Session 8D

Weed Population Management - Impact of Reduced Herbicide Dose and Threshold Strategies

Session Organiser Dr D H K DAVIES

Posters 8B-1 to 8D-8

POPULATION DYNAMICS AND COMPETITION OF WEEDS DEPENDING ON CROP ROTATION AND MECHANICAL AND CHEMICAL CONTROL MEASURES IN CEREALS

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ABSTRACT

Within the framework of a long-term trial, established to develop a field-based system of integrated weed control, the influence of crop rotation, mechanical weed control within winter wheat and spring cereals and herbicide application on the population dynamics and competition of weeds in cereals on sandy loam has been investigated. The increase in the percentage of cereals from 50 % to 100 % in the rotation led to an increase in weed infestation. After 4 years of continuous cropping, cereals required an additional application of isoproturon against *Apera spica-venti*. The omission of shallow ploughing led in continuous cereal cropping to a growing infestation with *Elymus repens*. By the alternate use of herbicides, even at half standard rates, and the threshold- and situation-related application of herbicides, it was possible to prevent the selection of single weed species and, in most cases, to sufficiently prevent weed competition in cereals.

INTRODUCTION

Influenced by crop rotation, intensity of mechanical and chemical weed control measures and other soil and crop cultivation factors such as fertilizing intensity, typical weed populations develop which are also subject to natural field conditions and seasonal and climatic variations (Bachthaler, 1969; Cremer, 1976; Cussans, 1975; Hintzsche, 1979; Heitefuss *et al.*, 1990; Zwerger *et al.*, 1990).

The development of concepts and methods of integrated weed management, aimed at the economically and ecologically justified restriction of weed growth, requires additional, primarily field-based research results from long-term trials for judging the effects of that complex of factors on the dynamics of weed infestation and on crops. For the sake of clarity this contribution is focusing on winter wheat, rye and barley.

MATERIAL AND METHODS

The trial was conducted at Glaubitz, Free State of Saxony, and commenced in 1985.

The field used is 75 m above sea level and has a sandy loam soil, with 1.1 % of organic matter and a pH of 6.0. Annual precipitation in the region is 574 mm, and average temperature is 8.8 ^{o}C.

The following crop rotations were tested:

a) potatoes - winter rye - maize (peas as of 1988) - spring barley - winter rape - red clover (field beans as of 1988) - winter wheat

b) winter wheat - oats - winter barley - winter rye

The weed control variants were:

factor A : mechanical weed control
- a_1: plough furrow
- a_2: plough furrow + shallow ploughing, harrowing of spring cereals and wheat

factor B : herbicide use
- b_1: no herbicide use
- b_2: 50 % standard rate
- b_3: 100 % standard rate
- b_4: 2 x 50 % standard rate (splitting)
- b_5: situation-related (use of thresholds, situation-related herbicide selection and dosage)

The trial design was a two-factor split block design with 4 replicates, factor A forming the main plots and factor B the sub-plots. The size of each plot was 3 m x 10 m = 30 m². Graduated herbicide dosages were applied only to cereals and, as of 1988, to grain legumes, because it was considered an unsuitable approach for the other crops.

The following herbicides were applied: Winter wheat: dichlorprop (1,980 g AI/ha = standard rate) or a tank-mix[1)] of dichlorprop (1,320 g AI/ha) + isoproturon (1,500 g AI/ha = standard rate). Winter barley: bromoxynil (450 g AI/ha) + dichlorprop (1,350 g AI/ha) or a tank-mix of bromoxynil (300 g AI/ha) + dichlorprop (900 g AI/ha) + isoproturon (1,500 g AI/ha). Winter rye: MCPA (1,200 g AI/ha) or a tank-mix of MCPA (800 g AI/ha) + isoproturon (1,125 g AI/ha). Half the standard rate was applied in the ZGS 13 to ZGS 21 periods of the cereal and the full rate in the ZGS 30 period.

1) As from 1989 tank-mixes have been applied only in continuous cereal rotations.

RESULTS

The entire trial area, which was planted with potatoes in 1983 and spring barley in 1984, was dominated by *Stellaria media* and *Lamium* species at the beginning of the trial followed, in terms of infestation, by *Thlaspi arvense* and *Viola arvensis*. *Matricaria inodora* and *Apera spica-venti* occurred only in isolated patches. There were clusters of up to 30 shoots per square metre of *Elymus repens*.

When compared to continuous cereal rotations, the sequence of cereal and foliage crops reduced the emergence of dicotyledonous weeds (Fig. 1), with the effect, as expected, being most evident in the spring of the 8th trial year (Table 1).

TABLE 1. Weed infestation (plants/m²) in the 8th year of trial.

Crop rotation	Initial infestation 1985	Follow-up infestation Intensity of herbicide use 0	50 %	100 %	2x50 %	situation-related
50 % cereals	239	147	112	106	93	103
100 % cereals	318	343	245	220	199	216

With regard to the individual species it seems that, particularly in continuous cereal rotations, *V. arvensis* is increasing at the expense of *S. media*. The sequence of cereal and foliage crops prevented the infestation by *A. spica-venti* from increasing even without the use of specific herbicides (Table 2).

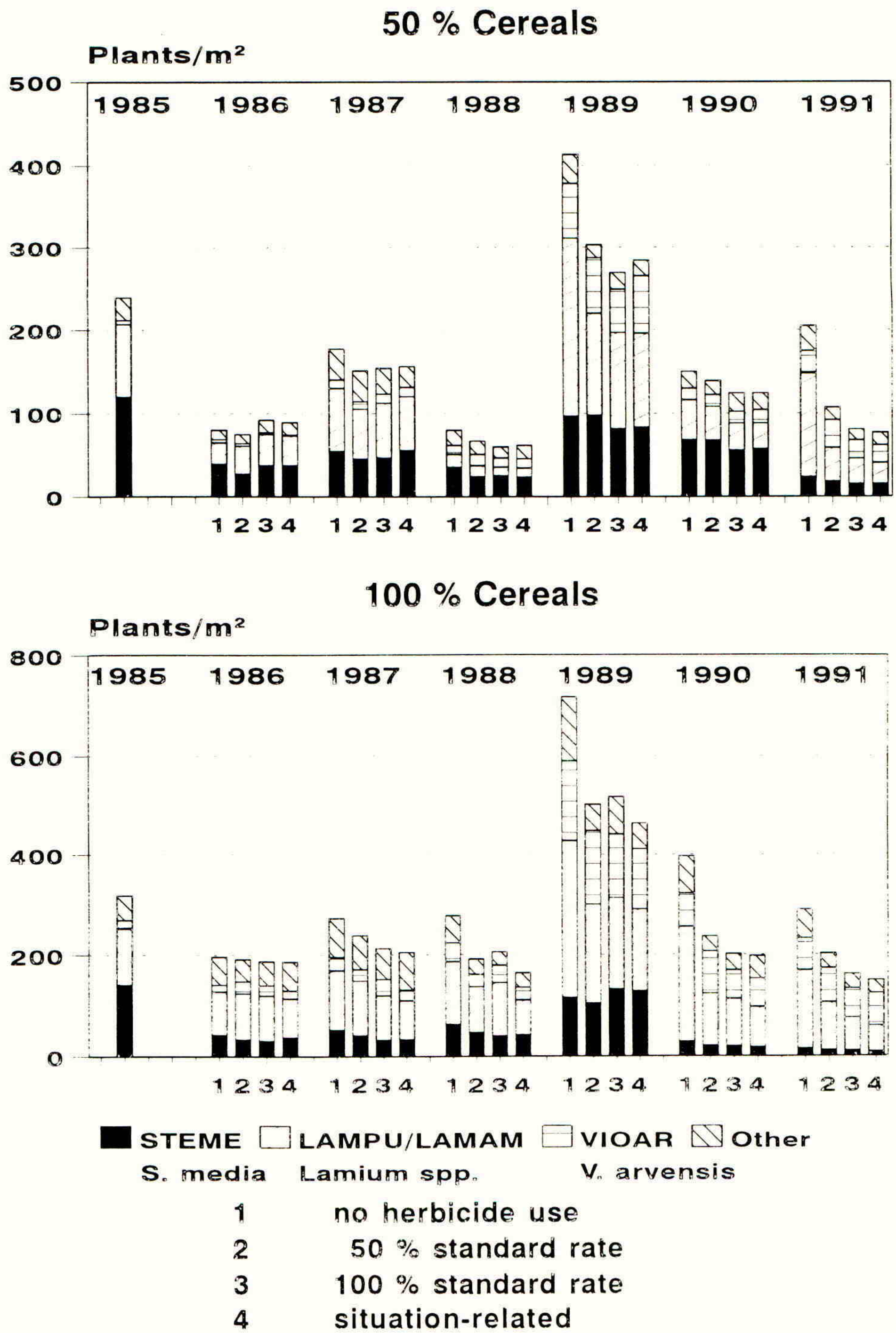

Figure 1. Density of dicotyledonous weeds

TABLE 2. Density of *A. spica-venti* (panicles/m²).

