SESSION 6C

IMPLICATIONS OF CHANGES IN STRAW MANAGEMENT AND OTHER CULTURAL PRACTICES ON WEED POPULATIONS AND THEIR CONTROL

SESSION ORGANISER DR S. R. MOSS

POSTERS 6C-1 to 6C-6

INTERACTIONS BETWEEN THREE WEED SPECIES OF WINTER WHEAT IN RESPONSE TO MANAGEMENT PRACTICES.

M. Mc CLOSKEY, L. G. FIRBANK

Dept. of Applied Sciences, Anglia Polytechnic, Cambridge. CB1 1PT

A. R. WATKINSON

School of Biological Sciences, University of East Anglia, Norwich. NR4 7TJ

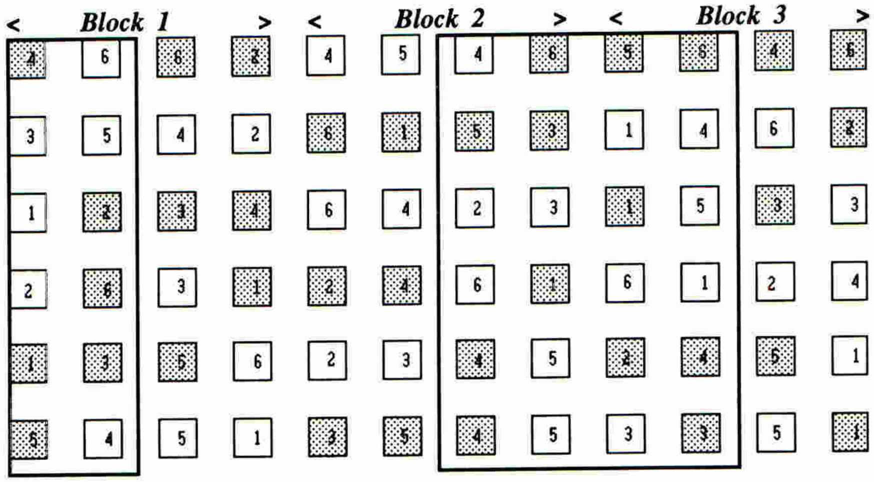
ABSTRACT

If the principles of organic and low input farming are to be successfully applied it will be necessary to improve our understanding of how different management strategies affect the structure and behaviour of weed communities. In an on-going experiment we have been investigating the effects of combinations of different methods of weed control (herbicide vs ploughing and hand roguing) and types of fertilizer (organic vs inorganic) on interactions between three weed species, *Bromus sterilis, Galium aparine* and *Papaver rhoeas,* in a field of continuous winter wheat. Results from the first two years show that (i) ploughing has effectively controlled all three weed species, (ii) *P. rhoeas* remains uncommon, (iii) on unploughed plots the populations of *B. sterilis* and *G. aparine* greatly increased until the application of herbicide, (iv) *G. aparine* was most numerous when grown on plots which were treated the previous year with organic fertilizer but populations were reduced when grown in mixture with *B. sterilis,* implying weed-weed competition.

INTRODUCTION

Concern over the environmental impact of agrochemicals has resulted in an increased interest in organic and low input farming. Weeds are usually seen as indicators of management practice in a farming system, but to the proponents of low input and organic farming it is the imbalances in farm management that are the major causes of weed problems (Marland, 1989). Many previous studies of the impact of weeds on crops have concentrated on one-weed-one-crop systems (Cousens, 1985; Firbank, 1991), but if organic farming affects plant communities as a whole then we need to assess its impact on the interactions between weed species. Intensive studies under natural conditions are needed in order to evaluate the impact of changes in management on the weed community. This paper presents some of the preliminary results from the first two years of a three year experiment conducted at Broom's Barn Experimental Station. The aim of this experiment was to investigate the interactions between continuous winter wheat, *Triticum aestivum* cv. Hornet, and three weed species, *Bromus sterilis* (barren brome), *Galium aparine* (cleavers) and *Papaver rhoeas* (common poppy) under different fertilizer and weed management regimes.

FIGURE 1. *Plan of experimental plots: The plots in the outlined areas were ploughed, the remainder cultivated. The shaded plots were treated with inorganic fertilizer, the others with an organic fertilizer. The numbers refer to weed treatments as follows; (1) no weeds, (2) background weeds, (3) a mixture of* B. sterilis, G. aparine *and* P. rhoeas, *(4)* B. sterilis *only, (5)* G. aparine *only, (6)* P. rhoeas *only.*



METHOD

The management strategies investigated were combinations of two methods of weed control, minimum tillage and herbicide vs ploughing and hoeing/hand roguing, and two sources of fertilizer, organic vs inorganic. The experiment was sited in a 72 x 48 m area in a field of heavy clay soil. The design of the experiment was constrained by the fact that the plots within the field could not be ploughed individually, so a split block design was used.

The experiment began on 23 October 1989 with the cultivation of the field. The area was divided up into three 24 m * 48 m blocks. One half of each block (chosen at random), was ploughed 20 cm deep using a three furrow reversible plough. The other half of each block was minimally cultivated using a rotary power harrow to a depth of 5 cm and the weeds controlled by spraying the wheat with chlorotoluron + bifenox. Following cultivation the whole field was sown with winter wheat at a seed rate of 216 kg/ha to give a seed density of 360 m^{-2}. The area within each half-block was divided up into twelve, 3 m * 3 m plots which were to be treated either with an organic or a inorganic fertilizer, the treatment being allocated at random (Fig. 1). The organic fertilizer was a composted poultry manure, produced by Organic Concentrates Ltd (brand name '6x'), which has typical NPK values of 4: 2: 2. The inorganic fertilizer was the ammonium nitrate product 'Nitram', NPK value of 34.5: 0: 0. The inorganic fertilizer was applied to each plot so that the nitrogen rate was 240 kg/ha. The application rate of the poultry manure was then calculated so that an equivalent amount of nitrogen was applied to all plots.

TABLE 1. *(a) Dates and rates of applications of fertilizer treatments and (b) dates of weed control treatments and rates of application of herbicide.*

a) Fertilizer treatments

Date	*Treatment*	*Product*	*Analysis*	*Rate - Kg/ha*
17-08-89	all plots	Compound	0: 18: 36	323
01-04-90	inorganic	Ammonium nitrate	34.5% N	40 N
01-04-90	organic	Poultry manure	3.25% N	40 N
24-04-90	inorganic	Ammonium nitrate	34.5% N	100 N
24-04-90	organic	Poultry manure	3.25% N	100 N
18-05-90	inorganic	Ammonium nitrate	34.5% N	100 N
18-05-90	organic	Poultry manure	3.25% N	100 N
12-04-91	inorganic	Ammonium nitrate	34.5% N	40 N
12-04-91	organic	Poultry manure	4% N	100 N
08-05-91	organic	Poultry manure	4% N	100 N

b) Weed control treatments

Date	*Area*	*Treatment*	*Method*	*Rate Kg AI / ha*
07-01-90	Min. till	Chlorotoluron	3m boom	1.95
	-	Bifenox	"	0.53
17/18-02-90	Ploughed	Hand Hoeing		
19/20-05-90	Ploughed	Hand Roguing		
24-04-91	Min. till	Chlorotoluron	3m Boom	1.95
		Bifenox	"	0.53
11/12-04-91	Ploughed	Hand Hoeing		
18/19-04-91	Ploughed	Hand Roguing		

As well as the four management treatments outlined above, there were six 'weed' treatments:

(1) No weeds - all weeds removed from the plot by being pulled up at as they emerged during the year.
(2) Background weeds - naturally occurring in the field were allowed to grow and any *B. sterilis*, *G. aparine* or *P. rhoeas* were counted to establish background levels for each of these species.
(3) A 1 : 1 : 1 mixture of *B. sterilis, G. aparine* and *P. rhoeas,* other weeds removed.
(4) *B. sterilis* sown, other weeds removed.
(5) *G. aparine* sown, other weeds removed.
(6) *P. rhoeas* sown, other weeds removed.

The crop was drilled on 23 October 1989, and one day later all the weed seeds/mixtures were sown at a density of 50 seeds/m^2 of each species. On treatment (3) plots the total weed seed density was therefore 150 seeds/m^2. Weed seeds were sown only at the beginning of the first year so that in later years the weed numbers would reflect the relative reproductive success of each species in response to the management practices employed on each plot. In each half-block all six weed treatments were replicated on both organic and inorganic fertilizer plots (Fig. 1). The timings and rates of application for the fertilizer treatments, herbicide treatments and weeding for the years 1989/90 and 1990/91 are given in Table 1. Note that due to bad weather weed control treatments were delayed in 1990/91.

From November 1989 to May 1990, monthly assessments were carried out to record weed densities; all weeds in the 4m^2 area in the middle of each plot were counted. In August 1990 a sample of the wheat from a 0.5m^2 area in each plot were harvested by hand and on the following day the rest of the wheat and whatever weeds were present were harvested using a combine harvester. The straw and chaff were collected and removed as the wheat was harvested to prevent weed seeds being moved between plots. In the autumn the Experiment was set up again exactly as before except that new weed seeds were not sown. The wheat was drilled on 3 October 1990, and the monthly surveys were continued from October 1990 to June 1991.

RESULTS

1989-90 Data

The background levels of *B. sterilis* were very low with a maximum density of 0.3 plants/m^2 before weed control treatments. Analysis of both years' data showed numbers of *B. sterilis* to be very similar on the organic and inorganic plots whether they were grown with wheat only or grown in mixture with other weeds and wheat. By December 1989 *B. sterilis* had reached average densities of 20 - 30 plants/m^2 on all plots where it had been sown. This figure dropped to 2-3 plants/m^2 following the application of herbicide in March 1991, though numbers recovered to 15-20 plants/m^2 as new plants germinated in the spring on these plots. On the ploughed plots, hoeing reduced the density by about half, with numbers increasing to between 15-20 plants/m^2 before roguing in May 1990.

The background levels of *G. aparine* in 1989/90 were low at 0.3 plants/m^2. Before herbicide application in January 1990 the average density on plots sown with *G. aparine* and wheat only was 1.5 plants/m^2. When grown in mixture, the average density at this time on the organic plots was 2.3 plants/m^2 and on inorganic plots 1.3 plants/m^2.

The effect of the herbicide on the minimum cultivation plots was to reduce the average density to 0.2 plants/m^2 on the mixed weed plots and to zero where *G. aparine* was grown with wheat only. Densities recovered between March and May on all plots as seeds continued to germinate. However differences between numbers on the chemical and organic plots were observed. By May the average density on the organic plots was 4 plants/m^2 and on the chemical plots the average was 1.3 plants/m^2. In contrast, on the ploughed plots where *G. aparine* was grown, average densities were 5.5 plants/m^2 on organic plots and 4.5 plants/m^2 on inorganic plots in February 1990. Hoeing between the rows in February had little effect on *G. aparine* in the single species plots where there was a slight fall in numbers, and there was an average density of 6-8 plants/m^2 before roguing in May 1990. Hoeing was more effective on the mixed weed plots, reducing the densities on the organic and inorganic plots to 3 and 2 plants/m^2 respectively. These figures rose by less than 1 plant/m^2 before hand roguing in May.

Average densities of *P. rhoeas* were very low in both years and therefore this species will not be discussed further in this paper.

Analysis of variance showed no significant differences in ears/m^2 of the crop associated with fertilizer, cultivation or weed treatments. However analysis of the grain weight indicated significant effects associated with fertilizer (yields were lower under organic fertilizer), cultivation, and the interaction of these two (yields under organic fertilizer were increased when minimum tillage and herbicides were used; effects of tillage were smaller under chemical fertilizer).

1990 - 91 Data

The 1990/91 weed assessment data showed that it was ploughing rather than application of a herbicide that was most effective in controlling these weeds. For *B. sterilis* (Fig. 2), the most obvious difference was that while on the ploughed areas the average density was only 1 - 2 plants/m^2, (compared with an average background density of 0.5 plants/m2), on the minimum cultivation areas the density was more than three times the previous year's final level, with little effect of herbicide.

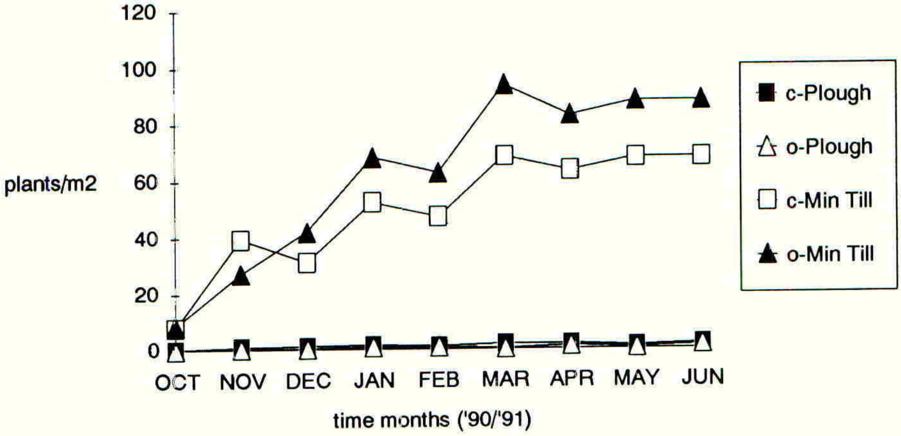
On the organic - minimum tillage plots the numbers of *G. aparine* rose rapidly to a maximum in the autumn of approximately 40 plants/m^2 in mixture with *B. sterilis* and *P. rhoeas* and 90 plants/m^2 when sown with wheat only (Fig. 3). The April application of herbicide caused a rapid decline in the population. Background densities averaged less than 0.1 plants/m^2.

