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The effects of timing of control of weeds on the yield of winter oilseed rape (*Brassica napus*), in the context of the potential commercialization of herbicide-tolerant winter rape

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SUMMARY

Three experiments have investigated the effect of the timing of control of infestations of volunteer barley (*Hordeum vulgare*), *Stellaria media* and *Galium aparine* on the growth and yield of winter oilseed rape (*Brassica napus*). Although the experiments used conventional herbicides to achieve the different timings of control, the work was done in the context of the commercialization of herbicide-tolerant oilseed rape, where treatments could be applied at any time from autumn to spring. In the three seasons studied, oilseed rape growth was particularly vigorous in the autumn and, as a consequence, the competitive impact of the weeds was lower than anticipated. Untreated volunteer barley and *G. aparine* reduced yields in one and two experiments, respectively. However, in all experiments volunteer barley reduced crop growth in winter and spring severely, even though January treatments prevented yield loss in these vigorous crops. Delayed control of this weed would not be advisable if the weed was particularly dense or the crop less vigorous. In contrast, the *G. aparine* had no effect on crop growth and was only really apparent in the crop in late summer, so delaying treatment until even March would not put yields at risk. In one year, *S. media* markedly reduced crop growth in late winter but in the second experiment this did not occur. Consequently, as with the *G. aparine*, delayed autumn control would be unlikely to jeopardize yields. Thus, if herbicide-tolerant crops are commercialized in Europe, there will be flexibility in timing of application of herbicides to control broad-leaved weeds in winter rape but there would be a risk of yield loss from delayed control of volunteer cereals.

INTRODUCTION

As economic and environmental pressures continue to increase in the UK, arable farmers face a need to optimize crop protection. In oilseed rape (*Brassica napus* L.), herbicide inputs can account for 9–12% of the variable inputs (Nix 2002), a cost that is often not balanced by increased yields (Davies 1987; Davies *et al*. 1989; Whytock *et al*. 1995). As the profitability of oilseed rape has dropped in recent years, prophylactic spraying of the crop has become uneconomical, meaning more emphasis has been put on managing weeds less intensively, while still minimizing their effects on the crop. A lot of research already exists on the competitive effects of weeds (mainly grasses and volunteer cereals) on the yields of oilseed rape (Lutman 1984; Orson 1984; Regnault 1984; Bowerman 1989; Lutman & Dixon 1991; Lutman *et al*. 1993). It is clear that the effects of weed competition can be variable from season to season and this, together with agronomic factors such as crop density, sowing date and available nitrogen, all contribute towards the overall variation in weed competition and in crop yields (Mendham *et al*. 1981; Leach *et al*. 1994, 1999). For example, research by Lutman (1984) and Lutman & Dixon (1985) indicated that rape sown early in the season (i.e. late August to early September) was less sensitive to competition, showing that establishment date can alter the impact of weeds.

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Research on the effects on crop growth and yield of the timing of weed control, especially grass weeds, has not given clear evidence as to the benefits of early control in winter oilseed rape. Although early control of grasses can be beneficial, a follow-up treatment is often required to control broad-leaved weeds later in the season (Lutman 1989). Field trials in the 1980s studying the effects of timing of control of volunteer cereals in winter rape have shown that if the rape is well established delayed control does not result in significantly reduced yields (Lutman & Dixon 1985; Regnault 1984). Ogilvy (1989) reported that in a vigorous rape crop, *H. vulgare* densities of 100 plants/m^2 caused 7–22% reductions in yield, while in a less vigorous crop yield losses increased to 40–42%. However, timing of control had no effect on the competitive impact of the weeds in four out of the five trials. Davies (1987) reported that in the absence of high levels of volunteer cereals, benefits from controlling broad-leaved weeds in rape were seldom seen. Information on the timing of weed control in spring oilseed rape indicates that weeds need to be removed at the 4-leaf stage (Martin *et al.* 2001; Harker *et al.* 2003), but this is not relevant to the longer growth period of winter oilseed rape, as there is little time for the spring crop to recover from early inhibitions to growth. Earlier work on volunteer barley in winter rape showed clearly that this recovery can occur (Lutman 1989).

Provided there is not a yield penalty, delayed weed control offers a number of advantages, as it enables the grower to assess weed levels and crop vigour prior to treatment, gives more flexibility as to the time of treatment and has the potential to avoid the need for re-treatment as a result of weed emergence after the early herbicide application (Clayton *et al.* 2002). In the United Kingdom, specific graminicides such as propaquizafop and cycloxydim, and broad-leaved weed products such as clopyralid, can be used later in the season, permitting this more flexible approach to weed control for some weed species. This flexibility in timing may be given a further boost in the future by the commercialization of genetically modified herbicide tolerant rape, where it is possible to apply broad-spectrum products such as glyphosate and glufosinate from seedling stages to the early stem extension stage of the crop (Clayton *et al.* 2002; Senior & Dale 2002; Harker *et al.* 2003). With the current European moratorium on the development of such crops it was impractical to carry out trials to explore the flexibility in timing of control using glyphosate and glufosinate. However, it was possible, within the context of a field experiment programme, to explore the impact of delayed control, using conventional herbicide treatments (sometimes requiring repeat applications). With more emphasis in the UK on the conservation of farmland plant, invertebrate and vertebrate species, a change in policy, encouraging delayed control and consequentially reduced herbicide inputs could help to enhance the biodiversity of arable rotations involving winter rape.