Crop rotation	Years 1985	1986	1987	1988	1989	1990	1991	1992
50 % cereals	0.1	3	2	6	5	1	1	6
100 % cereals	3.2	21	76	77	91	19	98	92

E. repens receded without special stubble cultivation measures taken in the 50 % cereal rotation, while in continuous cereal rotations the omission of stubble working was linked with an increase in *E. repens* (Fig. 2). Regular shallow ploughing, however, prevented such a development. In the first three years of the trial, shallow ploughing had no influence on the emergence of dicotyledonous weeds. Meanwhile there are signs that these species are decreasing by between ten and twenty per cent after stubble clearing. A gradually increasing reduction of infestation with dicotyledonous species was achieved by the application of herbicides. Their impact on follower crops markedly increased with the dose. In the 100 % cereal rotation, the response of *A. spica-venti* to the application of isoproturon was clearer than the reaction of dicotyledonous weeds to the application of all tested herbicides in this experiment (Table 3).

TABLE 3. Density of *A. spica-venti* and dicotyledonous weeds in winter barley (October 1992).

Intensity of herbicide use (% standard rate)	*A. spica-venti* (plants/m²)	Dicotyledonous weeds (plants/m²)
0	153	1471
50	24	981
100	36	1018
2 x 50	16	604
situation-related	18	705

The lack of herbicide application has accelerated the occurrence of *Centaurea cyanus* in cereals at this site (Table 4), particularly since 1988 in the 100 % cereal rotation.

TABLE 4. Density of *C. cyanus* (plants/m²).

Crop rotation	Years 1985	1986	1987	1988	1989	1990	1991	1992
a) 50 % cereals								
without herbicide	0.1	0	0	1.3	1.0	0.2	2.6	14.3
herbicide treated*	0.1	0	0.2	0.4	0.8	0	0.1	1.0
b) 100 % cereals								
without herbicide	0.8	0.3	1.9	3.9	10.9	1.3	13.6	20.0
herbicide treated*	0.3	0.2	0.1	0.4	0	0.5	1.9	0

* 100 % standard rate

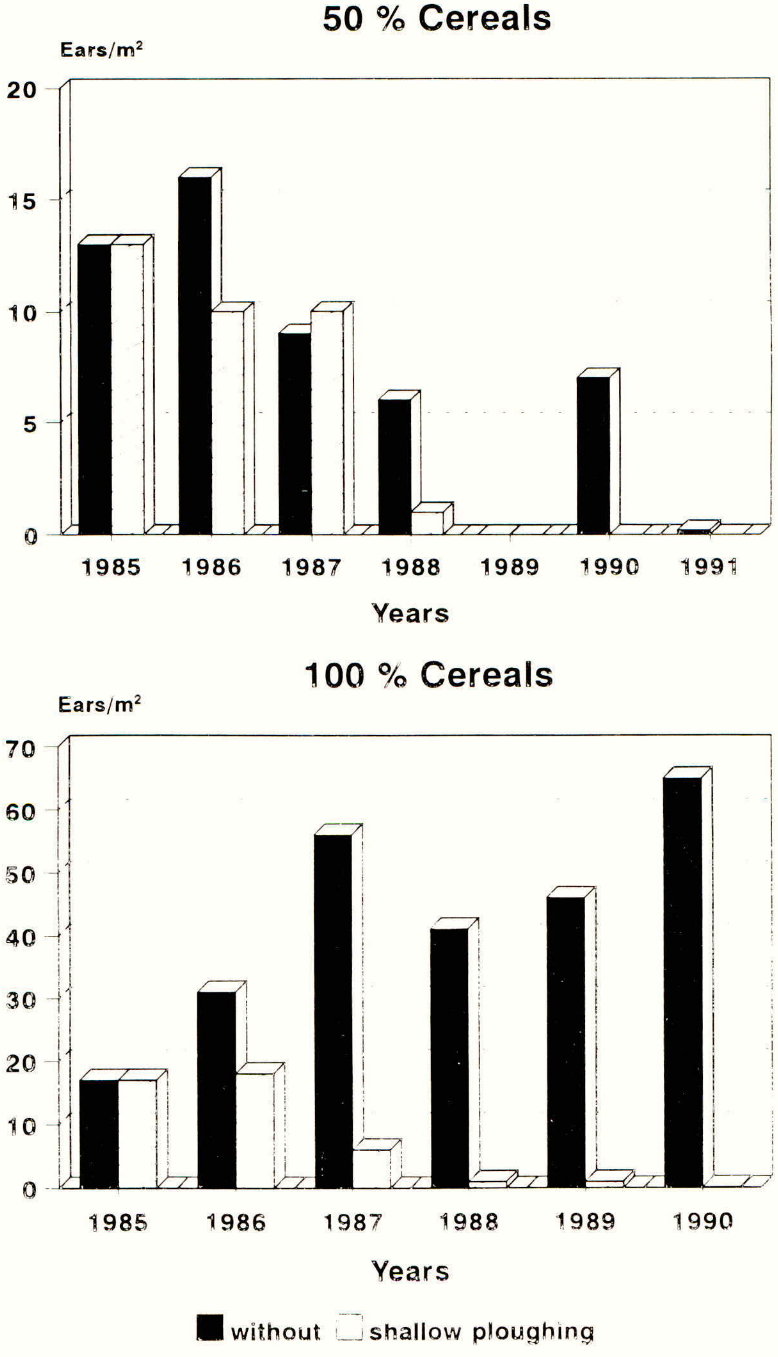

Figure 2. Density of *Elymus repens*

Ploughing led to significantly higher yields only in continuous cereal rotations (Table 5), due largely to improved control of *E. repens*.

TABLE 5. *E. repens* infestation (ears/m²) and grain yield (t/ha).

Stubble cultivation	Crop rotation			
	50 % cereals		100 % cereals	
	E. repens	Yield	*E. repens*	Yield
without ploughing	7	6.74	71	5.72
shallow ploughing	4	6.79	8	6.21
LSD 5 %		0.38		0.24

A survey of all winter grain yields (Table 6) emphasises that in the two crop rotations weed competition has to be considered a major cause of yield differences.

TABLE 6. Density of *A. spica-venti* (APESV, panicles/m²), degree of weed coverage (%) and yields (t/ha) of winter cereals (1989-1991).

Intensity of herbicide use (% standard rate)	Crop rotation					
	50 % cereals			100 % cereals		
	APESV	Weed coverage	Yield	APESV	Weed coverage	Yield
0	2	57	6.73	79	72	5.98
50	4	24	7.13	19	21	7.17
100	4	11	7.33	8	14	7.12
2 x 50	4	9	7.50	2	7	7.04
situation-related	3	12	7.24	33	13	6.97
LSD 5 %			0.54			0.74

Only when crops were grown in the 50 % cereal rotation did the varying intensity of herbicide use show some correlation between remaining weed infestation and yield. In both rotations, yields after "situation-related use of herbicides" were usually lower (but never significantly) than after standard doses or splitting. No influence on yields was recorded after the application of half the standard dose of hormone herbicides and of hormone herbicides plus bromoxynil and isoproturon in continuous cereal rotations.

Yield increases after the use of herbicides were biggest with winter barley, with weed competition being considerably more intense in continuous cereal rotations because of the presence of *A. spica-venti*. In winter rye, the herbicides used were less effective. After potatoes as the preceding crop no significant increase in yields could be proved. As expected, winter wheat reacted to herbicides with high yield increases in continuous cereal rotations.

DISCUSSION

Well-balanced multi-crop rotations limited, often markedly, the occurrence of annual monocotyledonous and dicotyledonous weeds and of perennial species such as *E. repens*. Annual and perennial grasses could often be kept below the threshold by a yearly alternating cultivation of foliage and cereal crops and without any additional use of herbicides.

By contrast, continuous cereal rotations without stubble clearance led to a steady increase in *E. repens*, so that infestation with an initial number of 10 to 15 shoots/m² went up to between 100 and 200 over 3 to 4 years and herbicide use became necessary after the 1988 and 1989 harvests.

A. spica-venti infestation developed similarly in continuous cereal rotations, entailing the use of isoproturon as of 1989 after initially negligible panicle numbers had increased to between 50 and 100/m² in the fourth year of the trial.

