.* 1976; Taylor *et al.* 1982; Turner and Ayres 1985; Chow 1988; Harker 1992; Holloway and Edgerton 1992; Smith and Vanden Born 1992; Ryan 1993). Hulme (1991) found that Ethokem®, at 0.75 and 1.00% v/v with flamprop-methyl had the potential to reduce flamprop-methyl rates by 20%. From the results within this chapter, addition of Ethokem® to all combinations of herbicides and rates caused an additional, although a non-significant different (P>0.05) 23.7% reduction in seed production compared with no addition of adjuvant (Figure 5.4). The major differences in Hulme's study and those of this chapter included; wild oat application growth stage (Zadoks DC = 23 and 25 or early tillering), growing conditions (glasshouse), rate of Ethokem®, and assessment of herbicide efficacy (no measure of seed production). It is therefore recommended that prudent comparisons between different adjuvant research be made.

A series of six field experiments were completed in the United Kingdom by Murphy *et al.* (1995) and found that adjuvants were beneficial when mixed with flamprop-isopropyl, increasing wild oat floret control from a mean value of 80% to 92%. The report also concluded that sub-registered herbicide rates of flamprop-M-isopropyl mixed with an adjuvant (Dobanol 25-7) resulted in 96% reductions of florets. It was also noted that the addition of adjuvants led to a greater risk of crop phytotoxicity and on a few occasions this level of phytotoxicity was unacceptable. Grayson *et al.* (1995) also concluded from results on leaf length that the adjuvant Dobanol 25-7 gave significant benefits when mixed with flamprop-M-isopropyl under glasshouse conditions. Other work undertaken by Grayson *et al.* (1995) made reference to enhancements with an adjuvant containing paraffinic oil. It was selected because of good performance, lending support to the superior performance of Uptake® in the present studies since the formulation of Uptake® contains an emulsifiable paraffinic oil at 647 g/L plus a non-ionic surfactant at 228 g/L.

Research by Wynen and Combellack (1992) involved the use of non-ionic surfactants and an emulsifiable oil with flamprop-methyl. These adjuvants had no effect on retention of flamprop-methyl on the upper, mid or lower canopy of the crop and the total spray retention did not correlate with herbicide efficacy. Therefore, the improved efficacy of flamprop-M-methyl by BS-1000® (non-ionic surfactant) and Uptake® (emulsifiable paraffinic oil) within this chapter was probably not due to changed spray retention but possibly other factors such as improved herbicide absorption or the different activity of adjuvants between this research and those of Wynen and Combellack (1992).

Therefore from the present experiments and literature there is evidence to support that Uptake® is the most likely adjuvant to give a synergistic effect with flamprop-M-methyl or fenoxaprop-p-ethyl when applied late post-emergence for the reduction of wild seed production. In addition, the use of half RDRs of either herbicide with Uptake®, when applied near the apparent optimum growth stage, reduced seed production greater than the critical purported levels (> 70%, Medd and Pandey (1993)) under favourable growing conditions. The application of full RDRs are recommended if higher levels of efficacy are desired or when sub-optimal conditions exist. These conditions include applications made to wild oat plants under moisture stress or to plants that are slightly more advanced than the apparent optimum growth stage (e.g. late jointing to early boot stage, Zadoks DC = 32 to 43).

The science of adjuvant evaluation and the understanding of the process by which they improve herbicide efficacy is very complex. This is made worse by knowing that most manufacturers do not legally have to disclose the exact composition of adjuvants or adjuvants that are within herbicides products (McWhorter 1982).

Having gained more information about the apparent optimum wild oat growth stage (Chapters Two and Three) and the correct selection of herbicide rate and adjuvant, a detailed investigation of potential crop safety / tolerance aspects needs to be completed to ensure treatment success in commercial situations.

Chapter 6. Effect of late post-emergence applications of selective herbicides on wheat phytotoxicity and grain quality.

6.1. *Introduction*

The previous chapters have reported on experiments undertaken to investigate the effects of late applications of flamprop-methyl (or flamprop-M-methyl) and fenoxaprop-p-ethyl on wild oat seed production without any detailed reference to phytotoxic effects on crops. Damage to wheat could occur as leaf symptoms, height reductions, abortion of developing wheat heads, pinched kernels, lower protein content of wheat, reduced yields and unacceptable herbicide residues in the harvested grain. Earlier work has found that wheat growth stage around the time for apparent optimum efficacy on wild oats would correspond to early jointing (Zadoks DC = 30) up to early boot stage (Zadoks DC = 43), depending on growing conditions and wheat cultivar. A more accurate relationship between wheat and wild oat growth stages is therefore required to estimate the likely wheat growth stage preceding and after the apparent optimum wild oat growth stage for maximum reductions in seed production. Although, there are ample data on crop safety for applications made prior to jointing of wheat, less is known about crop herbicide tolerance for later applications. Only Jeffcoat *et al.* (1977) and Tottman *et al.* (1982) have investigated phytotoxic effects of flamprop-methyl applied to wheat near the jointing growth stage. No crop damage was reported in the work of Jeffcoat *et al.* (1977) for wheat grown under glasshouse conditions in the United Kingdom. Notwithstanding this result, there is a need to investigate crop tolerance of various wheat cultivars to late applications of flamprop-M-methyl or fenoxaprop-p-ethyl in Australia and to identify any possible risk factors.

Current product label recommendations of flamprop-methyl and fenoxaprop-p-ethyl state the conditions necessary to prevent undesirable effects on wheat. The flamprop-methyl (Mataven®100) label states that to avoid crop damage applications cannot be made past the beginning of the jointing phase or on a range of specific wheat cultivars and the addition of a wetting agent is not recommended. In the case of fenoxaprop-p-ethyl (Puma®S), the label states that applications of the RDR cannot be made later than 70 days before harvest in order to satisfy maximum residue levels in harvested grain.