The three experiments described in the present paper were designed to compare the efficiency of differently timed applications of herbicide on the control and competitive impact of arable weeds. *Galium aparine L.* (cleavers) at different densities was studied in the first experiment, and *G. aparine*, *Stellaria media L.* (common chickweed) and *Hordeum vulgare L.* (volunteer barley) in the later two experiments. The species were chosen as common weeds in winter rape in the UK, and for their differing competitiveness (Lutman *et al.* 1993).

MATERIALS AND METHODS

Three experiments were set up at Rothamsted (heavy silty-clay loam with flints) in three seasons using oilseed rape variety Apex in all years. Each experiment consisted of three randomized blocks of 14 treatments, with a plot size of 4 × 16 m. The first experiment (1999/2000 season) had three target densities of *G. aparine* (8, 16 and 32 plants/m^2) plus two weed-free controls per block. In each replicate there were three different times of herbicide application (29 October, 20 January, 5 March), or no herbicide application. For the experiments in the 2000/01 and 2001/02 seasons each replicate consisted of single densities of *G. aparine*, *S. media* and *H. vulgare* at target densities of 16, 600 and 400 plants/m^2 respectively, as well as two weed-free control plots. Herbicide treatments were applied on three occasions, and one set of plots was untreated. Dates of treatment are given in Table 1. Because of the early vigour of volunteer barley herbicide treatments were applied in September, November and January, whilst the other two weeds were treated in November, January and March. In each experiment, weed seeds were hand broadcast over plots, prior to drilling the crop. The rape was sown at 120 seeds/m^2 in the 1999/2000 and 2001/02 experiments, and at 80 seeds/m^2 in the 2000/01 experiment. Quadrat counts were used to determine crop/weed establishment in October of each season. In the 1999/2000 experiment 16 × 0·5 m^2 quadrats were counted and in later experiments 16 × 0·1–0·25 m^2 quadrats, depending on the plant densities present. Four destructive 0·5 m^2 quadrat harvests were taken from one end of the plots at intervals throughout the experiments (November/December, March, May and July). Crop, sown weed and other weed species, were sorted, washed and dried at 80 °C for 48 h. Dry weights of all samples were recorded. Crop heights were measured and pod numbers/plant counted on 10 randomly selected plants from the harvested sample/plot in July. Rape yields (t/ha at 9% moisture) were determined from

Table 1. *Dates and details of herbicide treatments for 2000/01 and 2001/02 experiments*

Treatment	2000/01 Application date	2000/01 Active ingredient	2000/01 Herbicide	2001/02 Application date	2001/02 Active ingredient	2001/02 Herbicide
H. vulgare early	30 Sep	propaquizafop 50 g a.i./ha	Falcon 0·5 l/ha	25 Sep	cycloxydim 150 g a.i./ha	Laser 0·75 l/ha
S. media early	13 Nov	benazolin + clopyralid 375: 62·5 g a.i./ha	Benazalox 1·25 kg/ha	2 Nov	benazolin 250 g a.i./ha	Galtak 0·5 l/ha
G. aparine early	13 Nov	benazolin 500 g a.i./ha	Galtak 1·0 l/ha	2 Nov	benazolin 250 g a.i./ha	Galtak 0·5 l/ha
H. vulgare late	13 Nov	propaquizafop 50 g a.i./ha	Falcon 0·5 l/ha	2 Nov	cycloxydim 200 g a.i./ha	Laser 1·0 l/ha
S. media late	8 Jan, 14 Mar	benazolin 500 g a.i./ha	Galtak 1·0 l/ha	16 Jan	benazolin 500 g a.i./ha	Galtak 1·0 l/ha
G. aparine late	8 Jan, 14 Mar	benazolin 500 g a.i./ha	Galtak 1·0 l/ha	16 Jan	benazolin 500 g a.i./ha	Galtak 1·0 l/ha
H. vulgare winter	8 Jan	propaquizafop 50 g a.i./ha	Falcon 0·5 l/ha	16 Jan	cycloxydim 200 g a.i./ha	Laser 1·0 l/ha
S. media winter	14 Mar	benazolin 500 g a.i./ha	Galtak 1·0 l/ha	12 Mar	benazolin + clopyralid 690: 115 g a.i./ha	Benazalox 2·3 kg/ha
G. aparine winter	14 Mar	benazolin 500 g a.i./ha	Galtak 1·0 l/ha	12 Mar	benazolin + clopyralid 690: 115 g a.i./ha	Benazalox 2·3 kg/ha

All treatments were applied at 220 l/ha with the exception of the highest rate of benazolin + clopyralid applied in March 2002, which was applied at 400 l/ha.

Table 2. *Details of crop and weed establishment and of sampling and nitrogen application dates*

Year	1999/2000	2000/01	2001/02
Sowing date	1 Sep 1999	24 Aug 2000	5 Sep 2001
Crop density (plants/m^2)	106	68	91
G. aparine (plants/m^2)	2, 7·5, 8·8	35	45
S. media (plants/m^2)	–	567	228
H. vulgare (plants/m^2)	–	384	304
Sample date, sample 1	30 Nov 1999	28 Nov 2000	3 Dec 2001
sample 2	28 Mar 2000	19 Mar 2001	12 Mar 2002
sample 3	22 May 2000	30 May 2001	20 May 2002
sample 4	6 Jul 2000	9 Jul 2001	2 Jul 2002
Harvest date	24 Jul 2000	24 Jul 2001	25 Jul 2002
Nitrogen application dates (+kg/ha N)	19 Oct 1999 (30 kg/ha) 9 Feb 2000 (50 kg/ha) 17 Mar 2000 (130 kg/ha)	25 Sep 2000 (30 kg/ha) 15 Feb 2001 (80 kg/ha) 2 Apr 2001 (120 kg/ha)	28 Sep 2001 (30 kg/ha) 19 Feb 2002 (100 kg/ha) 22 Mar 2002 (80 kg/ha)

combine harvested areas (one combine swathe/plot = *c*. 30 m^2/plot) following desiccation with diquat in July. Details of crop and weed establishment and sampling dates are given in Table 2.