The limitation by shallow ploughing of the occurrence of perennial weeds renders herbicide use superfluous; even in crop rotations that show a big proportion of cereals. On the other hand, lessening intensity of soil working is, as a rule, linked with an increase in volunteer cereals and perennial weeds (Pallutt, 1989). In accordance with the results recorded on a loess field (Pallutt *et al.*, 1984), it can be concluded that stubble clearance only leads to a minor decrease in dicotyledonous weeds. The harrowing of winter wheat, too, which can reduce infestation presence by between 30 and 50 %, has only little bearing on weed infestation in the follower crop as the remaining weed plants make up for the losses in numbers by more intense growth. The application of herbicides, as expected, has the biggest impact on follow-up infestation with annual weed species. The after-effects of herbicides in grain crops correlate with the intensity of their use.

In neither of the crop rotations was the reduction of dosage and the use of the threshold principle linked with a grave increase in weed emergence, when compared to the continued application of the standard rate in the follower crops. The yearly differences in emergence that result from weather variations, however, are to be regarded as considerably bigger. If the herbicides are used according to requirements and with due consideration of the threshold principle and if they correspond to the weeds to be controlled and their rates are situation-related, there will be no danger of a sudden increase in infestation. However, according to Lawson and others (1992), reductions in the intensity of herbicide use lead to an augmentation of weed seed potentials in the soil. Furthermore long-term trials in Sweden (Fogelfors, 1990) have shown that selection effects may increasingly occur in continuous cereal rotations after the repeated application of only one herbicide. Due to the changes in herbicide use the increased occurrence of one weed species at the expense of another could not be proved after the use of either the standard dose or half of it.

Grain yields raised through shallow ploughing have in the first place to be attributed to the elimination of *E. repens*, of which Gummeson's studies (1990) also furnish proof. Winter wheat shows the biggest yield losses from *E. repens*. This mainly results from differences in the number of ear-bearing stalks, which was clearly lower only with wheat in continuous cereal cultivation; being some 100 ears per square metre less than in more complex crop rotation. The yield-raising efficacy of the herbicides shows that annual weeds are most competitive in winter barley while they are least competitive in winter rye, which has to be taken into account in setting the thresholds.

From yield analyses can be concluded that the damage to cereals from weeds essentially depends on the competitiveness of the cereal stand. In the case of winter wheat and winter barley, in particular, this competitiveness is strongly influenced by the preceding crop. If the latter is favorably chosen such as potato or rape, the yield reduced by weed emergence is definitely less low. Frequently the yield potential can be optimized with reduced herbicide doses. Slightly lower yields after the situation-related use of herbicides are evidence of a somewhat higher risk from the threshold concept in both crop sequences. The threshold concept should be combined with situation-related herbicide selection and dosage to lower the risk and to simultaneously reduce herbicide quantities.

Finally, this way of approaching the use of herbicides can be a component of integrated weed control which includes corresponding measures of soil and plant cultivation.

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ADAPTATION OF THE DOSE RATE OF HERBICIDES ON CEREALS IN FRANCE

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ABSTRACT

There is a clear trend in reduction in the use of inputs in cereals, including herbicides, in France. The objective is to diminish the cost of treatment, while at the same time retaining satisfactory efficiency and, as well, having a positive effect on the position of the environment. After more than 100 tests carried out by ITCF (The Technical Insitute for Cereals and Forage Crops) between 1989 and 1992, certain conclusions can now be established. Herbicides working by leaf absorption have been applied in the early post-emergence stage of the wheat. Acceptable levels of efficacy, expressed as percentage weed-control, were determined for each species of weed as a function of their threshold. From that base we have deduced the minimum effective dose by weed species and by growth stage. This study has in the first place allowed us to make a judgement on the sensitivity of weeds to the herbicides available in France. It is clear that the majority of dicotyledonous weeds (except *Galium aparine*) and *Lolium sp.* amongst the graminaceous weeds, always show a greater sensitivity when they are young. The stages of development of *Galium aparine*, *Avena sterilis*, *Avena fatua* and *Alopecurus myosuroïdes*, are less important than the choice of an effective herbicide and the climatic conditions. In the case of dicotyledons weeds, the greatest reductions in herbicide dose rates are obtained with mixtures of bromoxynil + ioxynil + diflufenican and of CMPP-D + bifenox + ioxynil. On *A. myosuroïdes*, *A. sterilis* and *A. fatua*, dose manupulation is possible, particularly with fenoxaprop-P ethyl + mineral oil and with clodinafop + mineral oil. Diclofop-methyl as well as clodinafop are effective at low doses against *Lolium sp* at young growth stages, while against *Galium aparine* the greatest possibility for dose rate reduction is in using fluroxypyr at the 5-6 verticils stage.

INTRODUCTION

In an economic context in which crop margins are becoming more difficult to support, it is an option to reduce the application of inputs (fertilizers, farm chemicals) in intensive agriculture. As well, account must be taken of the damaging effects of these products on the environment; particularly concerning the pollution of ground water. A reduction of inputs, including herbicides, is one solution to these problems. However, a reduction in efficiency at crop level should not be amongst the consequences. What is required is an optimization of use. The improvement in formulations by the chemical firms or the perfection of mixtures can be seen as a starting point in the reduction of quantities applied per hectare. (Gauvrit,1991 ; Orlando & Jouy, 1990 ; Bouchet & Beaufreton, 1988). To address in a more particular way the problems of the environment, the Scandinavian countries (Thonke, 1991) have adopted legal restrictions on the use of phytosanitary products. In Sweden, for example, the Government passed a five years action plan in 1986 with the objective of reducing by 50% the amount of such products used with reference to the average amounts used between the year 1981 and 1985. In Denmark, where agriculture is the most intensive of all the Scandinavian countries, the action plan envisaged a 25% reduction by 1990 of the average of the years 1981-85, than a further 25% again before 1997. In parallel, the technical optimization of treatment programmes became the subject of numerous research projects throughout Europe. The setting out of levels of intervention has been the major element in research carried out on weedkilling in cereals in Germany (Gerowitt & Heitefuss, 1990). These levels are expressed in weed densities below which treatment is not recommended. The adaptation of dose rates in accordance with given factors is a technique which was taken up again in Denmark (Streibig, 1989 ; Kudsk, 1989 ; Baandrup & Ballegaard, 1989). These researchers have described sigmoid dose response curves which allow the definition of efficacious doses. (efficacy dose = ED) with which a certain proportion of plants are destroyed, taking certain factors into account. In France, ITCF has wished to define the effective herbicide dose on weeds in crops of cereals by going down a different route from the Danes. The factors taken into account in this route are the type of weed, with an evaluation of it's damage potential, it's stage of development and the product employed.

The experiments on herbicide doses started in 1989. Already, at that time, ITCF were aware of the positive effects of an early post-emergence treatment. The goal therefore was to attack the weeds at an early stage of development when they are very sensitive to weedkillers and well before they have become competitive with the crop. (Real, 1989).

METHODS

The results of tests carried out from 1989 to 1992, in different part of France is reviewed. They consist of block type trials with one control plot for every treated. The surface of every plot was 20 m^2. Each weed studied, or group of flora, was the object of a specific protocol. The products used experimentally were not the same for all the weeds. With a view to define the level of sensitivity of each weed as a function of its development, three application stages have been studied. For graminaceous weeds, the development stages taken into account were: (a) 2 to 3 leaves present, (b) 1 to 2 tillers developed, (c) end of tillering - beginning of stem extention. For dicotyledons weeds, the following development stages were used: (a) cotyledon stage to first leaf apparent, or first verticil for *Galium aparine*, (b) plantule stage to young plant stage (2 to 3 leaves), (c) young plant stage to developed stage (5 to 6 leaves).

The choice of herbicides was defined as a function of their known efficiacy against each weed. This efficacy was judged on a preceeding year basis in "Knowledge of Spectrum" protocols. Herbicides known to have wide spectrum of action were used in situations where a broad weed flora was present. Conversely, under certain situations, we have tested more specific herbicides. This is the case with ureas of sulfonyl-ureas which have an action against *Matricaria* spp, *Stellaria media Capsella bursa-pastoris*; and graminaceous herbicides. The doses used experimentally were firstly the homologated, or generally recommended dose and then some lesser doses. These latter doses are generally 3 in number and defined as a function of the growth stage of the weed, as these are generally more active at the younger stages. Consequently, the doses used are increased with the development of the plant from stage to stage.

The chemicals were sprayed by means of back-pack sprayers equipped with fan type nozzles, delivering 300 to 400 l/ha at 2 to 3 bars.

Notes and analysis of the results

Assessment was undertaken at stem extension of wheat for the dicotyledonous weeds or at ear emergence in the case of grass-weeds. It is at these times the presence of weeds and the herbicidal effect are most easily quantifiable.

