SESSION 9C

WEED MANAGEMENT IN ARABLE CROPS

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INTEGRATED WEED MANAGEMENT - ITS PERFORMANCE OVER A FIVE-COURSE COMBINABLE CROP ROTATION

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ABSTRACT

At the Scottish site of the LINK Integrated Farming Systems project, mean herbicide input in the integrated system was 0.7 full dose equivalents compared with 0.9 in the conventional. Despite avoiding graminicides in cereals, there was no accumulation of weed problems. Small plot trials suggested that the use of low doses in the spring crops was more cost effective than the use of a full dose but that a small loss may have resulted from not using an autumn graminicide in the winter wheat.

INTRODUCTION

LINK Integrated Farming Systems (IFS) Project

The LINK IFS project tested the viability of integrated crop management over a five-course rotation from 1993 to 1997 at six sites across the UK; the design of the experiment was described by Ogilvy et. al. (1995). Fields split half with an integrated rotation and half with a conventional rotation were used to compare the two systems. Small plot validation trials on the integrated field halves tested each integrated treatment decision. The rotation at the Pathhead site was - conventional: winter oilseed rape, winter wheat, set aside, winter wheat, winter barley; integrated: spring oilseed rape, winter wheat, set aside, winter wheat, spring barley. Averaged over the first four years and all phases of the rotation, 40 kg/ha less nitrogen fertiliser and 1.33 kg/ha less pesticide active ingredient were used leading to a 10% reduction in output, but due to cost savings on inputs and better malting premiums for spring barley the integrated gross margin was similar to the conventional (Fisher 1997). The switch to some spring cropping and adoption of reduced doses were the main factors in input reduction at the Pathhead site. Sound decision making on reduced doses was possible due to previous HGCA funded work (Fisher et al 1993). However, reduced doses were largely untried as part of a whole system integrated approach where reduction in other inputs such as nitrogen might influence weed control with reduced doses.

Strategy

The weed control strategy adopted at Pathhead was to reduce the amount of herbicide applied as much as possible without compromising crop yield or profitability. Complete weed control was not the aim as it was realised in the early years of the project that some weed cover could increase numbers of some arthropod species that are aphid predators. Reductions were achieved mostly through well-timed reduced doses. In some cases herbicides were chosen to control only 'problem' weeds leaving less damaging weeds uncontrolled. Only half the Scottish wheat area is treated with graminicides (Snowden & Thomas 1994), no residual grass weed herbicide was used during the five years in the integrated system. Mechanical weed control was tested in small plots, but was not adopted on the full-field integrated system.

In Phase 1 of the integrated rotation, spring-sown oilseed rape was treated in all years, except 1994, pre-emergence within 48 hours of drilling with 250 g a.i./ha metazachlor, the intention being to check weeds enough to allow this vigorous crop to establish. In 1994 it was necessary to apply 375 g a.i./ha post-emergence. The oilseed rape was not desiccated in 1995, in 1993 it was desiccated with diquat, in 1994 and 1996 it was desiccated with glufosinate-ammonium. The conventional winter oilseed rape was generally treated with 1500 g a.i./ha metazachlor followed by post-emergence graminicide and in some years a desiccant. The integrated wheat (Phases 2&4) was generally drilled 2 weeks later than the conventional which made autumn weed control less urgent. Spring applied herbicides, either metsulfuron-methyl/mecoprop-P mixture or HBN/mecoprop-P mixture was used, followed in 1993 and 1995 with fluroxypyr for *Galium aparine* control, and in 1994 glyphosate to control *Elymus repens*. The conventional field half was generally treated with diflufenican+isoproturon residual for grass and broad-leaved weeds. Phase 3 was set aside, both integrated and conventional were allowed to regenerate naturally and both were treated with glyphosate in July. Phase 5 spring barley was treated with reduced dose HBN/mecoprop-P or metsulfuron-methyl+thifensulfuron-methyl; in the conventional winter barley grass and broad-leaved weeds were controlled with diflufenican/isoproturon. For herbicide doses see Table 1.

Extra treatments to control either *G. aparine* or *E. repens* or the need for desiccant in some crops gave rise to fluctuations in herbicide units over years, but not an increase. The conventional tended to fluctuate more than the integrated (Table 1).

Table 1. Mean amount of herbicide applied in g a.i./ha and pesticide units ( ) over five years

	1993	1994	1995	1996	1997	Mean
C winter oilseed rape	350 (0.68)	375 (0.30)	750 (1.15)	784 (0.74)	779 (0.67)	608 (0.71)
I spring oilseed rape	250 (0.20)	313 (0.25)	250 (0.20)	250 (0.20)	250 (0.20)	263 (0.21)
C winter wheat 1	340 (1.37)	130 (0.65)	2325 (1.91)	1313 (1.07)	1300 (0.60)	1082 (1.12)
I winter wheat 1	500 (0.78)	837 (0.98)	1323 (1.31)	922 (1.84)	619 (1.08)	840 (1.20)
C set aside	1080 (0.56)	720 (0.37)	960 (0.50)	1080 (0.56)	1080 (0.56)	984 (0.51)
I set aside	1080 (0.56)	720 (0.37)	960 (0.50)	1080 (0.56)	1080 (0.56)	984 (0.51)
C winter wheat 2	1810 (1.14)	50 (0.25)	1628 (1.44)	1055 (1.53)	1062 (1.15)	1121 (1.10)
I winter wheat 2	600 (0.93)	0 (0.00)	470 (0.99)	802 (1.24)	596 (1.15)	494 (0.86)
C winter barley	1695 (1.20)	100 (0.50)	1550 (1.00)	1326 (1.14)	1475 (0.96)	1229 (0.96)
I spring barley	1335 (1.31)	15 (0.86)	15 (0.50)	22 (0.75)	30 (1.00)	283 (0.88)
C mean	1055 (0.99)	275 (0.41)	1443 (1.20)	1112 (1.01)	1139 (0.79)	1005 (0.85)
I Mean	753 (0.76)	377 (0.49)	604 (0.70)	615 (0.92)	515 (0.80)	573 (0.73)

C = conventional; I = integrated. A pesticide unit is defined as the weight of active ingredient in the highest dose of that pesticide which can legally be applied to an arable crop.

Assessments

Weed counts were made at fixed points each year in each field half, both before and after herbicide application. Changes over years before treatment counts, were analysed by fitting orthogonal polynomials (Snedecor & Cochran 1980). Due to the slow action of reduced doses of some herbicides in some cases weeds counted post spraying were either severely stunted or dying. Arthropods were trapped in pit-fall traps over five-day periods at monthly intervals during the main periods of activity. There were six to eight trapping occasions per season. Yields of field halves were measured by conventional combine and weighbridge. A small plot combine was used to measure grain yield in the treatment validation trials which were small plot trials in the integrated field half of one field per crop.

RESULTS AND DISCUSSION

Weed flora

The constant term in Table 2 is used as a measure of the relative frequency of the weed species and is the log transformed fitted weed seedling density at the middle·year (1994-95). The species are arranged in decreasing density in the conventional treatment. Back-transformed, they vary from 21 seedlings per m^2 for *Poa annua* down to 0.08 shoots per m^2 for *Elymus repens*. There were no significant effects of cropping system. Eight species were less frequent in the integrated treatment and four species were more frequent.

The linear term gives an indication of trends over time in the fixed quadrats. *P. annua, Veronica hederifolia,* volunteer rape and cereals, *Lamium purpureum, Myosotis arvensis, Veronica persica, G. aparine* and *E. repens* all tended to increase in both systems. The coefficient was significantly greater than zero only for volunteer cereals and *E. repens* in both systems and for *V. persica* in the conventional system. *P. aviculare* and *Matricaria spp.* both declined and the coefficient was significantly less than zero for *P. aviculare* in both systems and *Matricaria* in the integrated. *Stellaria media* declined in the conventional system and increased in the integrated but the difference was not significant. The only significant difference ($P<0.05$) was that volunteer cereals increased more rapidly in the conventional system than in the integrated.

Most of the positive linear terms were associated with negative quadratic terms indicating that the increase was not accelerating. The exception was volunteer rape which does seem to be of increasing importance in both systems, perhaps reflecting the relative novelty of this crop on the farm. Similarly the species with negative linear terms had positive quadratic terms indicating a tendency for the decline to bottom out.

The level of weeds remaining following treatment differed between the two systems. There were 20% fewer weeds remaining in the conventional compared with the integrated (Table 3). In particular grass weed populations were higher in all instances apart from set aside - in the integrated these were predominantly *P. annua*, in the conventional they were volunteer cereals.

Table 2. Orthogonal coefficients of weed counts before spraying at Pathhead, 1993-1997.

Species	Mean of fitted constants									Fitted values - seedlings/m^2			
	Constant term			Linear term			Quadratic term			Conventional		Integrated	
	Conven -tional	Integ -rated	SEmean	Conven -tional	Integ -rated	SEmean	Conven -tional	Integ -rated	SE mean	Year1	Year 5	Year 1	Year 5
Poa annua	3.098	2.525	0.394	+0.190	+0.168	0.146	-0.240	-0.028	0.226	8.38	19.06	7.44	15.53
Stellaria media	1.885	1.149	0.252	-0.021	+0.132	0.059	-0.056	-0.012	0.062	5.14	4.65	1.37	3.01
Veronica hederifolia	1.084	0.535	0.258	+0.075	+0.084	0.119	-0.094	-0.007	0.037	1.11	1.85	0.42	0.99
Volunteer rape	0.998	1.087	0.166	+0.101	+0.126	0.090	+0.054	+0.073	0.086	1.47	2.70	1.67	3.42
Volunteer cereals	0.609	0.418	0.069	+0.250	+0.187	0.020 *	-0.142	-0.066	0.054	0	1.28	0	0.94
Lamium purpureum	0.391	0.260	0.160	+0.127	+0.072	0.068	-0.071	-0.020	0.049	0	0.65	0.08	0.44
Myosotis arvensis	0.326	0.223	0.050	+0.044	+0.056	0.054	-0.053	-0.028	0.033	0.14	0.36	0.06	0.32
Veronica persica	0.321	0.299	0.111	+0.113	+0.084	0.042	-0.089	-0.109	0.054	0	0.45	0	0.28
Polygonum aviculare	0.282	0.310	0.074	-0.213	-0.208	0.061	+0.071	+0.028	0.037	1.34	0	1.19	0
Galium aparine	0.249	0.065	0.061	+0.009	+0.001	0.022	-0.103	-0.031	0.030	0.03	0.06	0	0
Matricaria spp	0.105	0.366	0.097	-0.082	-0.230	0.087	+0.035	+0.044	0.064	0.40	0.01	1.49	0
Elymus repens	0.080	0.223	0.063	+0.034	+0.046	0.012	-0.033	-0.127	0.044	0	0.09	0	0.06

The constant, linear and quadratic terms were obtained for the function ln(w+1) as it varied over time for the five years of the experiment. w is the mean weed seedling count in 20 or 24 fixed quadrats per half-field taken just before spraying each year and expressed in seedlings per metre squared. The orthogonal coefficients were subject to analysis of variance regarding the seven fields as replicates of the two treatments. The degrees of freedom for all standard errors are six.

Table 3. Weed frequency of conventional and integrated crops after treatment, mean of the five years

	Mean no./m^2 grass weeds		Mean no./m^2 broad-leaved weeds		Mean no./m^2 broad-leaved weeds and grasses	
	I	C	I	C	I	C
spring/winter oilseed rape	31.5	2.7	31.0	55.5	62.5	58.2
winter wheat 1	57.3	5.7	7.3	13.7	64.6	19.4
set aside	176.6	127.2	9.8	103.7	186.4	230.9
winter wheat 2	45.9	29.9	2.7	25.9	48.6	55.8
spring/winter barley	213.6	71.5	13.0	12.8	226.6	84.3
mean	104.9	47.4	12.8	42.3	117.7	89.7

Crop yield and gross margin

Validation trials indicated that in the Phase 1 spring oilseed rape there was a financial benefit from reducing the herbicide dose to one third of the recommended dose of metazachlor. In fact full dose gave the lowest gross margin (Table 4).

Table 4. Yield response in integrated spring oilseed rape and weed control with metazachlor 1993, 1994 & 1996

kg a.i./ha metazachlor	Seed yield t/ha at 91% d.m.	Gross Margin £/ha	Weeds/m^2	
			Poa annua	Broad-leaved weeds
0	2.64	776	229	23.9
0.25	2.62	756	0.5	11.6
0.75	2.59	731	0	12.1
SED	0.096	15.04		

In Phase 2&4 winter wheat integrated weed control was by post-emergence sulfonyl urea or HBN / mecoprop-P mixture. Validation trials in 1995 and 1996 indicated that an autumn residual would have yielded significantly more (Table 5). It is not clear whether this is due to timing of weed removal, or competition from un-controlled grass weeds.

Table 5. Yield response in integrated winter wheat, mean of validation trials in 1995 and 1996.

Treatment	Grain yield t/ha at 85% d.m.	Gross margin /ha
Untreated	10.16	1134
Autumn residual	10.74	1175
Spring post-emergence (integrated)	10.39	1136
SED	0.185	21.1

In Phase 5 spring barley integrated reduced doses gave equivalent yield and gross margin compared with full dose (Table 6).

Table 6. Yield response in integrated spring barley, mean of validation trials 1993 - 1995.

Treatment	Grain yield t/ha at 85% d.m.	Gross margin /ha
Integrated (0.3 - 0.5 dose)	5.27	832
Full dose	5.22	817
SED	2.18	19.4

Beneficial arthropods

In some instances where there was a large difference between field halves in *Poa annua* ground cover which was reflected in increased arthropod numbers (Table 7).

Table 7. Effect of *Poa annua* ground cover on arthropod numbers in winter wheat in 1993

	Mean no./m2		Mean no. caught/trap/day*		
	Poa annua	Broad-leaved weeds	Carabidae	Staphylinidae	Linyphiidae
Integrated	110	2	5.7	1.0	2.9
Conventional	13	1	3.6	0.7	1.9

* mean of eight one-week trapping occasions between March and August

CONCLUSIONS

The weed control strategy adopted for the integrated system in the spring was successful in that it did not give rise to serious weed problems at the end of the five years. Most species increased over the five years but no more in the integrated than in the conventional system. However, small plot trials indicated that the absence of an autumn herbicide for wheat reduced yields in some years despite good control of broad-leaved species by low doses of spring herbicide. In the spring barley and spring rape, the low doses used for the integrated system gave yields as good or better than the full dose and therefore better gross margins.

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CHANGES IN WEED POPULATIONS IN THE CONVERSION OF TWO ARABLE FARMS TO ORGANIC FARMING

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ABSTRACT

There is increasing interest in policies encouraging organic or biological farming. Farmers in the UK are not converting to organic farming in large numbers, with one principal reason being the problem of weed control. There is some evidence that weed problems reduce over time, but it is uncertain to what degree weed populations increase during conversion at the field rather than plot scale and how management strategies affect that increase. The results of surveying two farms in conversion over 4 seasons suggest weed populations increase rapidly, but there is evidence on one farm with fields in longer conversion periods that the weed population growth stabilises. However, periods of grass ley of greater than two seasons duration greatly reduce weed population growth during the conversion period. There is no evidence of an increase in weed species number during the conversion period.

INTRODUCTION

There is increasing interest, with Government policy encouragement in the United Kingdom, in converting a proportion of farms to organic or biological systems of production. However, to date UK farmers have not converted in large numbers (Anon. 1997) with an estimated <1% of arable land farmed organically. One of the principal reasons given for the failure of farmers to convert their farms is the problem of weed control. Yarham & Turner (1992) found that organic wheat growers in England considered weeds as their worst crop protection problem, and Peacock (1990) found the same amongst organic vegetable growers. Nevertheless, there is some evidence from these and other surveys in the UK (Wookey, 1985) and Europe (eg Hannukala *et al.*, 1990), and from advisory discussions with organic growers, that the weed problem reduces with time. However, before this stage can be reached there are difficult weed problems to be controlled, with potential effects on crop yield and quality during the economically difficult transitional phase. We are not aware of other studies looking at the changes in weed populations during the conversion period to organic farming on a farm scale, and the study reported here was in part initiated to investigate whether weed populations did increase during conversion on two Scottish arable farms, and whether rotational management strategies affected the growth of the weed population. Field plot experiments have suggested that high proportions of arable crops in rotations increase weed seedbanks (Younie *et al.*, 1996).

MATERIALS AND METHODS

The farms used in the survey were Woodside, Elgin, Morayshire and Jamesfield, Abernethy, Fife. Both were largely arable with limited stocking, but this increased from 1989 with grass becoming an important part of the rotation (40% at Woodside, 25% at Jamesfield). Woodside began conversion to organic farming in 1989. Seven fields in arable/grass rotation were monitored, along with one in permanent grass and a field that remained farmed conventionally. At Jamesfield, six arable fields that had been converted between 1984 and 1986, plus another field that had never received conventional pesticides or fertilisers, and a neighbouring conventionally farmed field, were surveyed. All fields at both sites, except that in permanent grass, were subjected to inversion ploughing between each crop.

The data presented here compares the weed flora in 1991 and 1994, the first and last years of the surveys (4 years of rotation). Quadrats of 0.25 m^2 were placed at 20 m points along transects across the fields, avoiding the field headlands. Weeds were listed and counted at each point in June of each season, at least one month after any weed cultivation.

Four quadrat points in each field were fixed accurately. At these points 1000 g samples of soil from cores to 200 mm soil depth were taken from 1 m^2 quadrats in winter 1990/91 and autumn 1994. The soil samples were analysed at the Scottish Crop Research Institute to assess the weed seedbank.

The data from each site has been analysed on a rotational basis as fields were later split into various rotations (10 at each site), and the data has also been merged and re-analysed to look for overall trends within the two sites. The effects of splitting fields was to vary the number of quadrat points between rotations, but this was accounted for in the analysis.

RESULTS

Weed populations

Table 1 shows the impact of number of years in grass in the rotation on weed populations in 1991 and 1994. The presence of grass for more than two seasons reduced weed numbers, especially at Jamesfield, and merging the data for the two sites showed a significant overall effect. Weed numbers tended to increase in arable crop rotations at Woodside, but not consistently at Jamesfield.

There were significantly higher numbers of *Polygonum aviculare* amongst the common weed species found where there was no grass in the rotation at the two sites (Table 2), and also *Chenopodium album* where there was no grass, or just one year of grass in the rotation. There was no evidence of a change in the number of weed species present over the survey period, except a reduction with an increasing length of grass ley at Jamesfield.

Table 1. Impact of number of seasons of grass in organic rotations on weed numbers (log + 1)/ 0.25 m²

		Number of seasons in grass 0	3+	SED	LSD 5%	Significance
Jamesfield	91	3.81	0.77	0.73	1.73	**
	94	3.20	1.63	0.60	1.42	*
	94-91	-0.61	0.86	1.09	2.58	NS
Woodside	91	4.46	3.27	2.30	5.44	NS
	94	5.70	1.72	1.55	3.66	*
	94-91	1.24	-1.55	2.54	6.01	NS
Both	91	3.89	2.02	0.93	1.73	*
	94	3.51	1.68	0.66	1.23	**
	94-91	-0.38	-0.35	1.13	2.10	*
Number of fields		8	4			

* ≤ 0.05; ** ≤ 0.01

Table 2. Impact of grass in the rotation on major weed species at the two farms

Changes in weed number (log + 1) /0.25 m² from 1991-94

	Years of grass in rotation 0	3+	Max LSD (5%)	Significance
Poa spp.	-0.30	0.71	2.01	NS
Stellaria media	-0.60	0.26	1.68	NS
Polygonum aviculare	1.12	-0.22	1.06	*
Chenopodium album	0.84	-0.42	1.07	*
Spergula arvensis	0.56	0.00	1.70	NS
Matricaria spp.	0.75	0.87	1.95	NS
Number of fields	8	4		

* ≤ 0.05; ** ≤ 0.01

Weed seedbanks

Weed seedbank populations increased in every rotation at Woodside between 1991 and 1994 (Table 3) except where there was continuous grass (data not shown). The increase was greatest in rotations with no grass, and least in the conventional field. The trend was similar at Jamesfield, for conventional and no-grass rotations, but a slight drop in weed seed numbers occurred where there was grass in the rotations.

More specifically at Woodside, *Spergula arvensis* and *C album*, and to a lesser extent *P. aviculare,* increased in totally arable rotations; much more so than where grass was present (Table 4). At Jamesfield, there was again evidence that several species, including *P. aviculare* and *C. album*, increased in fully arable rotations and *P. annua* had declined in those rotations. Grass in the rotation encouraged *P. annua*, but had reduced *C. album* and *S. media*. *Matricaria* spp. increased in both rotations.

Table 3. Impact of grass in rotation on mean numbers of weed seeds/m² at the two farms.

	Mean weed seed numbers/m²	
	1991	1994
Jamesfield		
Conventional rotation (1)	5,710	12,167
Rotations with grass (3)	26,092	17,782
Rotations with no grass (7)	25,276	42,141
Woodside		
Conventional rotation (1)	10,500	16,000
Rotations with grass (7)	22,014	45,857
Rotations in grass for more than 2 years (4)	21,688	40,438
Rotations without grass (2)	29,500	153,999

DISCUSSION

Weed numbers and weed seedbank populations increased over the conversion period in fields that remained in arable crops at Woodside, but not at Jamesfield. The main difference between the two sites was that by the end of the survey Jamesfield had been in more years of conversion than Woodside, and this may indicate that the period of weed population increase had passed at Jamesfield. However, a confounding difference may have been the intensity of weed management, which may reflect the increasing skill of the farmer at Jamesfield who had had longer experience of managing organic crops, and the larger proportion of more intensively managed horticultural crops in this rotation. At both sites it was evident that periods of grass of more than one to two seasons duration significantly reduced weed abundance and at least moderated the increase in the weed seedbank.

The results help confirm field plot trial results suggesting that increasing the number of arable crops in rotation increases weed seedbank numbers (Younie *et al.*, 1996). This also has considerable significance for those developing stockless/grassless organic rotations (Bulson *et al.*, 1996) and indicates that much higher levels of weed management may be required during the conversion period, and thereafter, if there are no grass breaks. The conventionally farmed fields showed a small increase in weed seed numbers over the survey period, but numbers remained much lower than for fields in conversion.