In the 1999/2000 experiment, the herbicide used for all dates of *G. aparine* control was benazolin at 75 g a.i./ha (Galtak 50 SC, 1·5 litres in 220 l/ha). This was applied to 'early autumn' plots on 29 October and 20 January, to 'late autumn' plots on 20 January and 5 March, and to 'winter' plots on 5 March only. Repeat applications were necessary after the earlier treatments due to incomplete weed control. The same

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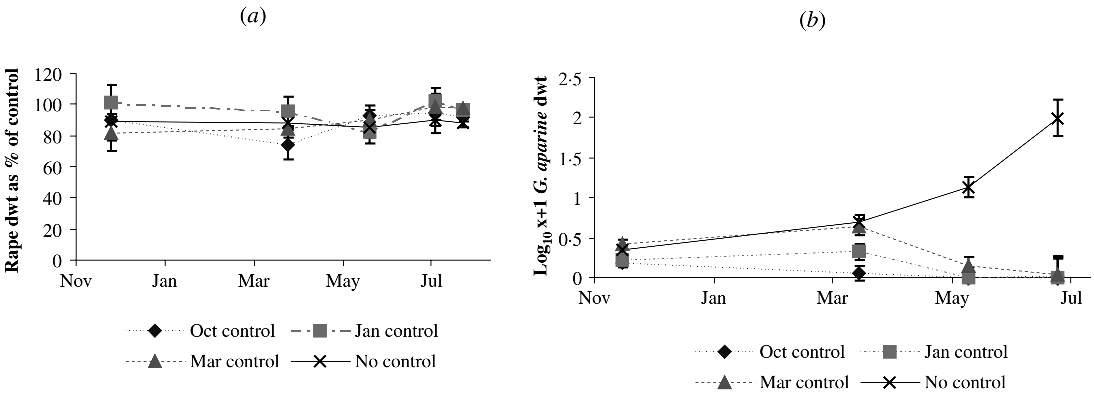

Fig. 1. The effects of the timing of control of *G. aparine* on (*a*) rape dry weight (dwt) and final yield as % of weed-free control values, and (*b*) *G. aparine* dry weight (g/m^2) (transformed $\text{Log}_{10}\,x+1$) at different sample dates for 1999/2000 experiment (all density treatments combined).

was sometimes true in the later two experiments. The details and dates of herbicide applications for the later experiments are given in Table 1. Either cycloxydim (Laser 200 g/l a.i.) or propaquizafop (Falcon 100 g/l a.i.) were used for the control of the barley and benazolin (Galtak – see above) or benazolin + clopyralid (Benazalox 30·5% w/w a.i.) for the *G. aparine* and *S. media*. In addition to the herbicide treatments, all three experiments received normal applications of insecticide and fungicide, as part of standard crop management procedures for this crop. Nitrogen levels, which reflected standard practice in the UK, are presented in Table 2.

All results were analysed by analysis of variance in Genstat (Copyright 2002, Lawes Agricultural Trust). Data for some analyses were transformed ($\text{Log}_{10}\,x+1$) to improve the homogeneity of the data. Standard errors were calculated for all data sets.

RESULTS

In 1999 the establishment of the *G. aparine* was well below the target, with a maximum mean density of only 8·8 plants/m^2 (Table 2). In autumn 2000 and 2001 *G. aparine* establishment was higher than the target (35 and 45 plants/m^2, respectively). The other two species were very similar to the target in 2000 (v. barley – 384, *S. media* – 567 plants/m^2) but were somewhat lower in 2001, especially *S. media* (v. barley – 304, *S. media* – 228 plants/m^2). Crop establishment was acceptable in all experiments, densities varying from 68 to 106 plants/m^2 (Table 2).

Galium aparine

The effects of differently timed herbicide applications on *G. aparine* were studied in all three experiments. In all years competitive effects on the biomass of the crop were negligible at all sampling dates (December–July) (Fig. 1*a*, 2*a* and 3*a*) and rape biomass was comparable to weed-free plots on all treatments (Table 3). In the 1999/2000 experiment, all dates of herbicide application gave good control. In 2000/01 and 2001/02 the early autumn treatment failed to kill all *G. aparine* plants, allowing some recovery of the plants by July (Fig. 2*b*, 3*b*), but amounts of *G. aparine* present were small. All other application dates gave good control. In 1999/2000, only the unsprayed densities of 7·5 and 8·8 *G. aparine* plants/m^2 caused significant yield losses (Table 4) compared with the weed-free plots. Yield was also reduced on the highest cleaver density early-sprayed treatment. Later herbicide treatments did not jeopardize yields. In the 2000/01 experiment, yields were significantly reduced on the non-sprayed treatments, but no detectable yield losses were recorded from the different times of weed control (Table 5). Significant yield losses were not detected in the 2001/02 experiment (Table 5), despite the presence of considerable numbers of *G. aparine* plants early in the season.