In order to determine the effectiveness of a particular product on a plot, we have used a visual assessment system. The assessment is based on criteria which integrate effectiveness, the level of infestation and the damage potential of the weed. This is presented as a percentage of weed destruction in relation to a non-treated control plot (TABLE 1). A threshold is defined for each weed species. In relation to it's direct damage potential, it's productivity and seed life. A list of thresholds is set out in TABLE 2. The minimum level of acceptable efficacy is set at 85%, exemplified by *Aphanes arvensis* or *Viola arvensis*, where even at about 100 plants per m^2, its presence has practically no ill effect on the crop. on the contrary, great importance is attached to weeds such as *Galium aparine* (where a low presence can mean very serious competition) or to graminaceous weeds of the same sensitivity family as cereals where the level of acceptable efficacy is 98%. In the case of *Papaver rhoes* and *Matricaria sp.*, a high threshold of 95% is used because of their very high seed reproduction. The same value is used for *Stellaria media* because of its direct damage potential and the long life of it's seeds. Other weeds have been given values dependant on our experience.

The minimum effective herbicide dose which will give weed control equal or greater than the threshold required is then evaluated.

TABLE 1. Assessment scale.

Notation	Vision	Judgement	Classification of weed sensitivity
0	No effect	No efficacy	Resistant
2 7 16	Slight product action without much importance	No efficacy Very weak efficacy Weak efficacy	Resistant
30 50	Noticable efficacy	Poor efficacy Average efficacy	Resistant to partly resistant
65	Product effect just below acceptable limit to advise use	Moderate efficacy	Partly resistant to partly susceptible
85	Effect is incomplete however effect is sufficient to allow use against certain weeds	Fairly good efficacy	Average sensitivity
95	Product result very good but some unaffected plants remain	Very good efficacy	Average sensitivity to sensitive
98	Product result very good but a few plants remain	Very good efficacy	Sensitive
100	Total control	Total efficacy	Sensitive

TABLE 2. Criteria of damage potential evaluation and level of acceptable efficacy used in the study.

Weeds	Threshold of loss number of plants per m^2 reducing yield by 5%: WILSON, 1986	ITCF	Seed number per stem	Seed life (years)	Level of acceptable efficacy (% destruction)
Avena spp	5,3	autumn : 15 to 20 spring : 50	50 to 500	15	**98**
A. myosoroïdes	26	25 to 30	3000	15	**98**
Lolium spp	-	25 to 30	1500	-	**98**
G. aparine	1,8	-	1100	10	**98**
P. rhoeas	22	20	50000	40	**95**
Matricaria spp	22	20	45000	20	**95**
S. media	26	east: 20; west:70	2500	80	**95**
Geranium spp	-	-	-	-	**95**
Veronica spp	26 to 44	50 to 60	100 to 200	10	**90**
Lamium spp	44	-	500	-	**90**
M. arvensis	66	-	2000	-	**90**
C. bursa-p.	-	-	-	40	**90**
V. tricolor	133	> 100	2500		**85**
A. arvensis	133	100	5000		**85**

RESULTS AND DISCUSSION

Dicotyledonous weeds. A range of herbicide products were tested for efficacy against the following weeds: *Veronica hederifolia, V. persica, V. arvensis, Viola arvensis, Stellaria media, Papaver rhoeas, Matricaria recutita, M. perforata, Lamium amplexicaule, L. purpurum, Myosotis arvensis, Aphanes arvensis, Capsella bursa pastoris, Geranium spp.*

The products show an overall level of efficacy which is better on weeds at the cotyledon stage than 2 to 3 or 5 to 6 leaves (TABLE 3). Dicotyledonous weeds appear therefore to be more sensitive at their younger stages of development regardless of product.

TABLE 3: The minimum dose giving efficicent weed control for each dicotyledonous weed, according to growth stage (l or kg or g/ha):
line 1=cotyledon stage, line 2=2 to 3 leaf stage, line 3=5 to 6 leaf stage

	HERBICIDES and AUTHORIZATION DOSES								
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
	2,5 l	2 l	2,5 l	3 l	2 l	0,5 kg	30 g	2 kg	1500 g
	EFFICACY DOSES								
Veronica	0,6	1,5	0,65	2,5	0,25	0,4	❑	1,5	▲
spp	2	2	0,65	3	1	0,5	▲	1,5	-
	2,5	2	1,25	3	1	0,5	-	2	-
S. media	2,5	1	1,8	2	0,5	0,2	10	1,5	1000
	2,5	2	2,5	-	1	0,5	15	2	-
	2,5	2	2,5	-	1,25	0,5	20	2	-
V. arvensis	1,25	1,5	0,4	1	0,25	0,5	30	1	▲
	1,25	❑	0,65	3	0,25	0,5	30	1,5	-
	2,5	❑	2	3	0,75	0,5	30	1,5	-
P. rhoeas	1,25	1	0,65	3	1	0,4	30	-	1250
	2,5	1	-	3	1	0,4	-	-	-
	❑	❑	❑	❑	1,5	❑	-	-	-
Matricaria	2,5	2	1,8	-	0,75	0,25	15	0,75	1000
spp.	-	2	1,8	-	1,25	0,5	20	-	-
	-	2	-	-	-	-	-	-	-
Lamium	0,6	1,5	0,4	2	0,5	-	-	0,5	▲
spp	2	2	-	2,5	-	-	-	-	-
	2,5	▲	-	❑	-	-	-	-	-
A. arvensis	-	0,5	0,65	1	0,75	0,5	-	-	1250
	-	2	2	3	-	0,4	-	-	-
	-	-	-	❑	-	❑	-	-	-
M. arvensis	1,25	1	0,65	2	0,5	0,2	-	-	▲
	2	2	-	2,5	-	0,3	-	-	-
	2,5	1,5	1,8	3	0,75	0,3	-	-	-
C.	2	1,5	1	3	0,25	-	-	0,5	1250
bursa-pastoris	2	1,5	-	3	0,5	0,5	-	0,75	-
	2	1,5	-	❑	0,75	0,5	❑	1	-
Geranium	-	0,5	0,65	-	0,5	-	-	-	-
spp	-	2	-	-	-	-	-	-	-
	-	-	-	❑	-	-	-	-	-

- : absence of results ❑ : results satisfactory under certain conditions

▲ : efficacy insufficient at the homologated dose

List of products used:
(a) EXEL D+ - Rhône Poulenc: CMPP-D (370 g/l) + bifenox (300 g/l)
(b) MAESTRO II - Ciba: CMPP (540 g/l) + ioxynil (180 g/l)
(c) FOXPRO D+ - Rhône Poulenc: CMPP-D (260 g/l) + bifenox (300 g/l) + ioxynil (92 g/l)
(d) LAZERIL - Rhône Poulenc: CMPP (312 g/l) + ioxynil (125 g/l) + diflufenican (17 g/l)
(e) FIRST - Rhône Poulenc: bromoxynil (125 g/l) + ioxynil (75 g/l) + diflufenican (40 g/l)
(f) SATIS - Ciba: fluorogylcolfen (8 %) + triasulfuron (3 %)
(g) ALLIE - Dupont: metsulfuron methyle (20%)
(h) ESTRAD - BASF: dichlorprop-P (48,5%) + fluorogylcofen (1,5%)
(i) isoproturon only on soils where the clay content is below 25%
(j) STARANE - Dow Elanco: fluroxypyr 200 g/l
(k) GRATIL - Procida: amidosulfuron 75%

Cleavers (*Galium aparine*)

The level of efficacy set for *G. aparine* is 98%. To retain that value, reductions in the herbicide dose rate are rarely possible with the products used (TABLE 4). Moreover, sensitivity of this weed does not seem to depend on growth stage so much as on product, on how it is utilized and most of all on whether *G. aparine* has emerged at the time of treatment. As a consequence, a two phases is adopted. In the Autumn, when the first *G. aparine* are at the cotyledon stage, one can be satisfied with an efficacy of 80%; easily obtained with the classical products. In the Spring, if there has been a further emergence of *G. aparine*, one should aim for a maximum efficiency of 98%, which can be obtained with fluroxypyr when the *G. aparine* is at the 5-6 verticil stage.

TABLE 4. Doses of acceptable efficacy on Cleavers according to growth stage (l or kg or g/ha).

Herbicides	Homologated dose	Development stage: cotyledon (L =80%)	cotyledon (L = 98%)	2-3 verticils (L = 98%)	5-6 verticils (L = 98%)
(a)	**2,5 l**	2	❑	❑	2,5
(b)	**2 l**	1,5	❑	❑	2
(c)	**2,5 l**	1,25	1,8	❑	2,5
(d)	**2 l**	0,75	1,25	1,5	1,5
(f)	**0,5 kg**	0,3	0,5	0,5	▲
(j)	**1 l**	▲	▲	❑	0,6
(k)	**40 g**	20	❑	40	❑

❑ : Results satisfactory under certain conditions ▲ : Insufficient efficacy at the homologated dose
L = Level of acceptable efficacy.