Specifically, *P. aviculare*, *S. arvensis* and *C. album* seem to be amongst the weed species benefiting most from the period of conversion, plus *Matricaria* spp. at Jamesfield. These species tend to reduce with grass breaks, except for *Matricaria* spp, but *P annua* showed an increase in population with grass breaks. There was no evidence for an increase in numbers of weed species in the fields over the period of the survey.

In conclusion, the newly converted Woodside Farm showed a clear trend to increased weediness in the first few years of the conversion period, mitigated where grass was present in the rotation. This was not as evident at Jamesfield; however, this farm had started large-scale conversion three to five years earlier, and possibly the current situation reflects some stabilisation in the weed levels later in the conversion period, or improved managerial ability to control weeds. The introduction of grass to Jamesfield during the 1991-4 seasons of the survey may, however, assist in reducing further future weed levels at the farm.

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Table 4. Impact of rotation on the mean weed seedbank populations (1000/m²) of the major weed species found at Jamesfield and Woodside.

	Capsella bursa-pastors		*Chenopodium album*		*Matricaria spp.*		*Poa spp.*		*Polygonum aviculare*		*Spergula arvensis*		*Stellaria media*	
Year 19' Farm/ rotation	91	94	91	94	91	94	91	94	91	94	91	94	91	94
<u>Jamesfield</u>														
With grass*	0.25	0.46	1.38	0.83	0.43	1.59	0.61	1.59	0.41	0.37	-	-	2.19	1.61
Without grass	0.83	1.14	0.91	1.58	0.57	1.43	1.93	1.57	0.79	1.86	-	-	2.64	1.79
Conventional	0.00	0.00	1.31	1.39	0.00	0.00	1.22	1.87	0.00	0.00	-	-	0.00	0.00
LSD (5%)	1.91		1.92		2.53		2.35		2.04		-		1.38	
<u>Woodside</u>														
With grass*	-	-	0.79	1.52	-	-	1.47	1.21	0.57	0.96	0.74	1.55	0.90	1.32
Without grass	-	-	2.59	4.66	-	-	1.87	1.99	1.79	3.31	1.25	4.46	1.10	2.23
Conventional	-	-	0.00	0.69	-	-	1.10	0.00	0.00	0.69	0.69	1.39	0.00	0.69
LSD (5%)	-		2.33		-		2.48		1.71		2.58		3.13	

*at least two seasons of grass

A BOTANICAL SURVEY OF CONSERVATION HEADLANDS IN BRECKLAND ENVIRONMENTALLY SENSITIVE AREA, UK

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ABSTRACT

We present the results of botanical field surveys of conservation headlands created as part of the Environmentally Sensitive Areas scheme in the Breckland, UK. In conservation headlands, common arable plant species were most frequently recorded, but some species characteristic of Breckland, and some nationally scarce or declining species were also present. Statistical analysis showed no differences between conservation headlands and normally sprayed headlands for measures of overall plant abundance and diversity but there was a greater proportion of dicotyledons, and of annuals and biennials, in conservation headlands. These results support the conclusions from previous experimental work and surveys that conservation headlands have a positive conservation value. They therefore contribute to the ESA scheme objective of safeguarding areas of national wildlife interest through use of beneficial farming practices.

INTRODUCTION

In the intensively farmed arable lowlands of Britain, linear landscape features form an important network of wildlife habitats where other semi-natural habitats are often scarce. The value of field margins as reservoirs of beneficial polyphagous insect predators (e.g. Coombes & Sotherton, 1986) and for wildlife conservation more generally (Way & Greig-Smith, 1987) is also well documented. More recently the value of arable field margins for the conservation of arable plant communities has been recognised (Wilson, 1994b).

The most important arable communities of sandy soils in Britain are found in Breckland (Wilson, 1994a). Some of the component species are long-established weeds of ancient cultivation. As well as widely distributed arable plant species typical of fertile base-rich soils, there are others which are associated with the high summer soil moisture deficit, and lower soil nutrient availability which are a consequence of the light soils and semi-continental climate of the area (Critchley, 1996b). These were recognised by Watt (1971) as being an important element of the Breckland flora, associated with disturbed conditions of arable field margins and tracks.

The Environmentally Sensitive Area (ESA) scheme was introduced in 1987 to encourage farmers to help safeguard areas of the countryside where the landscape, wildlife or historic interest is of national importance. Farmers and landowners receive annual payments for entering into voluntary 10-year management agreements (5-year before 1993), which require them to manage their land according to a set of management prescriptions. The Breckland ESA scheme allows management of arable field margins as conservation headlands. Conservation headlands are cereal headlands in which pesticide and herbicide inputs are restricted (Sotherton, 1991). On cereal headlands at least 6m wide, insecticide applications are prohibited between 1 January and 31 August. Also, herbicide inputs are restricted to application of specified chemicals (Table 1), with further restrictions on purpose, timing and method of application for some.

Table 1. Herbicides permitted for use on conservation headlands in Breckland ESA.

Herbicide	**Permitted use**
tri-allate, diclofop-methyl, difenzoquat, flamprop-m-isopropyl, fenoxaprop-ethyl	any
glyphosate	only in the pre- or post-harvest period
Fluroxypr	applied by spot treatment for the control of cleavers
other herbicides	subject to approval by the Ministry

This study formed part of a national ESA monitoring scheme designed to assess the success of individual ESAs. It compared the plant communities occurring in conservation headlands managed under ESA agreement with those on normally sprayed headlands. This allowed an assessment of the role of conservation headlands in maintaining and enhancing the wildlife conservation value of arable field margins.

MATERIALS AND METHODS

A single survey was carried out on a sample of farms during the period 17 May to 10 June 1993. All farms with ESA management agreements for conservation headlands at the time of the survey were included in the sample. Of these, nine farms contained both conservation headlands and normally sprayed cereal headlands. Within each of these farms, three conservation headlands and one normally sprayed headland were randomly selected. A number of farms had conservation headlands, but no normally sprayed headlands. From these, an additional 17 sites were randomly selected, making a total of 44 conservation headlands surveyed.

Within each headland a 100m long section was located randomly for the botanical survey. In each 100 m section, three transects, each 50 m apart, were located. Each transect was positioned at right angles to the field boundary. Three quadrats (0.5 m × 0.5 m) were placed on each transect, at distances of 1, 3, and 5 m from the field boundary in 6 m wide headlands, and 2, 6 and 10 m in 12 m wide headlands. The number of individuals of all plant species rooted in each quadrat was recorded (plant density). Vascular plants were recorded to species or subspecies level, but on occasions where it was not possible to do so reliably in the field, they were recorded to genus level. Mosses and liverworts were recorded collectively, with no separation of species. For grasses the number of tillers was also counted.

Comparisons were made between conservation headlands and normally sprayed headlands for a number of vegetation variables, notably species richness, plant density, grass tiller counts, and the ratio of dicotyledons to monocotyledons. In addition, three response variables were analysed to assess the extent to which the vegetation contained species suited to, and characteristic of, the specialised conditions of Breckland. These were the proportions of species recorded which were suited to regular physical disturbance of the soil surface (D score), high summer soil moisture deficit (M score) and moderate or low soil nutrient availability (N score) respectively (Critchley 1996b). In each case a high score indicated a high proportion of these species. In all cases, calculation of values was based on total counts per site.

Statistical analysis was done using General Linear Modelling (GLM) because of the unbalanced replication within a site between conservation headlands and normally sprayed headlands. For these analyses, the nine farms containing both conservation headlands and normally sprayed headlands were used. In the model, the term 'site' (a farm from which headlands were sampled) was defined as a fixed factor, and 'management' (conservation headland or normally sprayed headland) was nested within 'site'. Randomisation tests (Manly, 1991) were used to confirm the significances of differences between sample means, to account for the possibility of non-normally distributed data. Up to 5000 cycles of the randomisation were done for each analysis and the F values were compared with those derived from the original data.

RESULTS

A total of 44 species were recorded from conservation headlands and normally sprayed headlands (Table 2). Species recorded from conservation headlands which are typical of Breckland field margins included *Arenaria serpyllifolia* (Thyme-leaved sandwort), *Descurainia sophia* (Flixweed) and *Anthriscus caucalis* (Bur chervil). Nationally declining species included *D. sophia* (which has its British distribution centered on Breckland) and *Legousia hybrida* (Venus' looking glass).

No significant differences were detected between conservation headlands and normally sprayed headlands for species richness, plant density, grass tiller counts, M score or N score (Table 3). However, the D score for conservation headlands was significantly higher than for normally sprayed headlands, indicating a greater proportion of annuals and biennials to perennials. Similarly, the ratio of dicotyledons to monocotyledons was significantly higher in conservation headlands. The frequency distributions of species richness and plant density and, to a lesser extent M scores and N scores, all showed trends where higher values were recorded from conservation headlands than normally sprayed headlands. This suggests that with a larger sample size these apparent differences may have been detectable. Variation in species richness was lower in normally sprayed headlands, with most sites having fewer than ten species; in the analysis the difference was just outside the limits of significance. In the case of D scores, a number of normally sprayed headlands had very low values, whilst in others they were comparable to those of conservation headlands.

Table 2. Species ordered by frequency of occurrence in conservation headlands.

Latin name	Common Name	Frequency in conservation headlands (n = 44 sites)	Frequency in normally sprayed headlands (n = 9 sites)
Poa annua	Annual Meadow-grass	84.4	66.7
Stellaria media	Common Chickweed	62.2	22.2
Polygonum aviculare	Knotgrass	53.3	33.3
Veronica persica	Common Field-speedwell	48.9	22.2
Chenopodium album	Fat-hen	48.9	22.2
Fallopia convolvulus	Black-bindweed	46.7	11.1
Silene latifolia	White Campion	44.4	11.1
Sisymbrium officinale	Hedge Mustard	44.4	0
Urtica urens	Small Nettle	42.2	11.1
Viola arvensis	Field Pansy	42.2	33.3
Cirsium arvense	Creeping Thistle	40	11.1
Capsella bursa-pastoris	Shepherd's-purse	37.8	0
Tripleurospermum inodorum	Scentless Mayweed	37.8	22.2
Aphanes arvensis	Parsley-piert	35.6	11.1
Agrostis stolonifera	Creeping Bent	33.3	11.1
Arenaria serpyllifolia	Thyme-leaved Sandwort	31.1	11.1
Papaver rhoeas	Common Poppy	28.9	11.1
Veronica arvensis	Wall Speedwell	24.4	11.1
Arabidopsis thaliana	Thale Cress	22.2	0
Lamium amplexicaule	Henbit Dead-nettle	20	0
Urtica dioica	Common Nettle	17.8	11.1
Poa trivialis	Rough Meadow-grass	15.6	0
Anchusa arvensis	Bugloss	15.6	22.2
Reseda lutea	Wild Mignonette	13.3	0
Myosotis arvensis	Field Forget-me-not	13.3	0
Legousia hybrida	Venus'-looking-glass	13.3	0
Matricaria matricarioides	Pineapple-weed	13.3	11.1
Anthriscus caucalis	Bur Chervil	13.3	11.1
Descurainia sophia	Flixweed	13.3	11.1
Fumaria officinalis	Common Fumitory	11.1	0
Senecio vulgaris	Groundsel	11.1	0
Sonchus asper	Prickly Sowthistle	11.1	0
Cerastium fontanum	Common Mouse-ear	8.9	0
Veronica polita	Grey Field-speedwell	8.9	0
Elymus repens	Common Couch	8.9	0
Artemisia vulgaris	Mugwort	8.9	11.1
Raphanus raphanistrum	Wild Radish	8.9	11.1
Veronica hederifolia	Ivy-leaved Speedwell	8.9	22.2
Cirsium vulgare	Spear Thistle	6.7	0
Convolvulus arvensis	Field Bindweed	6.7	0
Rumex obtusifolius	Broad-leaved Dock	6.7	0
Anthriscus sylvestris	Cow Parsley	0	11.1
Acer pseudoplatanus	Sycamore	0	11.1
Lolium perenne	Perennial Ryegrass	0	22.2

Table 3. Results of GLM analyses comparing vegetation variables between conservation headlands and normally sprayed headlands. Data are means ± standard errors; n.s. = not significant, * P < 0.05.

Variable	**Conservation headlands**	**Normally sprayed headlands**	F **(df = 9)**
species richness	9.70 ± 1.08	4.78 ± 1.22	2.13 n.s.
plant density	99.1 ± 18.0	46.7 ± 21.9	0.97 n.s.
grass tiller count	73.0 ± 17.9	69.1 ± 31.4	0.61 n.s.
D score	0.667 ± 0.035	0.526 ± 0.115	5.11*
M score	0.206 ± 0.042	0.069 ± 0.039	0.57 n.s.
N score	0.086 ± 0.033	0.045 ± 0.032	0.41 n.s.
dicot: monocot ratio	0.775 ± 0.037	0.605 ± 0.130	4.76*

Significant differences between farms were also detected for the D score (n = 9, F = 9.49, P < 0.05) and the ratio of dicotyledons to monocotyledons (n = 9, F = 6.65, P < 0.05), but not for the other variables tested. This indicated that the vegetation varied significantly between farms.

DISCUSSION

Although no differences were found in the numbers of plant individuals, species or grass tillers between conservation headlands and normally sprayed headlands, the finding that conservation headlands had a greater proportion of annuals and biennials, and of dicotyledons, was important. Generally, it is annual dicotyledons which have declined most in arable fields with agricultural intensification (Fryer & Chancellor, 1970; Chancellor & Froud-Williams, 1984), while the currently widespread practice of direct drilling and minimal cultivations may favour perennial weeds (Chancellor & Froud-Williams, 1986). Thus, conservation headlands within the Breckland ESA have provided opportunities for these otherwise declining groups of species to prosper.

Other surveys of conservation headlands have shown increases in the numbers of both broadleaved (Sotherton *et al.*, 1985; Sotherton, 1991) and annual species (Davies & Carnegie, 1994). Similarly, some rare arable weeds are associated with field margins and will therefore benefit from reduced herbicide inputs along the field edge (Sotherton, 1991). Conservation headlands, along with other field margin management practices such as uncropped wildlife strips (Critchley 1996a), have positive value in this ESA by contributing to the conservation of the unique plant communities associated with arable systems.

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CAN SOWN FIELD BOUNDARY STRIPS REDUCE THE INGRESS OF AGGRESSIVE FIELD MARGIN WEEDS ?

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ABSTRACT

Four-metre wide field boundary strips, sown with various seed mixtures and compared with unsown (natural regeneration), were established in arable fields within three Environmentally Sensitive Areas in England. One objective was to determine the effect of boundary vegetation strips on the ingress of field margin weeds. Data on four aggressive weed species (*Cirsium arvense*, *Elymus repens*, *Galium aparine* and *Bromus sterilis*) were selected from all 14 sites for investigation. Results after three years indicate that, generally, the ingress of these weed species was more effectively suppressed (but not prevented) by sown boundary strips compared with unsown. Effects on other pernicious weeds causing problems at individual sites are also considered.

INTRODUCTION

Field margins have often been perceived as harbouring a threat to crops from weed invasion and this has promoted inappropriate management regimes. However, research has shown that only a few field margin plant species pose a real threat of spreading into adjacent crops (Marshall, 1989). These species are usually competitive annuals, such as *Galium aparine* and *Bromus sterilis*, or perennials with vigorous underground creeping root or rhizome systems, such as *Cirsium arvense* and *Elymus repens*, which thrive under conditions of high soil fertility and poor competition from the natural perennial vegetation in the field boundary. Various research initiatives in recent years have recognised that field margins with diverse vegetation can be important areas for conservation of some endangered plant species, encouraging beneficial insects and providing refuges for farmland wildlife. One research approach has been to create species-rich (mainly perennial) vegetation strips between the crop edge and field boundary, by sowing or through natural revegetation. This technique gives a simple means of increasing the size of semi-natural habitat and may give some agricultural benefits, such as reducing the spread of field margin weeds into the crop (Smith *et al.,* 1994). Our paper uses data on weed species abundance, collected over three years, extracted from a larger data-set recorded from our project involving the establishment and management of experimental arable field boundary strips as buffers to protect field boundary habitats (West & Marshall, 1996). We examine the occurrence of four major weed species as influenced by these introduced boundary strips.

MATERIALS AND METHODS

Three Environmentally Sensitive Areas (ESAs) in England with contrasting soil types were selected for study. A replicated field experiment was initiated using six sites in the Breckland ESA, and four sites in both the Somerset Levels & Moors and The South Wessex Downs ESAs. Within each ESA, half of the sites were established in autumn 1993 and the other sites established in spring 1994. One side of each field between the crop edge and the boundary was marked out into six plots, each 30m long and 4m wide. At each site, five of the 30m plots were sown with a different seed mixture, these being grass-only (EG1) or wild-flower/grass mixes (EM1, EM5, EM6 and EM7) supplied by Emorsgate Seeds, with one 30m unsown plot allowed to revegetate naturally. Each 30m plot was divided initially into three sub-plots and, subsequently, into six sub-sub-plots for various management treatments. Allocation of seed mixtures and management regimes to the plots was fully randomised. All plots at all sites were cut in autumn 1994 and 1995.

During the summers of 1994, 1995 and 1996, the development of the plant communities was assessed for each sub-sub-plot. Each higher plant species present was identified and given a modified Braun-Blanquet cover-abundance score (0 - 9) which was converted to an estimated percentage cover for analysis as follows: 0=0, 1=0.25, 2=0.5, 3=1, 4=2, 5=5, 6=12.5, 7=25, 8=50, 9=75%. Data were extracted from all sites for the four selected, commonly found, field margin weed species and from individual sites for four species selected as causing particular problems.

Analysis

The presence of the selected common weed species was recorded for all sub-sub-plots over all sites and, for analysis, the data were split only in respect of the unsown plots compared with the five sown plots combined. Data on occurrence were analysed for each species separately, using a generalised linear model assuming a binomial distribution and a logit link function.

The estimated percentage cover for the four selected species was analysed with respect to time (year assessed and season established) and the seeding regime on the main plots. Unsown and grass-sown plots were split from the other sown plots. Any effects due to ESAs or management treatments are not separated from the residual variation in order to give a `fair' assessment of the overall effects of the sown plots. It was only for *C. arvense* that any terms involving the comparisons between grass and the wild-flower/grass sown plots were statistically significant. Thus, for the other three species only the separation between unsown and the rest is retained. Analyses were performed using the transformation, $\log_e (\% + 0.25)$, and the results are presented on this scale with back-transformed percentage values in parentheses.

For the statistical analysis of weed species on individual sites, only comparisons of cover between unsown, grass-sown and the other sown plots combined, and the effects of the year were considered. No treatments on the sub-plots or sub-sub plots were estimated. The data were logarithmically transformed and results presented as previously described.

RESULTS

Occurrence of selected weed species (all sites included)

For *C. arvense* there was significant evidence of different trends of occurrence with time for sown and unsown plots (Table 1). Its occurrence in summer 1994 was similar for unsown and sown plots, but whereas the occurrence remained reasonably constant on the sown plots in 1995 and 1996, there was a significant increase in its presence on the unsown plots in 1995 and 1996. There was no evidence of differences in 1994 or 1995 between sown and unsown plots for the occurrence of *E. repens*, but a large increase in both plot types in 1996 compared with the previous two years. There were no clear differences in the occurrence of *G. aparine*, although there was some indication of an increase in its presence within the unsown plots over time. For *B. sterilis* there was clear evidence of differences of occurrence with time between plot types. In 1994 the occurrence of *B. sterilis* was similar for both plot types, followed by a large increase through 1995 and 1996 within the unsown plots, but only a small increase from 1994 to 1995 in the sown plots which remained at a similar level in 1996.

Table 1. Overall percentage occurrence in sub-sub-plots from all sites

	1994		1995		1996	
Species	Unsown	Sown	Unsown	Sown	Unsown	Sown
Cirsium arvense	56.0	54.5	67.9	52.4	77.4	56.0
Elymus repens	65.5	61.9	60.7	61.7	88.1	79.3
Galium aparine	34.5	41.7	38.1	27.4	46.4	37.1
Bromus sterilis	25.0	29.5	53.6	42.4	60.7	39.5

Estimated percentage cover of selected weed species (all sites included)

On both autumn- and spring-established sites, the percentage cover of *C. arvense* on unsown and grass-sown plots showed a significant increase with time, whereas on the other (wild-flower/grass-sown) plots there was little change between years (Table 2). However, there were no significant differences in abundance between any grass-sown and wild-flower/grass-sown plots within any given year and season of establishment, whereas for the autumn-established sites there was significantly greater abundance of *C. arvense* in the unsown plots compared with any of the sown plots.

Table 2. Overall estimated percentage cover for *Cirsium arvense* averaged over similar sub-sub-plots from all sites. (Numbers in parentheses are back-transformed means)

			Autumn-established			
Year	Unsown		Grass-sown		Other-sown	
1994	0.226	(1.00)	-0.612	(0.29)	-0.404	(0.42)
1995	0.774	(1.92)	-0.387	(0.43)	-0.313	(0.48)
1996	0.952	(2.34)	-0.089	(0.66)	-0.476	(0.37)
			Spring-established			
1994	-0.897	(0.16)	-1.028	(0.11)	-0.557	(0.32)
1995	-0.508	(0.35)	-0.845	(0.18)	-0.444	(0.39)
1996	-0.289	(0.50)	-0.538	(0.33)	-0.415	(0.41)

	LSD (p= 0.05)
a) Comparing unsown with grass within a year and season	0.678
b) Comparing unsown or grass with other-sown, within year and	0.536
c) Comparing years within a season for unsown and grass	0.281
d) Comparing years within a season for other-sown	0.141

Generally, the abundance of *E. repens* in unsown plots was greater than in sown plots, but in only one comparison (spring-established 1996) was the difference statistically significant (Table 3). Within the autumn-established sites there was a highly significant increase in abundance of *E. repens* over time from 1994-1996 on both unsown and sown plots. There was also an increase in abundance on the spring-established sites, but this was less consistent and showed a slight decrease from 1994 to 1995 before increasing again in 1996.