Stellaria media

Rape biomass was significantly reduced in December 2000 on all *Stellaria media* plots, compared with the weed-free plots (Fig. 2*c*). But by March, rape biomass was appreciably lower on the untreated chickweed plots (and those recently treated in March) than it was on those treated in November and January, which showed evidence of good recovery compared with the weed-free plots. During spring and summer the rape recovered, even on untreated *S. media* plots. There was some evidence that the rape after the last timing of control, and where the *S. media* was untreated, was still less vigorous than the weed-free in May, but the patterns of responses later in the

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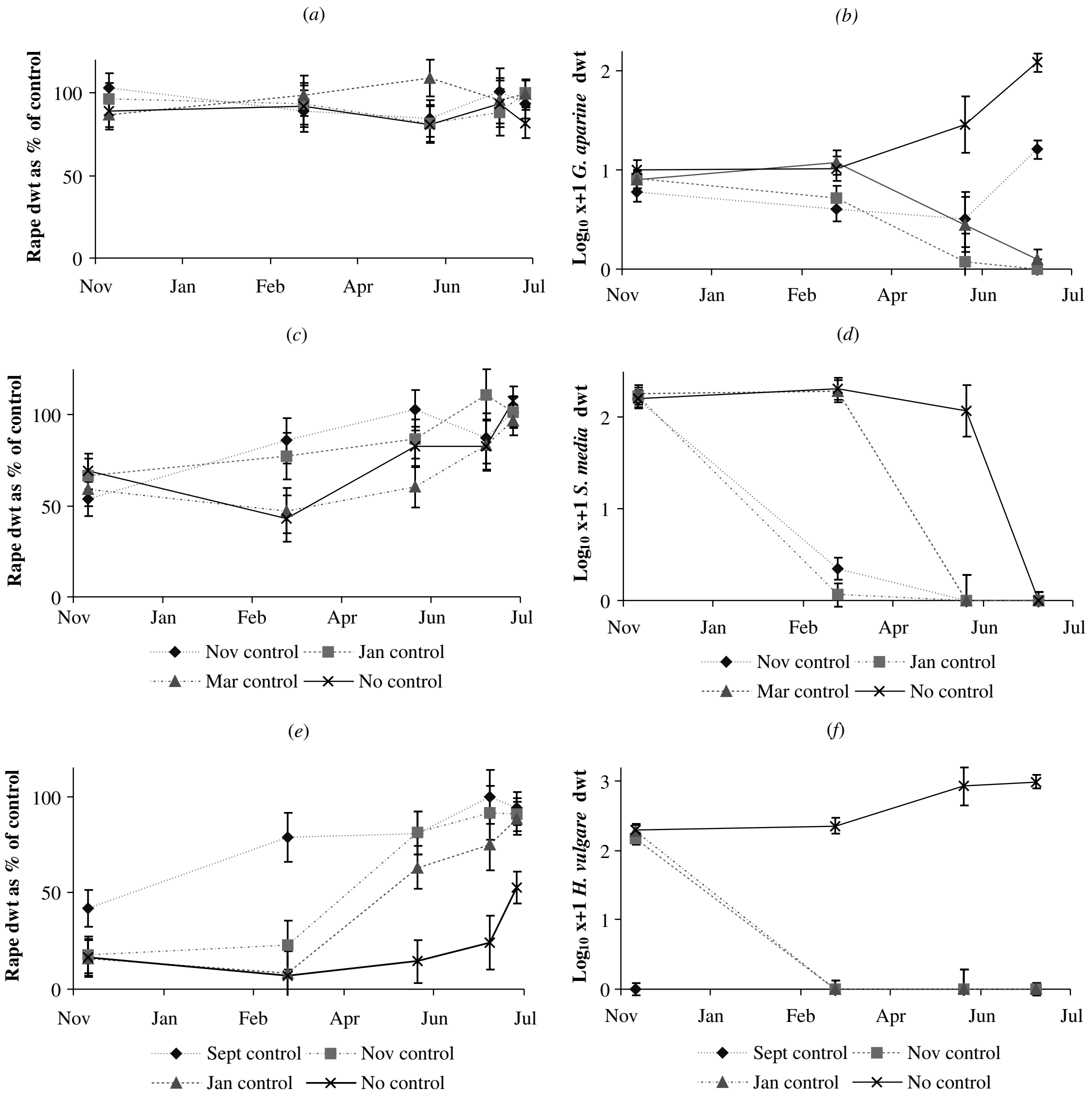

Fig. 2. The effects of the timing of control of three weeds on rape dry weight (dwt) and final yield, as % of weed-free controls and weed dry weight (g/m²) (transformed Log_{10} x+1), assessed at five different dates in 2000/01 experiment: rape weights (*a*) *G. aparine*, (*c*) *S. media* and (*e*) *H. vulgare*; weed weights (*b*) *G. aparine*, (*d*) *S. media*, (*f*) *H. vulgare*.

summer were not clear. In 2001/02 *S. media* had little effect on rape growth (Fig. 3*c*), despite the presence of appreciable quantities of the weed in the December sample. This may have been associated with the fact that the weed's density and biomass in December were lower in 2001/02 than in 2000/01 (Table 2, Fig. 2*d*, 3*d*). In 2000/01 there were on average 68 rape and 567 *S. media* plants/m², compared with 91 rape and 228 *S. media* in 2001/02 (Table 2). In both years the crop was vigorous, reaching weights of over 210 g/m² in December 2000, and over 240 g/m² in December 2001 (weed-free plots, Table 3).