Jutsum and Bryan (1992) stated that the first wild oat herbicides used commercially prior to the late 1950's were non-selective avenicides that damaged cereals. Soon afterwards a greater number of selective avenicides were developed and consequently the majority of selective avenicides available up until the early 1990's were used in wheat. These herbicides generally have minor warnings on the labels regarding possible phytotoxicity to wheat under favourable growing conditions. Selectivity of flamprop depends on the methyl ester undergoing hydrolysis to form the biologically active acid which is usually detoxified quickly in wheat by conjugation (Jeffcoat *et al.* 1977; Roberts 1977; Pallett 1980).

Although the active ingredient fenoxaprop-p-ethyl causes unacceptable phytotoxicity to wheat (Kocher *et al.* 1989), the safener HOE 70542 (fenchlorazole) in the product formulation provides selectivity. Fenchlorazole enables the rapid chemical transformation of the active ingredients to inactive products in wheat without any significant breakdown of the active component in wild oats (Yaacoby *et al.* 1991).

Apart from possible yield reductions as a direct consequence of herbicide damage to wheat, grain contamination with wild oat seed can occur if herbicide efficacy is poor. Dexter *et al.* (1984) found that wild oat caused reductions in the baking properties of red spring wheat. Such findings have resulted in quality assurance standards (maximum allowable levels) for wild oat seeds in Australian Standard White (ASW), general purpose (GP1A) and field wheat categories of 50, 150 and 500 seeds per half litre of grain, respectively (Madin *et al.* 1993).

6.2. *Aims*

The work reported in this chapter sets out to evaluate the phytotoxic effects on wheat of flamprop-methyl (including flamprop-M-methyl) and fenoxaprop-p-ethyl when applied late post-emergence under field conditions. Phytotoxicity is usually defined as damage incurred by the crop due to the application of herbicide(s) in the absence of weeds. The definition of phytotoxicity in this thesis is relaxed to also include the damage to wheat by the cumulative (or additive) effects of herbicides and weed competition. These effects will be described in terms of wheat yield, height, kernel weight, wild oat seed contamination in harvested grain and visual symptoms. Contributing factors such as herbicide rate, wheat cultivar, time of application and type of herbicide will be reported. The relationship between wheat and wild oat growth stages will be analysed to determine if growth and development of wild oats closely matches those of wheat.

6.3. *Materials and methods*

Wheat phytotoxicity data from field experiments reported in Chapters Three to Five, including experiments IN93MVM and CR93MVM (Appendix Three) are included in this chapter along with those of a specific tolerance experiment. Materials and methods for previously reported experiments are outlined in the general methodology (Chapter Two) and methodology specific to each experiment is in the relevant chapters.

A further experiment, coded T93WVT, was implemented at Tulloona (Lat. $28^0 57$'S, Long. $150^0 2$'E) to investigate the tolerance of seven wheat cultivars under weed-free conditions. The seven herbicide treatments, applied on 1.9.93, were half, full and twice RDRs of flamprop-M-methyl and fenoxaprop-p-ethyl (Chapter Two) plus the untreated control, replicated three times. The seven cultivars planted on 11.6.93 were Suneca, Sunmist, Yallaroi, Janz, Sunco, Meteor and Hartog, all sown at a seeding rate of 50 kg/ha. Experimental layout was a split plot design with herbicide treatments comprising the main blocks and the wheat cultivars as sub-plots. Plot dimensions were 2 m by 12 m. All wheat cultivars were sown along eight rows spaced 18 cm apart, leaving 28 cm on either longitudinal side of each plot as a buffer zone. The outer nozzles on the 3 m wide hand held boom were blocked so that only a 2 m wide by 12 m long application of herbicide could be applied to relevant plots. Herbicides were otherwise applied as described in general methodology (Chapter 2.1.1) with Teejet® 8002 nozzles and a herbicide spray volume of 156 L/ha. Weather conditions and wheat growth stages at the time of application are outlined in Table 6.1.

The paddock used for the experimental site had been planted to sorghum in 1991 then winter fallowed to minimise problems with wild oats. Despite this measure low numbers of wild oats emerged and these were hand weeded from the experiment on 5.8.93 and again on 24.8.93. The application of two fertilisers, 75 kg of Starter®15/ha having N:P:K = 15:13:0 and 25 kg N/ha applied as Nitram®, was made at sowing by direct drilling.

Harvesting of wheat was completed on 12.11.93 using a Kingaroy Engineering Works Pty. Ltd. small plot header to reap an area of 17 m^2 from each plot. Ten random wheat tillers were measured twice (18.9.93 and 11.11.93) to obtain estimates of height per plot, instead of the twenty tillers, outlined in the general methodology (Chapter 2.1.3).

Table 6.1. Site details for experiment T93WVT including spraying conditions at the time of spraying and growth stages of seven cultivars of wheat.

Spraying conditions:				
Temperature wet bulb (°C)			19	
Temperature dry bulb (°C)			26	
Relative humidity (%)			50	
Wind direction			N/NW	
Wind speed (m/s)			2.8 to 7.0	
Average wind speed (m/s)			4.9	
Cloud cover (%)			60	
Wheat growth stages[a]:				
Cultivar	*Vegetative (%)*	*Elongating (%)*	*Booting (%)*	*Zadoks DC for main stem only*
Suneca	30	70	0	33 to 39
Sunmist	37	63	0	31 to 37
Yallaroi	27	64	9	32 to 41
Janz	30	59	11	37 to 41
Sunco	24	76	0	33 to 39
Meteor	30	63	7	37 to 41
Hartog	26	39	35	41 to 45

[a] See Chapter 2.1.1 for method of determining growth stages.