Table 3. Overall estimated percentage cover for *Elymus repens* averaged over similar sub-sub-plots from all sites. (Numbers in parentheses are back-transformed means)

	Autumn-established				Spring-established			
Year	Unsown		Sown		Unsown		Sown	
1994	-0.012	(0.74)	0.054	(0.81)	0.448	(1.32)	0.175	(0.94)
1995	0.423	(1.28)	0.145	(0.91)	0.097	(0.85)	-0.058	(0.69)
1996	1.348	(3.60)	0.962	(2.37)	1.373	(3.70)	0.734	(1.83)

	LSD (p=0.05)
a) Comparing unsown with sown within a year and season	0.497
b) Comparing years within a season for unsown	0.404
c) Comparing years within a season for sown	0.181

The unsown plots generally had greater abundance of *G. aparine* than the sown plots, but percentage cover was only significantly more on the unsown plots compared with the sown plots for the spring-established sites in 1995 and 1996 (Table 4). The only time-trend of significance was the slightly increased abundance from 1994-1996 of *G. aparine* on the spring-established unsown plots, and the decrease on the autumn-established plots from 1994-1995.

Table 4. Overall estimated percentage cover for *Galium aparine* averaged over similar sub-sub-plots from all sites. (Numbers in parentheses are back-transformed means)

	Autumn-established				Spring-established			
Year	Unsown		Sown		Unsown		Sown	
1994	-0.502	(0.36)	-0.636	(0.28)	-1.013	(0.11)	-0.946	(0.14)
1995	-0.900	(0.16)	-1.060	(0.10)	-0.828	(0.19)	-1.096	(0.08)
1996	-0.666	(0.26)	-0.853	(0.18)	-0.742	(0.23)	-0.996	(0.12)

	LSD (p=0.05)
a) Comparing unsown with sown within a year and season	0.214
b) Comparing years within a season for unsown	0.231
c) Comparing years within a season for sown	0.103

There were low levels of *B. sterilis* in summer 1994 on the unsown and sown plots of both autumn- and spring-established sites (Table 5). In 1995, significantly greater quantities of *B. sterilis* were recorded on the unsown plots compared with sown plots within the autumn- or spring-established sites. Although abundance on both plot types had increased significantly from 1994, the increase was considerably more on the unsown plots. In summer 1996 the cover of *G. aparine* on the sown plots was similar to that in 1995, but while there was a very significant increase in abundance on the unsown plots within the spring-established sites, the cover on autumn-established unsown plots was reduced significantly, becoming similar to that found on sown plots.

Table 5. Overall estimated percentage cover for *Bromus sterilis* averaged over similar sub-sub-plots from all sites. (Numbers in parentheses are back-transformed means)

	Autumn-established				Spring-established			
Year	Unsown		Sown		Unsown		Sown	
1994	-1.118	(0.08)	-1.005	(0.12)	-0.938	(0.14)	-0.837	(0.18)
1995	-0.218	(0.55)	-0.746	(0.22)	0.153	(0.92)	-0.375	(0.44)
1996	-0.608	(0.29)	-0.798	(0.20)	1.220	(3.14)	-0.364	(0.44)

	LSD (p=0.05)
a) Comparing unsown with sown within a year and season	0.317
b) Comparing years within a season for unsown	0.345
c) Comparing years within a season for sown	0.155

Problem species at individual sites

At one Somerset, autumn-established site, *Ranunculus repens* increased from low levels in 1994 to dominate all unsown and sown plots by 1996 (65-75% cover). At a Somerset, spring-established site, *Bromus commutatus* dominated the unsown plots (70% cover) by 1996, while cover was significantly less on the grass-sown plots (13%) and significantly less again on the plots sown with the wild-flower/grass mix (3%). A similar trend was apparent at a Breckland, spring-established site, where *Urtica dioica* attained substantial cover (36%) on unsown plots by 1996 but only 9% cover on grass-sown plots and 3% on the wild-flower/grass sown plots. In summer 1996, on a S. Wessex site, *Heracleum sphondylium* had achieved dominant cover (55%) on the unsown plots but was significantly suppressed on all the sown plots.

Table 6. Estimated percentage cover of problem species at individual sites in 1996, averaged for sub-sub-plots. (Numbers in parentheses are back-transformed means)

Plot-type	*R. repens*		*B. commutatus*		*U. dioica*		*H. sphondylium*	
Unsown	4.25	(70.1)	4.25	(69.9)	3.57	(35.4)	4.00	(54.6)
Grass	4.32	(75.0)	2.59	(13.1)	2.19	(8.7)	2.40	(10.8)
Other	4.17	(64.7)	1.20	(3.1)	1.05	(2.6)	1.80	(5.8)
a) LSD (p=0.05)	1.030		1.439		1.204		1.369	
b) LSD (p=0.05)	0.814		1.138		0.952		1.082	

a) comparing unsown with grass-sown
b) comparing unsown and grass-sown with other-sown

DISCUSSION

Not all selected weed species were present at all sites. Hence, the overall mean percentage cover values appear low, especially for *G. aparine*, which had the lowest frequency of occurrence. Nevertheless, it is clear from our results that growth of the perennials, *C. arvense* and *E. repens*, was considerably suppressed by competition with sown species, compared with growth on unsown plots. Whereas cover of *C. arvense* on sown plots was similar in 1996 to its initial cover in summer 1994, the cover of *E. repens* had increased. Marshall (1990) also showed that spread of *E. repens* was reduced in competition with sown perennial grasses. Cover of *B. sterilis* was generally more abundant on the spring-established sites, where it appeared to exploit the more open swards often associated with this establishment regime (West & Marshall, 1996). However, its cover was substantially reduced on the sown plots. From the individual site examples we found that problem weeds, often unique to the site conditions, can dominate the unsown boundary strips but are usually effectively suppressed in the sown strips. Exceptions do occur, as seen in one Somerset site, where after winter-flooding the sown-strips were poorly established and these conditions promoted vigorous exploitation by *R. repens,* which dominated all plots on the boundary strip after two years.

Our results also show that, at the sites tested, the sown wild-flower/grass strips are as effective (or more so) for suppressing weed species as the sown grass-only strips. Some researchers have suggested that grass-only strips are more effective for weed suppression (Smith *et al.*, 1994). This is of importance when considering the use of sown strips. Sown grass-only strips tend to produce a habitat with low plant species richness, while wild-flower/grass sown strips are usually as diverse as, or more diverse, than naturally regenerated strips (West & Marshall, 1996).

In conclusion, our results suggest that where aggressive weeds are present in field margins, better suppression is generally given by successfully established boundary strips than by allowing vegetation to regenerate naturally. Leaving uncropped areas around field margins is gradually becoming an acceptable management practice, providing agronomic and environmental benefits. With the introduction of support schemes such as the UK Countryside Stewardship, opportunities with financial benefits now exist to improve overall on-farm conservation, including the establishment of sown field boundary strips.

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CONSERVING THE FLORA OF ARABLE FIELD MARGINS - HOW MUCH DOES IT COST?

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ABSTRACT

Arable plant communities have undergone considerable impoverishment in recent years, and their conservation is a priority. Management techniques are becoming better understood and more widely practiced, but there is a need to know how much they will cost the farmer. Experiments were carried out in 14 fields between 1992 and 1994, to determine the success and financial costs of three different field margin management methods; conservation headland, conservation headland without nitrogen and uncropped wildlife strip. The costs of all three methods were found to be within the amount payable under the Countryside Stewardship Scheme for arable field margins.

INTRODUCTION

The decline of population sizes, contraction of distribution of many species and impoverishment of communities of arable plants has been extensively documented throughout the whole of Europe in recent years (Wilson, 1990; Albrecht, 1995; Andraesen et al, 1996 etc). These changes have led to the formulation of management guidelines, and in some countries these have been included in environmental enhancement schemes for arable land (Klein, 1994; MAFF, 1996).

The management requirements for the conservation of arable plant communities are becoming better understood. For such management to become acceptable to the farming community however, it must be realistically costed to enable compensation for yield loss and inconvenience. In order to determine potential financial losses, yield losses, crop quality penalties and differences in variable costs must be taken into consideration.

METHODS

Experiments were carried out between 1992 and 1994 in cereal crops in 14 fields on eight farms in southern England (Table 1). Plots were situated in field headlands, as these are known to be the areas of highest botanical diversity (Wilson & Aebischer, 1995), and are also the areas at which the majority of agri-environmental management schemes are aimed. Plots measured between 15 and 20 metres in length and were six metres wide. They were arranged along the field headland in either three or four blocks of plots (Table 1), each of which contained one replicate of each treatment.

At each site there was a control treatment in which the standard farm agrochemical and fertiliser regime was followed, a treatment similar to the Conservation Headland (Sotherton, 1990) with full fertiliser application but no agrochemical application, and plots to which neither agrochemicals or fertilisers were applied. In some cases there were also plots which remained undrilled after cultivation (Uncropped Wildlife Strips; Critchley, 1996). At all sites, operations were carried out by farm staff using normal farm machinery in order to reproduce as completely as possible the conditions prevailing in a normal arable situation. Full details of all agrochemical and fertiliser inputs are given in Wilson (1995).

Table 1. Details of experimental sites. Soil types - zyl = silty loam, fsl = fine sandy loam, zycl = silty clay loam, cl = clay loam. All soils are calcareous to highly calcareous. Crop - wb = winter barley, ww = winter wheat, sb = spring barley. n = number of replicates of each treatment.

	County	soil	Year	Crop	Harvest	n
1	Hampshire	zyl	1992/3	wb	Combine	3
2	Norfolk	fsl	1992/3	wb	Combine	3
3	Hampshire	zyl	1992/3	ww	Combine	4
4	Wiltshire	zyl	1992/3	ww	Hand	4
5	Suffolk	fsl	1992/3	ww	Combine	3
6	Hampshire	zyl	1992/3	sb	Combine	3
7	Norfolk	fsl	1992/3	sb	Combine	3
8	Hampshire	zyl	1992/3	sb	Combine	3
9	Dorset	zyl	1992/3	sb	Hand	3
10	Hampshire	zyl	1992/3	sb	Hand	3
11	Hampshire	zyl	1993/4	wb	Combine	3
12	Hampshire	zycl	1993/4	ww	Combine	3
13	Norfolk	fsl	1993/4	sb	Combine	3
14	Hampshire	zyl	1993/4	sb	-	3
15	Hampshire	zyl	1993/4	sb	Combine	4

Plant numbers were counted in June and July in ten 0.25m^2 quadrats in each plot. Plots were harvested at the same time as the rest of the field from 14 of the 15 sites using either a small plot combine harvester or by hand. Yield of grain, and where possible, moisture content, hectolitre weight and 1000-grain weight were determined.

Results for numbers of plants and yield parameters were analysed by analysis of variance, considering the experimental treatments as categorical factors. Information about chemical and fertiliser inputs was collected from the farmers in order to calculate variable costs under each treatment. Where information was not readily available from farmers, mean costs were taken from Nix (1994). Variable costs included costs of cultivations, seed, fertilisers, agrochemicals, harvesting and drying.

RESULTS

At all sites there were significant differences between numbers of plant species present in the experimental treatments. At all sites the lowest numbers were present in herbicide treated plots, and numbers were lower in plots that had had nitrogen applied than in plots which had not been fertilised (Table 2). The greatest number of species were found in plots which had not been drilled. For full results see Wilson (1995).

Table 2. Mean numbers of species per m^2 under different treatments in 15 experiments.

	- herbicide -nitrogen -crop	-herbicide -nitrogen +crop	-herbicide +nitrogen +crop	+herbicide +nitrogen +crop
Means	27.40	21.86	17.45	7.74

At 12 of the 14 sites from which crop samples were taken, yield differed significantly between treatments. The greatest differences were between plots to which nitrogen had been applied and those to which it had not been applied. Yield was only significantly increased by pesticide application at two sites. Mean increases in yield due to nitrogen use were 210% in winter wheat, 175% in winter barley and 165% in spring barley, while increases resulting from agrochemical use were 10% in winter wheat, 8% in winter barley and 9% in spring barley. Mean yields from fully treated headland plots were 11.2% lower than those from the rest of the field (Table 3).

Table 3. Mean yields and sale values of crops under experimental treatments and from the rest of the field.

	- herbicide - nitrogen		- herbicide + nitrogen		+ herbicide + nitrogen		rest of field	
	T/ha	£/ha	T/ha	£/ha	T/ha	£/ha	T/ha	£/ha
Winter wheat mean	2.89	260	6.06	545	6.67	644	7.51	728
Winter barley mean	2.28	198	3.98	346	4.28	445	5.52	574
Spring barley mean	2.85	248	4.71	410	5.12	525	5.52	574

There were significant treatment differences for 1000-grain weight at only one of the sites. Hectolitre weight differed significantly between treatments at three sites, but at only one was it below the threshold level for sale as seed. It was however assumed that grain harvested from plots untreated with agrochemicals or nitrogen would be sold for feed, while grain from the fully treated plots would be sold for malting or milling.

Table 4. Mean gross margins £/ha for experimental headland treatments and from the normally farmed area of the rest of the field in three types of cereal crop. Gross margin is calculated as the sale value of the crop (Table 4) - variable costs.

	-herbicide -nitrogen	-herbicide +nitrogen	+herbicide +nitrogen	rest of field
Mean sale value of winter wheat	260	545	644	728
Mean variable costs	195	296	406	406
Mean gross margin	65	251	238	322
Mean sale value of winter barley	198	346	445	574
Mean variable costs	196	289	368	368
Mean gross margin	2	57	77	206
Mean sale value of spring barley	248	410	525	574
Mean variable costs	192	252	336	336
Mean gross margin	56	158	189	238

While yields were greater where agrochemicals were used, and considerably greater where nitrogen was applied, the costs of the inputs themselves and the labour involved in their application must be offset against any loss of profit (Table 4). The costs of cultivation are the same in all cases and were estimated at £54 (Nix, 1994).

In winter wheat, the costs of agrochemical application were so high that the highest mean gross margin was in plots where only nitrogen was applied. In the other two crops the highest gross margin was in the full application plots. The gross margin in the no-application plots was 27% of that in the fully treated plots in winter wheat, 3% in winter barley and 27% in spring barley.

DISCUSSION

Of the options tested, cultivated plots with no crop or subsequent inputs supported the highest number of species. Mean species number was lower where a crop was drilled, and was further reduced with nitrogen addition. Numbers were lowest where agrochemicals, most importantly herbicides, were applied. While species number is an insensitive measure of the effect of a treatment, it does give a broad indication of effect. The impact of herbicides on the composition of arable plant communities and the mortality of plants is well known (Roberts & Neilson, 1981; Wilson, 1990 etc.). Nitrogen application has also been shown to have a detrimental effect on plant survival within a cereal crop, and has an impoverishing effect on community composition (Wilson, 1990; Grundy, 1993; Pysek & Leps, 1991).

Cereal varieties have been developed for the responsiveness of yield to nitrogen addition. The increase in yield observed here with nitrogen addition is unsurprising. Much of the response to agrochemical addition is likely to be due to the application of fungicides rather than herbicides (Boatman, 1992). Any attempt to separate the effects of different agrochemical inputs would have made the experiments impractical to set up on a working farm. The difference between yield from the fully-treated headland plots and the central part of the field is typical in arable fields, and is a result of soil compaction, shading and other factors operating at field margins (Boatman & Sotherton, 1988). It was assumed that crops from low-input field headlands would be used for animal feed, although the barley could have been sold for malting especially where nitrogen inputs were low. Sale prices here therefore err on the side of caution. Although yield was lower in plots where conservation management was tested, this reduction was at least partly compensated for by lowered costs of inputs. In winter wheat, variable costs were so high in fully treated plots, that mean gross margin was actually higher when agrochemicals were not applied.

Table 5. Profit foregone in £ per 100m length of 6m wide field headland managed under conservation guidelines compared to conventionally managed headlands.

	-herbicide -nitrogen -crop	-herbicide -nitrogen +crop	-herbicide +nitrogen +crop
Winter wheat	17.52	10.38	-0.78
Winter barley	7.86	4.50	1.20
Spring barley	14.58	7.98	1.86

Current rates of payment for arable field margin management in the Countryside Stewardship Scheme are £35 for a 100m long, 6m wide headland strip (MAFF, 1996). Such strips can be cultivated at the same time as the rest of the field but not drilled or treated with agrochemicals or fertilisers. Such management is also supported within several ESAs and by the Habitat Scheme for former set-aside land (MAFF, 1994). Such schemes have been in place throughout Germany since 1986, and in 1994 attracted payments of between approximately £7.5 and £36 for a 100m headland strip (Klein, 1994). Profits foregone as a result of managing field margins for the conservation of arable plant communities are well within these levels of payment (Table 5). There would therefore appear to be little financial reason for a farmer with arable field margins of conservation importance not to enter them into a management agreement of some kind. The main obstacles at the moment appear to be deficient knowledge of the location of botanically-rich field margins, failure to appreciate their importance, insufficient funds within the available schemes, and problems in persuading farmers that “farming weeds” makes agronomic and economic sense. These problems must be remedied by a comprehensive programme of survey and interpretative work and vigorous campaigning for the reallocation of CAP funds.

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A LONG-TERM STUDY ON EFFECT OF NO-TILLAGE ON WEED DEVELOPMENT AND YIELD OF CONTINUOUS WHEAT AND BARLEY

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ABSTRACT

In field trials conducted in Thessaloniki, for five years and in Nea Zoi (NZ) for four years with different soil types, five tillage treatments and two levels of N fertilizer were compared with continuous wheat in the first and continuous barley in the second site. The soil tillage treatments tested were two conventional, a reduced system and two direct-drilling after glyphosate or paraquat spray to kill weeds. On no-tilled soil, less annual weed were found than on tilled soil, but grass weeds caused difficulties and perennial rhizomatous weeds only after paraquat. No- tillage has resulted in weed flora poor in species deversity but highly specialized for survival, where *Lolium rigidum* and *Alopecurus myosuroides* occurred at high density, because herbicide efficacy against these weeds was not sufficient. During the experiments grain yields were not significaly affected by seedbed preparation as well as N level applications. All tillage treatments attained similar yield with wheat and barley. Plant density were unaffected by tillage or by N levels.

INTRODUCTION

Wheat is a prodominant crop in Greece and is grown on 1,200 million ha, on about 90 % of the dryland. Barley is of minor importance, but is grown especially on low fertility soils which are unsuitable for other crops. Wheat and barley are grown on areas in Greece which are semiarid and crop yield are low because of limited and irregular distribution of percipitation and high evaporation; thus, production costs and soil erosion must be minimized especially on hilly areas where severe soil erosion and loss of moisture can occur under intensive tillage management for winter wheat. Under these conditions, conservation of precipitation is extremely important for dryland farming, to lower production costs, and in the future, to conserve a diminishing natural resource that controls the region's agricultural stability and prosperity. Reduced tillage systems that maintain surface residues and increase surface roughness are currently being utilized for erosion control.

Early research at Cereal Institute of Greece, on three different soil types, shallow, deep and very deep tillage showed that wheat and corn yields did not differ between treatments, either in the year of the treatment or the following year (Tallelis 1966). Consequently methods conserving crop residues and controlling seedbed weeds have been sought. However, the disability to control weeds as well as lower crop yields have limited the use of conservation tillage practices in the United States (Almaras and Dowdyn 1985). Early attemps to control weeds in fallow with herbicides were not successful. The weeds were not always controlled and sowing was difficult. A successful system was developed in 1970's using paraquat or glyphosate. However, partial or total elimination of tillage brings about major changes in weed communities by influencing species composition, relative importance of individual species, and rates of population growth (Weston, 1990). Success of conservation tillage practices vary across the world. Reasons cited for lower yields under reduced tillage systems are increased grass-weeds (Papendick and Miller, 1977), residue problems during seeding (Izaurrald *et al.*, 1986) and decreased fertilizer efficiency (Cochran *et al.*, 1980).

The object of this study was to determine the effect of long-term conservation tillage systems, weed species composition and nitrogen levels on winter wheat and barley yields.

METHODS AND MATERIALS

Two experiments were conducted; one at the Cereal Institute (CI), Thessaloniki on sandy-clay soil for 5 years (continuous wheat cv Vergina) and one in Nea Zoe (NZ) on silty-clay soil for 4 years (continuous barley cv Carina). The plots were large enough to use field-size equipment. Plots were arranged according to a split-plot design with tillage practices as the main factor and N levels as the sub-plot factor. Treatments were replicated 4 times. The sub-plot size was 23 by 4 m and separated by 2 m alley.

Tillage treatments consisted of T_1: one mouldboard plough (15-20 cm) during autumn followed by disc-harrow for weed control. T_2: two mouldboard plough (15-20 cm) the first early in autumn and the second some days before seeding day followed by disc-harrow which is the most widely used practice by farmers. T_3: one mouldboard plough in the fall (15-20 cm) followed by rolling (at Cl) or one shallow rotary tillage in autumn by rolling (in NZ). T_4: Tillage fallow (no-till) and weed control by paraquat in the 1st, 2nd and 5th* year 2 to 3 weeks before sowing at the rate 1.0 kg ai/ha. T_5: Tillage fallow (no-till) and weed control by glyphosate in the 1st and 4th* year 2 to 3 weeks before sowing at a rate 3.0 kg a.i./ha. In all tillage treatments two levels of nitrogen were applied. N_1: 30 + 30 kg/ha and N_2: 30 + 70 kg/ ha. Also 40 kg/ha of phosphorus were applied in all plots. Each year wheat and barley were seeded at 150 kg /ha in early November. All tillage treatments were planted with a double disk press drill with openers in 15 cm row spacing. In the same one-pass operation, a season-long supply of fertilizer was placed 5-10 cm below the surface between a set of paired rows. Spring fertilizer was surface broadcast in all tillage treatments. Weeds were controlled through the use of herbicides in all tillage treatments to elimanate weed problems in the experiment. Crop protection against broad-leaved and grass weeds were in accordance with good farm practice. Assessment of weeds were done in each plot on two quadrats measuring 0.25 x 0.25 m. Each weed plant was hand rouged and was counted when the weeds were at the early flower development stage. Except for harvest and sowing, all field operations were conducted with large-scale farm-size equipment. Wheat and barley were harvested annually in early June with a 1.5 m wide plot combine.

The data were analysed as a split plot analysis of variance repeated across years and tested for homogeneity of variance and normality of distribution.

- In these experiment years autumn precipitation was sufficient to germinate weed seeds and warrant herbicide application before planting no-till wheat or barley.

Table 1. The effect of soil tillage on yield of wheat at Cereal Institute (Kg/ha).