DISCUSSION

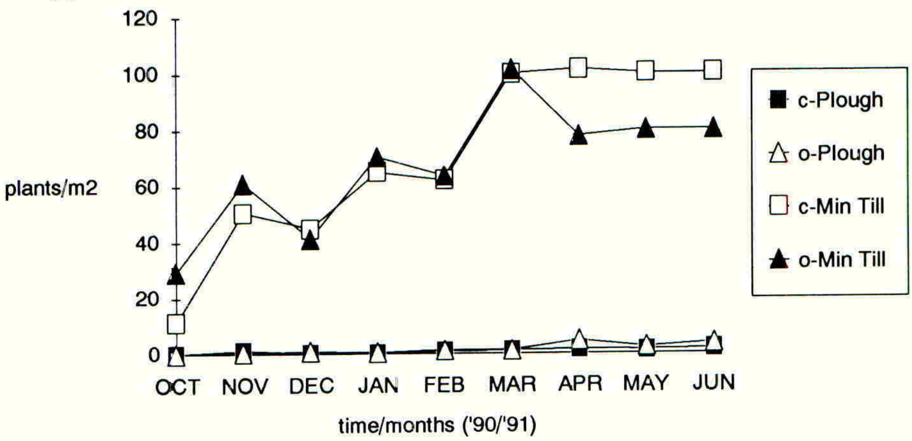
The 1990/91 data indicate that ploughing was a very effective method of weed control. In September 1990 before cultivation or drilling, a survey of the field showed approximately 400-800 seedlings/m^2 of *B. sterilis* seedlings in areas of the field which had been ploughed and sown with *B. sterilis* the previous year. The effect of ploughing in October was to destroy the seedlings and to bury most ungerminated seeds at a depth from which new seedlings could not emerge. Seed burial would also account for the control of *G. aparine* in these areas as the seed can only emerge from a maximum depth of 10 cm (Atwood, 1985). The low background count for *G. aparine* would indicate that the seed bank for this species was small and since *B. sterilis* has no permanent seed bank the net effect of

FIGURE 2: *Density of* Bromus sterilis *grown in (a) winter wheat in mixture with* Galium aparine *and* Papaver rhoeas *and (b) with wheat only, over a nine month period in 1990/1991 on plots classified according to fertilizer treatment (c: inorganic, o: organic and cultivation/weed control methods (Plough; ploughing, hoeing/hand roguing, Min Til; Minimum tillage & herbicide).*

(a) With other weeds



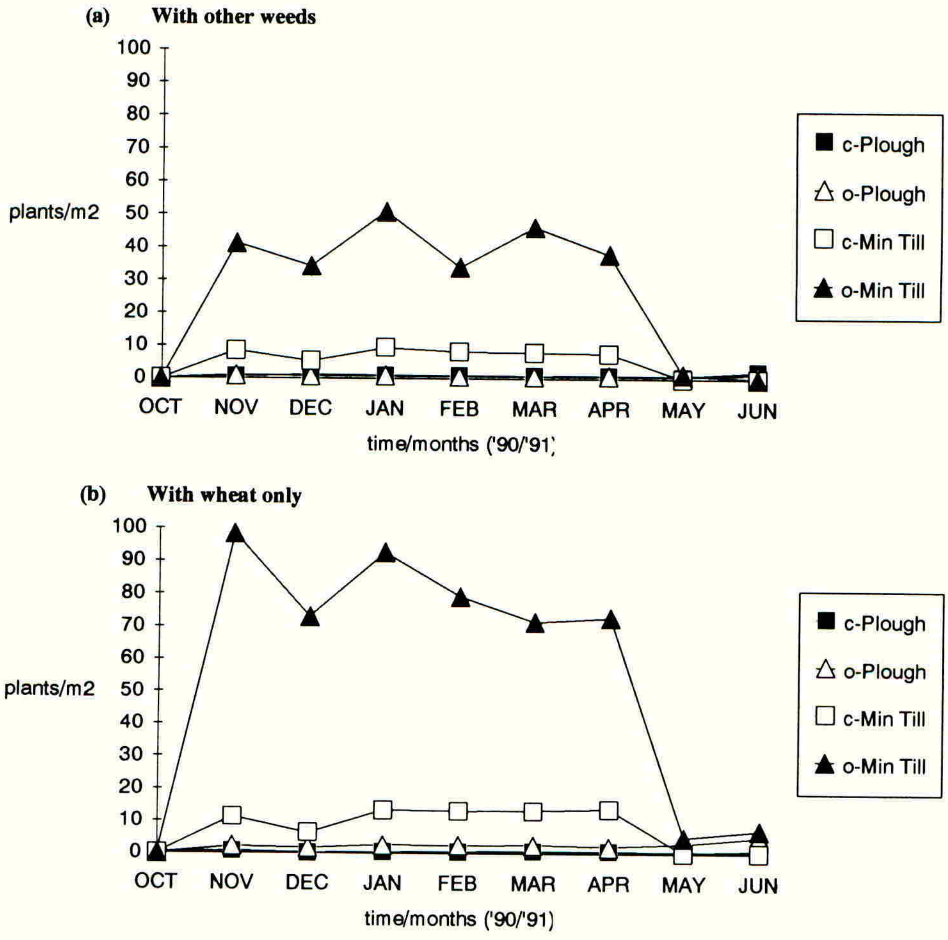
(b) With wheat only



ploughing was to reduce the numbers of these species. By contrast, minimum tillage would have encouraged the germination of both *B. sterilis* and *G. aparine* by burying seeds at their optimum depths for emergence (1 - 5 cm) (Froud-Williams *et al.*, 1984).

The behaviour of *G. aparine* on organically and inorganically fertilized plots is more difficult to account for. Rooney *et al.* (1990) and Baylis and Watkinson (this vol.) have investigated the effect of reduced nitrogen supply on competition between *G. aparine* and winter wheat. They found that at high rates of nitrogen *G. aparine* is highly competitive resulting in reduced grain yields. However at lower nitrogen rates wheat is more successful

FIGURE 3 : *Density of* Galium aparine *grown (a) in winter wheat in mixture with* Bromus sterilis *and* Papaver rhoeas *(b) with wheat only, over a nine month period in 1990/1991 on plots classified according to fertilizer treatment (c : inorganic, o : organic), and cultivation/weed control method (Plough : ploughing, hoeing and hand roguing, Min Til : Minimum tillage and herbicide).*



in acquiring nitrogen. The wheat harvested from the organic plots in 1989/1990 was smaller and tinged with yellow; this with the significant difference in grain weight suggests nitrogen was in short supply. So we should have expected fewer *G. aparine* seeds produced on these plots, yet the results for the following year show that there were on average more than twice the numbers compared with inorganically fertilized plots. *G. aparine* has a finer, shallower root system than wheat (Rooney, 1990), which, given adequate water supply, may have given it a greater advantage in capturing nutrients from the soil surface in the field than suggested by Rooney's (1990) and Baylis and Watkinson's (this vol.) data.

The numbers of *B. sterilis* on minimum cultivation plots were unaffected by the presence of *G. aparine* on organic or chemically fertilizer plots (Fig. 2). However the density of *G. aparine* on organic plots in mixtures was still only about half that achieved by *G. aparine* grown only in competition with wheat (Fig. 3). It appears that *B. sterilis* had a competitive advantage over *G. aparine* and has depressed its numbers when the two were found together (see also Lintell-Smith *et al.*, this vol.). Since this trend was apparent from the beginning of the second year it must have been established in the first year in terms of seed production by the two species in response to management and interspecific competition. The appearance of inter-weed effects at the relatively low densities observed in 1989/90 is surprising, and calls into question the wisdom of conventional weed population models which deal with one weed species at a time (Firbank, 1991). We expect even greater competitive effects in 1991/2 on these plots, as the densities of both weeds are currently (1990/91) higher than in 1989/90.

We expect the behaviour of the weed populations to remain highly dependent on the management treatments in other ways. The response to burial and the small seed banks for all three species in the first two years of the experiment allowed ploughing to be a successful method of control, and we expect this to continue. There seems no reason why the differential response of *G. aparine* to the fertilizer treatments should not also persist. However, the ineffectiveness of the herbicide in controlling *B. sterilis* in 1991 (Fig. 2) was largely due to its late application; we expect better control in 1992.

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THE EFFECT OF STRAW DISPOSAL METHOD ON WEED POPULATIONS AND THE EFFICACY OF HERBICIDES ON ALOPECURUS MYOSUROIDES, BROMUS STERILIS AND BROMUS COMMUTATUS IN WINTER WHEAT CROPS.

J.S. RULE

ADAS, Boxworth Experimental Husbandry Farm, Boxworth, Cambridge CB3 8NN.

ABSTRACT

A long term trial investigating the effect of straw disposal methods on the efficacy of herbicides is described. The trial was initiated in autumn 1983 at Boxworth on a chalky boulder clay with straw burning, straw baled and removed, or straw chopped and incorporated into the soil on the same plots each year. Tined cultivation at 10-12cm was used to incorporate the ash or straw residues. The method of straw disposal had a marked effect on the populations of _Alopecurus myosuroides_ (black-grass), _Bromus sterilis_ (barren brome) and _Bromus commutatus_ (meadow brome). Straw burning contained panicle numbers of Bromus spp. by 90-99% in unsprayed plots; in contrast control of _A. myosuroides_ by straw burning was more variable. Herbicides reduced levels of _A. myosuroides_ but control of _B. sterilis_ and especially _B. commutatus_ was much more variable. Control of populations of _A. myosuroides_ after straw burning was often less effective than where straw residues were incorporated. Yields were similar from all straw disposal methods where grass weed control was reasonably successful. Thus there were no serious or significant reductions of herbicide efficacy due to the presence of unburned straw residues.

INTRODUCTION

The proposed ban on straw burning to take place after autumn 1992 is likely to have important implications for weed populations and for the control of some difficult grass weeds in particular. Work at the Weed Research Organisation (Moss, 1985a) showed that straw burning can reduce grass weed populations, but with indications of important differences between species. The levels of control achieved by straw burning were 32 per cent for _Avena fatua_ (wild oats), 40-80 per cent _Alopecurus myosuroides_ and 40-97 per cent for _Bromus sterilis_. Consequently when straw burning is no longer permitted there is a high risk of increased grass weed incidence in fields where straw burning has been a regular practice. There will thus be a requirement for a higher percentage kill by herbicides to maintain a static population of _A. myosuroides_ and Bromus spp. to compensate for the absence of control by burning (Cussans _et al_., 1982). Effective grass weed control is essential especially in the autumn cropping sequences which predominate on heavy clay soils, where reduced tillage methods may be preferred to ploughing (Rule, 1977 & 1980). In the early years of the present series of straw disposal experiments there was widespread concern that straw residues in or near the surface would adversely affect the efficacy of soil-acting herbicides (Davies, 1985). This might be due to either an interception effect disrupting the even application of herbicide to the soil surface or to adsorption of the active ingredient by the surface straw or by the slowly increasing level of soil organic matter. This paper presents the results from a long term experiment in which various straw disposal treatments were applied annually since 1983, and with a range of herbicide treatments applied since 1985/86.

MATERIALS AND METHODS

Straw disposal methods were first implemented in this trial in 1983/84 to study their longer term consequences on the efficacy of a selection of grass weed herbicides.

Straw disposal treatments:- straw burnt in swaths
straw burnt after spreading
straw baled and removed
straw chopped and incorporated.

Straw was chopped at harvest by a combine mounted chopper for incorporation or burning, or discharged in a swath for burning or baling. Ash after burning was incorporated immediately by the same cultivation that was earlier used to incorporate straw residues or stubble. The primary cultivation was by two passes of a spring tined cultivator to a depth of 10cm, or with a heavy duty implement with helical tines used to 12-15cms depth in recent years. This was followed by rolling, and prior to drilling, by a pass of a power harrow to produce a final seedbed. For the 1987/88 season, in an attempt to disperse a very high population of grass weeds by deeper and more inversionary cultivation, a Rotadigger was used. This implement is a power take off operated rotary cultivator with tines to counter balance the forward thrust of the rotors. One pass normally achieves rather more soil inversion to 15cm than tined cultivation, but less than ploughing. Winter wheat seed rates of 175 kg/ha were used each year, and the site rolled after drilling when possible. Drilling took place in early October, except in 1987/88 when exceptionally wet conditions delayed sowing until 7 November. All husbandry inputs, fungicides, nitrogen and growth regulators were applied at normal rates and in accordance with good farm practice.

Herbicides. The herbicides applied to the straw disposal treatments in 1983/84 were pre-emergence tri-allate 2.25 kg ai/ha followed by either isoproturon at 2.5 kg ai/ha or methabenzthiazuron + chlorsulfuron at 2.45 + 0.02 kg ai/ha respectively. Each herbicide treatment was applied to one half of each main straw disposal plot by a tractor mounted sprayer. The main objective at this stage was containment of grass weeds within the various straw disposal treatment areas. With very low levels of grass weeds in 1983/84 (see Table 1) no herbicides were applied in 1984/85 to provide an increase in grass weeds to facilitate herbicide testing. In autumn 1985, ten herbicide treatments including an untreated control were tested. Plots 4m wide x 24m were sprayed with a hand-held sprayer crossing the tramlines used for tractor spraying previously. Having used the whole plot for herbicide treatments in 1985/86, no treatments were applied in 1986/87: winter wheat was grown and again, no herbicides were applied. Herbicide testing was resumed in 1987/88 using the four most interesting treatments tried in 1985/86 and with one untreated control. The reduced number of treatments was applied to half of each main straw disposal plot, leaving half for herbicide testing the following year.