In both years *S. media* biomass dropped sharply following herbicide treatment (Fig. 2*d*, 3*d*), giving good control at all application dates. *Stellaria media* even on non-sprayed plots had senesced by the 4th sample date in July in both years and was absent at the date of final harvest.

Hordeum vulgare

Effects of timing of herbicide application on *Hordeum vulgare* were studied in the 2000/01 and 2001/02 experiments. In both years all dates of herbicide

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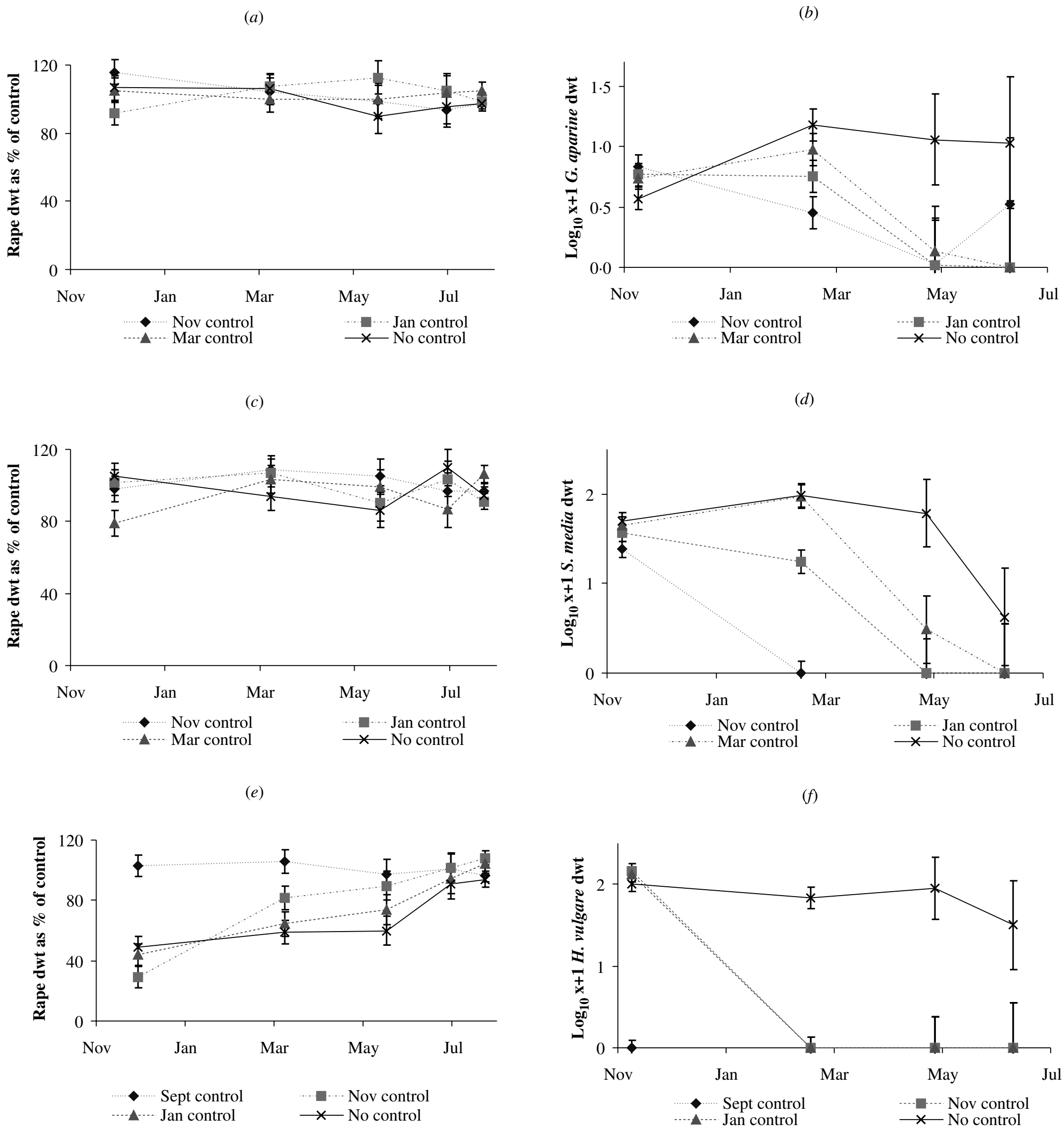

Fig. 3. The effects of the timing of control of three weeds on rape dry weight (dwt) and final yield, as % of weed-free controls and weed dry weight (g/m²) (transformed Log_{10} x + 1), assessed at five different dates in 2001/02 experiment: rape weights (*a*) *G. aparine*, (*c*) *S. media* and (*e*) *H. vulgare*; weed weights (*b*) *G. aparine*, (*d*) *S. media*, (*f*) *H. vulgare*.

application gave effective control (Fig. 2*f*, 3*f*). Reductions in rape biomass were more pronounced due to *H. vulgare* competition than for the other weeds studied (Fig. 2*e*, 3*e*). In both years rape biomass was substantially reduced in the autumn by competition from the *H. vulgare*, but it increased quickly following the weed's removal with herbicide (Fig. 2*e*, 3*e*). Recovery of the September treated plots was faster than that of the November or January treated ones. Full recovery of the rape also occurred on untreated plots in summer 2001/02 but not in the summer 2000/01. There was appreciably less barley present on the plots in the second experiment (199 g/m² in December '00 and 101 g/m² in December '01 for non-sprayed plots), partly resulting from the lower barley density in the latter year (Table 2). In both years no significant reductions in yield were detected on sprayed treatments (Table 5). The non-sprayed