Tillage	Fertilizer (kg/ha)	Year				
		1st	2nd	3rd	4th	5th
One mouldboard plough + disc-harrow	Ni:30+30	3810	2870	4150	4460	4280
	N2:30+70	3720	3000	3570	4160	3870
Two mouldboard plough + disc-harrow	Ni:30+30	3900	3120	4160	4860	4040
	N2:30+70	3690	3070	3430	4200	3680
One mouldboard plough + rotary tillage	Ni:30+30	3890	3070	4190	4330	4310
	N2:30+70	3710	3160	3760	4170	3870
No-till + paraquat spray	Ni:30+30	3660	2920	3990	5000	4200
	N2:30+70	3590	2710	3450	4190	3830
No-till+glyphosate spray	Ni:30+30	3840	2880	3990	4980	4350
	N2:30+70	3500	2740	3600	4400	3980
Mean	Ni:30+30	3820	2972	4078	4726	4236
	N2:30+70	3642	2936	3562	4224	3846
LSDTillage p=0.05		NS	NS	NS	NS	NS
LSD Fertilizer p=0.05		NS	NS	NS	279	315

Table 2. The effect of soil tillage on yield of barley at Nea Zoi (Kg/ha).

Tillage	Fertilizer (kg/ha)	Year			
		1st	2nd	3rd	4th
One mouldboard plough + disc-harrow	Ni:30+30	3550	3410	3120	3670
	N2:30+70	3520	3790	3270	3420
Two mouldboard plough + disc-harrow	Ni:30+30	3410	3500	3200	3470
	N2:30+70	3330	3880	3130	3620
One mouldboard plough + rotary tillage	Ni:30+30	3620	3310	3010	3310
	N2:30+70	3530	3550	3300	3150
No-till + paraquat spray	Ni:30+30	3540	3510	2860	3250
	N2:30+70	3470	3550	2970	3580
No-till+glyphosate spray	Ni:30+30	3540	3640	3110	3550
	N2:30+70	3570	3820	2890	3430
Mean	Ni:30+30	3532	3474	3058	3450
	N2:30+70	3844	3718	3112	3440
LSDTillage p=0.05		NS	NS	NS	NS
LSD Fertilizer p=0.05		NS	129	NS	279

RESULTS

Plant emergence and densities were unaffected by tillage, but in the fifth year in no-till plots some very small thin patches appeared because of high soil bulk density which did not affect yield. Wheat and barley yields under different tillage management did not differ. Significant differences in wheat and barley were observed between years (Table 1,2). Wheat yields at the Cereal Institute tended to be high in the low N level in all years, but only in the 4th year were significantly different. Barley yield at NZ were similar in the 1st and 3rd years with the two N levels but in two other years were significantly high at higher N level than those of lower N level.

Weeds were affected by the tillage systems (Table 3). In no-till plots annual grasses (*Avena ludoviciana, Lolium rigidum and Alopecurus myosuroides*) and small seeded broadleaf species (*Fumaria officinalis, Matricaria chamomilla, Papaver rhoeas, Chenopodium album)* increased whereas large seeded broadleaf decreased perennial weeds (*Elymus repens, Cirsium arvense and Convolvulus arvensis*) increased in no-till plots after paraquat but not after glyphosate.

Table 3. Effect of soil tillage on weed infestations (no/m^2)

Weed	T_1	T_4	T_5	T_1	T_4	T_5
Thessaloniki (CI)		First year			Fifth year	
Fumaria officinalis	3.3d	3.0d	4.3c	6.0b	6.8a	6.3ab
Matricaria chamomilla	5.0e	16.3a	17.1a	6.3d	8.8c	9.8b
Papaver rhoeas	11.0e	26.3a	20.3b	10.3e	17.3c	14.5d
Veronica spp.	13.0c	11.3d	10.6de	31.3a	15.0b	10.5e
Avena ludoviciana	3.0e	8.7c	6.3d	8.0c	21.3a	17.3b
Lolium rigidum	14.7d	15.7cd	18.7b	7.5e	23.8a	24.0a
Convolvulus arvensis	5.3d	12.0b	2.0e	9.0c	19.0a	5.0d
Nea Zoe (NZ)		First	year		Fourth	year
Capsella bursa pastroris	3.8b	2.3c	1.0d	9.0a	2.3c	1.0d
Chenopodium album	3.7d	7.3c	10.7b	3.7d	7.3c	16.0a
Galium spp.	3.7e	7.7c	10.3b	5.0d	8.6c	11.3a
Papaver rhoeas	10.6c	18.0a	14.0b	10.c	14.6b	10.0c
Alopecurus myosuroides	10.3f	32.7c	28.3d	15.3e	67.5a	60.0b
Elymus repens	8.3c	25.3a	2.3d	15.8b	25.3a	2.3d
Cirsium arvense	5.3c	13.3a	1.3d	9.3b	13.3a	1.3d

T_1: One mouldboard plough + disk-harrow T_4: No-till + paraquat spray 1.0 kg a.i/ha
T_5: No-till + glyphosate spray 3.0 kg a.i./ha
Figures with a common letter do not differ significanlty at $p<0.05$

DISCUSSION

Analysis of variance showed some singificant differences in wheat and barley yields between years. Differences between years were caused by climatic differences among years especially the amount and distribution of precipitation during the warm growing season. Wheat and barley yields were less during the year with the lowest rainfall during March to June, whereas the greatest yields were achieved during the year with the highest precipitation March through June. Annual variation of precipitation caused an interaction in the magnitute of yield, but not among tillage treatments as it has been found for other experiments (Young *et al.*, 1991).

Greece is characterised by a dry, warm climate from June (cereal harvest time) to October sometimes November which causes soil dryness. This limits the timing and effectiveness of management operations, thereby the time of optimum date of drilling.The delay of sowing time causes drastic yield reduction since seed filling will take place during the very dry period of the year (Skorda, 1981). Therefore it is not possible to take advantage of an opportunity to control emerged plants by seedbed preparation which would reduce weed and volunteer plant infestation since later emergence of new seedlings will be reduced.

In these experiments sowing time was the optimum for the region and was before the full emergence of a high number of seed of the most common weeds such as wild oat, ryegrass and others. However, primary tillage is extremelly effective on annual grass-weed and small-seeded weeds. By ploughing the fresh seeds are buried for one season. Small seeded species such as *Lolium rigidum, Alopecurus myosuroides, Papaver rhoeas, Fumaria officinalis* and others have practically no chance to germinate and emerge until they return to the upper soil layer one year later. In reduced tillage they remain in the upper layer and contribute immediately to the infestation. These results explain why reduced tillage, which is common now in wheat and barley growing areas of the country, is a major reason for the present problems with grass-weeds (Skorda, 1981, Cussans *et al.*, 1990). However no-till may reduce the weed seed number that survive on the soil surface (0-5 cm) (Mohler, 1993, Pratley, 1995).

Elymus repens as a perennial responds differently to the annual grasses. Tillage is of great importance and with reduced tillage or no-till the weed increases rapidly (Borressen, 1993). With regular stubble cultivation *E. repens* was kept at a farly low and tolerable level. The same was true with no-till glyphosate application, but not with paraquat. The development of perennial weed problems is by no means exclusive to conservation tillage systems, nor an obligate outcome of the adoption of such practices, but by herbicides. Weeds are strongly affected influenced by the production system, and changes in the weed flora can occur in a relatively short time (Mahn, 1984, Weston, 1990). Absence of tillage favoured the development of perennial weed stands. In tilled plots, perennial weeds as *E. repens* populations increased during the fourth or fifth year of experiments. Tillage influences regeneration of these weeds by favouring fragmentation and dispersal of rhizomes, and by affecting bud dormancy and distribution in the soil profile (Lemieux *et al.*, 1993) cause greater problems by no-till than by conventional tillage. Obviously, even ploughing alone cannot resolve the problem of perennial weeds and there is general dependence of glyphosate or other effective herbicides for perennial weed control which provide adequate control (Froud-Williams, 1988, Moyer *et al.*, 1994). All present perennials weeds showed some increase in fifth or fourth year of the experiments especially in no-till plots sprayed with paraquat, but the increase did not reach threshlold levels after post-emergence herbicide application.

In conclusion, conservation tillage and no-till planting, in addition to soil and moisture also have significant economic benefits. These benefits include significant reductions in labour, equipment, and fuel costs, together with more timely planting of wheat and barley cops. Long-term profit is the basis of farm family survival, and we need to keep in mind that, over time, conservation tillage systems to improve sustainability of Greek agriculture.

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27 YEARS OF RESEARCH IN MAIZE CULTIVATION ACCORDING TO THE MINIMUM TILLAGE AND ZERO TILLAGE TECHNOLOGY IN ROMANIAN AGRICULTURE

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ABSTRACT

In Romania maize is cultivated on more than 3.5 million hectares, representing more than 35% of the total 10 million hectares of arable land.

Due to the economic importance of maize the herbicide experiments for this crop between 1961-1997 are the most numerous. In the respective period we studied the efficiency of most herbicides released world wide.

In a special experiment for 27 years we studied in monoculture, maize cultivation based upon three methods: traditional (conventional) with 15 soil operations (without herbicides), minimum tillage with 10 soil operations and zero-tillage, without any agricultural operations according to which maize sowing is made by special machines.

On the basis of the researches performed it is concluded that Romanian chemical industry can assure the requirements of herbicides for zero-tillage method.

INTRODUCTION

Many specialists English and American - Brown 1968, Phillips & Young 1973, Elliot 1974, Egyptian-Mickieka & Maina 1990 etc., assert that maize cultivation without ploughing, according to zero-tillage method has five major purposes:

1. reduction of production expenses; 2. reduction of fuel consumption; 3. elimination of soil erosion; 4. increase of labour productivity; 5. increase of profit.

In Romania the first experiments in maize cultivation with minimum tillage began in 1962, and zero tillage in 1967 (Şarpe et al., 1966; Şarpe et al., 1970; Şarpe, 1974; Şarpe et al., 1992). Maize cultivation in minimum tillage is practised in Romania in many agricultural farms. Zero-tillage is not practised, because this tehnology implies the use of special sowing machines to implant the seeds without ploughing. But there are hopes that in the future zero-tillage will be applied in Romania agriculture too. Oltchim SA produces many herbicides, selective for maize which can control more than 200 species of annual and perennial weeds, to prepare the conditions for minimum tillage and zero tillage technology.

MATERIAL AND METHODS

Experiments with minimum tillage and zero-tillage have been organised in autumn 1966, in randomised blocks, 4 replications , each plot of 120 m^2. Maize was cultivated in monoculture. Each autumn, between 1966-1993 atrazine -based herbicides were applied in rates of 5 kg / ha and 10 kg a.i. / ha. Periodically, moisture content was determinated to 100 cm depth. Both technologies were compared to the conventional tehnology, with yearly ploughing and disking. During the vegetation period the effect of herbicides on weeds was observed and at maize harvest grain yield was determined.

Between 1990-1996, the experiments with different herbicides selective for maize and produced by OLTCHIM SA, were continued for minimum and for zero tillage. The herbicides used were based on the following a.i.: alachlor 420 g / l; acetochlor 240 g / l + safener; metolachlor 960 g / l; dimethenamid 900 g / l; dicamba + 2,4 D 400 g / l; dicamba + 2,4 D + nicosulfuron 480 g / l. A randomised block design of 4 replicate plots of 25 m^2 was used. Herbicides were applied by Knapsack sprayers with a TeeJet 8001 EWS flat fan nozzle at 207KPa. Observations were made according to EWRS scale; weight of weeds determined control efficacy and maize grain yield at 15% humidity.

RESULTS AND DISCUSSION

a) Regarding the efficacy of atrazine to control annual weeds

On the chernozem soil at Fundulea, containing 3.5 % humus and 36% clay, the following weed species were dominant: in the plots ploughed according to the conventional method (classical):

1. *Setaria glauca*
2. *Setaria verticillata*
3. *Sinapis arvensis*
4. *Papaver rhoeas*
5. *Chenopodium album*
6. *Erigeron canadensis*
7. *Echinochloa crus-galli*
8. *Digitaria sanguinalis*
9. *Thlaspi arvense*
10. *Xanthium strumarium*
11. *Hibiscus trionum*
12. *Polygonum aviculare*
13. *Amaranthus retroflexus*
14. *Capsella bursa pastoris*
15. *Polygonum convolvulus*
16. *Solanum nigrum*

Atrazine applied every year at rates of 5 kg a.i. / ha and 10 kg a.i. / ha controlled completely the annual weed species mentioned above.

It is remarkable that new biotypes of *Amaranthus retroflexus*, *Chenopodium album* resistant to atrazine did not occur, but on the other hand *Erigeron canadensis* proved very resistant even at 20 kg a.i. / ha.

b) Regarding soil moisture content

Zero-tillage promotion for maize crop is a continuous debate for agricultural specialists who think that "soil tillage, especially hoeings destroy the soil capillaries and water is preserved into the soil". This theory was valid until 1951 when atrazine was synthetised, because weeds, being water consumers, could be controlled only by manual and mechanical hoeings. Now all species are chemically controlled and hoeings have practically no role in preserving soil moisture content, as demonstrated by the data presented in Table 1 for 5 years with dry summers.

Table 1. Soil moisture content in the maize plots cultivated by conventional technology and zero-tillage

Year	Day and month	For 0 - 50 cm depth		For 0 - 50 cm depth	
		Conventional technology	Zero-tillage technology	Conventional technology	Zero-tillage technology
1967	10.VII	19,8	19,2	20,6	21,3
	20.VII	18,6	18,4	19,3	19,0
	10.IX	17,2	17,1	18,0	18,4
1976	19.VII	16,6	16,3	19,2	17,8
	9.VII	12,2	10,5	116,6	15,2
	20.IX	13,9	14,4	17,0	16,0
1979	19.VII	19,4	19,5	20,5	19,7
	31.VII	15,7	16,0	16,7	15,5
	20.IX	23,2	22,7	18,2	17,7
1980	31.VII	19,0	18,8	19,4	18,6
	20.VII	20,2	19,4	18,5	16,5
	19.IX	17,5	17,2	17,9	17,8
1984	19.VII	15,5	17,8	16,6	18,0
	29.VII	13,4	14,6	14,6	16,8
	25.IX	15,0	15,5	13,2	15,3

Specification: Soil probe were taken for every 10 cm layer and the average calculated for 0-50 cm and for 50-100 cm depths.

Table 2. Grain yields of maize in minimum - tillage and conventional technology

Conventional technology	Minimum tillage
1. Fertilised - autumn	1. Fertilised - autumn
2. Ploughed + harrowed - autumn	2. Disked - autumn
3. Harrowed - spring	3. Disked - autumn
4. Disked + harrowed	4. Atrazine treatment - autumn
5. Disked + harrowed	5. Disked + harrowed - spring
6. Sowed - with SPC - 6	6. Sowed - with SPC - 6
7. Harrowed after sowing	7. -
8. Harrowed with roto harrow	8. -
9. First mechanical hoeing	9. First mechanical hoeing
10. First manual hoeing	10. -
11. Second mechanical hoeing	11. -
12. Second manual hoeing	12. -
13. Third mechanical hoeing	13. -
14. Third manual hoeing	14. -
15. Mechanical harvesting	15. Mechanical harvesting

Average Years	Yield		Yield			
			5 kg atrazine/ ha		10 kg atrazine/ ha	
	kg/ ha	%	kg/ha	%	kg/ha	%
1967-1970	5110	100	5010	98	5202	102
1971-1975	4980	100	4366	88	4411	89
1976-1980	6067	100	5992	99	5186	85
1981-1985	8734	100	8022	92	8520	97
1986-1990	8607	100	8530	99	8670	101
1991-1993	8900	100	8855	99	8982	101
1967-1993	7003	100	6724	96	6729	96

LSD 0,05% for average 1967-1993 = 546 kg

Analysing the data presented in Table 1 it can be seen that in dry summers, soil moisture content in the plots with zero-tillage was practically equal with that of the conventional technology. These data confirm those obtained by American researchers Phillips & Young (1973).

c) Regarding the grain yield

In Table 2 and 3 grain yields comparatively are presented for the three cultivation methods.
As can be seen in Table 2 the grain yield average for 27 years was 7003 kg/ ha in conventional system; 6724 kg/ ha in minimum tillage with 5 kg and 6729 kg/ ha with 10 kg atrazine a i / ha. The average grain yields were practically equal for all the three systems..
Table 3 presents the grain yields obtained in zero compared to conventional tillage.

Table 3. The grain maize yields for zero-tillage and conventional technology

Conventional technology	Zero-tillage
1. Fertilised - autumn	1. Fertilised - autumn
2. Ploughed + harrowed - autumn	2. -
3. Harrowed - spring	3. Atrazine treatment - autumn
4. Disked + harrowed	4. -
5. Disked + harrowed	5. -
6. Sowed - with SPC - 6	6. Sowed - with "Gaspardo"
7. Harrowed after sowing	7. -
8. Roto harrowed	8. -
9. First mechanical hoeing	9. -
10. First manual hoeing	10. -
11. Second mechanical hoeing	11. -
12. Second manual hoeing	12. -
13. Third mechanical hoeing	13. -
14. Third manual hoeing	14. -
15. Mechanical harvesting	15. Mechanical harvesting

Average Years	Yield		Yield			
			5 kg atrazine/ ha		10 kg atrazine/ ha	
	kg/ ha	%	kg/ha	%	kg/ha	%
1967-1970	5110	100	5112	100	5657	111
1971-1975	4538	100	4466	98	5262	116
1976-1980	6067	100	6192	102	6352	105
1981-1985	8734	100	8635	99	9155	105
1986-1990	8607	100	8518	99	9151	106
1991-1993	8900	100	8930	100	8980	101
1967-1993	7003	100	6890	98	7377	105

LSD 0,05% for average 1967-1993 = 580 kg

As can be observed from these data in zero-tillage the grain yields were practically equal with that of the conventional technology. The average yield of 27 years in maize under zero-tillage was 6890 kg/ ha for the atrazine treatment 5 kg/ ha and 7377 kg/ ha for the atrazine treatment 10 kg/ ha and for conventional tillage the yield was 7003 kg/ ha. In some years in the treatment with 10 kg a.i. / ha the yields were 11-16% higher than in conventional technology. This situation occurred in rainy summers when the crop was strongly reinfested and weeds influenced negatively the grain yields.

d) Technical-economical advantages of maize cultivation in zero-tillage

To promote maize cultivation in Romania without ploughing, the special requirement is for an adequate machines system, or at least for sowing machines alike that made in Italy ("Gaspardo") or other trademarks (made in England, Germany or U.S.A.) .
In Table 4 are presented the data concerning labour productivity and fuel consumption.

Table 4. Labour and fuel consumption and productivity for two maize cultivation systems

Indicatories	Technology	
	Conventional	Zero-tillage
1. Man hours - necessary for manual work	170	0
1. Man hours - necessary for mechanical work	30	5
3. Total labour hours necessary to produce 1 t maize grain	38.2	1.3
4. Increase of labour productivity %	100	1500
5. Fuel consumption L/ ha	52.5	10.5

These data show that to produce 1 tonne of grain maize within the conventional system it consumes 38 labour hours, whereas in zero-tillage only 1.3 h. So in no-tillage system the labour productivity is 15 times higher compared to conventional. The decrease of expenses implies a direct reduction of cost and increase of profit. The highest fuel consumption is required by ploughing. Elimination of these operations means reduction of expenses and fuel consumption. Optimal conditions in conventional technology means 52.5 l fuel for all soil operations, while in zero-tillage only 10.5 l gas per ha.

e). Results of the experiments performed during 1990-1996 with herbicides produced by OLTCHIM SA for: minimum and zero-tillage

The researches were carried out in three experimental locations (Teleorman, Giurgiu and Moara Domneasca) where the following weeds were dominant:

1. *Echinochloa crus-galli*
2. *Polygonum persicaria*
3. *Polygonum convolvulus*
4. *Raphanus raphanistrum*
5. *Amaranthus retroflexus*
6. *Chenopodium album*
7. *Setaria viridis*
8. *Sinapis arvensis*
9. *Lathirus tuberosus*
10. *Hibiscus trionum*
11. *Cirsium arvense*
12. *Atriplex patula*
13. *Solanum nigrum*
14. *Setaria glauca*
15. *Galium aparine*
16. *Convolvulus arvensis*
17. *Digitaria sanguinalis*
18. *Amaranthus crispus*
19. *Amaranthus blitoides*
20. *Setaria verticillata*
21. *Xanthium strumarium*

Table 5 presents the results with herbicides that can be used in minimum and zero-tillage.
These herbicides based on alachlor, acetachlor, dimethenamid and metolachlor had a good efficacy in controlling the monocotyledonous weeds. All these herbicides, called "antigraminaceous" controlled dicotyledonous only partially, but applying dicamba + 2,4 - D controlled them completely, as well as annual and perennial species. In all ppi treatments followed by dicamba + 2,4 - D applied pre-em the degree of control was 95.8-97.8 %.
The maize yields in all treatments were closely correlated with the weed control percentage. In the non-hoed treatment the maize yield was reduced by 68% which means a loss of 5539 kg grains per ha. In the ppi treatment with alachlor, acetachlor, dimethenamid, metolachlor and

followed by a post-em. treatment with dicamba+2,4 - D, the maize yields were 95-97 %, from that of 3 hoed - check, treatment.

Table 5. Herbicide treatments weed control and maize yields. Average 1990-1996

Herbicides	Rate kg a.i. / ha	Time of application	Weed control %	Yield kg/ ha	Yield %
1. Control I, 3 hoeings	-	-	98,6	8069	100
2. Control II, not hoed	-	-	0,6	2530	32
3. Alachlor +	3,3	ppi 5 cm			
Dicamba + 2,4 -D	0,4	post-em	96,6	7650	95
4. Acetachlor +	1,89	ppi 5 cm			
Dicamba +2,4 - D	0,4	post-em	96,9	7720	96
5. Metolachlor +	2,4	ppi 5 cm			
Dicamba + 2,4 - D	0,4	post-em	95,8	7748	96
6. Dimethenamid +	1,35	ppi 5 cm			
Dicamba + 2,4 - D	0,4	post-em	96,0	7782	96
7. Nicosulfuron +	0,46	post-em			
Dicamba + 2,4 - D	0,4		97,8	7800	97
LSD 0,05%				650 kg	

CONCLUSIONS

1. At the present time in Romanian agriculture with actual mechanical equipment system it is possible to practice minimum tillage technology on a large surface area.
Maize cultivation according to zero-tillage technology will be possible in the near future.
2. Romanian chemical industry can make available for the farmers a large range of herbicides to control annual and perennial weeds in the maize crops.