TABLE 5. Doses of acceptable efficacy according to growth stage of *Avena spp, A. myosuroïdes* and *Lolium spp* (l or g/ha)

Herbicides	homolog. dose	*Avena spp* - Stages 2-3 L	1-2 T	End T	*A. myosuroïdes* - Stages 2-3 L	1-2 T	End T	*Lolium spp* - Stages 2-3 L	1-2 T	End T
(l)	**2 l**	2	2	❑	1,5	1,5	❑	2,5	2	❑
(m)	**5 l**	-	5	-	-	❑	▲	3,5	3,5	5
(n)	**1,2 l**	0,8	0,8	0,9	0,9	1	1	-	-	-
(n) + oil	**1,2+1 l**	0,7+1	0,7+1	0,7+1	0,8+1	0,7+1	0,7+1	-	-	-
(o)	**2500 g**	-	-	-	1500	-	-	1500	-	-
(i)	**1500 g**	-	-	-	1000	1250	1500	-	-	-
(p	**5 l**	4	❑	-	4	-	-	-	-	-
(q)	**2,5 l**	-	-	-	-	-	-	1,5	2,5	2,5
(r) + oil	**0,6+1 l**	-	-	-	0,4+1	0,3+1	0,3+1	0,3+1	0,5+1	❑

- : absence of results ❑ : Results satisfactory under certain conditions
▲: Efficacy insufficient at homologated dose L = Leaf T = Tiller

(l) DOPLER - Dupont: diclofop-methyl 250 g/l + fenoxaprop-P-ethyl 23 g/l
(m) GRASP 60 - Sopra: tralkoxydime 60 g/l
(n) PUMAS - Procida: fenoxaprop-P-ethyl 69 g/l
(o) chlorotoluron 500 g/l only on soils where the clay content is below 25%
(p) MEGAPLUS SC - Cyanamid: pendimethalin 200 g/l + imazamethabenz 125 g/l
(q) ILLOXAN CE - Procida: diclofop-methyl 360 g/l
(r) CELIO + m oil - Ciba: clodinafop 100 g/l
oil : mineral oil

Graminaceous weeds

Work was carried out on three types of detrimental graminaceous weed: *Avena ssp*, *A. myosuroïdes* and *Lolium spp* at three growth stages: 2 to 3 leaves (2-3 L), 1 to 2 tillers (1-2 T) and end of tillering (end T). It is apparent that for foliar acting products, the sensitivity of *Avena spp* and *A. myosuroïdes* does not depend on their stage of development. Climatic conditions are shown to be more important and mask the expected "stage" effect. In fact, the carriage or posture of these weeds remains the same at all stages until stem extension. Their leaves are exposed to the product in the same proportions; this is not the case with dicotyledonous weeds, where young upper leaf growth may shelter older leaves and limit the quantity of product applied to the totality of the plant. With *Lolium spp*, the results are close to those found with dicotyledonous types, that is to say a greater sensitivity at the young stages for the majority of herbicides, with the exception of diclofop + fenoxaprop. Contrary to other graminaceous types, *Lolium spp* foliage is a plant which is easy to wet, a characteristic which is found also with many dicotyledonous weeds. This peculiarity is due to the presence of surface waxes on the glossy face of the leaves; these favour the spreading out of the droplets and their penetration. The crystalline surface waxes which one finds on the leaves of most graminaceous plants, do not assist wettability (Gauvrit, 1990)

The potential for modulation of doses of foliar acting products on graminaceous weeds are given in TABLE 5. Against *Avena spp* and *Lolium spp*, fenoxoprop-P ethyl can be used at doses between 0.7 and 1.0 l/ha against the homologated dose of 1.2 l/ha. It should be noted that the addition of mineral oil permits a reduction of the effective dose (0.7 l/ha for the most part) and a greater persistence. Substituted ureas, like chlorotoluron and isproturon (which are of moderate cost to the user) and Clodinafop also give the opportunity of dose reduction against *Lolium* spp.

CONCLUSION

This study highlights the greater sensitivity of dicotyledonous weeds (with the exception of *G. aparine*) at their cotyledon stage. The same applies to *Lolium* spp. With *G. aparine*, *A. myosuroïdes* and *Avena* spp, the product effect seems to outweigh the growth stage effect, certainly because of the determining influence of climatic conditions on the type of herbicides used in the experiments. The association of bromoxynil, ioxynil and diflufenican on the one hand and of CMPP-D, bifenox and ioxynil on the other demonstrate the greatest possiblities for the reduction of dose rates against dicotyledonous weeds. Fluroxypyr is very effective at low dose rates against *G. aparine* at the later development stages. Fenoxoprop-P ethyl (particularly when used with oil) shows itself to be very adaptable against *Avena spp* and *A. myosuroïdes* at all development stages. Against the latter weed, at the 2-3 leaf stage, chlorotoluron and isoproturon can also be used effectively at low doses.

Where *Lolium* spp are at the 2-3 leaf stage, several products show efficacy at doses which are lower than the homologated dose. Clodinafop + oil can be used at low dose rates on *Avena spp* and *A. mysuroïdes* as well as on *Lolium* spp. All the results given here are presented in the form of **proportion of dose reduction** or of **minumum effective dose per hectare**. The consequences of using these minimal effective doses on the environment is evident. Taking the product price into account allows for satisfacory treatment programmes to be drawn up at a reasonable cost to the farmer. This has been the subject of a study in France and is now in use by the agricultural profession.

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AN APPROACH TO DEVELOPING APPROPRIATE HERBICIDE OPTIONS FOR WINTER WHEAT WHERE CLEAVERS ARE A PROBLEM

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ABSTRACT

An experiment was established at seven sites throughout the UK in 1991 to determine the interaction between the autumn- and spring-applied components of a herbicide programme to control *Galium aparine* in winter wheat. A common stock of *G. aparine* was sown at six sites to provide a uniform population of weeds for the experiment. This technique proved very successful. Assessed in the spring, over winter control of *G. aparine* by diflufenican + isoproturon ranged from about 48% for quarter rate to 85% for full rate. Assessments just before harvest demonstrated, perhaps contrary to prior expectations, that at rates of fluroxypyr greater than one quarter of the recommended dose there was little interaction between the autumn and spring herbicides. However when the rate of fluroxypyr was reduced to one eighth of the recommended dose, control of *G. aparine* was dependent on prior application of diflufenican. Grain yield was quite insensitive to herbicide treatment or weed biomass until diflufenican and fluroxypyr rates fell below about one quarter of that recommended. Overall, a programme using half rates of both herbicides was most appropriate, combining secure control of *G. aparine* and other weeds with optimum margin over herbicide costs.

INTRODUCTION

For winter cereals grown in the United Kingdom, weed control is a relatively important contributor to the total variable costs of production, particularly when it is deemed necessary to use herbicides at the full rates recommended by the manufacturers. Sometimes recommendations allowing for a degree of rate reduction are now included, while independent research in the UK (e.g. Proven *et al.*, 1991 ; Fisher *et al.*, 1991) and elsewhere in Europe (e.g. Gauvrit, 1991 ; Thonke, 1991 ; Salonen, 1992a) has demonstrated effective weed control using lower than recommended rates of a wide range of herbicides. Treatment thresholds have been shown to be a useful tool (Cousens, 1985 ; Cousens *et al.*, 1985 ; Proven *et al.*, 1991) but it is evident that it is easier to sustain a reduction in herbicide use by adopting a prophylactic approach while paying more attention to identifying the appropriate dose (Davies *et al.*, 1993).

The factors which help to determine a label-recommended rate for a herbicide include a component for reliable performance over a wide range of conditions (Finney, 1993). Conversely, the largest perceived problem with reduced or appropriate doses is the increased risk of failure under conditions which appear 'normal'. The focus of new work therefore needs to be directed towards identifying those factors which influence the reliability of reduced doses - or, less controversially perhaps, towards identifying those factors which influence the shape or position of the classical 'herbicide dose:weed response' curve (Streibig, 1989).

Some obvious effects of weed and crop densities have already been studied (Courtney, 1991 ; Salonen, 1992b). Numerous other factors may also be important. Much classical 'dose-response' work involves single applications of single chemicals or chemical mixtures. However in UK farming it is usual for weed control in cereals to be effected by a two- or three-spray programme, applying herbicides both in the autumn and in the spring. The work described in this paper investigated the interdependence of the autumn and spring components of a two-spray programme on the control of *G. aparine*. The impact of treatments on the biomass of other weeds was also recorded.

MATERIALS AND METHODS

Sites

The experiment was established in autumn 1991 on winter wheat crops (cv. 'Riband') throughout the UK. There were four sites in England (ADAS Boxworth, Cambridgeshire, ADAS Bridget's, Hampshire, ADAS Drayton, Warwickshire and ADAS Rosemaund, Herefordshire), two in Scotland (SAC Bush, Midlothian, and Haddington, East Lothian) and one in Northern Ireland (QUB Greenmount, Co. Down). All sites were in areas of intensive arable rotations and encompassed soil types from sandy clay loam to clay.