Table 3. *Weed-free rape dry weight* (*g/m²*) *at four sampling dates, and weed-free seed yields* (*t/ha at 9% moisture*) *for 1999/2000, 2000/01 and 2001/02 experiments* (*sample and harvest dates given in Table 2,* S.E.D *shown in parentheses*)

Sample date	1999/2000 experiment	2000/01 experiment	2001/02 experiment
Nov/Dec	153 (24·0)	241 (23·0)	215 (15·2)
Mar	428 (53·8)	278 (34·8)	361 (28·3)
May	1126 (105·6)	1256 (138·9)	1197 (117·2)
July	1331 (148·3)	1832 (254·3)	1527 (150·7)
Final yield	3·88 (0·154)	4·04 (0·343)	4·72 (0·220)

Table 4. *Effect of* G. aparine *density and time of weed removal on rape seed yields* (*t/ha at 9% moisture*) (*1999/00 experiment*)

Time of initial weed removal	*G. aparine* density Plants/m²			Mean
	2·2	7·5	8·8	
29 Oct	3·65	3·57	3·46	3·56
20 Jan	3·94	3·65	3·66	3·75
5 Mar	3·78	3·72	3·83	3·78
None	3·73	3·24	3·24	3·41
Weed-free		3·88		3·88
S.E.D.[1]		0·154		0·115
S.E.D.[2]		0·178		0·103

S.E.D.[1] used to compare treatments with weed-free values.
S.E.D.[2] used to compare treatment with treatment.

treatment in 2000/01 gave a significant yield loss but this did not occur in 2001/02, although the untreated plots had the lowest yields.

DISCUSSION

The overall conclusion to be drawn from the experiments detailed in this paper is that, given favourable weather conditions, early-sown winter oilseed rape can tolerate reasonable levels of weed competition with no significant effect on yield. Yield losses were detected from untreated cleavers in 2000 and 2001 and from *H. vulgare* in 2001. Davies (1987) reported similar findings from some trials in Scotland, where yield benefits barely covered the costs of the chemicals used. The ability of rape to compete so strongly in some years but not others is well documented, although reasons for this are not straightforward. In the three trials included in this paper September weather was favourable for good rape establishment, with ample rainfall and mild temperature conditions (Table 6). This meant that from the start the rape was growing vigorously (Table 3).

Table 5. *Effect of the timing of control of* G. aparine, S. media *and* H. vulgare *on oilseed rape seed yields in the 2000/01 and 2001/02 experiments* (*t/ha 9% moisture*)

Treatment	Time of control	Rape seed yield t/ha	
		2000/01	2001/02
Weed-free		4·04	4·72
H. vulgare	Sep	3·79	4·57
H. vulgare	Nov	3·66	5·10
H. vulgare	Jan	3·58	4·92
H. vulgare	No control	2·13	4·42
S. media	Nov	4·11	4·56
S. media	Jan	4·09	4·30
S. media	Mar	3·92	5·02
S. media	No control	4·34	4·45
G. aparine	Nov	3·76	4·60
G. aparine	Jan	4·04	4·66
G. aparine	Mar	4·01	4·96
G. aparine	No control	3·29	4·61
S.E.D.[1]		0·343	0·220
S.E.D.[2]		0·396	0·254

S.E.D.[1] used to compare treatments with weed-free values.
S.E.D.[2] used to compare treatment with treatment.

In all 3 years temperatures were higher than the long-term mean in both September and October, encouraging vigorous growth of the rape. Low rainfall did not inhibit early growth. Rape weights in all experiments in December exceeded 150 g/m², a factor which other work has shown to minimize the competitive effects of weeds (Lutman *et al.* 2000). Indeed, in experiments in the 1980s and 1990s rape dry weight at this time of the year rarely exceeded 100 g/m² (Lutman & Dixon 1990; Lutman *et al.* 2000). Similarly, the beginning of spring, when mean temperatures rose consistently to above 5 °C, was early (Table 6). This allowed good rape growth from February onwards, before the onset of flowering. For all three experiments presented in this paper pod numbers per m² were high (Table 7), generally in excess of 9000 pods/m². Other research has suggested that optimum pod density for yield is only 7500 pods/m² and that higher densities confer no yield benefit (Lunn *et al.* 2001). Consequently, it was not surprising, given the level of pod production, that yields were not greatly affected by the three weeds. In harvest year 2000, pod numbers in July were above 10 000 pods/m² for all treatments (Table 7). This suggests that the lower yields recorded on unsprayed plots were not associated with the direct competitive effects of *G. aparine*, but may be related to the effects of this weed on harvesting efficiency. In the other 2 years pod number/m² dropped below 10 000 for some treatments, but only fell below 7000 pods/m²

Table 6. *Mean values of average daily temperature and monthly rainfall for 1999/2000, 2000/01 and 2001/02 seasons*