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THE EFFECTS OF MAIZE CULTIVARS AND PLANTING PATTERNS OF MAIZE/PEA INTERCROPS ON WEED SUPPRESSION

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ABSTRACT

A field experiment was conducted to examine the effect of intercropping forage maize with field pea on weed suppression. Crop dry matter and protein yield, weed biomass and density were compared in sole crops and intercrops under weedy and weed-free treatments. Two contrasting maize cultivars (Agio and Anjou-207), two planting patterns (1:1 and 1:2) and two weed levels (weedy and weed-free) were evaluated. Intercropping maize with field pea suppressed weeds compared to sole maize. Weed growth and density in maize/pea intercrops and sole pea (cv. Bohatyr) were substantially less than in sole maize. Intercropping maize cultivars Agio and Anjou-207 with pea at ratios of 1:1 and 1:2 resulted in similar crop dry matter yields and weed suppression. Peas were more competitive than maize. Maize dry matter yield in intercrops was greatly reduced compared to sole crops. The relative protein yield of pea was greater than that of maize. Anjou-207/pea intercrops produced more relative yield total for protein value compared to Agio/pea intercrops.

INTRODUCTION

Maize is used extensively for forage in different parts of the world. As a complement to grass silage, it is becoming increasingly important in the UK to secure forage supply against summer drought. Whole maize crop has a very high potential dry matter, but a low nutritive (protein) value. The use of legumes such as field pea in mixture with maize reduces this limitation by increasing protein content in the forage. Other advantages of intercropping, over sole crops, include reduced growth of weeds, reduced disease incidence and pest infestation, increased yield security, improved soil fertility, and reduced soil erosion.

Intercropping has been reported to suppress weeds, but few experiments have actually investigated its effects on growth, density, and composition of associated weeds. Although intercropping has the potential for increasing crop dominance over weeds, the extent of weed control varies among crop combinations, and even between experiments studying the same intercrop combinations (Moody and Shetty, 1981; Leibman and Dyck, 1993). Crop density, spatial arrangement, species and cultivar selection together with fertilizer regime also affect weed growth in intercropping systems. A high degree of interaction between component crops is expected in intercropping systems (Willey, 1979). Improved understanding and management of interactions between component crops (Willey, 1979; Vandermeer, 1989; Leibman and Dyck, 1993) is vital to the success of intercropping systems.

The current study is part of a PhD research project that involves intercropping forage maize with field pea. Since maize is susceptible to weed competition, a fast growing leafy pea (cultivar Bohatyr) has been chosen to meet the requirements for weed suppression. The main objectives of the present study is to examine the intensity and composition of weeds in intercropping compared to sole cropping systems, and to understand the competition between maize, pea and weeds.

MATERIALS AND METHODS

The field experiment was conducted in the summer of 1995 at the University Farm Field Unit at Sonning on a sandy-loam soil. Both maize and pea were drilled on 19 May 1995. Pendimethalin was applied pre-emergence to weed-free designated plots at a rate of 1320 g a.i./ha (4 litres/ha product) using an 'Oxford Precision Sprayer' delivering 250 litre/ha at 2.1 bar. Additional weeding by hand was carried out when necessary to control *Elymus repens* (couch-grass). Ammonium nitrate was applied as Nitram (34.5%N) and was broadcast at a rate of 60 kg N/ha to all treatments, three weeks after crop emergence.

The experiment consisted of eight intercrops, four maize sole crops, two pea sole crops and a weedy control. There were two maize cultivars (Agio and Anjou-207), two maize-to-pea row planting patterns (1:1 and 1:2) and two weed levels (weedy and weed-free). The row spacing for maize was 60 cm in sole crops and in intercrops where maize-to-pea planting pattern was 1:2; but was 40 cm where the planting pattern was 1:1. The maize cultivar Agio is a tall (208 cm), late maturing type and Anjou-207, a short (165 cm), early maturing type. The pea cultivar used was Bohatyr, a leafy type. The 15 treatments were laid out in a randomized block design with three replications. The intercrop treatments were in an additive series with 100% of the recommended density of both component crops. The recommended densities for sole crops forage maize and field pea were 120,000 and 650,000 plants/ha, respectively.

Plot size was 7 m x 2 m. In the 1:2 planting pattern, there were four rows of maize and six rows of pea. Within the row, maize plants were 16 cm apart and pea plants, 4 cm apart. In the 1:1 planting pattern, there were five rows each of maize and pea. The distance between maize plants within the row was 21 cm and that of pea was 3 cm. Plant samples were taken at 53, 81 and 116 days after sowing (DAS). At each harvest, plants from an area of one metre square were removed at ground level from each plot, and separated into maize, pea and weed species. Individual weed species were separated, counted and weighed. At final harvest, plant samples were milled and nitrogen analysis was determined for the crops. Crude protein content of maize was obtained multiplying the nitrogen content by 6.25, and protein value, multiplying percentage protein content by total dry matter yield.

Relative yield total (RYT) of protein value was used to compare the intercrops for protein yield advantage. RYT developed by de Wit and van den Bergh (1965) = $(Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb})$, where Y_{ab} is yield of crop 'a' in mixture, Y_{aa} is yield of sole crop 'a', Y_{ba} is yield of crop 'b' in mixture, Y_{bb} is yield of sole crop 'b'.

RESULTS

Maize yield

The total dry matter (TDM) production of both maize cultivars was reduced significantly (P<0.001) by intercropping compared to sole cropping (Table 1). But among the intercrops, there were non-significant differences on maize TDM yield between maize cultivars, planting patterns and weed levels. The presence of weeds reduced TDM yield of both maize cultivars in sole cropping, and the effect was significant (P<0.01) at later stages of plant growth, 81 and 116 DAS. Although the effect was non-significant, weeds reduced the TDM yield of intercropped maize at all harvests.

Table 1. Total dry matter yield (t/ha) of maize in sole crops and intercrops 53, 81 and 116 days after sowing (DAS).

	53 DAS		81 DAS		116 DAS	
Cropping systems	Weed-free	Weedy	Weed-free	Weedy	Weed-free	Weedy
Sole maize, Agio	1.86	1.38	8.95	4.98	9.96	5.36
Sole maize, Anjou-207	1.68	1.35	6.27	4.76	9.74	6.57
Agio/pea (1:1)	0.43	0.30	1.20	0.66	2.06	0.99
Agio/pea (1:2)	0.45	0.28	0.81	0.60	1.57	1.16
Anjou-207/pea (1:1)	0.35	0.31	1.78	0.57	2.34	1.58
Anjou-207/pea (1:2)	0.32	0.26	1.49	0.81	2.23	1.40
LSD (0.05)	0.42		2.23		2.25	

Pea yield

Pea produced a significantly (P<0.001) greater TDM yield in sole cropping than in intercropping (Table 2). There were non-significant effects of maize cultivars and planting patterns on intercropped pea TDM yield. The TDM production of pea in both sole cropping and intercropping was not significantly affected by weeds.

Table 2. Total dry matter yield (t/ha) of pea in sole crops and intercrops 53 and 81 DAS.

	53 DAS		81 DAS	
Cropping systems	Weed-free	Weedy	Weed-free	Weedy
Sole pea	3.16	3.23	4.32	3.58
Agio/pea (1:1)	2.28	2.33	2.99	2.23
Agio/pea (1:2)	2.35	2.31	2.57	2.10
Anjou-207/pea (1:1)	2.22	2.61	2.34	2.29
Anjou-207/pea (1:1)	2.39	2.65	2.22	2.38
LSD (0.05)	0.70		0.83	

Weed growth and density

The most predominant weed species in this experiment were *Solanum nigrum* (black nightshade), *Chenopodium album* (fat-hen) and *Spergula arvensis* (corn spurrey). The relatively minor species were *Viola arvensis* (field pansy), *Senecio vulgaris* (groundsel), *Stellaria media* (Chickweed), *Capsella bursa-pastoris* (Shepherd's purse), *Tripleurospermum inodorum* (scentless mayweed), *Matricaria recutita* (scented mayweed), *Papaver spp.* (poppy), *Fallopia convolvulus* (black bindweed), *Raphanus raphanistrum* (runch or wild radish), *Polygonum aviculare* (Knotgrass), *Elymus repens* (couch-grass) and *Poa annua* (annual meadowgrass). The effects of maize cultivars and planting patterns on the dominant weeds were essentially the same as those on total weeds. Therefore, only the data on total weed DM and total weed density are considered here. The composition of weed flora was not affected by the cropping systems. The dominant weeds were the same in the intercrops, sole maize and sole pea treatments.

Compared to the weedy control, weed dry matter yield was suppressed significantly ($P<0.05$) by all cropping systems at all harvests (Table 3). Although non-significant, weed density in all cropping systems was less than in the weedy control. Both maize cultivars in sole cropping suppressed weed growth much less than intercropping, and the effect was significant ($P<0.05$) at 53 DAS. Averaged over maize cultivars and planting patterns, weed growth and density in intercrops and pea sole crops were less than in maize sole crops. Neither maize cultivar nor planting pattern of the intercrops had any significant effect on TDM yield and density of weeds. Weed TDM yield increased, whereas weed density decreased during the growing season.

Table 3. Weed total dry matter yield (t/ha) and density (number of weeds/m^2) in sole crops and intercrops at 53, 81 and 116 DAS.

	Weed yield			Weed density		
Cropping systems	53 DAS	81 DAS	116 DAS	53 DAS	81 DAS	116 DAS
Sole maize, Agio	0.63	0.98	1.46	112	96	62
Sole maize, Anjou-207	0.90	1.27	1.40	149	78	75
Sole pea	0.32	0.44	0.68	110	53	34
Agio/pea (1:1)	0.27	0.41	0.65	103	70	35
Agio/pea (1:2)	0.19	0.30	0.48	95	63	35
Anjou-207/pea (1:1)	0.16	0.68	0.65	106	86	49
Anjou-207/pea (1:2)	0.40	1.06	0.86	153	97	62
Weedy control	1.47	4.09	3.30	180	127	76
LSD (0.05)	0.55	1.27	1.60	NS	NS	NS

Relative crude protein yields

The relative yield total of protein value for Anjou-207/pea intercrops was significantly greater ($P<0.05$) than for Agio/pea intercrops (Table 4). Neither maize cultivar, planting pattern nor the presence of weeds had any significant effect on the relative protein yield of maize and pea. The relative protein yield of peas was consistently greater than that of maize.

Table 4. Relative yields of maize (RYm) and pea (RYp), and relative yield total of intercrops (RYT), based on protein value, at final harvest.

	RYm		RYp		RYT	
Cropping systems	Weed-free	Weedy	Weed-free	Weedy	Weed-free	Weedy
Agio/pea (1:1)	0.20	0.12	0.75	0.73	0.95	0.85
Agio/pea (1:2)	0.24	0.10	0.50	0.64	0.74	0.75
Anjou-207/pea (1:1)	0.33	0.30	0.67	0.56	1.00	0.85
Anjou-207/pea (1:2)	0.40	0.11	0.72	0.93	1.12	1.04
LSD (0.05)	NS		NS		0.15	

DISCUSSION

The results of this study showed that intercropping maize with field pea suppressed weeds compared to sole maize. Weed growth and density in maize/pea intercrops and sole pea were substantially less than in sole maize. The initial fast growth of field pea led to dense canopy cover over the soil surface thereby reducing the number of emerging weeds, and slowing growth of the emerging weeds early in the season. Because intercrops were formed as additive combinations, increased weed suppression by intercrops as compared to sole maize, was a result of the increased total crop density. Both maize cultivars in 1:1 and 1:2 planting patterns suppressed weeds to a similar extent.

Intercropping pea into maize suppressed weed growth but depressed maize yield as compared to weed-free sole maize. For pea, addition of maize also reduced crop dry matter yield but it did not have an effect on weeds. The results of yield data show that pea was more competitive than maize, and dominated both maize cultivars. The poor performance of the maize plants was probably due to interspecific competition from the associated pea particularly for soil moisture during the dry summer of 1995 (134 mm of rain during the entire growing season).

The similar weed suppression and dry matter yield recorded by Agio and Anjou-207 indicates that although both maize cultivars differed in their height and maturity, their response to intercropping was not as distinct as to sole cropping. This is because compared to fast growing associated peas which were planted on the same day, both maize cultivars grew very slowly. Their differences in height and maturity were lost as a result.

The similar total dry matter yields of intercrops at 1:1 and 1:2 planting pattern shows that both maize (Agio and Anjou-207) yields were equally suppressed by the associated peas regardless of the number of pea rows between maize rows. The density of the component crops was held constant, and the proximity of the maize to the pea rows was the same (i.e. 20 cm) in both planting patterns. This resulted in achieving a similar ground cover as well as a similar yield in all intercrops, consequently creating no difference in their weed suppressive ability.

The relative protein yield of pea was about twice as much as that of maize showing the potential advantage of including pea in the intercrops. Anjou-207/pea intercrops in 1:2 planting pattern recorded protein RYT of greater than one, indicating protein yield advantage of 12% and 4% under weed-free and weedy treatments, respectively, over sole crops. The RYT for protein yield, and for dry matter yield (data not shown) of most of the intercrops was, however, less than one. This shows that there was full competition between maize and pea, and no resource complementarity, i.e. they fully shared the same limiting environmental resources.

The results of this study clearly show weed suppression advantage of intercropping maize with field pea under the conditions of this experiment. Attention is, however, drawn to the substantial reduction of TDM yield of intercropped maize. Although the component crops maize and pea differ considerably in their morphological characteristics and growth requirements, maize dry matter yield in the intercrops was considerably reduced, consequently reducing intercrop yield advantage. This is possibly related to interspecific competition from the highly competitive pea cultivar Bohatyr, particularly selected for its leafiness and fast growth to aid early season weed suppression. Further study, therefore, is recommended to investigate if yields of maize could be improved and intercropping yield advantage obtained by using lower density of pea, less leafy pea cultivars (e.g. semi-leafless), less competitive legumes, or delaying the planting date of the pea component.

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THE INTERACTION BETWEEN SHADING BY WHEAT WITH THE LEVEL OF HERBICIDE ACTIVITY.

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ABSTRACT

The interaction of shading with sub-lethal herbicide doses was investigated in a series of pot experiments. Shade levels were recorded in a winter wheat crop and shades constructed to give an appropriate range of shade levels (30-75% shading). Shade increased the activity on *Galium aparine* (cleavers) of both bromoxynil/ioxynil/mecoprop(HBN)/mecoprop and metsufuron-methyl/fluroxypyr mixtures. Shade had little interaction with HBN/mecoprop or metsulfuron-methyl/fluroxypyr on *Stellaria media* (chickweed). Shade interacted much more with the activity of metsulfuron-methyl/fluroxypyr than of HBN/mecoprop on *Bilderdykia convolvulus* (black bindweed). Shading compensated for herbicide dose in some cases but this still needs to be investigated in the field and a robust method of easily estimating shading needs to be developed.

INTRODUCTION

An understanding of the interaction between shading and herbicide activity could help to optimise herbicide performance. Interaction between low doses of herbicide and crop density have already been reported (Courtney,1994; Davies,1997). Knowing when to discontinue spraying in low dose programmes in crops such as sugar-beet or being able to adjust the dose and rely on shading to control subsequent seedling development would enable herbicide doses to be targeted more effectively. In most situations shading is probably the most important factor for which there is competition in the early spring when broad-leaved weeds are controlled. The ability to reduce herbicide quantity may result in benefits to the environment and contribute to reducing costs.

MATERIALS AND METHODS

Tube solarimeters were positioned both in the base of and above a growing crop of winter wheat at Boxworth in 1994 and 1995 and solar radiation recorded between April and mid May. From the two readings the percentage interception of photosynthetically active radiation (PAR) by the crop was calculated.

Shades were constructed by covering wooden frames with different levels of green mesh. The levels of shading were selected to approximate to that measured in the field wheat crop in the spring at the time when broad-leaved weeds would be treated and these shades were used in the pot experiments described.

Seeds of *Stellaria media*, *Galium aparine* or *Bilderdykia convolvulus* were planted in 10 cm diameter pots in a Kettering loam soil (pH 6.6; P index 1; K index 2; Mg index 2 + grit (1 part in 5)) on 16 January 1996. The plants were raised in a heated glasshouse, thinned to 5 seedlings per pot and put under the shades for one week prior to herbicide treatment on 13 February 1996. The interaction between herbicide and shade was investigated in four experiments but only the results from one are used to illustrate the responses.

Herbicide treatments were applied using a purpose-built pot sprayer delivering 225 l/ha at 2.1 bars. Since herbicides tend to be much more active on plants growing in pots in a glasshouse, reduced rates were used. The full rates of herbicides would be for ; HBN/mecoprop - 5.0 l 'Swipe P'/ha (bromoxynil at 56 g/l + ioxynil at 56 g/l + mecoprop-P at 224 g/l) and for metsulfuron-methyl/fluroxypyr - 30g 'Ally' (20% w/w metsulfuron-methyl) + 1.0 l 'Starane 2' /ha (200 g fluroxypyr/l). *S.media* had 2-3 pairs of leaves, *G.aparine* 1-2 whorls and *B.convolvulus* 1-2 leaves at treatment.

Each level of shading was replicated 4 times. Within each shade, species and herbicide treatment were fully randomised.

Plants were grown for three weeks after treatment when plant dry weight was recorded.

Dry weights were analysed using ANOVA and percentage reductions in weights are plotted against the proportion of the full herbicide rates (Figures 2-7).

RESULTS

The levels of shading recorded in a field experiment at Boxworth in 1995 is illustrated in Figure 1.

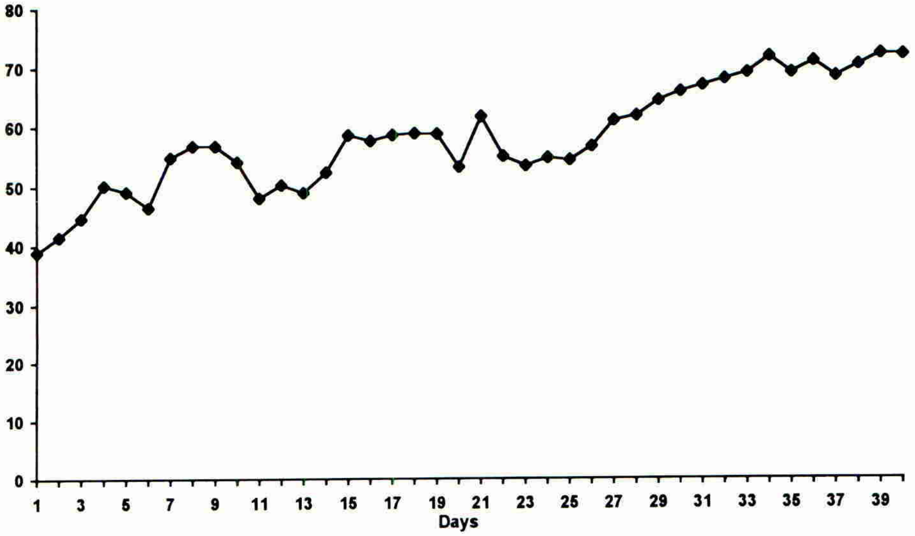
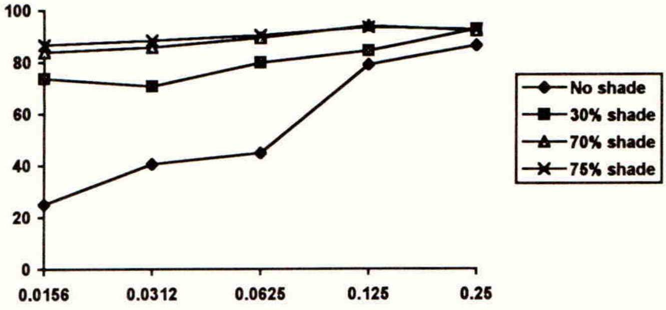


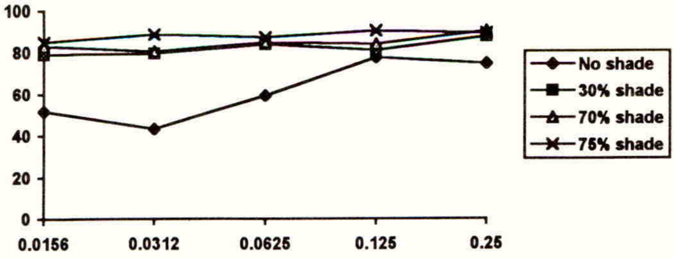
Figure 1. Percentage shading by winter wheat canopy (day 1 is 4 April 1995)

There was a clear effect of shading on the activity of HBN/mecoprop (Fig. 2) and metsulfuron-methyl/fluroxypyr (Fig. 3) on *G. aparine*. For example, a 16-fold increase in dose of HBN/mecoprop was required to give 80% reduction in dry weight of *G.aparine* under unshaded compared to 70% shade.



Proportion of full dose

Figure 2. Percentage reduction in dry weight of *G. aparine* by HBN/mecoprop expressed as % of unshaded untreated weight. SED =7.207, except when comparing means within the same level of shading = 6.990.



Proportion of full dose

Figure 3. Percentage reduction in dry weight of *G. aparine* by metsulfuron-methyl/fluroxypyr expressed as % of unshaded untreated weight. SED =7.207, except when comparing means within the same level of shading = 6.990.

There was a significant effect of shading, herbicide rate and the interaction between shading and rate indicating that that there were differences between the responses of *G.aparine* to the rate of herbicide under different shading levels.

In contrast, shading had much less effect on the reduction of *S. media* by either herbicide treatment (Figs. 4 and 5) but particularly so with metsulfuron-methyl/fluroxypyr.

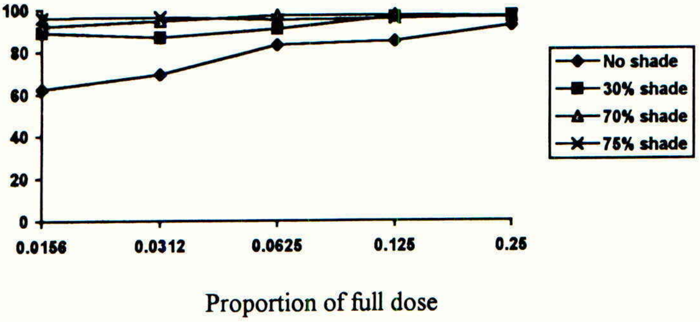


Figure 4. Percentage reduction of dry weight of *S. media* by HBN/mecoprop expressed as % of unshaded untreated weight. (SED = 3.632 except when comparing means within the same level of shading = 3.621.)