6.4. *Results*

6.4.1. Effect of late post-emergence applications of herbicides on wheat yield

Wheat yield effects recorded in the regional experiments are summarised in Tables A.8 and A.9 (Appendix Two), which show no consistent or strong effects on yield. Of the seven field experiments listed, there were no significant effects on two occasions (experiments CR93ADJ and IN92RXT), rate effects (P<0.05) twice (experiments SM94ADJ and CR92RXT), an adjuvant effect (P<0.05) for experiment CR94ADJ, an interaction between time of application and herbicide (P<0.001) for experiment SM94RXT and yield was not measured in experiment IN93RXT. Additionally, yield remained unaffected by treatments in experiment CR93MVM (Appendix Three, Table A.11). Analysing all of the field experiments independently, wheat yield was not significantly depressed by any herbicide treatment. Scatter plots of these results are given in Figures 6.1(a) and (b). The majority of points fall within the range of 100 to 125% of the untreated yield, regardless of herbicide. Average increases in yield relative to the untreated control, for all applications were 8.9 (fenoxaprop-p-ethyl) and 7.3% (flamprop).

Applications of half, full and twice RDRs of flamprop-M-methyl and fenoxaprop-p-ethyl on seven wheat cultivars, for experiment T93WVT, resulted in no significant herbicide or rate effect on grain yields. There was, however, a significant wheat cultivar effect (P<0.001) but no significant herbicide or rate effect (Appendix Two). A strong effect of wheat cultivar on yield without significant effects of herbicide treatments is shown in Figures 6.2(a) and (b).

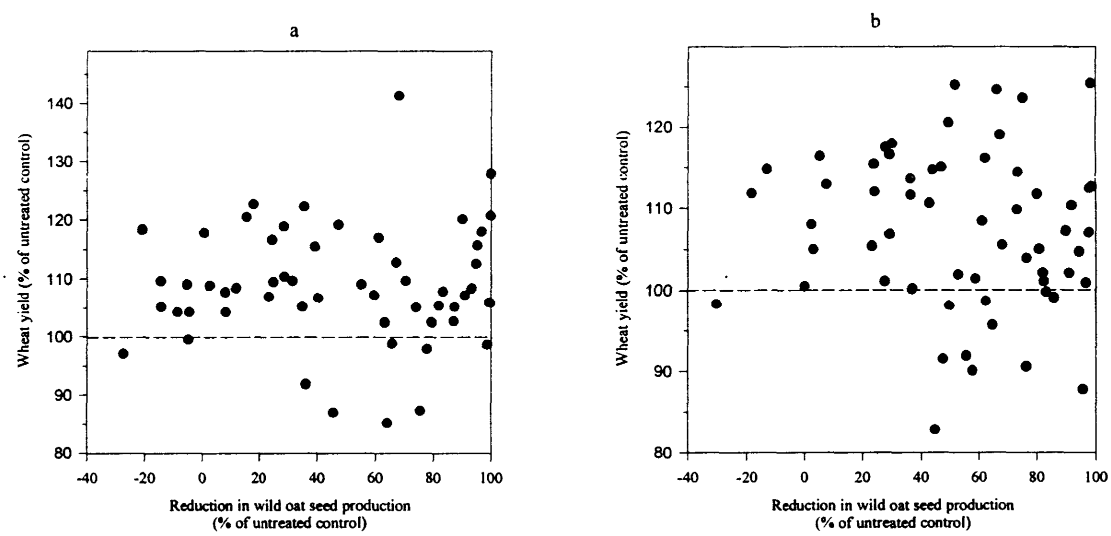


Figure 6.1. Relative effect of fenoxaprop-p-ethyl (a) and flamprop (b) on wheat yield for all field experiments (except 1993 Inverell experiments) completed in commercial crops. Wheat yields are presented as a proportion of their respective untreated control yields and are plotted against the reduction in wild oat seed production for that treatment.