Thus herbicide treatments were applied annually to alternate halves of main plots. Areas tested with herbicides in 1990/91 were given a spray of fenoxaprop ethyl in the preceding non-treatment crop to reduce the excessive predominance of A. myosuroides (see Table 1).

Herbicide treatment details (kg AI/ha) 1985/86 - 1990/91.

	Pre-emergence	post-emergence (autumn)	post-emergence (spring)
1.	Nil - control	-	-
2.	Tri-allate (2.25)	metoxuron (4.37)	-
3.	Cyanazine (2.25)	cyanazine (0.875)	-
	-	+ isoproturon (1.25)	-
4.		SMY1500 (1.75) (UK298)	-
5.	-	-	SMY1500 (1.75)

In 1985/86 there were five additional treatments which were less effective than the above and so results are not presented.

SMY1500 a new development herbicide from Bayer AG. formulated as a 60 per cent water disposable granule, (Hack et al., 1985) was applied pre-em 1985/6, post-em subsequently.

Application dates:-

	pre-emergence	post-em.(autumn)	post-em. (spring)
1985/86	14 November	25 November	12 March
1987/88	7 December	11 January	22 February
1988/89	31 October	7 December	8 February
1989/90	2 October	15 November	16 February
1990/91	9 November	21 November	17 December

Herbicides were applied using a 4m, Oxford Precision Sprayer, fitted with Lurmark 110° flat fan nozzles supplying 200 l/ha at 2 bars pressure.

Assessments: Grass weed counts were done using ten 0.365 x 0.365m quadrats/subplot to count panicles in May/June.

With little history at Boxworth of herbicide adsorption associated with high Kd levels, this measurement was not made until 1989/90 and 1990/91. Five trowelled samples to about 2.5cm were sampled from straw disposal treatments in autumn 1989 and 1990.

Experimental design: A fully randomised split plot design with straw disposal method on main plots and herbicide treatments on sub-plots with three replications at a single site.

RESULTS

TABLE 1. Seasonal, and interspecies competition effect on grass weeds within unsprayed plots, and cumulative percentage control by burning. (Mean of two burnt treatments)

	Bromus sterilis				Bromus commutatus				Alopecurus myosuroides			
	Panicles/m²			Burnt	Panicles/m²			Burnt	Panicles/m²			Burnt
	incorp.	baled	burnt	% control	incorp.	baled	burnt	% control	incorp.	baled	burnt	% control
1983/84	0.5	0.2	0.02	96	1.04	0.8	0.07	94	-	-		-
1984/85	3.3	0.9	<0.1	>97	6.6	4.3	0.25	96	4.6	3.1	5.9	-28
1985/86	125.7	116.0	0.4	>99	284.0	88.9	1.86	>99	107.6	120.8	30.9	71
1987/88	515.3	799.1	11.3	98	622.5	518.5	36.0	94	429	429.7	1240.6	-289
1988/89	101.1	75.1	0.25	>99	1.0	0.5	0.10	90	1407.4	1648.8	858.3	39
1989/90	110.7	114.3	1.5	99	29.3	48.3	0.33	99	773	963.3	789.6	-2
1990/91	227.3	209.3	4.7	98	1.2	0.5	0.0	100	240	196	181	25

Straw burning annually effectively maintained Bromus spp. at very low levels, (Table 1). Poor burning conditions in 1987/88 did not reduce head numbers of A. myosuroides, and numbers on burnt and non-burnt treatments increased substantially. Corresponding to this increase in A.myosuroides, amounts of B. commutatus declined dramatically, with some reduction in amounts of B. sterilis. As levels of these two Bromus spp. were low on burnt treatments, percentage control by herbicide figures were erratic, often negative, and are not presented here.

Over the five-year period there were few interactions of straw disposal method with herbicide and little indication of less effective control of A.myosuroides by herbicides in the presence of straw residues. Indeed, with the exception of 1987/88, the percentage control of A.myosuroides was usually better where straw was incorporated than where it was burnt. The poorer control of A. myosuroides in burnt treatments by herbicide sequences may have been affected by the presence of ash but this was not apparent with autumn applied SMY1500. Soil Kd values recorded and shown in Table 2 do not indicate potential problems for herbicide efficacy, (Cussans, et al, 1982).

TABLE 2. Soil Kd values (chlorotoluron)

	Burnt	Baled	Incorporated
Autumn 1989 (9 Oct.)	3.9	3.3	3.2
Autumn 1990 (12 Dec.)	3.2	2.7	2.5

The most interesting and marked interactions occurred in 1988/89 when A.myosuroides was the dominant grass weed, especially on baled and incorporated plots. In this year, percentage control of A.myosuroides by the three autumn herbicide treatments where straw and stubble was incorporated was better than that achieved on burnt treatments: control on burnt treatments averaged 83-88 percent compared with 97 and 98 per cent respectively for baled and incorporated plots. There was also additional control of B. sterilis notably on incorporated plots (Table 4). However, in contrast, low levels of B. commutatus tended to increase where herbicides reduced levels of A.myosuroides and B. sterilis due to the elimination of competition from those weeds, and the greater difficulty of controlling B. commutatus.

Substantial yield losses occurred as a result of the high grass weed populations on untreated plots particularly on baled and incorporated plots, when yield losses invariably exceeded more than 2t/ha (range 2.04 -> 4.25t/ha). Following the use of herbicides yield differences between the four straw disposal methods were largely eliminated; yield data is not presented in this paper.

TABLE 3. Alopecurus myosuroides heads/m² in untreated plots and control by herbicides.

	Straw disposal:	Burnt in swath	Burnt spread	Baled removed	Incorporated chopped
Untreated	1985/86	21	41	121	108
heads/m²	1987/88	1513	969	430	429
	1988/89	730	986	1649	1407
	1989/90	644	935	963	773
	1990/91	146	216	196	240
Percent control:-					
Tri-allate	1985/86	100	100	75	99
+ metoxuron	1987/88	57	45	25	35
post-em	1988/89	92	83	98	99
	1989/90	71	63	77	79
	1990/91	74	70	94	88
Cyanazine pre-em	1985/86	100	100	100	100
+ cyanazine +	1987/88	86	52	83	46
IPU post-em	1988/89	78	71	95	94
	1989/90	76	78	91	80
	1990/91	94	87	98	95
SMY1500 autumn	1985/86	100	100	100	98
post-em	1987/88	94	86	63	79
	1988/89	95	94	97	100
	1989/90	63	81	67	69
	1990/91	90	99	99	98
SMY1500 spring	1985/86	99	100	100	99
post-em	1987/88	71	84	62	54
	1988/89	83	86	93	83
	1989/90	42	80	78	50
	1990/91	99	99	100	93

TABLE 4. Bromus spp. panicles/m² untreated, in untreated plots and percent control by herbicides within unburnt treatments.

		Bromus sterilis		Bromus commutatus	
		Straw: Baled	incorporated	Baled	incorporated
Panicles/m² untreated	1985/86	116	126	90	284
	1987/88	799	515	519	622
	1988/89	75	101	0.5	1
	1989/90	114	111	48	29
	1990/91	209	227	0.5	1
Percent control:-					
Tri-allate pre-em.+ metoxuron post-em.	1985/86	28	87	30	26
	1987/88	38	43	49	12
	1988/89	86	90	*	*
	1989/90	24	70	53	*
	1990/91	81	43	*	*
Cyanazine pre-em. Cyanazine + isoproturon post -em.	1985/86	98	73	96	94
	1987/88	89	89	70	80
	1988/89	68	83	*	*
	1989/90	37	57	67	*
	1990/91	89	68	*	*
SMY1500 post-em. autumn	1985/86	95	72	69	68
	1987/88	71	59	80	72
	1988/89	69	96	*	*
	1989/90	20	64	60	*
	1990/91	96	81	100	*
SMY1500 post-em. spring	1986	100	98	100	99
	1988	83	67	91	65
	1989	75	84	*	*
	1990	65	24	79	49
	1991	97	82	100	*

* Negative values are a reflection of the very low numbers on the untreated plots due to interspecific competition from high populations of A. myosuroides and B. sterilis which when removed by herbicide treatment led to the negative control of B. commutatus.

DISCUSSION

Grass weed incidence was low in 1983/84, and to increase numbers for herbicide testing no herbicides were applied for the 1984/85 season. This action facilitated more comprehensive herbicide testing in 1985/86, with the increased numbers of A.myosuroides, B. sterilis and B. commutatus. Some reduction of the predominant A.myosuroides population was necessary in spring 1990 and fenoxaprop ethyl was applied to the area of main plots to be given herbicide treatments in 1990/91. A. myosuroides levels were reduced, with some increase in B. sterilis in consequence (Table 1).

Seasonal differences in grass weed control by straw burning were most apparent with A.myosuroides where control by straw burning was variable, due in part to differing degrees of interspecific competition. In contrast, control by straw burning of B. sterilis and B. commutatus was consistently good and unaffected by seasonal variations .

There were seasonal differences in the effectiveness of grass weed control. Date of drilling, notably late in 1987/88 on 7 November, did not have a marked effect on grass weed incidence; indeed the late sowing in wet conditions resulted in a poorly established crop offering poor competition to the high number of grass weeds that occurred, with greater than usual tillering in the gappy, weakly established crop: an earlier winter plant count showed no significant differences between straw disposal treatments.

In contrast, winter wheat establishment in 1989/90 following drilling on 9 October, was good but the very mild open winter led to variable and extended periods of growth, and grass weed control was generally poor.

B. commutatus was the dominant grass weed during the 1985/86 - 1987/88 period, with a marked increase of A.myosuroides during 1987/88 - 1989/90. This increase of A.myosuroides led to a suppression of levels of both Bromus spp., especially B. commutatus. Such interspecific competition can affect weed density in a mixed population and can distort percentage control figures due to the differing competition within untreated and treated plots. This was clearly demonstrated in 1988/89 and 1989/90 when good percentage control of A.myosuroides and B. sterilis led to large negative control values for B. commutatus, notably with the tri-allate followed by metoxuron treatment. These negative values for B. commutatus declined with herbicides showing some activity against B. commutatus, notably SMY1500, particularly when applied in spring. Herbicides, (with the exception of SMY1500) have been relatively ineffective against bromes, particularly B. commutatus, but sequences based on pre-emergence tri-allate or cyanazine have often been effective, but variable in other herbicide trials (Rule, 1989).

Thus, with the prospect of a potential increase in levels of Bromus spp. when straw burning is banned, and with the best currently available herbicides not especially effective against bromes, there are clearly some problems for the future. Nevertheless, with modest levels of control, yield differences between straw disposal methods have been negligible. Furthermore, the efficacy of the herbicides tested in this trial has not been seriously impaired by accumulating straw residues. Indeed, ash residues appear to have reduced the efficacy of tri-allate + metoxuron or cyanazine + isoproturon sequences more than straw residues: however SMY1500 appeared to be less affected by possible adsorption by straw ash. Other studies demonstrated adsorption differences from different soil cultivations to be greater than organic matter differences (Moss, 1985b). Thus in the short and medium term small increases in soil organic matter resulting from longer term straw incorporation (Rule, et al 1991) are unlikely to significantly affect soil acting herbicide efficacy.

It is concluded that the straw burning ban is likely to exacerbate grass weed infestations, particularly Bromus spp. which have proved difficult to control with herbicides alone if rotation, sowing date or cultivation method are not adjusted. However, straw residues incorporated regularly over a period have not lead to any serious deterioration of grass weed herbicide efficacy; soil adsorption (Kd) values have not increased as a result of straw incorporation as much as they have from straw burning. Where grass weeds have been contained with reasonable success, yields have not on average been affected by the method of straw disposal.

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ECOFALLOW AND WINTER WHEAT WEED CONTROL WITH UCC C4243

A.R. BELL

Uniroyal Chemical Co., Inc., Bethany, Connecticut 06525 USA

A.W. WALZ

Uniroyal Chemical Co., Inc., West Des Moines, Iowa 50265 USA

D.N. JOY

Uniroyal Chemical Co., Inc., Fresno, California 93710 USA

ABSTRACT

UCC C4243, 1-methylethyl 2-Chloro-5-[3,6-dihydro-3-methyl-4-trifluoromethyl-2,6-dioxo-1(2H)-pyrimidinyl]-benzoate, is active pre-emergence and post-emergence at application rates of 0.03 to 0.14 kg AI/ha for control of many annual broadleaf and small seeded grass weeds. The post-emergence activity resembles of that paraquat, but unlike paraquat, UCC C4243 has substantial residual activity as a pre-emergence herbicide. This combination of attributes is ideal for use in ecofallow where there is a need to control existing weeds without cultivation and prevent additional weeds emerging and so depleting the soil moisture prior to sowing a dryland wheat crop. Control of grasses including volunteer cereals is improved by the addition of glyphosate at 0.4 kg AI/ha to the spray mixture. The residual life may be extended, if desired, by the addition of atrazine at 0.56 kg AI/ha. UCC C4243 is especially effective for control of *Amaranthus retroflexus*, *Kochia scoparia* and other species which have become resistant to atrazine. Winter wheat will tolerate a pre-emergence application of UCC C4243 at 0.14 kg AI/ha, but rates of 0.03 to 0.07 kg AI/ha are recommended for control of many common annual weeds in winter wheat.

INTRODUCTION

Ecofallow refers to a system of farming used in low rainfall wheat growing areas whereby the wheat stubble is retained after harvest (June to mid August) to reduce wind erosion and catch snow for moisture. Tillage for weed control is undesirable because moisture stored beneath the soil surface will be exposed to the air and allowed to evaporate. In addition, tillage breaks down the stubble and reduces its effectiveness for erosion control and trapping moisture. Weeds must be controlled, however, to avoid moisture loss through transpiration.