	Average temperature (°C)				Total rainfall (mm)			
Month	1999/ 2000	2000/01	2001/02	30 yr mean	1999/ 2000	2000/01	2001/02	30 yr mean
Sep	16·0	15·0	13·3	13·7	70·5	90·7	73·8	65·3
Oct	10·5	10·3	13·4	10·2	46·5	166·7	115·7	79·7
Nov	7·4	6·6	6·9	6·4	35·6	138·6	49·0	70·9
Dec	4·4	5·5	3·3	4·6	95·9	107·7	19·5	74·5
Jan	4·4	3·0	5·3	3·6	25·4	76·1	70·0	73·1
Feb	5·9	4·6	6·7	3·7	74·6	104·9	84·0	51·8
Mar	7·2	5·4	7·4	5·9	13·1	91·4	49·3	56·5
Apr	7·8	7·8	9·3	7·8	132·5	83·7	55·7	56·9
May	12·0	12·6	11·8	11·0	90·4	50·1	81·0	53·1
Jun	15·3	14·2	14·4	13·9	12·7	27·8	29·2	63·5
Jul	15·3	17·5	16·4	16·4	48·5	56·1	93·5	44·6

Table 7. *Effects of the treatments on pod numbers in July 2000, 2001 and 2002*

Weed species	Month of weed control	Pod numbers in July (pods/m²) 1999/2000	2000/01	2001/02
Weed-free		13 064	10 977	9934
H. vulgare	Sep		11 677	6953
H. vulgare	Nov		11 385	10 929
H. vulgare	Jan		9463	9406
H. vulgare	No control		2164	7241
S. media	Nov		8840	10 223
S. media	Jan		14 617	9009
S. media	Mar		11 312	10 663
S. media	No control		9347	10 401
G. aparine	Oct–Nov	10 406*	8464	7726
G. aparine	Jan	13 208*	9862	9284
G. aparine	Mar	12 036*	12 147	9155
G. aparine	No control	11 440*	10 622	8574
S.E.D.[1]		1030	1482·4	1697·6
S.E.D.[2]		1152	1711·7	1960·2

* Mean of three cleavers densities.
S.E.D.[1] used to compare treatments with weed-free values.
S.E.D.[2] used to compare treatment with treatment.

on the untreated barley plots in 2001 (mean 2164 pods/m²), where significant yield reductions were recorded.

One of the aims of the three experiments was to expose rape to the risk of yield loss that could arise from the delayed application of herbicides. Delayed control of volunteer cereals had been studied in the past (Orson 1984; Ogilvy 1989) with mixed results, as delayed control sometimes led to yield loss and sometimes not. As late post-emergence broad-spectrum herbicides have not been available in the UK (with the exception of propyzamide), little work had been done on the timing of control of the major broad-leaved weeds. This situation could change if herbicide-tolerant rape crops resistant to glyphosate and glufosinate are commercialized. Is it practical to exploit the greater timing flexibility available with these products or would delaying treatment put yields in jeopardy? The experiments reported here provide some answers. As untreated *S. media* (even at densities in excess of 300 plants/m²) only reduced rape growth temporarily in early spring and failed to affect crop yields, it can only be concluded that there was no risk to the crop from delayed herbicide application. Indeed, the conclusion can be reached that there was no economic benefit from using herbicides to control this weed. With *G. aparine*, most weed growth occurred on the untreated plots, and as in other experiments very late in the season (Wright 2001). There was no risk to the yield of the crop arising from delaying *G. aparine* control until early spring, provided the treatment killed the weed. In two experiments, untreated *G. aparine* plants reduced yields. The situation with volunteer barley (*H. vulgare*) is more difficult to summarize. In these experiments there was a major effect of the barley on the growth of the rape in the early autumn, especially in autumn 2000. The September herbicide treatment enabled the crop to recover by the following March, and for later treatments the crop had substantially recovered by May. As a result of this, yields on the treated plots were not reduced. Consequently, it could be argued that there was no risk to yield from delayed application. However, as has been shown earlier in the present paper, the rape crops in the three experiments were particularly vigorous and, despite this, their biomass in winter and spring was greatly reduced by the volunteer barley in both years.

Consequently, any factor that reduced crop growth, such as unsuitable weather or disease attack, could prevent the crop recovering fully from the massive reduction in crop vigour (up to 80%) that can be caused by this weed species. Consequently, it seems prudent not to delay the control of *H. vulgare*, if the density of the weed is high and/or if the vigour of the crop is low.

It should be noted that some of the treatments of the *G. aparine* and *S. media* with benazolin or benazolin+cloypyralid were not ones that would be recommended in practice. The early treatments needed later additional treatments to ensure high level of control (which exceeded the recommended rate) and in some situations there was evidence that the 'early' treatments caused some reduction in crop vigour and a lowering of the yields. This did not always reach statistical significance but would be a cause for concern if such treatments were to be proposed for on-farm use. Since the end of the research work benazolin has been withdrawn from sale, further emphasising the lack of products available for late weed control.

These three weeds are quite representative of those likely to be present in winter rape in the UK and so one can conclude that delayed control of broad-leaved weeds in herbicide-tolerant crops would be acceptable, but that control of appreciable infestations of annual grass weeds should not be greatly delayed.

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REFERENCES

BOWERMAN, P. (1989). Weed control in winter oilseed rape – review of ADAS trials 1985–87. *Aspects of Applied Biology* **23**, *Production and Protection of Oilseed Rape and Other Brassica Crops*, 219–226.

CLAYTON, G. W., HARKER, N. K., O'DONOVAN, J. T., BAIG, M. N. & KIDNIE, M. J. (2002). Glyphosate timing and tillage system effects on glyphosate-resistant canola (*Brassica napus*). *Weed Technology* **16**, 124–130.

DAVIES, D. H. K. (1987). Effect of herbicides on weed control and crop yield in winter oilseed rape in south-east Scotland. *Proceedings of the British Crop Protection Conference – Weeds* **3**, 815–820. Farnham, Surrey: BCPC.