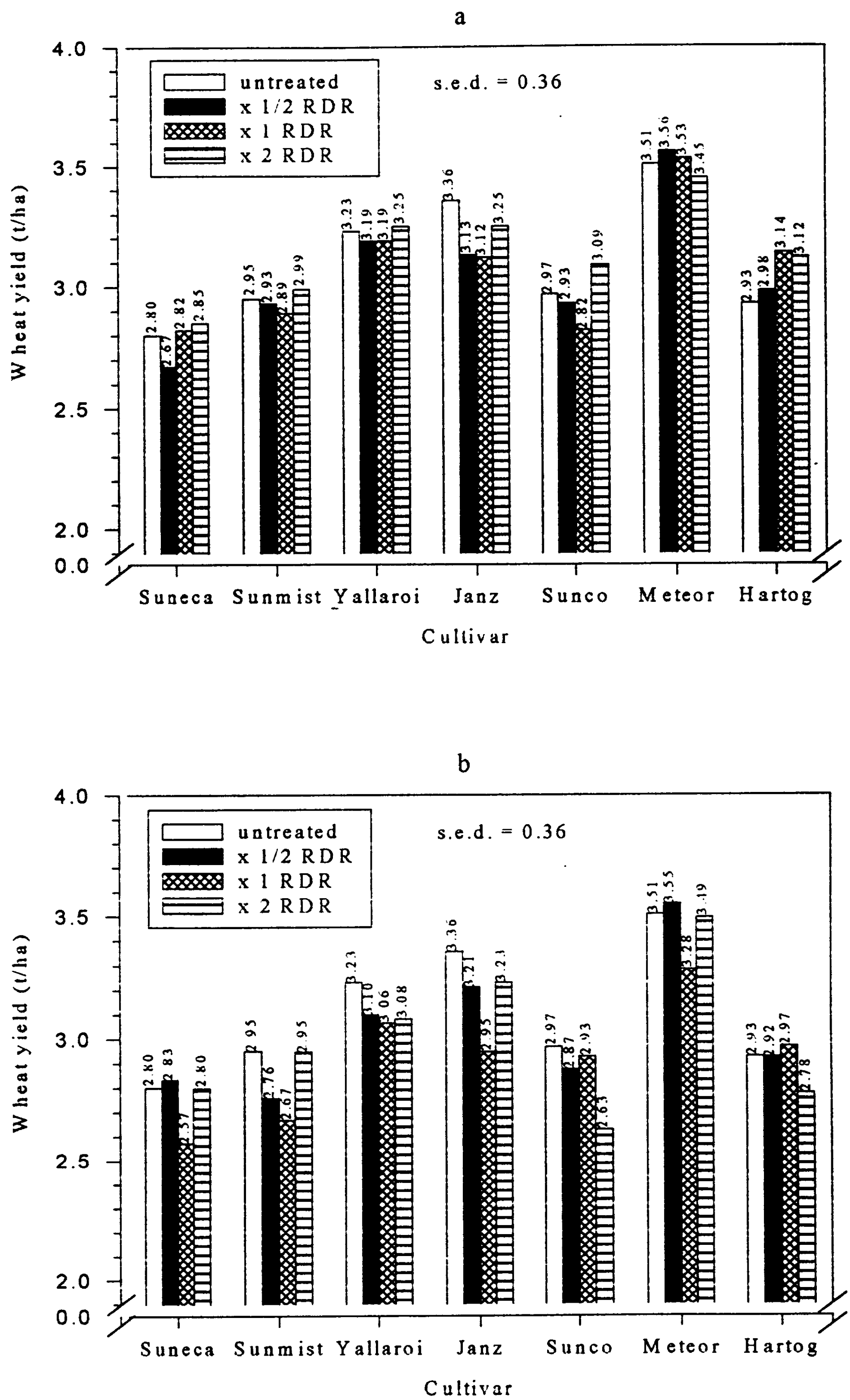
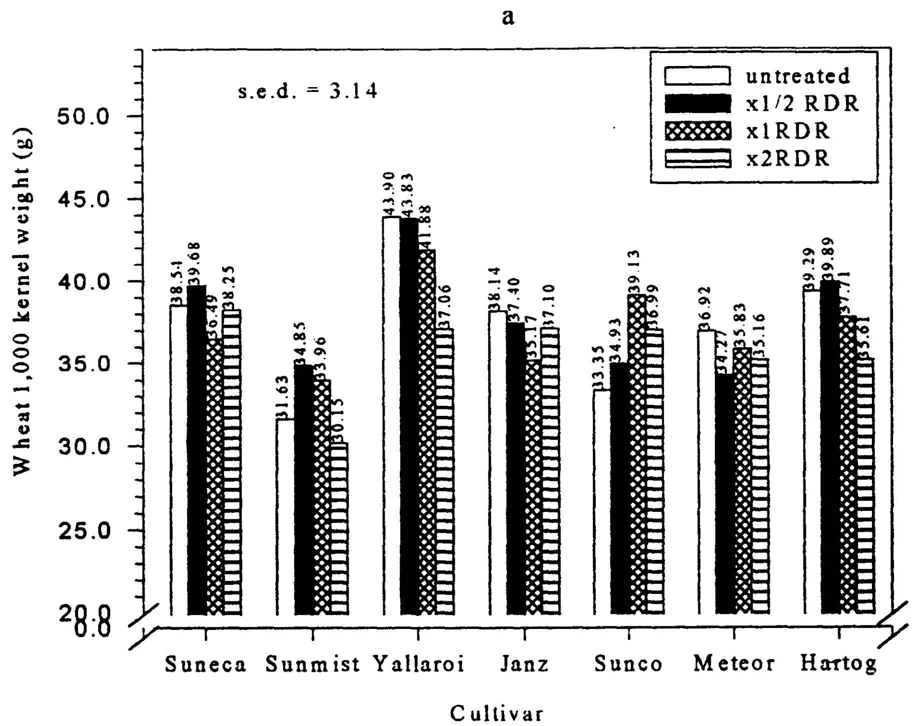


Figure 6.2. Experiment T93WVT: Effect of three rates of fenoxaprop-p-ethyl (a) and flamprop-M-methyl (b), applied late post-emergence, on wheat yield (t/ha) for seven wheat cultivars.

6.4.2. Effect of late post-emergence applications of herbicides on wheat kernel weight

The late post-emergence application of herbicides did not cause any significant differences in kernel weight (g/1,000 kernels) for experiment T93WVT (Figures 6.3(a) and (b)). Other significant treatment effects were detected for 1,000 kernel weight in experiments IN92RXT (herbicide by time interaction, $P<0.01$) and SM94RXT (rate effect, $P<0.05$) (Appendix Two, Table A.8). The extent of the herbicide by time interaction in experiment IN92RXT was such that applications of flamprop-methyl to wheat at the early ear emergence stage (74% tillers elongating or more advanced, Zadoks DC $\geq$ 30) caused significant reductions in kernel weight. The 1,000 kernel weight of wheat from this very late applied flamprop-M-methyl treatment was 35.5 g compared with 37.9 g for untreated wheat (s.e.d. = 0.8). Higher rates of both herbicides (full RDRs) in experiment SM94RXT increased 1,000 kernel weight compared with half RDRs (34.3 compared with 33.8 g, s.e.d. = 0.3). However, neither rates were significantly different to the untreated kernel weights. Late applications of post-emergence herbicides had a non-significant effect on 1,000 kernel weight in all the other experiments (Appendix Two, Tables A.8 and A.9).

Scatter plots of kernel weight data recorded from all field experiments in 1992 and 1994, including experiment CR93ADJ are given in Figures 6.4(a) and (b). Both graphs indicate that values are uniformly distributed around the 'nil effect' line which equates to 100% of the respective untreated control kernel weights. The scattering of points remained consistent regardless of the level of wild oat seed reduction and most data fell between 96 and 102%, relative to the untreated control.