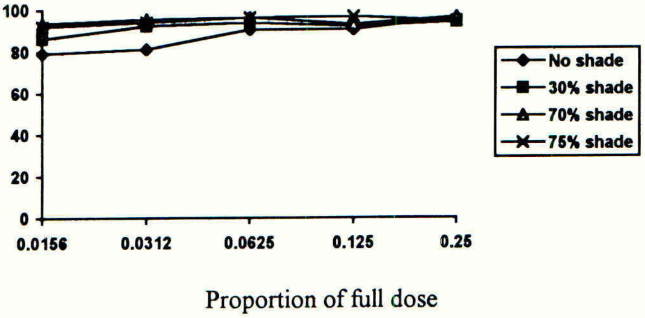


Figure 5. Percentage reduction of dry weight of *S. media* by metsulfuron-methyl/fluroxypyr expressed as % of unshaded untreated weight. (SED = 3.632 except when comparing means within the same level of shading = 3.621.)

The effect of shading, herbicide, shading by rate and shading by herbicide interactions were also significant for *S.media*.

Shading interacted much less with the activity of HBN/mecoprop on *B. convolvulus* (Fig. 6) than of metsulfuron-methyl/fluroxypyr (Fig. 7). Under the unshaded conditions the levels of control of *B. convolvulus* by metsulfuron-methyl/fluroxypyr never reached 80%.

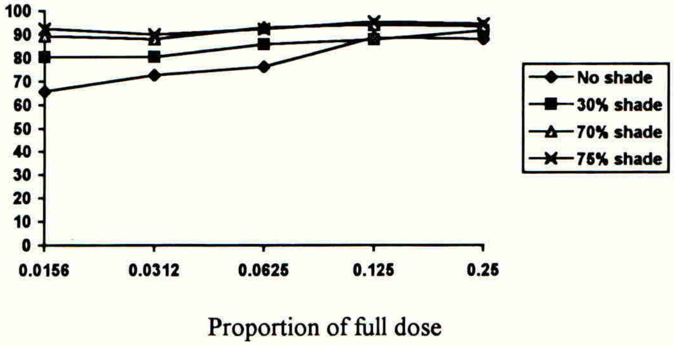


Figure 6. Percentage reduction in dry weight of *B. convolvulus* by HBN/mecoprop expressed as % of unshaded untreated weight. SED = 8.394 except when comparing means within the same level of shading or shading.herbicide = 6.907.)

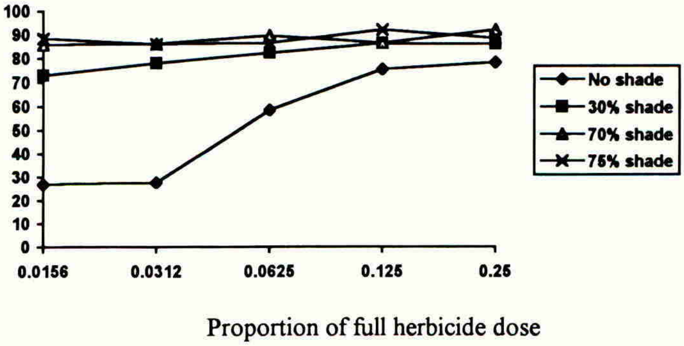


Figure 7. Percentage reduction in dry weight of *B. convolvulus* by metsulfuron-methyl/fluroxypyr expressed as % of unshaded untreated weight.

The effect of shading, herbicide, the shading by rate and shading by herbicide interactions were all significant for *B.convolvulus* indicating that there was a difference between dose responses to shade levels and between the different herbicides.

DISCUSSION

Courtney (1994) suggested that crop density influenced the degree of weed competition and the consequent benefits of weed control and that competition normally complemented herbicide activity.

Early work with barban for the control of *Avena fatua* indicated that the level of infestation depended upon crop competition (Pfeiffer & Holmes, 1961). Higher rates of barban were needed in a thin than in a dense highly competitive crop to reduce the wild-oat population to a given level.

The results from experiments reported here indicated that herbicide rate can be varied in response to levels of shading, but it varied with species and herbicide. The observation on *G.aparine* supported the field observations that competition is necessary for the full activity of fluroxypyr in the field (Davies, 1997) *S.media* response to both herbicides was less affected than was either of the other two species.

In these experiments no account has been taken of reduced quantities of herbicide reaching the weeds due to canopy interception. The implications of this would need to be investigated so that this could also be accommodated in any dose adjustment.

The possibility of manipulating weeds by selecting varieties which are more competitive has been investigated (Richards & Whytock, 1993, Christensen, 1994, Seavers & Wright, 1995) but for this to be successful as a management tool each new variety would need to be categorised. Where the main competition is for light then a measure of shading would be independent of variety and the crop and its management. An easy cheap method is required to assess this in the field and test the system as all the experiments reported here were based on plants growing in pots.

Crops will often be subjected to less shading where the crop canopy is managed to optimise light interception. This will result in higher optimum doses of some herbicides in some years.

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RESPONSE OF WHEAT TO *PHALARIS MINOR* RETZ. POPULATION DENSITY

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ABSTRACT

A field experiment was conducted for three years in which *Phalaris minor* was artificially established in wheat crop. Crop density was kept constant while weed density varied from 0 to 500 plants/m^2. As the density of weed increased , wheat yield decreased exponentially. A 10 % reduction in wheat yield occurred at *P.minor* density of 60-70 plants/m^2. Yield losses exceeded 50 % with density of 500 plants/m^2. Reduction in wheat yield is mainly attributed to reduction in number of ears. Wheat yield loss can also be related to the dry weight of *P.minor*. Their relationship fitted well the same exponential model that was used for the weed density.

INTRODUCTION

Wheat occupies a prime position in Indian agriculture. *Phalaris minor* Retz. (wild canary grass) is a major weed of wheat grown in rice - wheat system in northern India. At present this weed is posing a serious threat to its successful cultivation in important wheat growing areas of India. Depending upon its intensity 15-25 % losses in grain yield are quite usual (Walia and Gill, 1985). One of the major factors affecting the relationship between weeds and crop yield is weed density. In *P. minor* most of the work in India has been concentrated on chemical/mechanical control often under very heterogenous densities. In order to increase the cost effectiveness of herbicide applications there is a need for identifying the threshold levels of this weed. Hence for the development of refined technology of weed management understanding of crop weed relationships is a must.

The objective of this paper is to analyse the relationship between infestation of *P. minor* and wheat under Punjab conditions.

MATERIALS AND METHODS

Field trials were conducted for three years in winter season of 1990 - 1993 at the research farm of department of Agronomy of Punjab Agricultural University, Ludhiana. Ludhiana is situated at an altitude of 247 m above sea level, $30^0 56'$ North latitude $75^0 52'$ East longitude. Experiments were performed on a sandy loam soil (having 72.7 % sand, 11.1 % silt and 15% clay) low in organic carbon and nitrogen, medium in P and K content. Crop was sown on 22 Nov. in 1990 and on 15 Nov. in 1991and 1992 with a drill at a rate 100 Kg/ha with row spacing of 22.5 cm. *P. minor* seeds were spread evenly over various plots and covered with the soil by hand harrowing. The seed had been collected during the previous year. *P.minor* density was maintained by thinning out extra seedlings. Experiments were conducted by using a randomised block design with four replicates per treatment in first and third year and three in second year. Crop was applied 125 Kg N (half at sowing and half one month after sowing) and 60 Kg P_2O_5 (all at sowing). Net plot size was one metre square in all the experiments. Before harvesting plant height of 10 wheat plants was recorded and a count of number of ears per metre row length was made. Weed was harvested earlier than the crop to avoid seed shedding. Crop was harvested in first fortnight of April for all the three years. Dry weight of *P.minor* was recorded after drying in an oven for 48 h at 70^0 C. Wheat crop was hand threshed to record its grain yield.

The relationship between *P. minor* infestation and wheat yield was described by using the following exponential model :

$$Y = a. \exp.^{-bx}$$

Y = wheat yield, x = *P.minor* density or biomass , a = estimate of wheat yield in the absence of *P.minor* and b = estimate of the rate of reduction in wheat yield as *P.minor* infestation increases. This model was fitted to the experimental data using cs13 statistical package.

RESULTS AND DISCUSSION

In the absence of *P. minor* wheat yield varied from 4000 - 4814 Kg/ha. These yields were substantially reduced by *P.minor* competition in all the experiments. Relationship between weed density and grain yield fitted well the exponential model . The response curves obtained during first and third year are relatively uniform with slopes ranging from 0.0014 (1992-93) to 0.0017 in 1990-91 (Table 1 & Fig 1). In both years 10 % loss in yield occurred at a range of 60 - 70 plants/m^2 and yield loss exceeded 50 % at 500 plants of *P. Minor*/m^2(Fig 1). Sat Paul (1977) reported that 250 plants of *P. minor* reduced the grain yield of wheat by 44%. In second year yield losses were comparatively higher. For instance in first season 5 plants of *P.minor* reduced wheat yield by <1% whereas in second season yield reduction by 5 plants was 4 times that of first season . Similarly yield reduction by 200 plants of *P.minor* was 3 times greater in second season compared to first and third season data. This variation in yield loss may be attributed to variable emergence time of *P.minor*. In second year it emerged almost at the same time as crop whereas in first and third year emergence of weed was delayed due to prevailing high temperature conditions. The effect of time of emergence of weeds in relation to crop on outcome of competition has been reported by many workers (Martin & Field,1988).

Reduction in grain yield due to *P.minor* competition seems to be due to reduction in number of ears though ear length is also affected. Many other workers have also reported that effect of competition of weeds on grain yield of cereals is mainly through reduction in number of effective tillers (Sat Paul,1977 ; Walia & Brar,1996). Magnitude of competitive effects of *P. minor* on number of ears is highest (30.7%) in the second year and almost similar in first and third year. This observation strongly supports the yield data. Ear length was reduced significantly by *P. minor* competition in 1991 and 1993 only while no effect was observed in 1992 (Table 2).

Wheat yield losses can also be related to the total dry weight of *P.minor* present at harvest. The relationship between weed dry weight and wheat grain yield fitted reasonably the same exponential model that was used for weed density (Fig 2 & Table 3).

Table 1 . Regression estimates of wheat yield response to increasing densities of *Phalaris minor*.

Year	a	b	d.f
1990-91	4302	-0.0017 (0.00015)	18
1991-92	4695	-0.007 (0.00048)	13
1992-93	4114	-0.0014 (0.00010)	9

Values in parentheses are s.e. of the estimate.

Fig 1 . Relationship between density of *P.minor* and yield of wheat during three years.

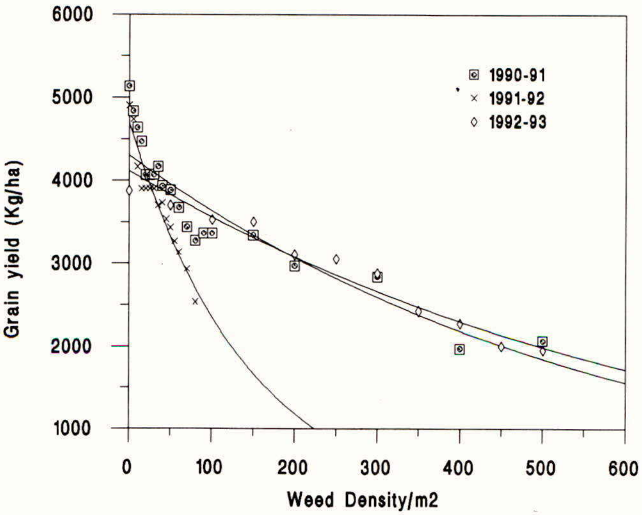

Table 2 . Effect of *P.minor* presence on grain yield, number of ears/m row length and ear length of wheat.

Year	Treatment	Grain yield (Kg/ha)	No. of ears	Ear length (cm)
1990-91	Phalaris free	4302	95	11.1
	200 Phalaris/m^2	3065	78*	9.7*
1991-92	Phalaris free	4695	101	11.2
	200 Phalaris/m^2	1182	70*	10.5
1992-93	Phalaris free	4114	98	11.0
	200 Phalaris/m^2	3073	71*	9.5*

* Effect of *P.minor* presence significant (P<0.05).

Fig 2 . Relationship between dry weight of *P.minor* and yield of wheat during three years.

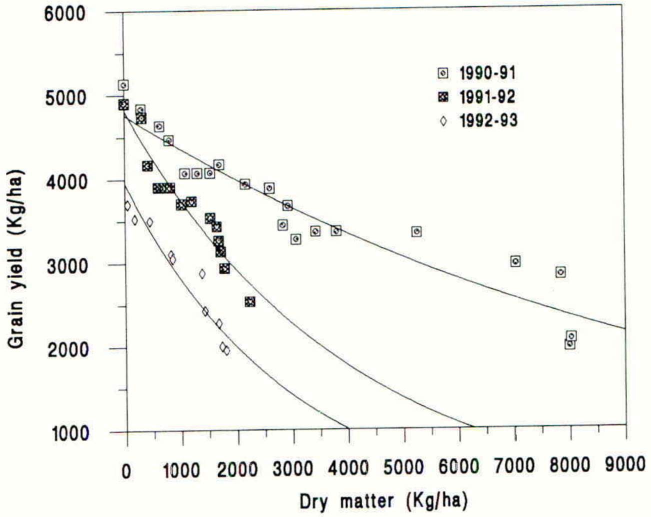

Table 3 . Regression estimates of wheat yield response to increasing dry weight of *Phalaris minor*.

Year	a	b	d.f
1990-91	4759	-0.0009 (0.00008)	18
1991-92	4814	-0.0025 (0.0002)	13
1992-93	4005	-0.0028 (0.00035)	9

Values in parentheses are s.e. of the estimate.

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THE IMPORTANCE OF MORTALITY IN WEED POPULATIONS BETWEEN AUTUMN AND SPRING ON THE RELIABILITY OF YIELD LOSS PREDICTIONS IN WINTER WHEAT

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ABSTRACT

Fifteen field trials, carried out at five sites over three years, were used to study the variability in winter mortality of three common UK weed species; black-grass (*Alopecurus myosuroides*), chickweed (*Stellaria media*) and cleavers (*Galium aparine*) and the consequences for using weed density to predict yield loss in winter wheat. The three species appear to be different in their vulnerability to over-winter mortality, with the density of cleavers being the most stable, and populations of chickweed appearing most vulnerable to mortality during this period. The ability of a weed population to survive the winter also varied according to the site and the year. The variation in winter mortality had repercussions on the application of the empirical model for predicting yield loss from weed density; the percentage yield loss per unit density of weed being dependent on the assessment date. The ability of the model to describe data sets between sites and years was not improved by using a later date for density assessment.

INTRODUCTION

The development of a simple empirical model for predicting yield loss from weed density early in the growing season (Cousens, 1985) has raised the possibility of identifying economic thresholds for weed management in winter cereals. For the model to be integrated into a weed control strategy, there are two possible opportunities for assessing weed density. For herbicides targeted at weed species where early control is necessary a weed population assessment must be carried out in the autumn; for other herbicides, population assessments may be carried out in the spring. However, the model depends for its usefulness on predictions being made while the chosen method of chemical control is still effective. The timing of the assessment of the weed populations is, therefore, critical. The present study uses a data set of weed competition experiments carried out at five sites over three years to examine the effect on the percentage yield loss per unit density of weed of assessing weed populations in the autumn and the spring.

For the density model to be an effective management tool, a single set of parameters must also demonstrate a robustness across sites and years. This would be compromised if changes in weed populations post assessment were shown to be variable. This paper presents the change in density of three contrasting weed species in winter wheat between October and March. The data are used to test the assumption that removing the variation in winter mortality between trials, by using a spring density assessment, will improve the robustness of the model in predicting weed damage between sites and years. The repercussions for the future potential of density based yield loss predictions being used in weed management are discussed.

MATERIALS AND METHODS

The results presented in this paper form part of a larger data set obtained from a series of crop / weed interference trials sown at five sites over three years from 1995 to 1997. Identical protocols were used for each trial (a fuller description of the protocol can be found in Cussans *et al.* 1996). Populations of three weed species; *Galium aparine*, *Stellaria media* and *Alopecurus myosuroides* were hand sown prior to drilling a crop of winter wheat (*Triticum aestivum* var *aestivum* cv. Mercia). The experimental design consisted of three blocks of five weed densities for each of the three weed species plus three weed free control plots in each replicate (a total of 54 plots). Emergence was monitored until crop and weed populations levelled off at which point autumn weed density was assessed by taking the mean of two counts from each of six fixed quadrats in each plot. A second identical count was made in March to quantify the change in weed populations over winter. In the case of chickweed it was not possible at all the sites to count individual plants accurately at this stage. Yields were assessed at maturity by hand harvesting a $2m^2$ area from each plot and weed free yields calculated from the mean yield from the control plots for each trial. Using the weed free yields, crop yields from each plot were converted to percentage yield loss and regressed against weed density in the autumn and the spring using Equation 1 (Cousens 1985):

$$\%YL = (Id)/\{1+[(I/A)*d]\} \qquad \text{Equation 1}$$

where YL = percentage yield loss, I = percentage yield loss per unit weed density as d nears zero , d = weed density and A = percentage yield loss as d approaches infinity.

RESULTS

Over winter mortality, expressed as the percentage of the autumn population surviving in the spring (Figure 1), varied between species, sites and years. The incomplete data set for chickweed is associated with the difficulty in counting individual plants in the spring. Populations of cleavers appeared the most stable while mortality was generally highest for chickweed. No one site emerged as having high or low overall weed mortality suggesting specific site characteristics affected the three species differently. Similarly, differences in mortality between years varied between the different species and sites although mortality was generally highest in 1995 and lowest in 1997. Several trials displayed an increase in weed density over winter. This is particularly apparent for cleavers which, due to its dormancy characteristics, continued to emerge into the spring and at the most northern site, High Mowthorpe, where a cooler climate delayed

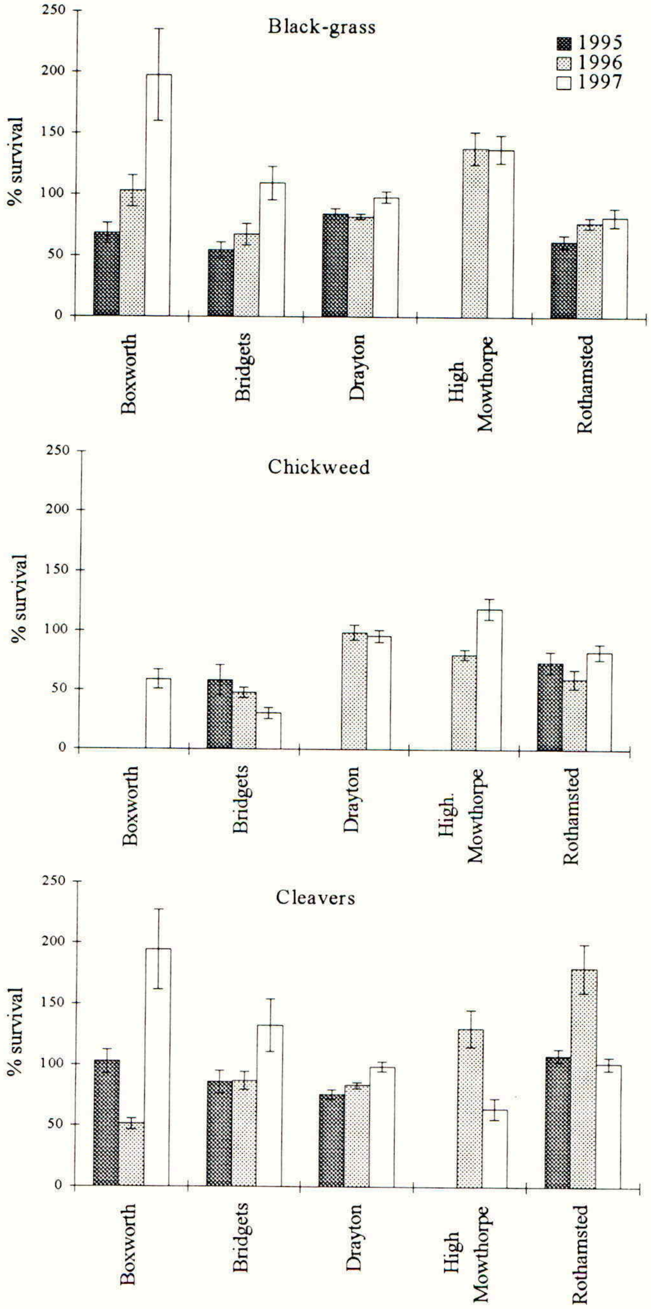

Figure 1. Differences in over winter mortality (expressed as the percentage of autumn population surviving in the spring), between species, sites and years. Vertical bars are standard errors of the mean of 15 plots.

the emergence of some individuals of all three species until after the autumn density assessment. Increases in the populations of black-grass over winter may also have been due to a second flush of an emerging background population.

The density / yield loss model described the data from many individual trials well (Ingle & Blair 1997). There were, however, clear differences in the competitiveness of all three species between sites and years (Table 1). The values for percentage yield loss per unit weed density revealed cleavers as the most competitive weed and chickweed as the least competitive.

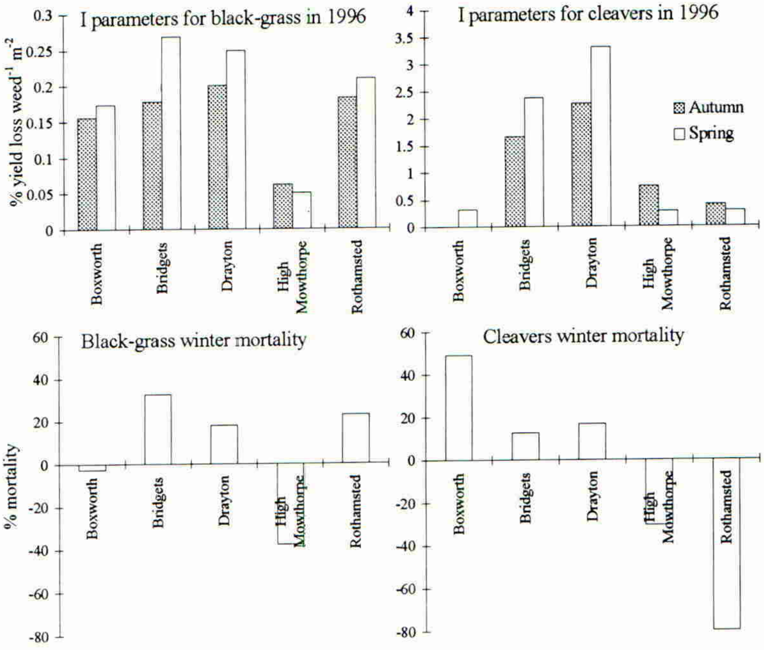

Figure 2. Change in value of 'I' in relation to over winter mortality. At sites where mortality is high 'I' increases; where weed populations increase over winter (negative mortality) 'I' decreases. No fit was found for yield loss against the density of cleavers in the autumn at Boxworth.