Weed control is accomplished through carefully planned herbicide applications. The herbicides used should provide weed control throughout the fallow period but dissipate sufficiently to allow proper development of the new crop when it is sown. Many factors influence the choice of herbicide treatment including the weed species to be controlled, the crop rotation and the length of the fallow period. Some of the many possible

ecofallow situations used in the U.S. great plains include:
1. Herbicide treatment of winter wheat stubble immediately after harvest and sowing winter wheat again 2-3 months later.
2. Herbicide treatment of winter wheat stubble in late summer with the next crop of winter wheat to be sown 12-14 months later.
3. Spring herbicide treatment of winter wheat stubble either pre-emergence or post-emergence of the weeds, with the next crop of winter wheat to be sown 4-5 months later.
The foregoing ecofallow situations may be modified by sowing sorghum or other crops at appropriate times in rotation with winter wheat.

Triazines such as atrazine, a frequent component of ecofallow herbicide treatments, must be applied at sufficiently low rates to avoid carry over into the next crop. However, frequent use of low triazine rates has apparently led to a build up of triazine resistance in species such as Kochia scoparia. A broad spectrum herbicide such as UCC C4243 with selectivity in winter wheat and a moderate level of residual activity can play a useful role as an ecofallow and winter wheat herbicide. UCC C4243, 1-methylethyl 2-Chloro-5-[3,6-dihydro-3-methyl-4-trifluoromethyl-2,6-dioxo-1 (2H) pyrimidinyl] benzoate, is a substituted uracil herbicide currently under development by Uniroyal Chemical Co.

MATERIALS AND METHODS

Forty five trials involving UCC C4243 as an ecofallow herbicide were conducted on non irrigated wheat (or other cereal) land in the U.S. great plains and Pacific northwest during the years 1987 to 1991. Plots were 19.2 to 37.2 m^2 with 3 to 4 replications per treatment. Applications of UCC C4243 were made with CO2 powered small plot sprayers in 75 to 250 l/ha water. A COC or crop oil concentrate such as AGRIDEX (83% light petroleum oil and 17% non ionic surfactant) at 2.3 l/ha was added to most post-emergence applications. UCC C4243 was formulated as a 100 g per litre EC and applied at rates of 0.07 to 0.28 kg AI/ha.

Most trials were conducted where extremely cold winter temperatures killed the weeds growing after a June to mid August harvest, and involved primarily spring applications pre-emergence or post-emergence of the weeds (see 3 above). In addition, some treatments were applied in the autumn post-emergence of the weeds growing after harvest (See 2 above). Combinations of UCC C4243 with other herbicides such as atrazine at 0.56 kg AI/ha, cyanazine at 2.2 kg AI/ha, clomazone at 0.56 kg AI/ha or glyphosate at 0.42 kg AI/ha were included in most of the tests along with commonly used standard treatments such as atrazine or cyanazine alone at 0.84 or 2.8 kg AI/ha, respectively.

Tests were scored by visual comparison of each species in treated plots and untreated checks and recorded as a percent control. The number and identity of weed species involved varied considerably among locations and years. Therefore, data from representative tests were selected for discussion.

Ninety wheat trials were conducted between 1987 and 1991 using equipment, plot size and test design similar to the above description. Treatments were applied pre-emergence after sowing wheat in September or October since post-emergence treatment in the spring caused phytotoxicity to the crop.

RESULTS

UCC C4243 applied pre-emergence in the spring at 0.14 kg AI/ha provided good control of various annual broadleaf weeds such as Amaranthus retroflexus, K. scoparia and others as may be seen in Tables 1 and 2. Grass control was less reliable but UCC C4243 applied pre-emergence did effectively contribute to control of several small seeded grass species.

Post-emergence spring applications of UCC C4243 at 0.07 kg AI/ha were effective for control of A. retroflexus and K. scoparia but were less effective for control of other broadleaves such as Anthemus cotula or grasses such as Eriochloa gracilis as may be seen in Tables 3 and 4. However, UCC C4243 at 0.07 to 0.21 kg AI/ha alone or mixed with glyphosate at 0.35 to 0.42 kg AI/ha gave weed control generally equal to or better than the standard mixture of glyphosate plus 2,4-D.

Post-emergence autumn applications of UCC C4243 alone did not provide good weed control on fallow land into the following spring. However, mixtures with atrazine at 0.56 kg AI/ha were effective for this use (Table 5).

Pre-emergence autumn applications of UCC C4243 in winter wheat provided good control of several broadleaf species as indicated in Table 6. Weed control continued into the spring because of competition from the actively growing wheat.

The slight wheat injury noted in UCC C4243 treated plots did not reduce wheat yield compared to the diuron treated plots. All treatments resulted in yield increases above that of the untreated check.

TABLE 1. Percent control of annual weeds following pre-em spring application - Archer, Wyoming (1987).

Treatment	Rate kg AI/ha	Percent weed Percent control 85 DAT		
		ST	DP	BT
UCC C4243	0.07	100	83	73
UCC C4243	0.28	100	93	87
cyanazine+ metribuzin	1.7+ 0.7	97	100	99

Key: Weed Species:
ST Solanum triflorum, DP Descurainia pinnata,
BT Bromus tectorum.

TABLE 2. Percent control of annual weeds following pre-em spring application - Hays, Kansas (1988-1989).

Treatment	Year	Rate kg AI/ha	Percent control of weeds 91 DAT AR	AA	KS	SV	ECG	PC
UCC C4243	88-89	0.07	98	80	100	49	32	48
UCC C4243	89	0.14	100	97	100	10	40	37
UCC C4243	88	0.28	100	72	100	95	68	100
UCC C4243+ cyanazine	88-89	0.07+ 2.24	96	82	100	76	62	60
cyanazine	89	2.8	78	53	100	80	0	10
cyanazine+ clomazone	88	2.24+ 0.84	88	70	100	89	97	90

Key: Weed Species:
AR *Amaranthus retroflexus*, AA *Amaranthus albus*, KS *Kochia scoparia*, SV *Setaria viridis*, ECG *Echinochloa crus-galli*, PC *Panicum capillare*.

TABLE 3. Percent control of annual weeds[1] following post-em spring application - Garfield, Washington (1989).

Treatment[2]	Rate kg AI/ha	Percent weed control 18 DAT LA	AC	LS
UCC C4243+ COC	0.14	35	22	75
UCC C4243+ COC	0.21	28	35	88
UCC C4243+ glyphosate+ R-11 0.5% v/v	0.21+ 0.42	59	49	90
glyphosate+ 2,4-D	0.42+ 0.42	20	12	45

1. Weeds were 2.5 to 5.0 cm in height at time of treatment.
2. Spray volume was 187 l/ha. COC=crop oil concentrate at 1.1 l/ha (AGRIDEX). R-11=non-ionic silicone based surfactant.

Key: Weed Species:
LA *Lamiun amplexicaule*, AC *Anthemis cotula*, LS *Lactuca serriola*.

TABLE 4. Percent control of annual weeds[1] following post-em spring application - Hays, Kansas (1990).

Treatment[2]	Rate kg AI/ha	Percent weed control 28 DAT AR	KS	SV	EG	PC
UCC C4243+ COC	0.07	100	100	45	10	10
UCC C4243+ glyphosate+ 1% AMS+0.25% X77	0.07+ 0.35	100	85	100	40	82
glyphosate+ 2,4-D+ 1% AMS	0.35+ 0.42	100	100	90	35	85

1. Weeds were 2.5 to 5.0 cm in height at time of treatment.
2. Spray volume was 94 l/ha. AMS=ammonium sulphate at 1% w/v used to enhance activity of glyphosate. COC=crop oil concentrate at 2.3 l/ha (AGRIDEX). X77= non-ionic surfactant.
   Key: Weed Species:
   AR Amaranthus retroflexus, SV Setaria viridis,
   KS Kochia scoparia, EG Eriochloa gracilis,
   PC Panicum capillare.

TABLE 5. Percent weed control[2] in spring following post-em autumn treatment Chugwater, Wyoming (1989).

Treatment[1]	Rate kg AI/ha	Percent weed control 260 DAT SI	ST	KS	DP	VW
UCC C4243	0.07	28	45	42	98	0
UCC C4243+ atrazine	0.07+ 0.56	78	93	93	100	90
cyanazine+ atrazine	2.24+ 0.56	58	97	99	100	90
atrazine	0.84	87	100	97	100	93

1. Treatments were applied 15 Sept. 1988 in a spray volume of 187 l/ha without adjuvants.
2. Weed control data was assessed 15 June 1989.
   Key: Weed Species:
   SI Salsola iberica, DP Descurainia pinnata,
   ST Solanum triflorum, KS Kochia scoparia,
   VW Volunteer wheat.

TABLE 6. Percent weed control[2] in winter wheat following pre-em autumn treatment - Corvallis, Oregon (1989).

Treatment[1]	Rate-kg AI/ha	Yield t/ha	Wheat %Injury	Percent weed control 148 DAT DC	AC	RA	VS	SV
UCC C4243	0.035	10.6	2	33	70	99	93	95
UCC C4243	0.07	10.6	7	60	69	92	97	99
UCC C4243	0.14	10.2	13	73	88	92	100	100
diuron	1.8	10.6	3	77	97	95	37	93
untreated	--	9.0	--	--	--	--	--	--
LSD (P ≤ .05)		1.45	--	--	--	--	--	--

1. Treatments were applied 18 October 1988 in a spray volume of 234 l/ha.
2. Percent wheat injury and weed control determined 15 March 1989.
   Key: Weed Species:
   DC *Daucus carota*, RA *Rumex acetosella*,
   AC *Anthemis cotula*, VS *Vicia sativa*,
   SV *Senecio vulgaris*.

CONCLUSION

UCC C4243 at 0.14 kg AI/ha applied pre-emergence in the spring as in situation 3 outlined in the introduction effectively controlled several broadleaf species in ecofallow. Weeds such as *Amaranthus* sp. or *K. scoparia* which are often resistant to triazines were effectively controlled by UCC C4243. However, the spectrum of weed control by UCC C4243 was increased by the addition of a triazine such as cyanazine. Post-emergence applications of UCC C4243 either in the spring (Situation 3) or autumn (Situation 2) were effective for control of broadleaf species and the addition of glyphosate increased spectrum of control to include some grass weeds. Pre-emergence application of UCC C4243 to winter wheat crops in the autumn gave effective broadleaf weed control without significant injury to wheat.

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EFFECTS OF CULTIVATION AND SEED SHEDDING ON THE POPULATION DYNAMICS OF *GALIUM APARINE* IN WINTER WHEAT CROPS

B.J. WILSON, K.J. WRIGHT

Department of Agricultural Sciences, University of Bristol,
AFRC, Institute of Arable Crops Research, Long Ashton Research Station,
Long Ashton, Bristol BS18 9AF, UK.

ABSTRACT

The population dynamics of *Galium aparine* (cleavers) were studied in five successive winter wheat crops. In the first year plant densities built up most rapidly with no tillage, followed by shallow tine cultivation, and least rapidly with ploughing. A large proportion of the weed seeds produced were removed in the harvested grain. Complete control with herbicides reduced seedling populations in the next cropping year by an average of 77%. Seedbanks declined by an average of 60% per year. A population model for *G. aparine*, based on these and previous data, shows that almost complete control (97-99%) would be needed to prevent populations from increasing. It is concluded that maintaining populations below threshold levels is not practicable for *G. aparine* because of the risk of a rapid increase if plants are allowed to survive and seed.

INTRODUCTION

In many countries, *Galium aparine* (cleavers) is an economically important weed which reduces yields, interferes with harvest and contaminates grain. It is recognised as the most competitive broad-leaved weed in cereals in the United Kingdom (Wilson and Wright, 1990). Control decisions need to take account of the potential increase of future populations as well as economic losses in the current crop (Cousens, Wilson and Cussans, 1985). Future populations will be influenced by the numbers of seeds, produced by surviving plants and which enter the seedbank, and by the cultivation regime, which has been shown to affect the dynamics of annual grass weed populations (Cussans *et al.*, 1979).

The experiment reported here concerns the effects of cultivation regime, and seed shedding in one year, on the dynamics of *G. aparine* populations in continuous crops of winter wheat.

METHODS AND MATERIALS

The experiment was carried out between September 1986 and July 1991 at Long Ashton Research Station, Bristol. The design was a randomised complete block with five replicates. Each replicate contained three cultivation treatments which were subsequently split to allow or prevent seed production and the return of *G. aparine* seeds to the soil.

Dates of the main operations are listed in Table 1. *G. aparine* seeds were sown at a low seeding rate (16g per plot of 12 x 4 m), just before sowing winter wheat. Resulting seedlings were counted in 20 random quadrats of $0.1m^2$ per plot. These plants were allowed to grow and seed freely during 1987 to build up the infestation. Plough, shallow tine and no tillage treatments began in autumn 1987. Plots were either mouldboard ploughed to 25 cm, cultivated to 10-15 cm twice with a coiled spring tine cultivator, or left uncultivated. Plots were drilled to wheat with a Moore direct drill. These cultivation treatments were repeated each autumn. Straw was baled and removed each year.

TABLE 1. Dates of main operations.