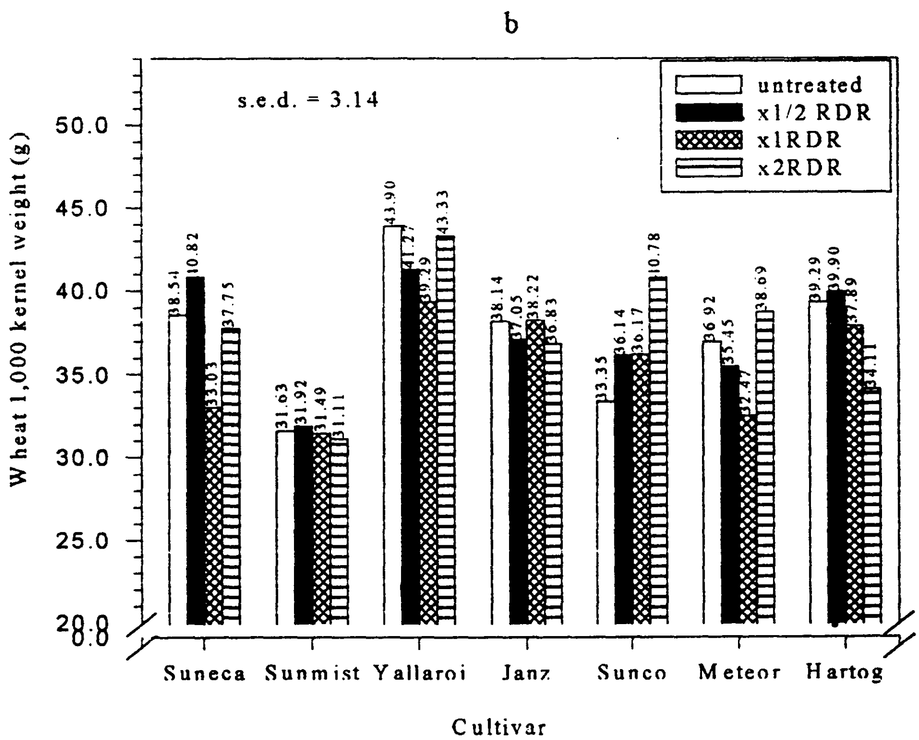


Figure 6.3. Experiment T93WVT: Effect of three rates of fenoxaprop-p-ethyl (a) and flamprop-M-methyl (b), applied late post-emergence, on wheat 1,000 kernel weight (g) for seven wheat cultivars obtained from a mechanical small plot header.

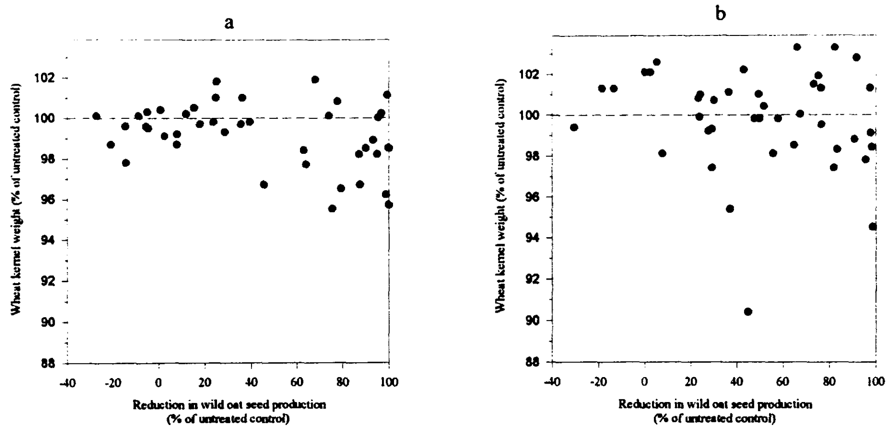
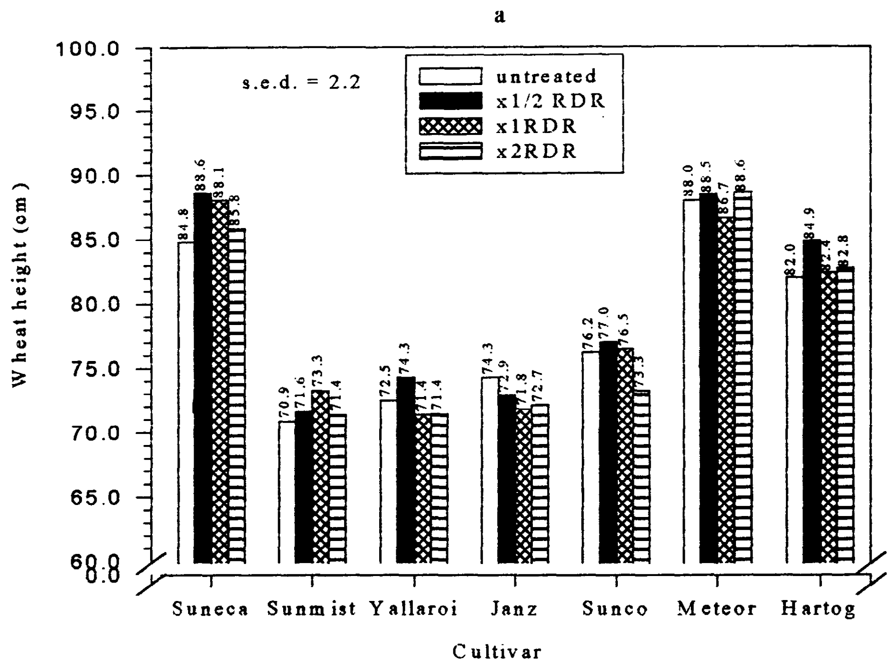


Figure 6.4. Effect of fenoxaprop-p-ethyl (a) and flamprop (b) on wheat kernel weight (g) for all 1992 and 1994 field experiments (including experiment CR93ADJ) completed in commercial crops. Wheat kernel weights are presented as a proportion of their respective untreated control kernel weights and are plotted against the reduction in wild oat seed production for that treatment.

6.4.3. Effect of late post-emergence applications of herbicides on wheat height

A significant herbicide / rate / cultivar interaction ($P<0.01$) on wheat height following applications of three rates of fenoxaprop-p-ethyl and flamprop-M-methyl to seven wheat cultivars is presented in Figures 6.5(a) and (b). No applications of fenoxaprop-p-ethyl caused height reductions to any of the seven wheat cultivars (Figure 6.5(a)), whereas, flamprop-M-methyl caused significant reductions in the height of Yallaroi (x 2 RDR), Sunco (x 2 RDR), Meteor (x 1 and x 2 RDRs) and Hartog (x 2 RDR) (Figure 6.5(b)).