Experimental design

The sites all used a randomised complete block design with three replicates. The two treatment factors were tested at all levels in a complete factorial design. There were two additional untreated plots in each replicate. Plot size was 18-24m x 2.1-2.5m.

Treatments

Two treatment factors were tested at four or five levels:

1. Autumn application of diflufenican + isoproturon ('Panther', g AI/ha)

nil
25 + 250
50 + 500
100 + 1000

2. Spring application of fluroxypyr ('Starane 2', g AI/ha)
nil
25
50
100
200

All treatments were applied through flat fan nozzles delivering 200-250l/ha water as a medium quality (BCPC) spray using knapsack sprayers. The target timing for the autumn sprays was early post-crop emergence (spray dates ranged from mid November to end December) whereas for the spring sprays the target was crop GS31 (spray dates ranged from late March to mid April).

At six of the seven sites, a common population of *G. aparine* seeds was sown at approximately 50 seeds/m^2 immediately before the wheat crop was planted. The *G. aparine* seeds were either sown by hand, bulked up with inert material to ensure even distribution, or were applied using a precision plot drill. The subsequent operations of drilling, harrowing and consolidating the seedbed ensured that the seeds were well incorporated. These sites also had relatively wide ranges of other native weeds. No *G. aparine* seed was sown at the SAC Haddington site which had a high native population of the species.

Assessments

Weed counts in the autumn and early spring were done to estimate the establishment rate for the sown *G. aparine*.

The principle method by which the effect of herbicides on *G. aparine* and other weeds was assessed was by measurement of above-ground biomass. Immediately before the application of the fluroxypyr treatments in the spring, and again in July/August when both components of the herbicide programmes had taken effect, crop, *G. aparine* and 'other weed' biomass was measured in three 0.5m^2 quadrats positioned evenly along the plots. Samples were taken, separated into their component parts, dried in a forced-draught oven and the dry weights of each component expressed 'per square metre'.

Grain yield (t/ha at 85% DM) was measured by combine harvester cut. Grain dry matter (%) and specific weight (kg/hl at 85% DM) were determined.

RESULTS

At the six sites where they were sown, the technique of broadcasting *G. aparine* seed was very successful. Establishment figures were a little variable between sites and could not be established unequivocally because of the contribution from indigenous plants. However establishment rates all appeared to be in the range 15-25%, and there was less variability than this within any one site. As a result, the ensuing herbicide dose:response measurements were conducted in the context of an even, testing, but not atypically high *G. aparine* population of about 10 plants/m^2.

Grain yield

Mean grain yields for the seven sites are shown in Table 1. Overall, grain yields were quite high and were relatively insensitive to herbicide rates. However when either herbicide was used alone, grain yield was reduced by between 3 and 12% from the maximum. Conversely, as soon as the programme incorporated application of both diflufenican and fluroxypyr, average grain yield was 99% of the highest figure recorded.

TABLE 1 Mean grain yield (seven sites; t/ha at 85% DM)

	Diflufenican (g AI/ha)				
	0	25	50	100	Mean
Fluroxypyr (g AI/ha)					
0	7.12	7.65	7.86	7.88	7.63
25	7.19	8.05	8.03	8.08	7.84
50	7.80	8.01	8.04	8.15	8.00
100	7.75	8.01	7.93	8.05	7.93
200	7.76	8.09	7.89	8.04	7.94
Mean	7.52	7.96	7.95	8.04	7.86

The overall figures hide some important site differences. At Boxworth, Drayton and Rosemaund average yields were around 7 t/ha whereas at Bridget's and Bush they were about 9.5 t/ha. At these sites the response to herbicide treatment was similar to the overall picture. At Haddington, average grain yield was 12.12 t/ha, weed biomass (and particularly *G. aparine* biomass) was much lower than the other sites and the response of grain yield to herbicide rate was attenuated. Greenmount, in contrast, had an average grain yield of only 2.7 t/ha. Wet conditions, particularly in the autumn led to poor crop establishment and vigour. Perhaps as a consequence the activity of the herbicides was greatly reduced and *G. aparine*, other broad-leaved weed and grass weed biomass were high and relatively insensitive to herbicide dose.

Weed biomass

Biomass data for *G. aparine* are shown in Table 2. The full-rate sequence overall gave 99% control of *G. aparine* biomass and this dropped to around 94% when fluroxypyr was used alone. Conversely, full rate diflufenican + isoproturon alone gave 85% control. This pattern of response was similar for all combinations of the sequence. The lowest dose combinations to give around 90% control were 100g AI/ha fluroxypyr following 25g AI/ha diflufenican and 50g AI/ha fluroxypyr following 100g AI/ha diflufenican. Some activity was seen at the lowest individual rates tested, with fluroxypyr giving around 11% reduction in *G. aparine* biomass at 25g AI/ha (one eighth normal dose) and diflufenican giving a 48% reduction at 25g AI/ha (one quarter normal dose).

TABLE 2 Mean biomass of *G. aparine* measured in July after all treatments had taken effect (g DM/m^2)

	Diflufenican (g AI/ha)				
	0	25	50	100	Mean
Fluroxypyr (g AI/ha)					
0	53.8	27.8	20.9	8.1	27.7
25	47.8	18.2	15.7	6.4	22.1
50	18.5	13.6	9.5	5.8	11.9
100	8.4	4.8	2.9	2.5	4.6
200	3.4	4.2	4.9	0.6	3.3
Mean	26.4	13.7	10.8	4.7	13.8

For weeds other than *G. aparine*, patchiness of distribution, the interaction between broad-leaved (BLW) and grass weeds at some sites and variation in crop competition resulted in a less clear pattern of response to the herbicide combinations. Generally, when untreated, BLW biomass was about half that of *G. aparine*. To achieve better than 80% control required the use of both diflufenican + isoproturon in the autumn and fluroxypyr in the spring, although this level could be attained with the lowest rates tested (25g AI/ha diflufenican followed by 25g AI/ha fluroxypyr). In contrast with this overall picture, at the Northern Irish site untreated BLW biomass was more than twice that of *G. aparine* and some treatments appeared to increase the level of BLW - presumably by reducing competition from the cleavers. In this much more testing environment, only full rate diflufenican + isoproturon followed by at least 50g AI/ha fluroxypyr achieved 80% control.

DISCUSSION

The efficacy of products tested varied between sites, but the general pattern of response suggests that a sequential approach to weed control is the best route to achieving a reduction in the application rates of both ingredients of the sequence. Other studies have shown the efficacy of some autumn treatments, such as diflufenican + isoproturon to be such on weeds other than *G. aparine* and some grasses, that flexibility in dose is possible (Fisher *et al.*, 1993). The current research programme suggests that a reduction in diflufenican + isoproturon dose to around 50% of that recommended - sufficient to control many less competitive weeds - would be sufficient to allow reduction in the recommended dose of fluroxypyr to around 50% also, and still maintain good control of *G. aparine*. In farming practice, decisions on the best strategy for weed control are always complicated by the need to estimate the consequence of actions in one year upon the events in subsequent years. Care must be taken when extrapolating from single year experiments. In the study reported here, the relative insensitivity of wheat yield to weed competition meant that the most cost-effective options were those employing the lowest rates of herbicides tested. However these programmes achieved levels of weed control which, aside from any considerations of aesthetic unsuitability, would present serious risks for build-up of the weed seedbank.

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HERBICIDE DOSE ADJUSTMENT AND CROP WEED COMPETITION

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ABSTRACT

Dose-response experiments in winter wheat showed significant effects of varying sowing date and crop density in terms of final weed d.m. A comparison of the dose-response curves at a low level of weed d.m. showed that the recommended herbicide dose could be reduced when sowing was delayed. Another experiment showed that a crop density of 100 plants m^{-2} demanded a significantly higher herbicide dose than crop densities of 200 and 400 plants m^{-2} in order to achieve the same low level of weed d.m.

The analyses verified that varying crop weed competition only modified the d-parameter, which corresponds to weed d.m. of untreated controls, in the described dose-response model. It suggests that varying crop weed interaction can be incorporated in a dose-response model by using a competition model to "predict" the d-parameter. Adjustment of the herbicide dose based on crop weed competition can be estimated when a target weed d.m. is specified for short term and long term requirements of weed control.

INTRODUCTION

The development of more cost effective and environmental sound use of herbicides in cereals has been an objective for several national research programmes in Europe. A dominant approach in these programmes has been a quantitative description of the impact of weed density for different weed species that can be used to estimate economic thresholds. Several field experiments have shown that the short term impact of weeds in cereals is often lower than the cost of the treatment (cf. Jensen 1986; Gerowitt & Heitefuss 1990; Davies et al. 1993). However, a treatment may still be beneficial in a long term because it reduces the carry-over effect of weed seed production in the following crops (Doyle et al. 1986; Melander 1993), but more results are required. Therefore, the thresholds concept is still connected with uncertainty. Further, Davies et al. (1993) argued that the cost of the current method to assess weed density is higher than the cost of treatment.