Operation	1986/87	1987/88	1988/89	1989/90	1990/91
Tillage treatments					
Plough		12 Aug'87	11 Sep'88	7 Sep'89	17 Sep'90
Tine		8 Sep "	8 Sep "	17 Aug "	22 Aug "
		18 Sep "	13 Sep "	7 Sep "	14 Sep "
Initial seeding	19 Sep'86				
Wheat drilled	19 Sep'86	21 Sep'87	16 Sep'88	25 Sep'89	26 Sep'90
G. aparine counted (random quadrats)					
No Tillage	7 Nov'86	5 Oct'87	1 Oct'88	16 Oct'89	6 Nov'90
Shallow tine	7 Nov "	5 Oct "	19 Oct "	25 Oct "	6 Nov "
Plough	7 Nov "	5 Oct "	26 Oct "	25 Oct "	6 Nov "
Soil sampled			15 Dec'88	13 Dec'89	8 Dec'90
Herbicides		15 Jan'88	20 Jan'89	12 Mar'90	29 Mar'91
		11 Apr "	10 Feb "		
Harvest		10 Aug "	10 Aug "	28 Jul "	28 Jul "
Seeds recovered from soil surface		17 Aug "			

Each year, seedlings of *G. aparine* were counted in 20 random quadrats of 0.05 m^2 per plot soon after emergence. At the same time the numbers of *G. aparine* seedlings were recorded in four fixed quadrats per plot and then removed. These counts were repeated at intervals to show the pattern of emergence and survival of *G. aparine* seedlings, and enabled the random counts to be adjusted for late emerging seedlings.

In January 1988 half of each plot (6 x 4m) was sprayed with ioxynil/bromoxynil/mecoprop followed by fluroxypyr in April to control *G. aparine* and prevent seeding. On the unsprayed half plots, seed production was estimated after harvest, both on the ground and in the combined grain. Seeds on the ground were recovered from four randomly placed quadrats of $0.09m^2$ with a portable vacuum cleaner. The material from the four quadrats was bulked and sub-sampled, seeds were counted and converted to numbers of seeds/m^2. Seeds removed in the grain were estimated by sampling the combined grain from each plot, separating the *G. aparine* seeds from the grain, and calculating the area from which the sample was derived and thence the numbers of *G. aparine* seeds originating per m^2.

From early 1989 *G. aparine* was controlled with fluroxypyr on the whole area of each plot to prevent seeding.

Numbers of seeds in the soil were determined by taking soil samples in December of each year after 1988. Thirty cores (2.54 cm diam.) were taken from the previously unsprayed half plots, 15 cm deep with no tillage and 20 cm deep with shallow tine and ploughing. Samples were bulked, air dried and then wet sieved to retain *G. aparine* seeds, which, after air drying, were removed and counted. Only whole seeds were regarded as being viable.

RESULTS

Uncontrolled population changes - 1987/88 and 1988/89

In November 1986 *G. aparine* populations averaged 8 plants/m². Seeding by these plants during the summer of 1987 resulted in a considerable population increase in the winter of 1987/88 (Table 2). The rate of increase was significantly affected by cultivation; seedling populations increased by factors of x341, x193 and x34 for no tillage, shallow tine and plough, respectively. The high populations with no tillage and shallow tine cultivation showed little further increase in the following year; for ploughing, seedling numbers increased further to 814 plants/m² in 1988/89.

TABLE 2. *G. aparine* populations (seedlings/m²) in successive years.

Cultivation	Seeding prevented from	1987/88	1988/89	1989/90	1990/91
No Tillage	1988 onwards	2726	538	294	52
	1989 "	2726	2519	736	86
Shallow tine	1988 "	1541	309	83	90
	1989 "	1541	1534	260	177
Plough	1988 "	271	251	184	156
	1989 "	271	814	244	121
SED		414.2	255.9	133.0	41.2

Population changes following herbicide use

Seedlings emerging during winter 1988/89 originated from seeds shed either in the summer of 1988 or in the summer of 1987. These two cohorts were distinguished by comparing numbers emerging where seeding was allowed with those emerging where seeding was prevented in the summer of 1988 (Table 2). Where seeding occurred, the average number of plants in 1988/89 was about five times greater following no tillage and shallow tine, and three times greater after ploughing. Where seeding had been prevented in 1988, plant numbers declined, between 1987/88 and 1988/89, by 80%, 80% and 7% for no tillage, shallow tine and ploughing, respectively. Populations declined further with control in subsequent years; the overall decline from 1987/88 to 1990/91 was 98%, 94% and 42% for the respective cultivations.

Patterns of seedling emergence

In each crop year most seedlings emerged before the end of December (Table 3). Ploughing in newly shed seeds in the first year delayed emergence, but ultimately, there was little difference between cultivations, with 86-90% of the total having emerged by the end of December. In 1988/89 the age of seeds from which seedlings emerged affected patterns of emergence. New seeds (shed in 1988) gave rise to 93%, 90% and 92%, and older seeds (shed in 1987) to 74%, 79% and 86% of the total emergence by the end of December, for no tillage, shallow tine and ploughing respectively, indicating a higher proportional spring emergence from the older cohort of seeds.

TABLE 3. Patterns of *G. aparine* emergence - % of total seedlings recorded at the first random count, and before the end of December, for no tillage (NT), shallow tine (ST) and ploughing (P) treatments.

	% emerging at first count						% emerging before end of Dec.					
	New seed			Old seed			New seed			Old seed		
Year	NT	ST	P	NT	ST	P	NT	ST	P	NT	ST	P
1987/88	36	38	16				90	90	86			
1988/89	84	79	78	55	65	68	93	90	92	74	79	86
1989/90				29	34	18				76	81	84
1990/91				55	75	71				83	98	96

Seed production - Summer 1988

Similar numbers of seeds per unit area were produced after the different cultivations (Table 4). Total seed production was estimated to be between 13 000 and 15 000 seeds/m^2. About 30% of these were recovered from the grain and 70% from the ground with no tillage and shallow tine treatments; a higher proportion (57%) was recovered from the grain with the ploughing treatment.

TABLE 4. Numbers of *G. aparine* seeds/m^2 recovered from the ground and from the harvested grain in 1988.

Cultivation	Total seeds	Seeds in grain	Seeds on ground
No Tillage	13194	3557	9637
Shallow tine	14148	4284	9864
Plough	14123	8400	5723
SED	2699.3	1187.1	3619.3

Seedbanks

The residual seedbanks, after most seedlings had emerged in 1988/89, were similar at 2000-3000 seeds/m^2 for each of the three cultivations (Table 5). Viable seeds in the soil declined, between 1988/89 and 1990/91, by an average of 58%, 61% and 59% per year for no tillage, shallow tine and ploughing respectively.

TABLE 5. Numbers of *G. aparine* seeds/m^2 recovered from the soil in successive years.

Cultivation	1988/89	1989/90	1990/91	Mean
				(SED 304.5)
No Tillage	2395	737	395	1176
Shallow tine	2790	1250	408	1483
Plough	2948	856	461	1421
Mean (SED 289.7)	2711	948	421	
SED	510.7 (501.8 when comparing same cultivation)			

MODELLING POPULATION CHANGES

Data from this and a similar experiment carried out in 1983-86 (Wilson and Froud-Williams, 1988) have been used to model changes in *G. aparine* populations in continuous winter wheat crops in response to cultivation. The model shows the effect of cultivation on the rate of population build-up in the absence of herbicides, the rate of population decline with complete control of seed production, and the level of control of seeding needed to stabilise, or contain, the population over a long period.

The model, which is deterministic, is based on the population cycle of *G. aparine* (Figure 1).

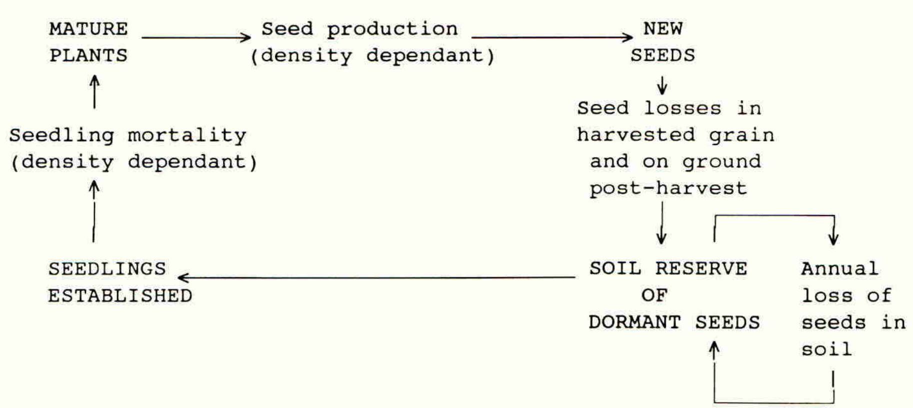

Figure 1. A schematic population cycle for *G. aparine*

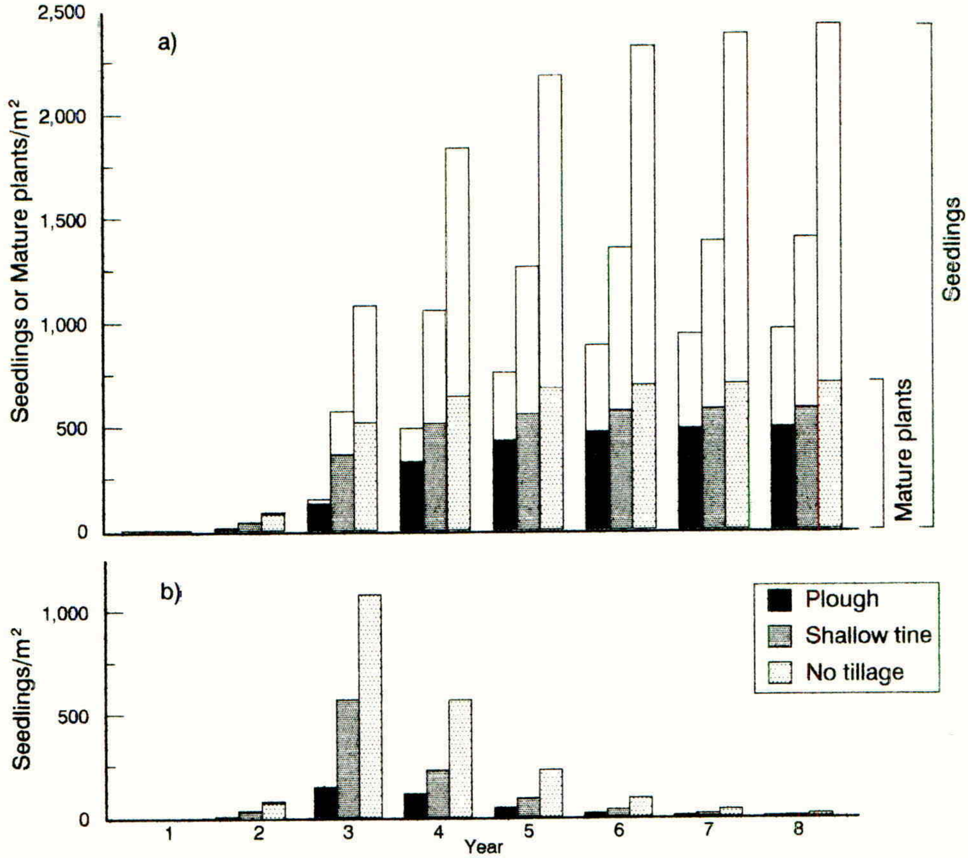

Fig 2. Model of a) uncontrolled build-up of seedlings and mature plants and b) population decline when seeding was prevented from year 3 onwards

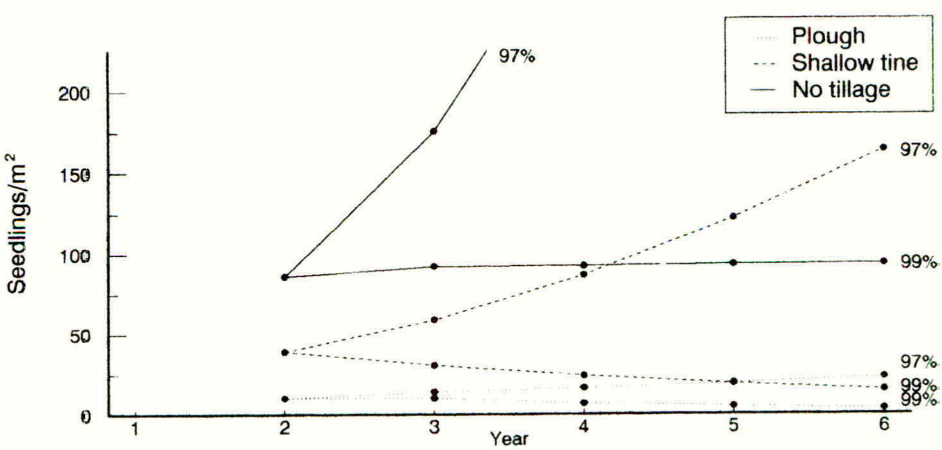

Fig 3. Model of population changes following 97% and 99% control of seeding from year 2 onwards

The seed is the basic unit in this population model. Factors which govern the changes in the number of seeds in the different pathways of the life cycle are derived from data from the two experiments, and, for the density dependant relationships, from additional data. Peters (1984) inversely related seed production per plant and plant density. In this model a hyperbolic relationship;

$$y/x = C / (1+Dx)$$

is used where y = number of seeds/m^2, x = number of weeds/m^2, C = number of seeds per plant in the absence of intra-specific competition, and D is the rate of decrease in seeds per plant as weed density (x) increases. Seedling mortality is based on a similar relationship where y = number of mature plants/m^2 surviving, x = number of seedlings/m^2, C = number of mature plants surviving in the absence of intra-specific competition, and D is the rate of decrease of mature plants as weed density (x) increases.