The late post-emergence application of fenoxaprop-p-ethyl or flamprop-M-methyl in experiments completed in 1994 caused a slight depression in wheat heights. Most values fell within the range of 95 to 102% of their respective untreated control wheat heights (Figures 6.6(a) and (b)). A high proportion of these data include very late applications, well past the apparent optimum growth stage and account for only two cultivars of wheat (Sunstate and Suneca).



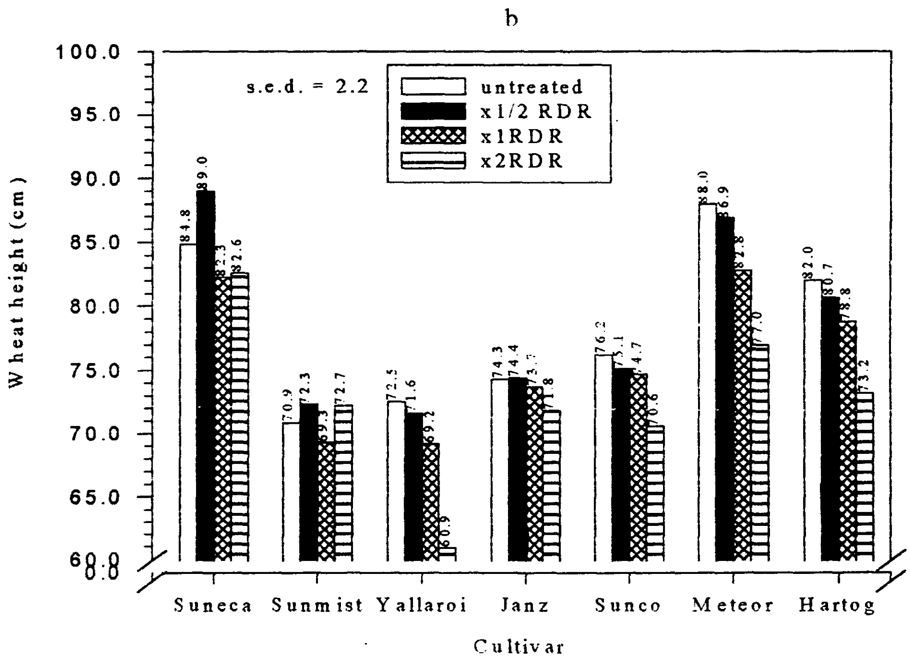


Figure 6.5. Experiment T93WVT: Effect of three rates of fenoxaprop-p-ethyl (a) and flamprop-M-methyl (b), applied late post-emergence, on wheat height (cm) assessed 70 days after treatment of seven wheat cultivars.

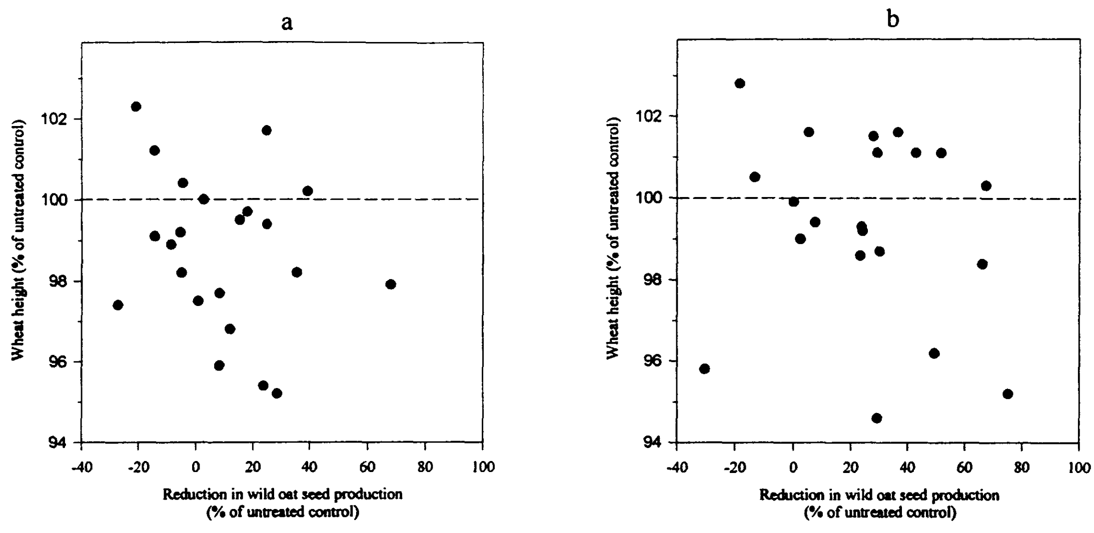


Figure 6.6. Effect of fenoxaprop-p-ethyl (a) and flamprop-M-methyl (b) on wheat height (cm) for all field experiments completed in 1994. Wheat heights are presented as a proportion of their respective untreated control heights and are plotted against the reduction in wild oat seed production for that treatment.

Whilst monitoring plots occasional visual symptoms were evident such as wheat height reduction, and leaf tip chlorosis combined with tip necrosis for more severe cases.

6.4.4. Effect of late post-emergence applications of herbicides on wild oat contamination of wheat

Wild oat contamination was measured in all 1994 field experiments, but only in experiment SM94RXT were significant effects detected. Despite this, a significant ($P<0.001$) rate / herbicide / time of application interaction was detected (Table 6.2). Applications of fenoxaprop-p-ethyl made at times one and two and including full RDR at time four significantly lowered wild oat contamination compared with the untreated control. Fenoxaprop-p-ethyl applied at time one at full RDR was significantly better than all other treatments, reducing wild oat contamination by 85.7% relative to the untreated control. Flamprop-M-methyl at full RDRs significantly reduced the level wild oat contamination relative to the untreated control by 73.0 and 57.6% at times of application three and four, respectively. Other applications of flamprop-M-methyl did not have significant effects on this parameter.