The value for 'I' for a specific trial was dependent on whether the density assessment used was made in the autumn or the spring, any changes being determined by over winter mortality (Figure 2). Generally, a high winter mortality was accompanied by a proportional increase in 'I', whereas an increase in the weed population over winter resulted in a decrease in 'I'. Using a spring density assessment instead of autumn did not increase the percentage variance accounted for by the model when fitted to all of the data combined for black-grass and cleavers and only increased it marginally for chickweed.

Table 1. 'I' values calculated from autumn densities for all sites over two years (percentage variance accounted for in brackets; standard errors in italics)

	Black-grass		Chickweed		Cleavers	
Site	1995	1996	1995	1996	1995	1996
Boxworth	0.86 *0.272* (78.1)	0.16 *0.055* (72.9)	No fit	0.2 *0.057* (79.0)	2.25 *1.51* (36.5)	No fit
Bridgets	0.09 *0.051* (47.3)	0.18 *0.066* (71.0)	0.02* - (15.8)	0.18 *0.136* (48.2)	No fit	1.66 *0.37* (87.5)
Drayton	0.46 *0.096* (91.3)	0.2 *0.047* (85.7)	0.28 *0.222* (43.2)	0.17 *0.053* (78.1)	3.06 *0.862* (78.0)	2.27 *0.569* (86.1)
High Mowthorpe	0.34 *0.087* (82.8)	0.06* - (66.5)	0.37 *0.272* (61.7)	0.52 *0.359* (72.0)	No fit	0.74 *0.534* (31.6)
Rothamsted	1.43 *1.23* (93.8)	0.18 *0.136* (33.0)	0.79 *0.391* (72.7)	0.12* - (58.1)	1.52 *0.495* (69.9)	0.41* - (41.7)

*Only one parameter fully optimised

DISCUSSION

In order for weeds to be managed in response to economic thresholds, a prediction of the cost of weed damage needs to be made while there is still the opportunity for chemical control. If the density / yield loss model (Cousens 1985) is to be used as a basis for predicting yield loss in winter cereals the timing of the assessment of weed numbers is , therefore, critical and will be constrained by whether the chosen method of control needs to be applied in the autumn or the spring.

The results of winter mortality presented in this paper identify the need for two separate sets of parameters to be used according to when density assessments are made. It was assumed that, due to variation in winter mortality between the trials, it would be preferable to delay the density assessment until the spring. Although this could limit the available methods of chemical control, it was expected that a delay would increase the effectiveness of one set of model parameters, based on spring assessments, predicting yield loss across sites and years. However, little or no improvement was found between autumn and spring assessments in the percentage variance accounted for by the model fitted to all the combined data for each species. This suggests that differences in over winter mortality between trials are relatively unimportant in governing the variation in 'I' and there is little theoretical advantage in delaying the time of density assessment. The implication is that, for the three species in this study, the majority of weed interference occurs after the spring density assessment date. That is, weed populations were assessed before the factors causing variation in weed competitiveness between trials had become apparent. A second practical implication of this study was the difficulty in counting individual weed plants later in the season and this may have accounted for the poorer than expected performance of the model when based on spring density assessments.

In the present study, when the model was applied to individual data sets using autumn densities a good fit was found in most cases. Parameter values for 'I' were comparable with those found elsewhere (Wilson and Wright 1990). However, the model was not robust enough for one set of parameters to be used to make universal predictions. The site specific reasons for these variations in weed competitiveness have been discussed elsewhere (Cussans *et al* 1996). Delaying the time of assessment seemed to do little to improve the robustness of the model. The results presented here, therefore, highlight the limitations associated with using weed density as a basis for predicting yield loss. Such assessments take no account of relative time of emergence or variations in weed size. Initial attempts to incorporate information on relative time of emergence from the trials discussed here into the density yield loss model (Cousens *et al* 1987) have successfully accounted for some of the variation between the trials. But the results appear to confirm that for empirical models to be effective in predicting yield loss in winter cereals from weeds growing in a range of conditions, some other measure of weed infestation such as relative crop/weed leaf area (Kropff *et al.* 1995) or relative dry weight (Lutman *et al* 1996) is required.

ACKNOWLEDGEMENTS

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EVALUATION OF SEED KILL AS A BROADLEAF WEED CONTROL TECHNIQUE IN WHEAT

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ABSTRACT

Herbicides applied at an early stage in development to conserve yield often do not provide a sufficiently high level of control to prevent reinfestation, as some plants escape treatment and produce seeds. Persistence of weeds requires new inputs to the seedbank, hence prevention of seed production would lead to declining populations over time. Herbicides when applied at the reproductive stage of development can be used to target seed production, a technique known as "seed kill".

Field experiments in Australia undertaken in 1996 and 1997 aimed to evaluate the effectiveness of eight post emergent herbicides for use in the seed kill program against *Raphanus raphanistrum* and *Sisymbrium officinale* which are important weeds in the central west of NSW. The herbicides were applied from the early to late flowering stage of weed development, corresponding with wheat at GS 35 to 63 of Zadoks decimal growth scale. All herbicides reduced the seed production of the two target species, some by up to 100%. Reductions in seed production of *R. raphanistrum* were less from all herbicide treatments when the stage of spraying was delayed beyond early flowering. At the rates evaluated, triasulfuron and chlorsulfuron gave the highest reductions of seed production. Yield was unaffected by most herbicides with the exception of reductions from dicamba (44%) and 2,4-D (13%) when applied at GS 57 to 65.

These experiments indicate considerable potential exists for the management of weed populations by targeting seed production through the use of strategically applied herbicides.

INTRODUCTION

In Australia, *Raphanus raphanistrum* is an aggressive competitor in wheat and at densities of 7 plants/m^2 can cause a 10% yield loss and at 200 plants/m^2 a 50% yield loss (Code & Reeves, 1981). *Sisymbrium officinale* is also a competitive weed, 20 and 100 plants/m^2 have been found to reduce yield by 11 and 17% (Madafiglio *et al.*, 1996). *R. raphanistrum* and *Sisymbrium* spp. are increasing in importance (Lemerle *et al.*, 1996) despite the many effective herbicides available.

To control *R. raphanistrum* herbicides have traditionally been applied at Zadoks *et al.* (1974) GS 12 to 23 or GS 30 stage of crop development. Experiments comparing various times of application by Code & Reeves (1981) found that early applications of bromoxynil plus MCPA gave excellent biomass reductions, however some plants survived, matured and produced 60 seeds/m^2 compared with untreated plants which produced 1,400 seeds/m^2. The alternative late application timing at GS 30 of 2,4-D or MCPA resulted in a yield loss due to competitive effects but there was little seed production.

We are further exploring this direct method of preventing seed production. This technique has been termed "seed kill", as seed production is targeted in contrast to the conventional plant kill which aims to reduce weed biomass.

The seed kill technique utilises selective herbicides applied at strategic times in the crops' reproductive phase to prevent viable seed production. Broadleaf herbicides have been evaluated in various studies and chlorsulfuron, dicamba and 2,4-D when applied to *Carduus nutans* before or at early flowering were found to reduce viable achene production by up to 99% (Beck *et al.*, 1990). Large reductions in seed set have also been obtained on *Fallopia convolvulus* after the application of tribenuron-methyl and MCPA even at reduced rates (Andersson, 1995). Likewise the seed kill technique has been successfully demonstrated on wild oats (Medd *et al.,* 1995).

The aim of this study was to investigate the effect of various herbicides on reducing seed production of *R. raphanistrum* and *S. officinale* and to assess associated phytotoxic effects on wheat when applied at reproductive stages of development.

MATERIALS AND METHODS

Three experiments (1, 2 & 3) were conducted in commercial wheat crops (cv. Dollarbird) in 1996/97 at Bathurst, New South Wales, Australia (latitude 33°24'S, longitude 149°34'E, elevation 745 m). Seven herbicides alone or in mixtures were applied at full and half the commercially recommended rate. The target weeds in each experiment and the developmental stage at spraying are described in Table 1. The weeds were naturally occurring with average *R. raphanistrum* densities of 4.6 to 7.6 plants/m^2 and *S. officinale* densities of 0.3 to 6 plants/m^2.

A further experiment (4) was conducted in a field at the Orange Agricultural Institute near Orange, New South Wales, Australia (latitude 33°19'S, longitude 149°5'E, elevation 926 metres) in 1997. *R. raphanistrum* was established to a density of 0.5 plants/m^2 from seedlings and grown as an out of season experiment in monoculture over the summer and autumn. Five herbicides were applied alone or in mixtures at two developmental stages of *R. raphanistrum* (Table 1).

The experiments were designed as randomised complete block experiments with 3 or 4 replications. Herbicides were applied using an experimental 2.5 m wide plot sprayer in a volume of 126 litres/ha with Hardie® 4110-10 flat fan nozzles.

Table 1. Description of weeds and crop at the time of spraying for each experiment

	Experiment 1	**Experiment 2**	**Experiment 3**	**Experiment 4**
Weed	*R. raphanistrum*	*S. officinale*	*R. raphanistrum*	*R. raphanistrum*
Weed stage at spraying	early flowering	early to mid flowering	mid flowering to early seed development	1. early to mid flowering 2. late flowering to early seed development
Crop stage	GS 39 to 45	GS 41 to 47	GS 57 to 65	no crop

Weed seed production was measured by counting the number of pods on individual plants 4 to 8 weeks after spraying. Pods with well developed segments were expected to contain viable seeds and were harvested. These pods were dissected in the laboratory and the number of entire seed recorded. Seeds which appeared entire and contained developed cotyledons were assumed to be viable. Grain yield was determined by selecting 100 heads/plot and assessing each for grain number and weight. Yield was calculated from measurements of wheat head density.

RESULTS

Weed control

R. raphanistrum plants were severely injured by all herbicides and seed production was reduced by up to 100% compared to the untreated control (Tables 2 and 3). Triasulfuron, chlorsulfuron and metsulfuron at recommended rates provided 99 to 100% reduction in seed produced from *R. raphanistrum* when applied at early and mid flowering but when applied at late flowering seed reductions were 68 to 85% of the untreated control. Similarly when dicamba + MCPA, diflufenican + MCPA, flumetsulam and 2,4-D were applied to *R. raphanistrum* at the recommended rate at early flowering seed production was reduced by greater than 99%, compared with the mid flowering timings when seed production was reduced by 82 to 92%. Earlier developed seeds had matured sufficiently by the later spraying time to resist herbicide damage.

Lowering the rate of herbicide generally resulted in higher seed production for *R. raphanistrum*. The addition of MCPA at 150 g/ha to triasulfuron and chlorsulfuron reduced seed production compared with triasulfuron and chlorsulfuron alone (Table 3).

S. officinale plants were killed by all herbicide treatments. Plants in the untreated control yielded and average 456 pods/m^2.

Crop effects

The wheat cultivar was Dollarbird in all experiments which allows direct comparisons to be made between the application timings. Grain yield was significantly reduced by dicamba + MCPA when applied at GS 41 to 47 (16%) and GS 57 to 65 (44%) through a reduction in the number of grains per head (Table 4). Significant grain yield reductions also resulted from the application of 2,4-D 400g/ha at GS 39 to 45 (9%) and 200g/ha and 400g/ha at GS 57 to 65 (13%) stages of development. Yield reductions also resulted from the application of metsulfuron + MCPA at GS 39 to 45 (11%).

Diflufenican + MCPA caused significant bleaching of the flag leaf but this did not affect grain yield. Other herbicides evaluated did not cause any visible injury symptoms to wheat.

Table 2. Effects of herbicide treatments applied at two development stages on seed production (number per m^2) of *R. raphanistrum*.

		Stage of development	
Herbicide	Rate (g a.i./ha)	Early flowering	Mid flowering to early seed development
Dicamba+MCPA amine	80+350	4.47 (19.5)	18.11 (327.5)
Dicamba+MCPA amine	40+175	19.35 (373.9)	9.64 (92.4)
Diflufenican+MCPA ester	19+188	0.71 (0.0)	18.32 (335.1)
Diflufenican+MCPA ester	9+94	10.73 (114.6)	22.28 (495.9)
Flumetsulam[2]	20	0.71 (0.0)	12.22 (148.8)
Flumetsulam[2]	10	9.47 (89.2)	10.01 (99.7)
Metsulfuron+MCPA ester	3+150	0.71 (0.0)	3.21 (9.8)
Metsulfuron+MCPA ester	1.5+75	1.61 (2.1)	7.82 (60.7)
Triasulfuron[3]	22	0.71 (0.0)	2.58 (6.2)
Triasulfuron[3]	11	0.71 (0.0)	1.26 (1.1)
2,4-D amine	400	3.97 (15.3)	12.09 (145.7)
2,4-D amine	200	10.44 (108.5)	10.14 (102.3)
Untreated control		3084.0[1]	1732.0
Untreated control		2539.0	1863.0
SEM		3.46	4.08

Statistical analysis was conducted on transformed data (square root (x+0.5)). [1]Untreated controls were omitted from the analysis. Data presented in parentheses is retransformed. [2] plus crop oil 0.5% V/V, [3] plus crop oil 1.0% V/V

Table 3. Effects of herbicide treatments applied at two development stages on seed production (number per m^2) of *R. raphanistrum*.

		Stage of development	
Herbicide	Rate (g a.i./ha)	Early to mid flowering, early seed development	Late flowering to mid seed development
Flumetsulam[2]	20	5.35 (28.1)	33.7 (1135.2)
Flumetsulam+MCPA ester	20+150	8.91 (78.9)	39.0 (1520.5)
Triasulfuron[2]	11	3.63 (12.7)	16.5 (271.8)
Triasulfuron+MCPA ester	11+150	0.71 (0.0)	11.8 (138.7)
Triasulfuron+MCPA ester	6+150	2.80 (7.3)	18.8 (352.9)
Chlorsulfuron[2]	11	2.51 (5.8)	23.9 (570.7)
Chlorsulfuron+MCPA ester	11+150	1.10 (0.7)	10.1 (101.5)
Chlorsulfuron+MCPA ester	6+150	3.85 (14.3)	14.4 (206.9)
Bromoxynil+MCPA ester	140+175	7.23 (51.8)	36.9 (1361.1)
Bromoxynil+MCPA ester	70+175	3.80 (13.9)	29.7 (881.6)
Untreated control		1805.0[1]	1805.0
SEM		1.98	4.90

Statistical analysis was conducted on transformed data (square root (x+0.5)). [1]Untreated controls were omitted from the analysis. Data presented in parentheses is retransformed. [2] plus crop oil 0.5% V/V

Table 4. Effect of herbicide treatments applied at different stages of development (Zadoks decimal growth scale) on relative wheat grain yield, 1000 seed weight and number of seeds per head. Results are expressed as a percentage of the untreated control.

		Yield			1000 seed weight			Seed number per head		
Herbicide	Rate (g a.i./ha)	Zadoks decimal growth scale for cereals								
		39 to 45	41 to 47	57 to 65	39 to 45	41 to 47	57 to 65	39 to 45	41 to 47	57 to 65
Dicamba+MCPA amine	80+350	92	**84**	**56**	100	**105**	**107**	92	**80**	**53**
Dicamba+MCPA amine	40+175	96	92	91	101	103	**104**	95	**89**	**87**
Diflufenican+MCPA ester	19+188	94	93	102	101	100	101	93	92	101
Diflufenican+MCPA ester	9+94	94	103	98	100	101	99	93	102	99
Flumetsulam[1]	20	98	92	102	100	97	100	98	95	102
Flumetsulam[1]	10	96	98	99	100	98	100	95	99	99
Metsulfuron+MCPA ester	3+150	**89**	106	94	**96**	100	99	93	106	95
Metsulfuron+MCPA ester	1.5+75	98	98	102	99	99	101	98	98	101
Triasulfuron[2]	22	96	112	106	100	101	100	95	110	106
Triasulfuron[2]	11	92	96	98	98	99	98	93	97	100
2,4-D amine	400	**91**	100	**87**	101	**105**	**107**	89	96	**81**
2,4-D amine	200	95	96	**87**	101	102	99	94	94	**88**
Untreated control		100	100	100	100	100	100	100	100	100
SEM		3.9	6.9	4.8	1.9	2.3	2.1	4.0	5.2	4.6

[1] plus crop oil 0.5%, [2] plus crop oil 1.0%, values presented in bold are significantly different from the untreated control at p=0.05.

DISCUSSION

These results indicate that the application of a range herbicides from different chemical groups can effectively reduce seed production of *R. raphanistrum* and *S. officinale* when applied at various stages of flowering. Some herbicides were found to reduce wheat yields. The effectiveness of the herbicides and injury to the crop was found to vary with the mode of action of the herbicide.

Triasulfuron, chlorsulfuron, flumetsulam and metsulfuron are systemic herbicides that inhibit production of acetolactate synthase and disrupt cell division. They were found to effectively reduce *R. raphanistrum* and *S. officinale* seed production and caused minimal phytotoxic effects to wheat. However the value of these herbicides for late application is in doubt given that resistance of *R. raphanistrum* and *Sisymbrium* spp. to these herbicides has been recorded in Australia (Holmes, 1996). A management strategy to delay and manage resistance of these weeds will require the rotation and mixture of herbicides with different modes of action.

Diflufenican and bromoxynil are inhibitors of photosynthesis and have limited systemic activity. They were found to reduce seed production in *R. raphanistrum* when applied at flowering, although were not as effective as the acetolactate synthase inhibitors. Diflufenican injured the flag leaf, however no reductions in grain yield resulted. Given their different mode of action diflufenican and bromoxynil will be useful tools to prevent seed production and assist in herbicide resistance management.

The auxin analog herbicides 2,4-D, dicamba and MCPA all significantly reduced *R. raphanistrum* seed production, however their late application is known to have the potential to reduce yield (Pinthus & Natowitz, 1967). MCPA is considered less phytotoxic than 2,4-D or dicamba (Roberts, 1982) and is commonly used in mixtures with other herbicides and in these experiments did not reduce yield.

To be successful the seed kill technique will require a near zero input of seed rain. *R. raphanistrum* can flower over long periods and based on our initial results herbicide timing needs to be targeted as the first flowers develop. At the flowering stage of development *S. officinale* was found to be very susceptible to the herbicides evaluated which prevented any seed production. The impact of the seed kill technique on seedbanks will be evaluated in ongoing studies. If weed seedbanks can be reduced using the seed kill method this technique will have benefits in an integrated weed management strategy.

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GLASSHOUSE AND LABORATORY RESPONSE OF SOME SPECIES OF CEREALS AND *BROMUS DIANDRUS* TO THE NEW HERBICIDE MON 37500

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ABSTRACT

Bromus diandrus has become a problematic weed in Spain, as a consequence of continuous harvesting of winter cereals through minimal tillage systems and because of the ineffectiveness of herbicides in this system. Biological assays have been carried out *in vitro* in nutrient solution and in glasshouse with application of MON 37500, a new grass active sulphonylurea herbicide, in order to determine the varietal selectivity of some cultivars of *Triticum turgidum* var. *durum* and *Hordeum vulgare*. *Bromus diandrus* from 29 different origins in Spain have also been studied. The response to MON 37500 confirms the susceptibility of all accessions in glasshouse assays, even at an application rate of 10 g a.i./ha, and a good response of the *Triticum aestivum* even at 40 g a.i./ha and of *Triticum turgidum* at 20 g a.i./ha, with sensitivity in cultivar response of *Hordeum vulgare*.

INTRODUCTION

Reduced tillage systems, such as no-till, can significantly save water, reduce soil erosion and costs associated with land preparation in comparison to conventional tillage systems, an aspect of enormous importance in dry climates. However no-till creates a much greater dependence on herbicides for weed control (Fawcett, 1983).

Bromus spp. are vigorous competitors in winter cereals in many parts of the world . *Bromus tectorum* can reduce wheat yields by about 20% (Stahlman & Miller, 1990) to 68% (Blackshaw, 1993). Cultural methods continue to be the basis for brome control in wheat (Fenster & McCalla, 1970, Wicks, 1984, Baker & Peeper, 1990), because the most frequently used herbicides for cereals are not effective in controlling brome grass. Conservation tillage practices, and a lack of economical herbicidal control have caused increased populations of annual brome species in winter wheat (Klemmondson & Smith, 1964, Massee, 1976, Morrow & Stahlman 1984, Peter & Weber, 1985).

Downy brome has become a severe problem in some areas of the United States and Australia (Poole and Gill, 1986). In Europe, *Bromus sterilis* became a major concern in England in the 1970's (Froud-Williams *et al.* , 1981, Marshall & Smith, 1987, Roebuck, 1987) and the same occurred at a later date in Spain *Bromus diandrus* (García-Baudín, 1984, Riba *et al* .,1990).

A new sulphonylurea herbicide MON 37500 (Parrish *et al* .,1995) for control of grass and broadleaf weeds in cereal crops has shown a good control of *Bromus tectorum*, *B. japonicus* and *B. secalinus* with tolerance for winter *Triticum aestivum* with less tolerance in spring wheats and sensitivity in barley and oats. MON 37500 is a post-emergence herbicide (Parrish *et al* ., 1995, Dobrovodsky, 1995) with a good effect against *Bromus s*pp.

This study shows the response of durum wheat and barley cultivars compared with tolerance of *Triticum aestivum* and of different populations of *Bromus diandrus* in *in vitro* and in glasshouse controlled conditions to MON 37500, to determine the efficacy of this herbicide in the control of *B. diandrus* in cereal crops.

MATERIALS AND METHODS

Vegetal Material

The vegetal material studied was *Triticum aestivum* cv Anza; *Triticum turgidum* var *durum* cvs Anton, Vitron and Clarofino; *Hordeum vulgare* cvs Barbarrosa, Amaji Nijo (AN), Alfa, Beka, Orria, Oralia, Volga and Alexis and 29 accessions of *Bromus diandrus* collected in cereal infested fields in the Duero region and Cataluña in Spain.