Other factors, which have been derived from these experimental data, and which are used in this model, are:-

Seed losses in the harvested grain and on the ground after harvest- 50%
Annual losses of viable seeds from the seedbank, similar for each cultivation - 60%
Seedling recruitment as a % of the total *G. aparine* seeds in the seedbank, influenced by the age of seed and by cultivation:-

	New seeds	Old seeds
No tillage	15	20
Tine cults	10	10
Plough	5	10

The model was run with a starting population of 10 new seeds/m^2 in the soil. Population changes are shown in Figs 2 and 3.

DISCUSSION

This work extends that of a previous study of *G. aparine* (Wilson and Froud-Williams, 1988) by providing information on population changes and seedbank persistence over a 5 year period. The model, based on these studies for *G. aparine* in continuous winter wheat, complements the more complex models of Aarts (1986) and Van der Weide and van Groenendael (1990) which take account of different cropping systems. It confirms the very rapid potential increase of populations in non-ploughing cultivation systems where seeds are retained in the surface soil from which they can readily germinate (Fig.2). In the experiment plant density rapidly increased as a result of seeding in the first year. The experiment was sited on a deep moisture retentive clay loam, that encouraged rapid growth of *G. aparine* which overtopped the wheat crop, and seeded profusely. Rates of increase in subsequent years were less as populations increased, confirming that the rate of weed population increase is very much influenced by intra-specific competition affecting the numbers of seeds produced per plant. The model shows that maximum populations of mature plants were attained after 3 years with no cultivation and after 4-5 years with ploughing. The rate of population build-up is much faster than that modelled for *Avena fatua* (Wilson, Cousens and Cussans, 1984), due largely to the much greater seed production per plant for *G. aparine*. Other factors influencing seed production, such as moisture and nitrogen availability, and time of emergence relative to the crop, could be included as data becomes available.

Complete control of *G. aparine* seeding was achieved with herbicides. Where necessary two herbicide applications were made. Control of seeding resulted in an exponential decline of seedbanks at an average rate of about 60% per year. This rate is similar to that found for *G. aparine* in other work at Long Ashton (Wilson and Lawson, in press), and corresponds to that found by Aarts (1986), who recorded an average annual decline of 62% of *G. aparine* seeds in the top 20cm of soil over a 4 year period. The model of population decline indicates that it would take at least 5 years of complete control to get populations down to low levels of little economic significance. The very high levels of control (97-99%, Figure 3), needed to prevent the population from increasing, are attributed to the increasing seed production from plants as density is reduced.

Our work suggests that allowing economic threshold populations of *G. aparine* to seed is too risky in terms of population build-up, and it does not therefore appear practicable to consider thresholds for this weed.

ACKNOWLEDGEMENT

We are grateful to the Experimental Husbandry Team at Long Ashton for carrying out the husbandry operations.

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THE DISPERSAL OF WEEDS : SEED MOVEMENT IN ARABLE AGRICULTURE

C. L. HOWARD[‡], A. M. MORTIMER[‡], P. GOULD[*], P. D. PUTWAIN[‡]

Department of Environmental and Evolutionary Biology[‡] and Department of Applied Mathematics and Theoretical Physics[*], University of Liverpool, P.O. Box 147, Liverpool L69 3BX. U.K.

R. COUSENS

School of Crop Sciences, University of Sydney, Sydney, NSW 2006, Australia.

G. W. CUSSANS

AFRC Institute of Arable Crops Research, Department of Crop Management, Rothamsted Experimental Station, Harpenden, Herts, AL5 2JQ. U.K.

ABSTRACT

Comparative studies of patterns of seed dispersal in two grasses *Bromus interruptus* and *B. sterilis*, a common weed of wheat, are described. In both species dispersal occurs by natural dissemination and as a consequence of seed movement by combine harvesting and soil cultivation. Seed spread around parent plants by natural dissemination did not exceed 1 m and were normally distributed. Conversely seeds were more extensively moved by combine harvesting being distributed log normally, with a maximum observed dispersal of 20 m. Soil cultivation by rotary harrow in the autumn had the potential to move seeds by 2 m. The implications of these seed distribution patterns for species spread are assessed by mathematical models.

INTRODUCTION

Many weed species characteristically exhibit patchiness in their distribution within arable fields. Whilst high densities are most apparent in field margins and headlands, monospecific infestations may also persist as localised groups of plants within the crop over several cropping seasons (Wilson and Brain, 1990 ; Marshall and Smith, 1987). The ecological factors that restrict the distribution of weed populations in this manner are largely unknown. Whilst limited natural dispersal has been postulated as one cause, agricultural practices, particularly combine harvesting, have been shown to promote the rapid spread of weed species (McCanny and Cavers, 1988). This paper reports a series of field studies on the dispersal and fates of seeds of two grasses, *Bromus sterilis* (Barren brome) and *B. interruptus* (Interrupted brome) over the period from seed dissemination from adult plants in summer through to establishment of seedlings in the crop in autumn. The term 'seed' is used to describe the natural unit of dispersal comprising caryopsis enclosed by lemma and palea.

MATERIALS AND METHODS

Experimental

Natural seed dissemination

Two experiments were conducted with both brome species in winter wheat cv. Avalon. In the first, the rate of seed dissemination from individual plants was measured by counting the number of seeds remaining within panicles over time. Individual plants of each species were established in 0.25 m^2 plots within wheat (sowing rate 188kg/ha) in October 1988 on a randomised block design to enable 20 destructive harvests of 10 replicates. Harvests at weekly intervals commenced on 30 June 1989 when seeds of *B. sterilis* were mature. In the second experiment, brome plants were sown along a 1.5m transect line to give plants separated by 0.1m. Three replicate transects were established, each within a 3 x 3 m plot containing wheat for each species in randomised blocks. Seeds and seedlings were then counted in October 1989 in quadrats (0.1 x 0.1 m) placed at right angles to the transect line prior to wheat harvest. Two loci along the central 1m of each transect were randomly chosen as initiation points for monitoring which was continued until two successive quadrats yielded no counts. Plots in both experiments received 90 kg N/ha/annum.

Dispersal by combine harvester

Painted brome seeds were introduced into a combine harvester during the combining of a winter barley crop. The combine, a Claas Compact with a cutting width of 2.15 m, was modified to allow a polythene sheet to be unrolled from the rear as the machine moved forward. This sheet collected all chaff and straw that was deposited. Seventy gram lots of threshed seeds of both bromes were spray painted and then dropped in mixture with barley grain on the auger as the combine moved past a fixed point. During each of two continuous runs, four seed lots of each species, differentiated by colour, were introduced. At the end of each run, straw was carefully shaken and lifted from the polythene which was then cut into quadrats. The chaff containing painted seeds in each quadrat was then bagged. Five 1 x 1.2 m quadrats were taken either side of the point of seed introduction and a further four 5 x 1.2 m quadrats taken in the forward direction of combine movement. During each combine run, volumetric grain samples were taken at 5 m intervals from the threshed material about to enter the grain storage tank. The average combine speed was 1.75 km/h. Painted seeds in subsampled chaff lots and grain samples were then counted, results weighted in relation to the numbers introduced and subsequently recovered, and pooled across introductions and runs (Howard, 1991).

Fate of seeds post-harvest

One hundred seeds of each species were sown in 0.5 x 0.5 m field plots onto either an uncultivated soil surface under a winter wheat stubble or into freshly cultivated soil to a depth of 5 cm. Sowings were made in four replicate blocks in early September 1989 and seedling counts made 14 days later during which there had been intermittent precipitation amounting to 6 mm.

Dispersal by cultivation

Seeds of both species were sown separately into rectangular plots (0.25 x 1 m) on bare ground in November 1988. A rotary power harrow (model 'Roterra') was then drawn over these plots by tractor (at 1.2 km/h) in a direction perpendicular to the longest side, on the day of sowing. Counts of the number of seedlings established one month later was made in 0.25 x 1 m quadrats along a line transect in the plane of the cultivator passage. Monitoring was continued until no further seedlings were found in either direction from the sampling location. Four replicate plots for each species were cultivated. Counts per quadrat were expressed as the fraction of the total number of seedlings recorded.

Analytical

Initial inspection of the distributions of seeds and seedlings, both by combine and power harrow, indicated that individuals were dispersed according to a lognormal distribution with some individuals being found behind the point of introduction. Each lognormal distribution was decomposed into a Gaussian distribution around the point of introduction and an exponential distribution describing the dispersion of seeds in the forward direction of vehicle movement. The physical processes of seed dispersion justify this approach. Dispersal by the combine on the one hand was observed to occur by bulk movement of seeds with straw and chaff to the rear of the machine and on the other through temporary lodging on machine parts (for instance auger and cutter-bar). Assuming a constant rate of release of lodged seeds these two processes may be modelled by the combination of the two distribution curves. Prior observations of the effects of cultivation implements indicated that seeds on friable soil surfaces moved by rakes and seed drills were distributed around the point of origin in a Gaussian manner whilst most forward seed movement was associated with bulk soil movement by the cultivator. Seeds dispersed naturally were found to fall around plants in the crop on a Gaussian distribution. Frequency data were fitted to Gaussian ($f(x) = 1/\sigma\sqrt{2\pi} \exp(-0.5((x-\mu)/\sigma)^2)$) and exponential ($f(x) = b \exp(-bx)$) distributions using the Maximum Likelihood Program (Ross, 1987).

RESULTS

Natural seed dissemination

B. interruptus achieved seed maturity approximately 14 days later than *B. sterilis* but thereafter rates of seed dissemination were similar. By mid August 1989, approximately 40% of seeds of *B. sterilis* were retained within panicles in contrast to 60% in *B. interruptus*. This difference had largely disappeared by October 1989, (Figure 1).

Figure 1. The temporal pattern of dissemination of seeds from panicles of *Bromus sterilis* (□) and *Bromus interruptus* (♦).

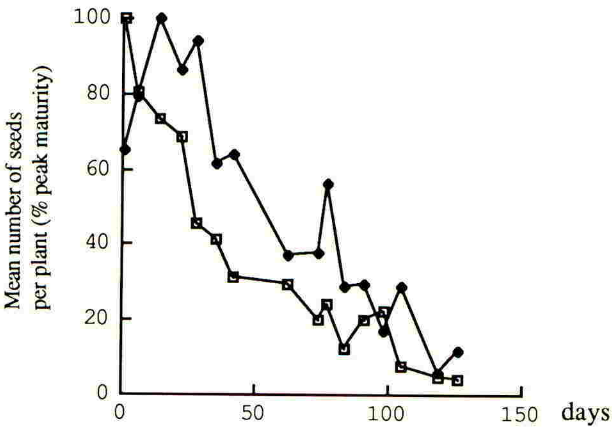
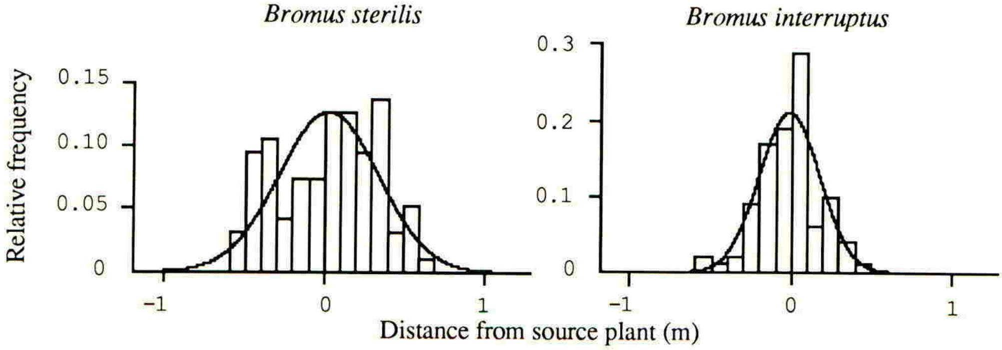


Figure 2. Seed dispersion by natural dissemination. Fitted lines are Gaussian distributions. Note ordinates are on different scales.

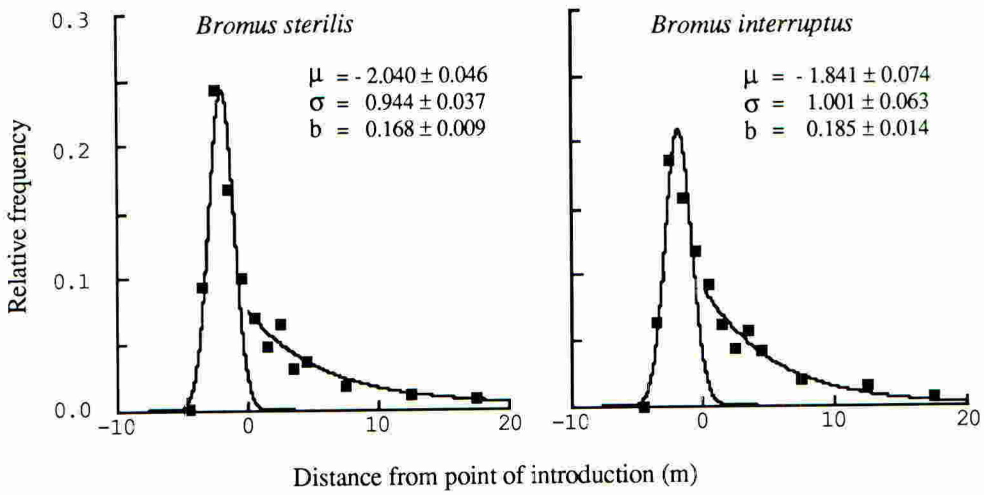


Most seeds of both species were dispersed close (< 0.50 m) to source plants, dispersal distances being at random (Figure 2). Dispersal in *B. sterilis* was over a significantly greater range than in *B. interruptus* but in neither case were seeds observed more than 1m away from the source, standard deviations (± S.E. of estimate) were 0.187 ± 0.013 and 0.312 ± 0.022 for *B. interruptus* and *B. sterilis* respectively.