Table 6.2. Experiment SM94RXT: Effect of fenoxaprop-p-ethyl and flamprop-M-methyl rate and time of application on wild oat contamination in wheat (seeds/m^2). Logarithmic transformed data are presented in parentheses. The herbicide / rate / application time interaction was statistically significant (P<0.001), s.e.d. = 0.19 (logarithmic transformed). Data presented were covariate adjusted.

Application time	Dose rate	Fenoxaprop-p-ethyl	Flamprop-M-methyl
untreated		146.5 (4.99)	156.7 (5.06)
One	Half	83.1 (4.43)	117.3 (4.77)
One	Full	21.0 (3.09)	124.1 (4.83)
Two	Half	96.7 (4.58)	130.4 (4.88)
Two	Full	82.5 (4.43)	198.1 (5.29)
Three	Half	140.2 (4.95)	200.1 (5.30)
Three	Full	139.6 (4.95)	42.3 (3.77)
Four	Half	108.9 (4.70)	144.8 (4.98)
Four	Full	93.1 (4.54)	66.4 (4.21)

6.4.5. Comparison of wild oat with wheat growth stages for late post-emergence applications of herbicides

Wild oat growth and wheat stages were strongly linked by a linear relationship (Figure 6.7). Advanced wheat growth stages around the apparent time of application, possibly due to cultivar and/or climatic variation, may be a cause for unacceptable levels of crop phytotoxicity (see discussion), and is why the relationship is important. Approximately 77% of the variation in wheat growth stage, expressed as a proportion of tillers elongating, was linked to wild oat growth stage. This relationship incorporates nine experiments, three sites, five wheat cultivars and growth stages of wheat / wild oats ranging from fully tillered to early panicle emergence (Zadoks DC = 29 to 55). Although, the scattering of data points near or soon after the apparent optimum time seems more variable, the most advanced wheat growth stage prior to 45% of wild oat tillers elongating, is less than 60% tillers elongating.

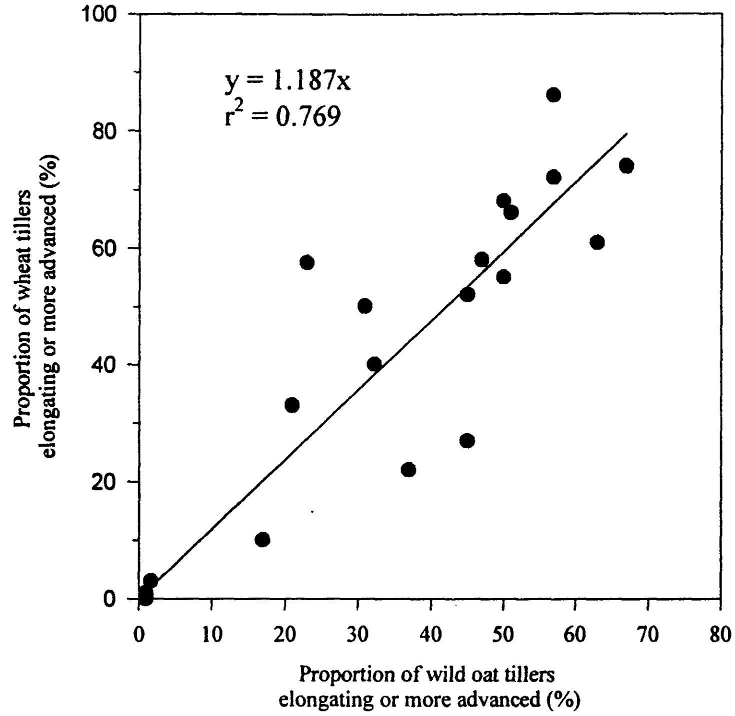


Figure 6.7. Linear relationship between wild oat and wheat growth stages at time of herbicide application. Growth stages are expressed as the proportion of tillers that are categorised as elongating or more advanced (see Chapter 2.1.1 for method of determining growth stages). Data presented come from all field experiments except for experiment T93WVT.

6.5. *Discussion*

The results presented in this chapter illustrate the low degree of wheat phytotoxicity following late post-emergence application of herbicides before and after the apparent optimum growth stage for maximum reduction in wild oat seed production. Applications of fenoxaprop-p-ethyl were generally less phytotoxic to wheat compared with flamprop which tended to reduce wheat height. Although a low to moderate proportion of flamprop treatments resulted in lower wheat height, this did not result in significant yield reductions in any of the eight cultivars of wheat commonly grown in the northern grain belt. Rapparini *et al.* (1982) likewise found a lack of correlation between observed symptoms and yield of eight wheat cultivars when L-flamprop-isopropyl was sprayed at early jointing (Zadoks DC = 31). The definition of phytotoxicity used in this thesis included the effects of weed competition and herbicide application, and essentially negligible phytotoxicity was reported, it therefore can be inferred that if the effects of wild oat competition are removed (most experiments) it is likely that the 'true' effect of herbicides should not be an issue.

In the majority of cases, higher wheat yields were recorded in the regional field experiments infested with wild oats. Yield gains were mainly of the order of to 0 to 25% above the respective untreated control yields, implying that some yield advantage is obtained from late post-emergence applications of herbicides. These yield gains are less than those to be expected from either pre-emergence herbicides (yield increases of mostly 30 to 79% were reported by Umbers (1994)) or early applications of post-emergence herbicides (yield increases of between 7 and 72% (Chow and Dryden 1975), 6 to 24% (Reeves *et al.* 1973) and 6 to 75% (Wilson and Cussans 1978)). Nevertheless, the small yield gains could be economically beneficial.

A component of wheat yield, kernel weight, was generally unaffected by late post-emergence herbicide treatments. Only in one experiment (IN92RXT) was a significant decline in kernel weight detected after flamprop-M-methyl was applied to wheat at the early ear emergence stage (74% tillers elongating or more advanced, Zadoks DC $\geq$ 30). This wheat growth stage is likely to correspond to similar wild oat growth stages (Figure 6.7), which is well beyond the apparent optimum time for reductions in seed production of wild oats.