DAVIES, D. H. K., WALKER, K. C. & WHYTOCK, G. P. (1989). Herbicide use and yield response in winter oilseed rape in Scotland. *Aspects of Applied Biology* **23**, *Production and Protection of Oilseed Rape and Other Brassica Crops*, 227–235.

HARKER, N. K., CLAYTON, G. W., BLACKSHAW, R. E., O'DONOVAN, J. T. & STEVENSON, F. C. (2003). Seeding rate, herbicide timing and competitive hybrids contribute to integrated weed management in canola (*Brassica napus*). *Canadian Journal of Plant Science* **83**, 433–440.

LEACH, J. E., DARBY, R. J., WILLIAMS, I. H., FITT, B. D. L. & RAWLINSON, C. J. (1994). Factors affecting growth and yield of winter oilseed rape (*Brassica napus*), 1985–89. *Journal of Agricultural Science, Cambridge* **122**, 405–413.

LEACH, J. E., STEVENSON, H. J., RAINBOW, A. J. & MULLEN, L. A. (1999). Effects of high plant populations on the growth and yield of winter oilseed rape (*Brassica napus*). *Journal of Agricultural Science, Cambridge* **132**, 173–180.

LUNN, G. D., SPINK, J. H., STOKES, D. T., WADE, A., CLARE, R. W. & SCOTT, R. K. (2001). *Canopy Management in Winter Oilseed Rape*. HGCA Project Report OS49. London: HGCA.

LUTMAN, P. J. W. (1984). The effects of weed competition on the growth and yield of oilseed rape. *Aspects of Applied Biology* **6**, *Agronomy, Physiology, Plant Breeding and Crop Protection of Oilseed Rape*, 209–220.

LUTMAN, P. J. W. (1989). Objectives of weed control in oilseed rape. *Aspects of Applied Biology* **23**, *Production and Protection of Oilseed Rape and Other Brassica Crops*, 199–210.

LUTMAN, P. J. W. & DIXON, F. L. (1985). The effect of the timing of control of grass weeds on the yield of oilseed rape. *Proceedings of the British Crop Protection Conference – Weeds*, pp. 209–216. Farnham, Surrey: BCPC.

LUTMAN, P. J. W. & DIXON, F. L. (1990). The competitive effects of volunteer barley (*Hordeum vulgare*) on the growth of oilseed rape (*Brassica napus*). *Annals of Applied Biology* **117**, 633–644.

LUTMAN, P. J. W. & DIXON, F. L. (1991). Weed competition in winter oilseed rape in the United Kingdom. *International Organisation for Biological Control Conference*, Integrated Control of Oilseed Crops. *WPRS Bulletin* **14**, 234–242.

LUTMAN, P. J. W., BOWERMAN, P., PALMER, G. M. & WHYTOCK, G. P. (1993). The competitive effects of broad-leaved weeds in winter oilseed rape. *Proceedings of the Brighton Crop Protection Conference – Weeds*, pp. 1023–1028. Farnham, Surrey: BCPC.

LUTMAN, P. J. W., BOWERMAN, P., PALMER, G. M. & WHYTOCK, G. P. (2000). Prediction of competition between oilseed rape and *Stellaria media*. *Weed Research* **40**, 255–270.

MARTIN, S. G., VAN-ACKER, R. C. & FRIESEN, L. F. (2001). Critical period of weed control in spring canola. *Weed Science* **49**, 326–333.

MENDHAM, N. J., SHIPWAY, P. A. & SCOTT, R. K. (1981). The effects of seed size, autumn nitrogen and plant population density on the response to delayed sowing in winter oilseed rape (*Brassica napus*). *Journal of Agricultural Science, Cambridge* **96**, 417–428.

NIX, J. (2002). *Farm Management Pocketbook*, 32nd edn. The Anderson Centre, Melton Mowbray, UK: Imperial College at Wye.

OGILVY, S. E. (1989). The effects of severity and duration of volunteer barley competition on the yield of winter oilseed rape – review of ADAS trials, 1986–87. *Aspects of Applied Biology* **23**, *Production and Protection of Oilseed Rape and Other Brassica Crops*, 237–243.

ORSON, J. H. (1984). The control of volunteer cereals in winter oilseed rape. Agricultural Development and Advisory Service results – harvest years 1982 and 1983. *Aspects of Applied Biology* **6**, *Agronomy, Physiology, Plant Breeding and Crop Protection of Oilseed Rape*, 179–184.

REGNAULT, Y. (1984). The control of grass-weeds in oilseed rape in France. *Aspects of Applied Biology* **6**, *Agronomy, Physiology, Plant Breeding and Crop Protection of Oilseed Rape*, 185–189.

SENIOR, I. J. & DALE, P. J. (2002). Herbicide-tolerant crops in agriculture: oilseed rape as a case study. *Plant Breeding* **121**, 97–107.

WHYTOCK, G. P., BINGHAM, I. J. & NAYLOR, R. E. L. (1995). Developing cost-effective strategies for weed control in winter oilseed rape. *Proceedings of the Brighton Crop Protection Conference – Weeds*, pp. 883–888. Farnham, Surrey: BCPC.

WRIGHT, K. J. (2001). Competition between *Galium aparine* and winter wheat: optimum timing of herbicide application to minimise yield loss. *Proceedings of the BCPC Conference – Weeds*, pp. 615–620. Farnham, Surrey: BCPC.