Dispersal by combine harvester

The seeds of both species were deposited in a similar manner with a peak density occurring, on average, 1.9 m behind the point of introduction in association with straw and chaff (Figure 3). However more than 40% of seeds recovered were carried forward in the direction of machine passage. Species differed with regard to the absolute numbers of seeds dispersed to the ground. In *B. sterilis* twice as many seeds were recovered from within harvested grain than in *B. interruptus*, proportions being 34 and 15% of seed intake respectively. Whilst there was equi-proportional deposition of seeds of *B. interruptus* either side of the origin a significantly greater proportion of *B. sterilis* seed were deposited behind the source point than in front of it (Table 2). Description of the spread of seeds behind the source (x=0) by a Gaussian distribution gave statistically similar estimates of mean and standard deviation for both species. Similarly, estimates of the parameter (b) describing the exponential decline in seed density in front of the point of introduction did not differ significantly. No seeds of either species were observed beyond 20 m from the source of introduction in this experiment.

Figure 3. The dispersal of seeds by combine harvester. Fitted lines are predicted Gaussian (x<0) and exponential distributions (x>0) Parameter estimates ± S.E. .



Fate of seeds post-harvest

Soil surface characteristics determined the likelihood of seedling establishment post harvest and species differed in their response, (Table 1). Shallow burial of seeds below the surface of cultivated soil promoted establishment in both species with the highest being seen in *B. sterilis*. Conversely within crop stubbles, seedling densities were four fold greater in *B. interruptus* than in *B. sterilis* over the corresponding time period.

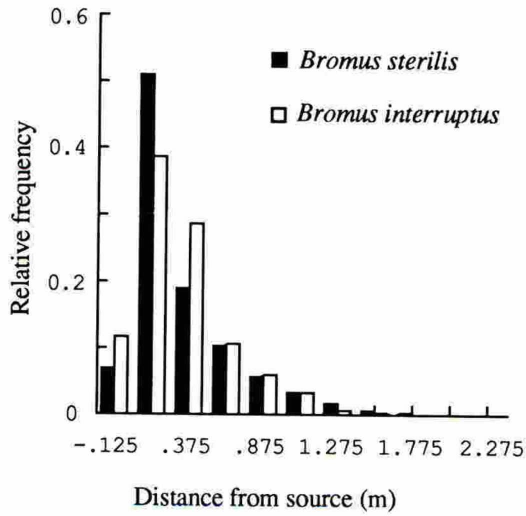
TABLE 1. The probability of a seedling establishing by late September (1989) from sowing 14 days earlier on two soil surfaces. L.S.D. ($P \leq 0.05$) = 0.164.

	Bromus sterilis	*Bromus interruptus*
Uncultivated soil within stubble	0.09	0.38
Soil cultivated 5 cm deep	0.65	0.45

Dispersal by cultivation

The mechanical cultivation of soil by rotary harrow dispersed seeds on a distribution that was similar in shape to that observed under combining but over a much more restricted range, and there were no statistical differences between species when distributions were analysed (Figure 4). Most seeds were distributed around the origin with some being dispersed backwards to the direction of movement. However the distribution was skewed to the left with seeds being found as far as 1.8 m from the source. Fitting Gaussian and exponential distribution functions to pooled data gave parameter estimates, $\mu = 0.025$ m, $\sigma = 0.15$ m and $b = 1.685\ m^{-1}$.

Figure 4. Seed dispersal resulting from the passage of a rotary harrow over a line of seeds. Class intervals are 0.25 m .



DISCUSSION

Howard (1991) observed that the seed production of both bromes growing in winter wheat as isolated individuals was in excess of 400 seeds per plant. The agencies that disperse these seeds are sequential in action leading to a shadow of seeds around the parent plant that may be augmented, diminished and modified as dispersal progresses. This study illustrates the scale and extent of three of these agencies. Not surprisingly combine harvesting had the potential to spread seeds over the greatest distance (20 m) and in contrast both natural dissemination and cultivation were much more restricted in effect (1-2 m). Whilst seed dispersal patterns arising naturally differed between species, the agricultural processes did not differentiate substantially between them. However the relative proportions of seeds that were subjected to these agencies reflected autecological differences between species in floral and germination biology and in mechanical selection during combining. Thus seeds of *B. sterilis* were more likely to be naturally dispersed due to early maturity and ready seed disarticulation, and more likely to be removed with grain by the combine in comparison to *B. interruptus*. The subsequent fate of seeds dispersed to the ground post-combining will then determine the likelihood of seed movement along the ground surface by cultivation. Significant seedling establishment occurred in *B. interruptus* even on soil surfaces within stubbles restricting the numbers available for dispersal during soil cultivation.

The cumulative seed distribution pattern arising post soil cultivation is the synthesis of the individual influences of each agent of dispersal acting sequentially. Table 2 details the analysis of the sequence of seed dispersion in relation to life cycle events with the initial assumption that N seeds occur at a point source (a single panicle). From seed production (event 1) seeds may

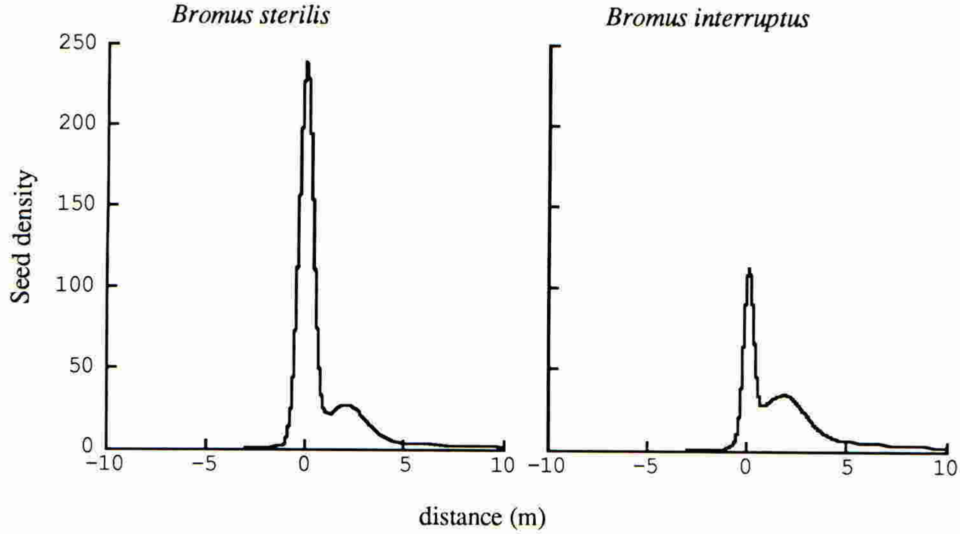
TABLE 2. The analysis of seed dispersal patterns and modelling of seed distributions.

Life cycle event	Parameter / Distribution (G=Gaussian, E= exponential)		Parameter values *Bromus sterilis*	*Bromus interruptus*
1. Seed production	Seeds per plant	N	479	413
2. Natural dispersal (n)	Proportion of seeds naturally dispersed	p_1	0.60	0.38
	G_n	μ_n, σ_n	0.028 , 0.312	-0.013 , 0.188
3. Dispersal by combine harvester (c)	Proportion of seeds removed with grain	l_1	0.34	0.15
	Proportion dispersed by combine on G distribution.	p_2	0.58	0.52
	Proportion dispersed by combine on E distribution.	$(1-p_2)$	0.42	0.48
	G_c	μ_c , σ_c	-2.04 , 0.944	-1.841 , 1.001
	E_c	b_c	0.168	0.185
4. Seed fate post harvest	Proportion lost	l_2	0.09	0.38
5. Dispersal by soil cultivator (v)	Proportion dispersed on G_v distribution	p_3	0.77	0.77
	Proportion dispersed on E_v distribution	$(1-p_3)$	0.23	0.23
	G_v	μ_v , σ_v	0.025 , 0.15	0.025 , 0.15
	E_v	b_v	1.68	1.68

be dispersed naturally (event 2) and by the action of the combine harvester (event 3). Post crop harvest, seeds may be lost (event 4) prior to being dispersed during land cultivation (event 5). The final distribution of all seeds post autumn cultivation may then be formed by the addition of two components - those seeds naturally dispersed and latterly spread by cultivator (component 1) and those initially dispersed by combine harvester and subsequently by cultivator (component 2). Convolution integrals (Table 3) were used to model the resultant distributions of seeds dispersed a) in component 1, on a Gaussian (G) distribution followed by Gaussian plus exponential ({G, E}); and b) in component 2, on two Gaussian plus exponential distributions. Implicit assumptions are that combine and cultivator move in the same plane in a single pass over seeds and that combining does not move seeds previously dispersed.

Figure 5 shows the predicted distributions of seeds for the two species. Characteristically both distributions are bimodal with the dominant mode being marginally displaced in a negative direction away from the origin. In *B. sterilis*, most (65%) of the seeds were distributed within 1.3 m of the source whilst in *B. interruptus* at least 50% were predicted to be further than 1 m away from the source in the forward direction of machine passage. Both species exhibited a leading tail reflecting the influence of the combine. Fewer seeds were distributed in *B. interruptus* due to the assumption of significant losses of seeds post harvest to germination and subsequent death by cultivation. No account is taken of seed losses due to straw baling or seed burial which may further reduce seed densities, probably by a constant fraction that is independent of dispersal processes.

Figure 5. The predicted distribution of seeds in autumn after the cumulative effects of dispersal by natural dissemination, combining and soil cultivation. Distributions to the right of the origin of the abscissa are truncated where seed densities are less than unity.



Whilst these simulations are based on predicates that simplify the ecological description of dispersal processes, they support empirical observations that weed seed dispersal within a cereal crop may occur predominantly over a restricted range, certainly for the brome species in question. This will inevitably lead to a tendency for stasis in the distribution of existing patches of bromes in cereal fields in the absence of intensive weed control. Nevertheless the influence of the combine in dispersing seeds is clearly evident and results suggest that the rate of spread of a population could be up to 10 m per annum if dispersed seeds produce plants that survive to reproduce in the next season. This is more likely to occur in *B. sterilis* than in *B. interruptus* since the former is a more vigorous competitor in wheat (Howard *at al.*, 1989). Such conclusions are necessarily specific to the grasses studied, the machinery used and the experimental conditions encountered.

Sensitivity analysis of the models underlying resultant seed distributions is hampered at present by an absence of data on the ranges that parameter values may encompass. In a comparison of species and cultivation implements, Howard (1991) found that seed movement during soil cultivation was rarely greater than 3 m from source. Seed size was an important determinant of the extent of movement in addition to the implement used, and soil type may also be significant. The spread of weed seeds by combine has received little attention and it is possible that weed species may differ markedly in the response to combining. Small readily disarticulated seeds may be dispersed by shaking at the point of cut and not be dispersed by passage through the machine whilst both seed coat and appendages may influence the likelihood of passage with straw and matter other than grain. Likewise the forward speed of the combine and the relative speed of passage of matter other than grain may well influence the deposition of weed seeds at crop harvest.

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TABLE 3. Dispersal functions and convolution integrals used in the description of dispersal processes indicated in Table 2. ERF is the error function. (Gould and Mortimer, unpublished).

Dispersal functions	Event 2.	Gaussian	$G_n(x) = 1/\sigma_n\sqrt{2\pi}\exp(-0.5((x-\mu_n)/\sigma_n)^2)$
	Event 3.	Gaussian	$G_c(x) = 1/\sigma_c\sqrt{2\pi}\exp(-0.5((x-\mu_c)/\sigma_c)^2)$
		Exponential	$E_c(x) = 0\ (x<0);\ b_c \exp(-b_c x)\ (x\geq 0)$
	Event 5.	Gaussian	$G_v(x) = 1/\sigma_v\sqrt{2\pi}\exp(-0.5((x-\mu_v)/\sigma_v)^2)$
		Exponential	$E_v(x) = 0\ (x<0);\ b_v \exp(-b_v x)\ (x\geq 0)$

Convolution integrals

$$\{G_n, G_v\} = 1/\sqrt{2\pi(\sigma_n^2+\sigma_v^2)}\exp(-0.5[x-(\mu_v-\mu_n)]^2/(\sigma_n^2+\sigma_v^2))$$

$$\{G_n, E_v\} = b_v/2\exp(b_v(\mu_n+0.5b_v\sigma_n^2)\ \exp(-b_v x)$$

$$\text{X}\ \begin{cases} 1+\mathrm{ERF}\left[(x-(\mu_n+b_v\sigma_n^2))/\sigma_n\sqrt{2}\right] & (\text{for } x>\mu_n+b_v\sigma_n^2) \\ 1-\mathrm{ERF}\left[((\mu_n+b_v\sigma_n^2)-x)/\sigma_n\sqrt{2}\right] & (\text{for } x<\mu_n+b_v\sigma_n^2) \end{cases}$$

$$\{G_c, G_v\} = 1/\sqrt{2\pi(\sigma_c^2+\sigma_v^2)}\exp(-0.5[x-(\mu_v-\mu_c)]^2/(\sigma_c^2+\sigma_v^2))$$

$$\{G_c, E_v\} = b_v/2\exp(b_v(\mu_c+0.5b_v\sigma_c^2)\ \exp(-b_v x)$$

$$\text{X}\ \begin{cases} 1+\mathrm{ERF}\left[(x-(\mu_c+b_v\sigma_c^2))/\sigma_c\sqrt{2}\right] & (\text{for } x>\mu_c+b_v\sigma_c^2) \\ 1-\mathrm{ERF}\left[((\mu_c+b_v\sigma_c^2)-x)/\sigma_c\sqrt{2}\right] & (\text{for } x<\mu_c+b_v\sigma_c^2) \end{cases}$$

$$\{E_c, G_v\} = b_c/2\exp(b_c(\mu_v+0.5b_c\sigma_v^2)\ \exp(-b_c x)$$

$$\text{X}\ \begin{cases} 1+\mathrm{ERF}\left[(x-(\mu_v+b_c\sigma_v^2))/\sigma_v\sqrt{2}\right] & (\text{for } x>\mu_v+b_c\sigma_v^2) \\ 1-\mathrm{ERF}\left[((\mu_v+b_c\sigma_v^2)-x)/\sigma_v\sqrt{2}\right] & (\text{for } x<\mu_v+b_c\sigma_v^2) \end{cases}$$

$$\{E_c, E_v\} = b_c b_v/(b_v-b_c)[\exp(-b_c x)-\exp(-b_v x)]\ (\text{for } b_c\neq b_v);\ 0\ (\text{for } x\leq 0)$$

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SURVEYS OF STRAW DISPOSAL METHODS IN ENGLAND AND WALES AND FARMERS' ATTITUDES TO THE FORTHCOMING BAN ON BURNING STRAW.