The reported effects of fenoxaprop or flamprop (or either of their closely related analogues) on wheat are varied. In Europe, Bieringer *et al.* (1982) concluded that fenoxaprop applied at rates that controlled wild oats could also damage wheat and barley. Likewise, Liu *et al.* (1994) found damage in three cultivars of wheat whereas Montazeri (1994) recorded only slight and transient chlorosis of wheat leaves for two cultivars when treated with fenoxaprop-p-ethyl from the two to three leaf stage up to the late tillering stage of wheat. Australian research suggests that the use of fenoxaprop is likely to be safe in wheat when applied to wheat between Zadoks DC = 11 to 24 over nine experiments across two seasons and involving all mainland wheat growing regions (Anderson and Howat 1990).

All overseas references outlining flamprop-methyl / wheat phytotoxicity effects found little if any detrimental effects on wheat. The application of flamprop-methyl to wheat cv. Neepawa near early tillering did not have any detrimental effect on yield or nitrogen content of harvested wheat grain, using rates as high as 1.05 kg a.i./ha, more than twice the RDR (0.450 kg a.i./ha) that is used in Australia (Moyer *et al.* 1979). Other work by Jeffcoat *et al.* (1977) and Tottman *et al.* (1982) involving late post-emergence applications of flamprop-methyl made to wheat near jointing stage found no adverse effects on the wheat.

In Australia, Lemerle *et al.* (1981) applied three times the RDR of flamprop-methyl to two bread and five durum wheat cultivars, seven weeks after sowing. It is estimated that wheat in this experiment would not have been any more advanced than mid-tillering. Although flamprop-methyl significantly reduced the yield of two durum cultivars, it was preferred over other herbicides such as difenzoquat and diclofop-methyl because it was the only herbicide tolerated by the only commercial cultivar. In similar experimentation, Lemerle *et al.* (1985) screened 16 wheat cultivars at the five leaf stage against full and three times RDRs of flamprop-methyl, causing the least effect or heading delay (ear emergence) and least likely to reduce yields compared with barban and diclofop-methyl. Wilson (1979b) also found no detrimental yield effects with the use of flamprop-methyl, applied at Zadoks DC = 31, with five cultivars grown under Australian conditions in weed-free paddocks. However, the cultivar Kite exhibited reduced height and yields. This finding has little commercial importance as Kite is now rarely grown in Australia and the label recommendation states that applications to cv. Kite should not be made after the end of tillering. The study also demonstrated that significant height reductions, particularly with the application of three times the RDR on two other cultivars, did not affect wheat yield. From the same report, Wilson concluded that time of application of flamprop-methyl strongly affected wheat phytotoxicity, with application to wheat at the end of tillering resulting in significant reductions in height or yield, particularly following application of higher herbicide dose rates. A similar effect on wheat height was seen in experiment T93WVT, with higher rates of flamprop-M-methyl resulting in greater reductions in wheat height for some cultivars of wheat. Furthermore, the observed leaf symptoms of flamprop-M-methyl in experiment IN93RXT were similar to those reported by Lemerle *et al.* (1986).

In light of the previous paragraph, wheat phytotoxicity following flamprop applications needs to be minimised. Applications of flamprop before the early boot stage of wheat (Zadoks DC = 43) and rates not exceeding the full RDR are limitations that should minimise the risk of wheat injury. It is highly unlikely that applications of herbicides made near the apparent optimum wild oat growth stage will correspond to growth stages that are beyond the late jointing / early boot stage of wheat, since growth stages of wild oats and wheat have been shown to be approximately synchronised (Figure 6.7). The most advanced wheat near the apparent optimum wild oat growth stage was recorded in experiment CR93ADJ when 57% of wheat (cv. Hartog) tillers were elongating (none in boot stage) whilst 23% of wild oat tillers were elongating (Table 5.2).

Further herbicide screening is recommended to ensure that a wider range of currently grown wheat cultivars are suitable for late post-emergence applications. Time and resources for this project were only sufficient to test a small number of the commonly used cultivars. More research investigating the effects of time of application (wheat growth stage) of flamprop-M-methyl on crop phytotoxicity is crucial to explain and predict possible unacceptable levels of crop phytotoxicity from late post-emergence applications. Furthermore, these tolerance experiments must consider the use of herbicide with the addition of adjuvants, namely Uptake®. Reports are available that demonstrate the increased phytotoxicity of herbicides due to the addition of adjuvants. For example, Madin and Martin (1990) could not improve tralkoxydim activity on wild oats with surfactants, but in one case one adjuvant significantly increased crop phytotoxicity. It has been noted that some adjuvants do have phytotoxic effects on crops (Behrens 1964; Murphy *et al.* 1995) which could result from dewaxing and dehydration of the leaves.

Another possible phytotoxic effect relates to the level of herbicide residue in the harvested grain. The label of fenoxaprop-p-ethyl (Puma®S) states that application of the RDR cannot be made later than 70 days prior harvest, giving a withholding period (WHP) to allow sufficient time for degradation / transformation of herbicides to ensure maximum reside levels are met for the safety of end users. From present the experiments, late post-emergence applications of fenoxaprop-p-ethyl made near the apparent optimum application time were at least 70 days prior to harvest, and so would satisfying the normal WHP. The flamprop-M-methyl (Mataven®L) label, however, has a wheat development stage limitation instead of a WHP, stating that wheat be sprayed no later than the beginning of jointing. The limitation set by the flamprop-methyl label will clearly be breached by application to wheat plants in jointing or possibly boot stage. However, the label also states that wheat cannot be grazed or cut for stock food within six weeks after treatment. This period (42 days) is considerably less than the shortest time between application of flamprop and the harvesting of wheat reported in this thesis (63 days in experiment SM94RXT).

In summary, it is not likely that applications of either fenoxaprop-p-ethyl or flamprop at half or full RDRs near the apparent optimum wild oat growth stage will result in unacceptable levels of phytotoxicity.