In Denmark, another approach has been used to obtain a reduction in herbicide input. The core of the Danish approach is to adjust the herbicide dose due to the factual effect by means of the dose-response models. In cereal crops, which possess a high competitive ability, herbicide doses below the recommended dose will often be sufficient to retard the growth of weeds to such an extent that they will be suppressed completely by the crop. Pot experiments have shown that several factors affect the herbicide performance (cf. Kudsk 1989; Kudsk et al. 1990; Mathiassen & Kudsk 1993). Christensen (1993) also found significant differences in the effect of reduced herbicide doses among cereal varieties.

Generally, the relationship between weed response and the logarithm of the herbicide dose is adequately described by a sigmoid curve. Streibig (1988) derived a method to calculate the relative potency of herbicides with the same mode of action and with the same upper and lower asymptotes of the dose response curves. The method has successfully been used to calculate the relative potency of formulation and adjuvants (Kudsk & Streibig 1993). Christensen (1993) found that the method could not describe varying herbicide performance in cereal cultivars with different weed suppression abilities because the upper asymptotes were not the same for all cultivars. Therefore an arbitrary response level of weed d.m. was specified in order to estimate a varietal calibration of the herbicide dose. The objectives of this paper are to show that this method can be used to calibrate the herbicide dose for different crop densities and sowing dates of winter wheat. The paper also discuss how to amalgamate the dose response model and a competition model, and how to specify a target weed response level for short term and long term requirements of weed control.

METHOD

Two dose-response experiments were conducted in winter wheat cv. Slejpner on a sandy loam at the Department of Weed Control in Flakkebjerg, Denmark in 1990-1991. The experiments were split plot designs with different sowing dates and crop densities as main plots and herbicide doses as subplots. Plot size was 10 m x 2.5 m and rows were 12 cm apart. Both experiments were treated with fertilizer (145 N, 28 P and 70 K kg/ha) at the beginning of April and fungicides were applied when required.

Experiment 1 consisted of four main plots that were ploughed, prepared with a rotary harrow and sown on 13 September, 3 October, 9 October and 16 October 1990. Crop density was approximately 400 wheat plants m^{-2} in this experiment. Experiment 2 was sown on 13 September with seed rates that corresponded to 100, 200 and 400 wheat plants m^{-2} approximately.

Oil seed rape, which was used as an artificial weed, was broadcast immediately before sowing in both experiments. However, oil seed rape became a minor part of the weed population because many plants were damaged by frost in the winter; especially in the late sown crops. In spring, weed density was the same in all plots sown on 13 September in both experiments but in experiment 1 it was lower in the late sown plots than in the early sown plots.

The herbicide mixture ioxynil + mecoprop (Mylone Power) was applied in spring when the oil seed rape of sowing date '13 September' had developed 4 leaves. The applied doses were 0, 1/32, 1/16, 1/8, 1/4, 1/2, and 1/1 of the recommended dose (240 + 720 g a.i./ha). The herbicide was applied with Hardi 8680-15E nozzles at 2.5 bar resulting in medium spray volume of 200 l/ha.

The final foliar d.m. of weeds was measured on 22 June by taking two samples of 0.25 m^2 from all plots. The samples were dried at 80°C and weighed.

Statistical methods

Non-linear regressions with categorical variables were used to analyze the relationship between weed d.m. (W) and the logarithm of herbicide doses (x) in the two experiments. A logistic model,

$$W = d(1 + \exp(a - bx))^{-1} \quad (1)$$

was fitted to the data. Transform-both-sides method was applied to achieve normal distribution and homogeneity of variance. The parameter, d, is the upper asymptote that corresponds to weed d.m. in untreated control. The parameters, a and b, describe the horizontal location and the slope of the curve around ED_{50}.

The effects of different sowing times and crop densities were incorporated in Eqn. 1 as described in Christensen (1993). This approach is similar to multiple regression models including categorical variables. The model was coded so that the parameters were estimated relatively to the first sowing date and the highest crop density. In general, another sowing date or crop density could have been used as reference without changing the estimates.

RESULTS

The effects of sowing dates and crop densities were most obvious in the untreated control plots. In experiment 1, weed d.m. of these plots ranged from 163 g m^{-2} in the sowing date '13 September' to 44 g m^{-2} in the sowing date '16 October'. Weed d.m. decreased with later sowing dates because the final weed density and survival were lower in the late sown plots than in the early sown plots. In experiment 2, weed d.m. of the untreated plots ranged from 149 g m^{-2} in the crop density '400 plants m^{-2}' to 420 g m^{-2} in the crop density '100 plants m^{-2}'.

The fitted dose-response curves of the two experiments are shown in Figs. 1 and 2. Analyses confirmed the result in Christensen (1993) that varying levels of crop weed competition only modified the d-parameter. That is, the relative weed d.m. differences of the sowing dates and the crop densities were the same irrespectively the herbicide dose.

In experiment 1, weed d.m. ratios between the sowing date '13 September' and the sowing dates '3, 9 and 16 October' were 0.36, 0.14 and 0.16 for all applied doses and the untreated controls. In experiment 2 weed d.m. ratios between the crop density '400 plants m^{-2}' and the densities '200 and 100 plants m^{-2}' were 1.68 and 2.78.

The effects of sowing date and crop density were also assessed as the differences of herbicide doses at the same weed d.m.. The effects were estimated by transposition of the predictor to the left side of Eqn. 1. This approach correspond to the vertical assessment described by Streibig (1988). Christensen (1993) suggested a specific weed response level for weed control in different cereal varieties in order to calculate the doses that were necessary to achieve the same weed d.m. in all cultivars.

The estimates in Table 1 show the herbicide dose ratios of the sowing dates and the crop densities at three d.m. levels. In experiment 1, the d.m. levels were achieved with lower herbicide doses than recommended in all sowing dates, e.g. 10 g m^{-2} of weed d.m. was achieved with 0.44, 0.21, 0.11 and 0.12 of the recommended dose in the sowing dates '13 September', '3', '9' and '16 October', respectively. It appeared that the early

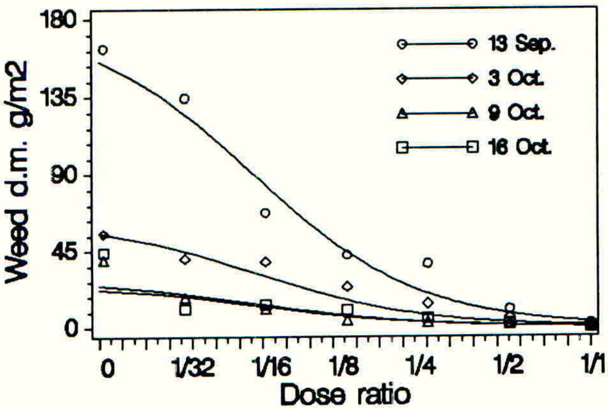

Figure 1. Dose-response curves for varying sowing dates of winter wheat sprayed with a range of ioxynil + mecoprop doses. 1/1 is the recommended dose.

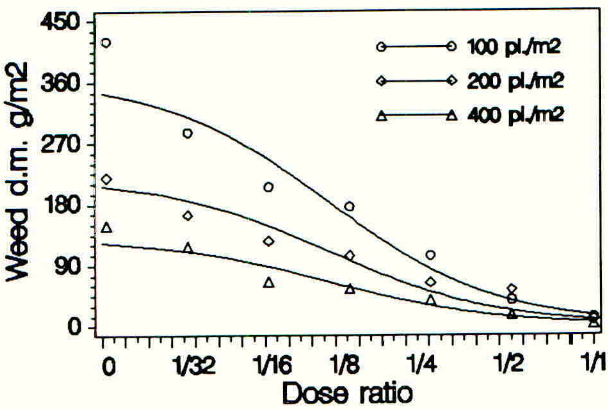

Figure 2. Dose-response curves for varying crop densities of winter wheat sprayed with a range of ioxynil + mecoprop doses. 1/1 is the recommended dose.

sowing date was more sensitive to choice of response level than the late sowing dates.

In experiment 2, a higher herbicide dose than the recommended was necessary to achieve all three d.m. levels in the crop density '100 plants m^{-2}'. At the '200 and 400 plants m^{-2}' crop densities the competitive balance between crop and weed changed so that the response level 10 and 15 g m^{-2} were achievable with lower doses than that recommended.

Table 1. Calculated ratios of the recommended herbicide dose for varying sowing dates and crop densities at three weed d.m. levels.