G.M. TOWNSEND

Conservation Policy Division, Ministry of Agriculture Fisheries and Food, Nobel House, 17 Smith Square, London SW1P 3JR.

E. WRIGHT

Statistics (Census and Prices) Division, Ministry of Agriculture Fisheries and Food, Government Buildings, Epsom Road, Guildford, Surrey, GU1 2LD.

J.H. ORSON

ADAS Boxworth, Boxworth, Cambridge, CB3 8NN.

ABSTRACT

The background to the ban on the burning of crop residues in England and Wales from the harvest of 1992 is outlined along with some detail of the legislation that has been introduced. The stratified survey carried out by the Ministry of Agriculture, Fisheries and Food shows that the area of cereal straw burnt in the field in England and Wales has more than halved between 1983 and 1990. The reasons for this trend are discussed. During 1990 the Agricultural Development and Advisory Service undertook a farmers' attitude survey to the impending ban on the burning of crop residues. Approximately 40% of the farmers of heavy land interviewed considered that weed control will be a major problem after the ban has been imposed.

INTRODUCTION

The summer of 1989 was very hot and dry and the post-harvest burning brought with it an unprecedented level of problems - smoke and ash drifting into people's homes and across roads, penetrating even into hospital operating theatres. Over 3,500 complaints were received by the Ministry of Agriculture, Fisheries and Food (MAFF). It is believed that many other people suffered in silence. The Minister of Agriculture decided that something had to be done to control the very serious public nuisance which straw burning had become.

In November 1989, after much deliberation and consultation with the National Farmers' Union (NFU) and other interests, the Minister announced his decision to ban the burning of all crop residues. It was realised, however, that farmers could not just stop burning and that they would need to find other outlets for their straw. They would also need time to adopt straw incorporation techniques. The Minister, therefore, decided that in order to allow for this adjustment, a three year interim period should be allowed and that the ban should come into effect after the disposal of crop residues from the 1992 harvest.

It was also recognised that there might be circumstances where it would be impossible to dispose of crop residues without burning. Exemptions to the ban will, therefore, be considered although it is intended that these should be kept to a minimum. MAFF officials will be discussing with interested parties those crops/situations which have been identified as creating particular problems. It is envisaged that some exemptions would need to be more or less permanent, as in the case of linseed straw, where it is said that equipment which could chop the straw satisfactorily has yet to be developed commercially. There will also be times when certain soil and climate conditions combine to render all alternatives to burning impractical. For example, on some heavier soils in a particularly wet year, it may not be possible to prepare a seedbed in time for the following crop if the previous crop residue is not burnt. In such exceptional circumstances, a series of temporary exemptions may be necessary, probably applicable only to a limited area for one season at a time and possibly further limited to specific crops. Discussion and evaluation will continue. Further consultation will be made before any decisions are made.

LEGISLATION AND PUBLICITY

Powers are available in the Environmental Protection Act 1990 to provide for a ban and to allow exemptions and also to control conditions under which burning may be carried out. Regulations were introduced in July 1991 which effectively consolidate local authority bye-laws and the 1990 NFU Straw Burning Code. To ensure that farmers are aware of the new law and to enable them to comply with it, all farmers in England and all cereal growers in Wales were sent guidance notes, prior to the 1991 cereal harvest, which explained the new laws . These were sent together with the MAFF 1991 publicity leaflet which reminded them of the forthcoming ban, the alternative uses for straw and informed them of the new regulations. Radio and television fillers were also broadcast as part of the 1991 publicity campaign which, it is hoped, will get the message across to both farmers and the public that whilst the ban will not be in place until 1993 now is the time to look for alternatives. However, if farmers decide to burn, the Regulations must be followed to provide safe and nuisance-free burning.

The Government is spending over £1 million per annum on straw research including its use as a fuel. Of this expenditure about three quarters is on methods of handling and storage of straw and its incorporation in the soil. Research into alternative uses for straw has assisted in developing the technology enabling straw to be used to manufacture board for building and furniture, paper pulp, compost and animal bedding and feeding.

STRAW DISPOSAL SURVEY

Each year MAFF surveys straw disposal in England and Wales. Information is collected on wheat, barley and oats straw which is:-

i) baled and removed from the field

ii) ploughed or cultivated in

iii) burned in the field (excluding area of stubble burnt after removal of the straw)

The survey is of topical interest at the moment because of the forthcoming ban but the results do have a wider use:

i) in the calculations of net margins for cereals
ii) in the calculation of net farm incomes
iii) in the justification of European Agricultural Guidance and Guarantee Fund (FEOGA) aid for investment in forms of straw processing
iv) for the identification of research and development needs by the Chief Scientists Group and Conservation Policy Division
v) monitoring incidences of straw burning and assessment of farmers' reaction to new legislation.

Data are collected using a stratified random sample of holdings that grow wheat and/or barley and/or oats at the time of the June census preceding the survey date. The sample is stratified into five size groups determined by the total area of these crops grown. Two percent of the total number of holdings are mailed in August/September with a questionnaire (Table 1). An 80% response rate is usually achieved after several reminders have been sent to farmers. Data received are validated and any problems are cleared with the farmer. The sample results are then raised within each stratum group to provide population estimates. The estimates should be accurate to within + or - 10%.

TABLE 1. Number of holdings in each size group in the 1990 survey.

Area of wheat, barley & oats	No. of holdings
0-20 ha	275
20-50 ha	310
50-100 ha	338
100-200 ha	202
>200 ha	60

The results show that the area of cereal straw burned has dropped since 1983 from 1,270,400 ha to 541,100 ha in 1990 although there is of course a variation between crops (Tables 3-6). It is possible that this decrease could be related to the introduction of the local bye-laws (introduced in 1984) controlling the burning of crop residues and the additional controls with which farmers had to comply. In addition, many farms acknowledged that straw burning was not an acceptable practice and that viable alternatives existed and consequently decided to incorporate straw. Between 1989 and 1990 there was a reduction of 36% in the straw area burnt. It is believed that this was partly a response to the Minister's announcement of the forthcoming ban, partly due to the very dry and therefore potentially dangerous conditions during the 1990 harvest and partly due to a shortage of hay owing to the dry summer. Over the period of the survey, the area of straw incorporated by ploughing or cultivation has increased ten-fold, whilst the area baled has remained fairly constant (Table 2).

TABLE 2. Wheat, barley & oats data combined - area (thousands hectares) and % of total area according to straw disposal method

	1983	1984	1985	1986	1987	1988	1989	1990
Straw baled & removed	2039 60%	1928 56%	2115 62%	2067 61%	1843 55%	1938 59%	1864 56%	1921 61%
Straw ploughed or cultivated in	59 2%	243 7%	354 10%	423 12%	585 18%	582 18%	619 19%	677 22%
Straw burnt in the field	1270 38%	1261 37%	946 28%	927 27%	909 27%	785 24%	841 25%	541 17%
Total	3368	3432	3415	3417	3337	3305	3324	3139

TABLE 3. Winter and spring wheat - area (thousands hectares) and % of total area according to straw disposal method

	1983	1984	1985	1986	1987	1988	1989	1990
Straw baled & removed	651 40%	638 34%	783 43%	800 42%	692 37%	708 40%	774 38%	857 45%
Straw ploughed or cultivated in	35 2%	184 10%	262 14%	326 17%	466 25%	440 25%	508 25%	575 30%
Straw burnt in the field	958 58%	1041 56%	768 42%	777 41%	715 38%	632 36%	727 36%	492 26%
Total	1644	1863	1813	1903	1873	1780	2009	1924

TABLE 4. Winter barley - area (thousands hectares) and % of total area according to straw disposal method

	1983	1984	1985	1986	1987	1988	1989	1990
Straw baled & removed	673 80%	732 80%	737 79%	722 81%	676 77%	636 82%	663 82%	704 86%
Straw ploughed or cultivated in	6 1%	33 4%	62 7%	60 7%	73 8%	58 8%	62 8%	75 9%
Straw burnt in the field	158 19%	152 17%	129 14%	110 12%	132 15%	86 11%	81 10%	37 5%
Total	837	917	928	892	881	780	806	816

TABLE 5. Spring barley - area (thousands hectares) and % of total area according to straw disposal method

	1983	1984	1985	1986	1987	1988	1989	1990
Straw baled	647	491	509	492	424	529	361	293
& removed	80%	85%	89%	88%	83%	80%	85%	90%
Straw ploughed	18	24	26	32	40	78	44	22
or cultivated in	2%	4%	5%	6%	8%	12%	10%	7%
Straw burnt in	142	60	37	33	49	57	22	10
the field	18%	10%	6%	6%	10%	9%	5%	3%
Total	807	575	572	557	513	664	427	325

TABLE 6. Winter and spring oats - area (thousands hectares) and % of total area according to straw disposal method

	1983	1984	1985	1986	1987	1988	1989	1990
Straw baled	68	67	86	56	51	65	66	66
& removed	85%	86%	85%	81%	73%	80%	80%	90%
Straw ploughed	0.4	2	4	5	6	6	5	5
or cultivated in	<1%	2%	4%	7%	9%	7%	6%	6%
Straw burnt in	12	9	12	8	13	11	11	13
the field	15%	12%	12%	12%	18%	13%	14%	4%
Total	80	78	102	69	70	82	82	74

It is hoped that the survey will show further reductions in the area of straw burnt after the 1991 and 1992 harvests. Until such time as farmers find outlets for their straw, incorporation will continue to be the most widely used method of disposal.

FARMERS' ATTITUDE TO THE BAN ON BURNING CEREAL STRAW

Two surveys have been carried out by the Agricultural Development and Advisory Service (ADAS) to establish farmers' attitudes to the ban on the burning of cereal straw. These were undertaken at the 1990 'The Last Straw' straw disposal field demonstration at ADAS Bridget's Experimental Husbandry Farm and at 'Grain 90', a grain handling and storage demonstration at the National Agricultural Centre. From the results, the majority of farmers attending the 'Last Straw' were farming on medium to light soils, whereas those attending 'Grain 90' represented medium to heavy land farmers. The response was, of course, limited to those who attended the events. It must be assumed that they would have a more positive attitude towards this issue than farmers who chose not to attend.

The surveys sought farmers' opinions on a range of topics including the extent to which problems may occur as a result of the ban on straw burning (major, minor or no problem at all). The topics included extra labour needed, extra machinery need, crop establishment, crop pest or disease, weed control and loss of yield.

The responses to the question on weed control were similar at the two events and the total of 199 interviews have been combined (Figure 1). The results show that approximately 40% of the farmers on heavy land considered that the ban on the burning of straw would lead to major problems from weeds. It must be assumed that the majority of these farmers had systems based on autumn sown crops and that they foresaw increased problems with annual grass weeds such as the Bromus spp. and Alopecurus myosuroides (black-grass). Experimental evidence suggests that such a situation will occur, particularly where non-plough tillage takes place (Cussans et al, 1987). It was interesting to note that the vast majority of farmers indicated that they would not change their crop rotation as a result of the ban on burning crop residues.

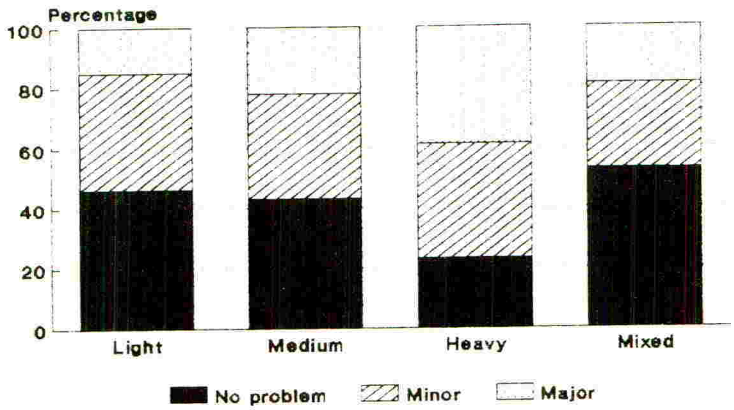

FIGURE 1. Farmers' attitude survey - level of anticipated weed control problems on different soil types after the ban on straw burning.

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