Hydroponic herbicide treatment

Seeds of wheat, barley and *Bromus diandrus* were germinated until coleoptiles were 2-3 mm long. Five germinated seeds were disposed on a plastic grid in a 200ml beaker wrapped in black cardboard and filled with 175 ml of Hewitt nutrient solution which was maintained at the grid level. Vessels containing 10 day old plants, 5 replicates per treatment, were selected and the nutrient solution was replaced by the Hewitt solution containing MON 37500 during 24 hours. Seedlings were sampled six days after treatment. Seedlings were grown in growth chambers at 24±1°C (14±1°C at darkness) with 110 $\mu Em^{-2} s^{-1}$ illumination.

The herbicide dose employed was 0; 0.02; 0.04; 0.08; 0.16 and 0.32 ppm for *B. diandrus* and barley and 0, 0.5; 1; 2; 4 and 8 ppm for wheat.

Glasshouse treatment

Soft wheat seeds, hard wheat and barley were sown in lines of 16 plantlets, 8 lines per tray in trays with a mixture of soil: manure: sand (1:1:1), when the plants have reached the stage of two leaves, they were sprayed with a solution of MON 37500 at a dose of 0, 20 and 40 g a.i./ha. Three weeks after the treatment, the aerial part of the plant was cut and weighed.

Seeds from the 29 accessions of *B. diandrus* were sown in the same way as was done with the cereals and was treated with an equivalent dose of MON 37500 at 0, 10, and 20 g a.i./ha. The procedure followed was identical to that used for the cereals.

The plants were kept in the glasshouse with a temperature control of 25 ± 5°C during the day and 15 ± 2°C during the night without any artificial light.

RESULTS AND DISCUSSION

Hydroponic treatment

Table 1 shows the response in fresh weight (control %) of one winter wheat and three durum wheats to the application of MON 37500 with radicle absorption in hydroponic treatment in a cultivation chamber. The inhibiting 50 dose has been calculated (ID_{50}) for the four cultivars, it is greater than 8 ppm for soft wheat, and 5.1 for Anton, 5.3 for Vitron and 5.9 ppm for Clarofino. The response of the barley and of *B. diandrus* can be seen in Table 2. The ID_{50} of *B. diandrus* is 0.08 and the barley cultivars exhibited an ID_{50} between 0.10 and 0.26.

Table 1. Effect of hydroponic MON 37500 treatment on wheat cultivars.

Herbicide dose ppm	Fresh weight (% of control)			
	Anza	Anton	Vitron	Clarofino
0	100	100	100	100
0.5	77	77	79	81
1	74	80	82	77
2	78	70	72	72
4	66	52	54	58
8	55	38	38	42
ID_{50}	>8	5.1	5.3	5.9

Table 2. Effect of hydroponic MON 37500 treatment on barley cultivars and *B. diandrus*.

Herbicide dose ppm	Fresh weight (% of control)								
	Barb.	AN	Alpha	Beka	Orria	Oralia	Volga	Alexis	*B.diandrus*
0	100	100	100	100	100	100	100	100	100
0.02	69	69	61	64	60	84	81	73	66
0.04	62	74	67	65	67	68	75	73	51
0.08	50	58	44	38	56	71	69	45	37
0.16	43	46	23	33	48	58	47	48	29
0.32	30	47	35	28	43	46	41	38	21
ID_{50}	0.13	0.23	0.10	0.10	0.20	0.26	0.21	0.17	0.08

Glasshouse Treatment

Table 3 shows the response of some of the cultivars studied with hydroponic treatment in a glasshouse with the dose normally used in the fields and with a dose double that recommended. Representative cultivars have been chosen for each type of response. There is no significant difference with the untreated control for any of the doses for soft wheat. The durum wheat Anton showed the same response as the two other cultivars studied, Vitron and Clarofino, and did not exhibit herbicide phytotoxicity from a dose of 20 g a.i./ha, but it did show a 30% reduction in weight relative to the untreated control when 40 g a.i./ha was used.

The four barley cultivars studied showed a significant weight reduction in relation to the untreated control at the two doses used (Table 3) with a weight loss of between 41% for Orria and 63% for Beka at a dose of 20 g a.i./ha and between 68 and 83% for these same cultivars at a dose of 40 g a.i./ha.

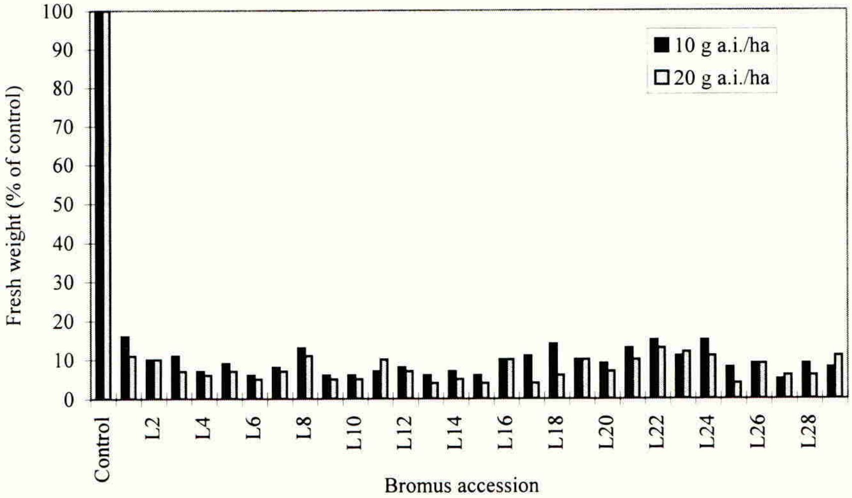
Table 3. The effect of the MON 37500 herbicide on fresh weight in some barley and wheat cultivars treated in glasshouses

Species	Cultivar	MON 37500 doses		
		0 g/ha	20 g/ha	40 g/ha
T. aestivum	Anza	5.91 a	6.86 a	5.52 a
T. turgidum	Anton	11.19 a	9.62 ab	7.95 b
H. vulgare	Barbarrosa	7.01 a	3.46 b	2.10 b
	Beka	15.51 a	5.72 b	2.59 b
	Orria	9.73 a	5.78 b	3.09 c
	Volga	9.14 a	5.04 b	2.26 c

Values followed by the same letter in each cultivar are not different at the 0.05 level. Duncan Test.

The results of the treatment of the 29 accessions of *Bromus diandrus* can be seen in Figure 1, the values are the fresh weight of the plants in relation to its control without treatment which is taken at a value of 100. In all accessions growth did not attain 20% of the untreated control and in the majority of them was less than 10%, and most of the plants died, even at half the recommended field dose.

Figure 1. *Bromus diandrus* response to MON 37500 treatment.



We can conclude from the project carried out that wheat is tolerant to this herbicide although the durum wheats were affected by the double dose of the herbicide. Barley is sensitive to this herbicide with a slight variability in the response. All the accessions of *B. diandrus* studied were very sensitive to this herbicide, which would permit its control in wheat and favour the development of reduced cultivation techniques.

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UTILIZATION OF HERBICIDE RESISTANT CROPS FOR WEED MANAGEMENT IN MIDWESTERN UNITED STATES CORN AND SOYBEAN PRODUCTION

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ABSTRACT

The utilization of herbicide resistant crops (HRCs) in weed management present several potential advantages to Midwestern maize corn and soybean growers over currently used weed management systems. One potential advantage of HRCs is that they may provide more consistent and better preforming weed management systems with a greater degree of crop safety as compared to conventional weed management systems. HRCs may also offer new options for control of problem weeds such as perennial broadleaf weeds and annual and perennial grasses.

In this paper we present research on the effect of soybean row spacing on weed management systems in glyphosate resistant soybeans and the utilization of sethoxydim resistant (SR) maize corn for *Eriochloa villosa* management.

INTRODUCTION

Eriochloa villosa is an annual grass species in the *Paniceae* family. Concern over *E. villosa* derives from the increasing levels of infestation of maize corn in Illinois, Iowa, Minnesota, and Wisconsin. *E. villosa* is characterized as being a highly competitive weed in corn with multiple germination events (Owen, 1990). In addition, the relatively large seed allows for germination at depths from 5 to 10 cm. The spread of *E. villosa* as a problem weed has been attributed to its adaptability to varying environments and herbicide selection as *E. villosa* is tolerant to some preemergence grass herbicides (Schuh and Harvey, 1989; Rabaey et al. 1994; Rabaey et al. 1996) or may germinate later in the growing season when grass herbicides have not persisted long enough (Pecinovsky, 1994). Post-emergent options for *E. villosa* control in maize corn rely on applications of nicosulfuron (Accent 75 WDG) which can provide adequate suppression of *E. villosa* if applied at the appropriate growth stage (Rabaey et al. 1994). The recent commercialization of sethoxydim resistant (SR) maize corn presents growers with the option of utilizing sethoxydim (Poast Plus 1.0 EC) for post-emergent control of *E. villosa* in maize corn. The objectives of the first trial series (A) reported was to evaluate the potential for sethoxydim to control *E. villosa* in maize corn.

The use of glyphosate for weed control has several advantages, including proven broad spectrum control of many grass and broadleaf weeds, favourable environmental profile and low mammalian toxicity, and a unique mode of action that is an alternative to herbicides which inhibit acetolactate synthase. However, there is limited information on the use of glyphosate for control of summer annual weed species in row crops. In addition, the lack of soil residual activity may present an obstacle to the use of a single application of glyphosate for season long weed control. Planting soybeans in narrow rows could provide a potential solution to this problem. The objective of the second trial series (B) reported was to determine the effect of row spacing on timing and number of glyphosate applications required for season long weed control.

MATERIALS AND METHODS

Trial Series A

Studies were conducted at Dwight, Illinois, USA, in 1995 and 1996. Maize corn (Asgrow 560 SX) was planted in 76 cm rows at 69,200 seeds/ha into 3 m by 9 m plots. Herbicide applications were made with a CO_2 compressed air backpack sprayer system calibrated for 187 L/ha and 275 kPa. Herbicide treatments including application rates and timings are summarized in Table 1. All foliar applied treatments contained crop oil concentrate at 1.0% v/v. *E. villosa* was 2 to 8 cm, 2 to 15 cm, and 3 to 20 cm at early postemergence (EPOST), post-emergent (POST), and late post-emergence (LPOST) timings, respectively. Visual control ratings from 0% (no control) to 100% (complete control) were taken at 60 DAT following the POST application timing. Weed density counts per 1 m^2 were taken by randomly placing two 0.5 m^2 quadrants in the two middle rows of each plot at 60 DAT. Studies were conducted as randomized complete block designs with three replications. Data were analyzed using analysis of variance and means separated by Fisher's Protected LSD test at the 0.05 probability level.

Trial Series B

Experiments were conducted at Dekalb and Urbana, Illinois, USA, in 1995 and 1996. Experimental design was a split plot with row spacing as the main plot and herbicide treatments as subplots randomized within the main plot. Soybeans (Asgrow 3001 RR) were planted in 18 and 76 cm row spacings into 3 m by 9 m plots at 440,000 and 305,000 seeds/ha, respectively. Glyphosate (Roundup Ultra 360 g a.e./l SL) treatments included single application rates of 0.63 kg a.e./ha applied POST or LPOST and two sequential applications of 0.63 kg a.e./ha. An imazethapyr (Pursuit 70 WDG) treatment applied EPOST was included (0.07 kg ai/ha) for comparison as well as weed free and weedy checks. Imazethapyr was applied with 0.75% v/v methylated seed oil and 28% urea ammonium nitrate at 1.25% v/v. Herbicide applications were made as described in trial series A. Weeds were 2.5 to 7.5 cm at EPOST applications, 7.5 to 13 cm at POST applications, and 15 to 23 cm tall at LPOST applications. Visual weed control was evaluated 30 days after application of LPOST treatments and soybean yield was measured at maturity. Data were analyzed using analysis of variance and means separated by Fisher's Protected LSD test at the 0.05 probability level.

Table 1. Visual control and density counts for *Eriochloa villosa* in 1995 and 1996.

	Application		1995		1996	
Treatment[a]	Timing	Rate (kg a.i./ha)	Visual control(%)[b]	Plant density/m^2	Visual control (%)	Plant density/m^2
Acetochlor	PRE	2.1	55	60	88	5
Acetochlor / sethoxydim	PRE / POST	2.1 / 0.21	91	7	98	0
Acetochlor / nicosulfuron	PRE / POST	2.1 / 0.035	83	27	98	0
Sethoxydim / sethoxydim	EPOST / LPOST	0.21 / 0.21	99	1	99	0
Nicosulfuron	POST	0.035	60	76	82	11
Sethoxydim	POST	0.21	90	6	93	4
Untreated check			-----	207	-----	20
LSD (0.05)			10	17	8	3

[a] Treatments applied with crop oil concentrate at 1.0% v/v.

[b] Percent control from 0% (no control) to 100% (complete control) and plant densities taken at 60 DAT.

RESULTS and DISCUSSION

Trial Series A

High amounts of spring rainfall delayed planting in 1996. Due to the late planting in 1996, cultivation for seedbed preparation reduced *E. villosa* populations as compared to 1995. *E. villosa* densities per m^2 for the untreated checks were 207 and 20 plants for 1995 and 1996, respectively (Table 1). A significant year interaction was observed so the data are presented separately. *E. villosa* densities followed the same general trend as the visual control data and are helpful for comparing overall treatment performance.

In 1995, a single PRE application of acetochlor (Harness 7 E.C.) provided only 55% control of *E. villosa* at 60 DAT. Applying sethoxydim or nicosulfuron following an acetochlor treatment improved *E. villosa* control to at least 83%. These sequential treatments reduced *E. villosa* densities to 27 plants per m^2 or less compared to 60 plants per m^2 for acetochlor alone. A single POST application of sethoxydim provided 90% control of *E. villosa* while nicosulfuron provided only 60% control. *E. villosa* densities in the sethoxydim and nicosulfuron treatments were 6 and 76 plants per m^2, respectively. Split applications of sethoxydim at 0.21 kg a.i./ha gave the greatest level of *E. villosa* control at 99% and the lowest *E. villosa* density of only 1 plant per m^2. In 1996, a single PRE treatment of acetochlor provided 88% *E. villosa* control. However, following the acetochlor treatment with either sethoxydim or nicosulfuron achieved greater control (98%). The split application of sethoxydim at 0.21 kg/ha also provided 98% or greater control of *E. villosa*. Sethoxydim applied alone gave 11% better *E. villosa* control compared to nicosulfuron applied alone. In conclusion, the performance of sethoxydim for control of *E. villosa* was the same or better than the commercial standards of a PRE application of acetochlor or a POST application of nicosulfuron. As seen in 1995 and 1996, the high *E. villosa* density in the nicosulfuron treatment as compared to the sethoxydim treatment suggests nicosulfuron only suppressed *E. villosa* and regrowth was evident later in the season. The results of these studies demonstrate that the use of sethoxydim in SR corn will provide growers with a new and effective POST grass herbicide option that is comparable or superior to traditional herbicide programs for *E. villosa* control.

Trial Series B

Analysis of variance revealed a significant location interaction within years and a significant year interaction within locations so the data are presented separately for each location in each year. In 1995 at Urbana, glyphosate treatments provided at least 93% and 85% control of *Setaria faberi* and *Digitaria sanguinalis,* respectively. The control of both species was equal in both row spacings (Table 2). *D. sanguinalis* control tended to be lower with single applications of glyphosate applied LPOST as compared to POST or sequential applications. In 76 cm rows *Chenopodium album* control was increased to 99% with sequential applications of glyphosate as compared to 88 and 86% control obtained with single POST or LPOST applications, respectively. *Abutilon theophrasti* control was 16% greater when a single application of glyphosate was applied POST in 18 cm rows as compared to 76 cm rows. *A. theophrasti* control was 98% or greater with POST applications of glyphosate in

18 cm rows or with sequential glyphosate applications in either row spacing. With a few exceptions weed control with glyphosate treatments was equal to weed control with imazethapyr applied EPOST. All herbicide treatments were able to provide adequate weed suppression and soybean yields were equal to hand weeded treatments (Table 2). Yields in 18 cm row soybeans were consistently greater than yields in 76 cm row soybeans.

At Dekalb in 1995, control of *Polygonum pensylvanicum* was 14% greater in 18 cm rows when a single application glyphosate was applied LPOST (Table 2). An increase of 16% control of *C. album* was also observed when a single application glyphosate was applied POST in 18 cm rows as compared to 76 cm rows. Sequential applications of glyphosate also improved control of these species. No increase in *S. faberi* control was observed in 18 cm rows but control was greatest with LPOST or sequential applications of glyphosate. *A. theophrasti* control improved substantially in the 18 cm rows as compared to 76 cm rows when single applications of glyphosate were applied POST or LPOST. However, *A. theophrasti* control was similar in both row spacings with sequential applications of glyphosate. The control of *C. album* and *A. theophrasti* was also improved in 18 cm rows as compared to 76 cm rows with EPOST application of imazethapyr. All herbicide programs with the exception of imazethapyr applied EPOST in 76 cm rows were able to provide adequate weed suppression and soybean yields were equal to hand weeded treatments (Table 2). Yields were similar in the hand weeded treatments for both 18 and 76 cm row spacings.

In 1996 at Urbana, control of *S. faberi* was similar for all glyphosate applications in both row spacings (Table 3). Control of *S. faberi* was greater than control observed with imazethapyr. Control of *Amaranthus rudis* and *A. theophrasti* was greater when single applications of glyphosate were applied in 18 cm rows as compared to 76 cm rows. Control of *A. rudis* and *A. theophrasti* was also greater in 76 cm rows when a second application of glyphosate was applied. Weed control with single applications of glyphosate in 18 cm rows were equal to imazethapyr. All herbicide programs with the able to provide adequate weed suppression and soybean yields were equal to hand weeded treatments (Table 3). Yields were similar in the hand weeded treatments for both 18 and 76 cm row spacings.

In 1996 at Dekalb, Glyphosate provided 95% control or greater of *S. faberi* regardless of application timing or row spacing (Table 3). Control of *S. faberi* was greater than control observed with imazethapyr. Control of *C. album* was 98% or greater for all glyphosate treatments except the LPOST timing in the 76 cm row spacing. *C. album* control increased to 98% with this treatment in the 18 cm row spacing. A single application of glyphosate POST or LPOST achieved 75% control of *A. theophrasti*. Control improved to 83% with these treatments in 18 cm rows. Applying a second application of glyphosate improved control of *A. theophrasti* to 88% in 18 cm rows. All herbicide programs were able to provide adequate weed suppression and soybean yields were equal to hand weeded soybeans (Table 3). Yields were similar in the hand weeded treatments for both 18 and 76 cm row spacings.

These studies demonstrate that a single application of glyphosate can provide effective control of a variety of weed species in 18 cm row soybeans. However, in some experiments control of *A. theophrasti* tended to be lower with glyphosate as compared to the other weed species. *A. theophrasti* control was consistently improved in 18 cm rows for single applications of glyphosate or by making a second application of glyphosate in 76 cm rows. In 18 cm rows weed control with glyphosate was equal to imazethapyr. These studies demonstrate that the use of glyphosate for weed control is optimized in narrow row soybeans, presumably due to more rapid canopy closure and greater competition.

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Table 2. Weed control (%) with glyphosate in 18 and 76 cm soybean row spacings.

Urbana '95

	Applications		*S. faberi*		*D. sanguinalis*		*C. album*		*A. theophasti*		Yield (kg/ha)	
Treatment	Timing	Rate (kg/ha)	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm	76 cm	20 cm	76 cm	18 cm
Glyphosate	POST	0.56 a.e.	93	99	92	98	88	96	82	98	2350	3090
Glyphosate	LPOST	0.56 a.e.	96	99	85	88	86	92	90	88	2410	2960
Glyphosate	POST	0.56 a.e.	99	99	98	99	99	99	99	99	2410	3400
Glyphosate	LPOST	0.56 a.e.										
Imazethapyr	EPOST	0.07 a.i.	95	99	99	96	98	86	99	96	2410	3210
Handweeded			99	99	99	99	99	99	99	99	2660	3210
LSD(0.05)			NS		10		4		10		430	

DeKalb '95

	Applications		*S.faberi*		*P.pensylvanicum*		*C.album*		*A.theophrasti*		Yield (kg/ha)	
Treatment	Timing	Rate	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm
Glyphosate	POST	0.56 a.e.	85	99	99	99	77	93	48	92	2040	1980
Glyphosate	LPOST	0.56 a.e.	95	96	85	99	99	99	68	91	1980	2220
Glyphosate	POST	0.56 a.e.	95	99	99	96	96	99	78	83	2040	2160
Glyphosate	LPOST	0.56 a.e										
Imazethapyr	EPOST	0.07 a.i.	72	92	99	99	52	95	73	87	1910	2100
Handweeded			99	99	99	99	99	99	99	99	2280	2160
LSD(0.05)			6		5		7		10		250	

Table 3. Weed control (%) with Glyphosate in 18 and 76 cm soybean row spacings.

Urbana '96

	Applications		*S.faberi*		*A.rudis*		*A.theophrasti*		Yield (kg/ha)	
Treatment	Timing	Rate (kg/ha)	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm
Glyphosate	POST	0.56 a.e.	95	99	90	99	75	87	3580	4260
Glyphosate	LPOST	0.56 a.e.	95	96	88	96	70	87	3330	4630
Glyphosate	POST	0.56 a.e.	98	99	99	99	87	96	3210	4510
Glyphosate	LPOST	0.56 a.e.								
Imazethapyr^b	EPOST	0.07 a.i.	87	92	94	99	78	90	3210	3950
Handweeded			99	99	99	99	99	99	3710	4010
LSD(0.05)			4		7		9		NS	

DeKalb '96

	Applications		*S.faberi*		*C.album*		*A.theophrasti*		Grain Yield	
Treatment	Timing	Rate (kg/ha)	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm	76 cm	18 cm
Glyphosate	POST	0.56	95	99	98	99	75	83	2660	2660
Glyphosate	LPOST	0.56	95	99	88	99	75	83	2590	2590
Glyphosate	POST	0.56	96	99	98	99	88	90	2470	2660
Glyphosate	LPOST	0.56								
Imazethapyr	EPOST	0.07	78	77	87	95	82	87	2530	2590
Handweeded			99	99	99	99	99	99	2410	2470
LSD(0.05)			5		9		7		NS	