Sowing date	Weed d.m. g m^{-2} 5	10	15	Crop density	Weed d.m. g m^{-2} 5	10	15
13 Sep.	0.72	0.44	0.33	100	2.36	1.43	1.06
3 Oct.	0.35	0.21	0.16	200	1.64	0.99	0.74
9 Oct.	0.18	0.11	0.08	400	1.12	0.68	0.50
16 Oct.	0.19	0.12	0.09				

DISCUSSION

Adjustment of the herbicide dose due to the benefit of controlling the present weeds is an important component for development of an entire weed control strategy that aims at an environmentally sound use of herbicides. The core of such a strategy is an amalgamation of a competition model that includes the major variables of competition with a dose-response model that includes the ordinary variables of herbicide performance like susceptibility of weed species, weed growth stage and climatic conditions. Furthermore, a specification of a target weed d.m. based on short term and long term requirements for weed control is essential for an entire weed control strategy.

A convenient result of the present analyses and the analyses in Christensen (1993) is that the estimates of the a- and b-parameters of Eqn. 1 were the same for varying sowing dates, crop densities and cultivars. Certainly, the a- and b-parameters vary for different weed species, growth stage, climatic conditions etc., but the experiments demonstrate that varying crop weed competition only modified the d-parameter that corresponded to weed d.m. of the untreated controls. A consequence of this result is the possibility of using a competition model to "predict" the d-parameter of varying weed density and crop management practices.

In the short term, a target weed d.m. can be specified as the response level where the cost of treatment and herbicide dose balance the profitable effect of the herbicide in the present crop. Such economic calculations can be done when the relationship between final weed d.m. and crop d.m. loss is known. Christensen (unpublished data) showed that a linear relationship exists between weed d.m. and crop d.m. loss in experiments with spring barley cultivars.

In the long term, a target weed d.m. can be specified as the response level that will maintain a target seed bank. Rasmussen (1993) showed that a linear relationship exists between weed d.m. and weed seed production irrespective the herbicide dose. It suggests that it is possible to derive a target weed d.m. from a seed bank model by using a simple weed d.m. to seed ratio. A target seed bank may be specified as a level where the input of seeds balance the output.

Further research is needed to validate the suggested approach. In particular, applied research on the relationships between weed d.m. and crop d.m. loss, and weed d.m. and weed seed production is essential for development of a complete herbicide use strategy.

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RELIABILITY OF BROAD-LEAVED WEED CONTROL IN CEREALS USING LOW DOSES OF HERBICIDE

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ABSTRACT

The dose response of a variety of herbicides was examined in 19 winter cereal trials and 24 spring barley trials on sites in Scotland with general rather than pernicious weed problems. A quarter dose of a product based on diflufenican or pendimethalin, applied in autumn, gave satisfactory weed control in 75% of winter cereal trial situations. In the other 25%, a low dose of spring herbicide was generally sufficient to control escaping broad-leaved weeds. A quarter dose of a tank mix of metsulfuron-methyl with mecoprop or of a proprietary mix of ioxynil, bromoxynil and fluroxypyr gave adequate weed control in 65% of the spring barley trial situations.

INTRODUCTION

Cereal weed floras in Scotland tend to be dominated by *Poa annua* and a variety of annual broadleaved weeds among which *Stellaria media* is almost universal. In fields without noxious weeds, there is evidence that the yield response of winter wheat and spring barley is only rarely sufficient to cover the cost of a typical herbicide programme (Davies *et al*., 1989). On the other hand, leaving the weeds uncontrolled when weed emergence falls below a threshold is likely to give an unacceptable seed return and lead to higher herbicide inputs in the long term (Davies *et al*., 1993). The solution has long seemed to be to modify the dose of herbicide according to the individual field circumstances.

This series of trials funded from the Home-Grown Cereals Authority levy between harvest years 1990 and 1992 was designed to define more accurately the conditions where low doses could be used and to assess the increased risk of failing to achieve acceptable weed control.

Yield is not the only factor to be considered in deciding the required herbicide dose. It is important to minimise seed return in the cereals where weed control is relatively cheap and straightforward. Visual assessments of weed cover in the summer (June-July) period give some indication of weed seed return. For the relatively uncompetitive broad-leaved species which occurred in the trials, a total ground cover by broad-leaved weeds of 5% in the summer is considered to be a reasonable target. This is acceptable to most farmers and is unlikely to increase the weed seedbank.

TABLE 1. Names, active ingredients and manufacturers' recommended dose of the herbicides used in the trial series.

Code	Active ingredients	Recommended dose	Product name
HBN+flu	100 g/l bromoxynil + 100 g/l ioxynil + 90 g/l fluroxypyr	1.5 l/ha	Advance
metsulf	200 g/kg metsulfuron-methyl	30 g/ha	Ally
HBN+ben	50 g/l benazolin + 125 g/l bromoxynil + 62.5 g/l ioxynil	2.0 l/ha	Asset
dic+mec+MCPA	18 g/l dicamba + 252 g/l MCPA + 84 g/l mecoprop	4.0 l/ha	Banlene Plus
mec	570 g/l mecoprop - salt	3.75 l/ha	CMPP
OR	600 g/l mecoprop-P	2.0 l/ha	Duplosan
dic+mec	112 g/l dicamba + 265 g/l mecoprop	5.0 l/ha	Condox
clop+cyan	60 g/l clopyralid + 350 g/l cyanazine	0.7 l/ha	Coupler SC
pend+IPU	250 g/l pendimethalin + 125 g/l isoproturon	4.0 l/ha	Encore
cyan	200 g/l cyanazine	0.5 l/ha	Fortrol
met+thifen	70 g/kg metsulfuron-methyl + 680 g/kg thifensulfuron-methyl	60 g/ha	Harmony M
isox+IPU	19 g/l isoxaben + 450 g/l isoproturon	4.0 l/ha	Ipso
clop+diclor +MCPA	15 g/l clopyralid + 420 g/l dichlorprop + 175 g/l MCPA	4.0 l/ha	Lontrel Plus
MCPA	500 g/l MCPA	1.5 l/ha	MCPA
DFF+IPU	50 g/l diflufenican + 500 g/l isoproturon	2.0 l/ha	Panther
cyan+IPU	200 g/l cyanazine + 300 g/l isoproturon	2.5 l/ha	Quiver
dichlor+MCPA	350 g/l dichlorprop + 150 g/l MCPA	5.6 l/ha	Redipon Extra
flu	200 g/l fluroxypyr	0.75 l/ha	Starane 2
pend	330 g/l pendimethalin	3.0 l/ha	Stomp 330

MATERIALS AND METHODS

The field trials were located in the arable areas of Scotland. Sites were chosen which did not have known infestations of *A. fatua, G. aparine or Bromus sterilis*. Plot size was either 24 x 2 m in sown trials or 24 x 3m in superimposed trials. In each randomised block trial, three to seven herbicide combinations were compared. For winter cereals, these included autumn applications, autumn and spring sequences and spring only applications. For spring barley, a range of propietary and tank mixes were compared. Most commonly the treatments included the manufacturers' recommended dose (full dose) of each product in the sequence or mixture, one half, one quarter and one eighth of that dose. The herbicides used are

TABLE 2. Ground cover by broad-leaved weeds in summer in winter cereal trials at quarter dose of the herbicides specified.

	Trial code																			No of trials	Adjusted mean ground cover %	
	WW 90 01	WW 90 02	WW 90 03	WW 91 01	WW 91 02	WW 91 03	WW 91 04	WW 91 05	WW 91 06	WW 92 01	WW 92 02	WW 92 03	WW 92 04	WW 92 05	WB 90 01	WB 90 02	WB 91 01	WB 91 02	WB 91 03		Quarter dose	Full dose
	Ground cover at quarter dose, %																					
DFF+IPU	1	50	3	3						2	5	3	0		0	26	0	2	2	13	6.2	0.7
isox+IPU				4	15	54	23	2	1											6	18.4	3.1
pend+IPU										5	17	10		0			1	2		6	8.0	1.0
pend	1		3												2	36				4	8.7	1.0
cyan+IPU																	1	4	4	3	6.0	1.1
DFF+IPU / mec	0	1	2	2											0	5	0	1	2	9	0	0
isox+IPU / mec				3	5	11	7	1	0											6	6.2	0.9
pend/mec	0	31	1												3	5				5	1.1	0
cyan+IPU / mec																	1	2	1	3	4.4	0.3
pend+IPU / mec																	0	1		2	4.6	0.4
mec			15	8	5	35			1	7	26	10	1	0			1			11	11.7	1.9
metsulf & mec	0	42	6		8	6	6		0	1		13								9	6.7	1.0
clop+cyan & mec				7	8	16	7	0	1											6	8.2	1.3
met+thifen & mec										1	16									2	7.1	0.7

Notes: + denotes proprietary mix; & denotes tank mix;
/ denotes autumn herbicide followed by spring herbicide

listed in Table 1. There was an untreated control in every trial. The ground cover of each weed species at a date in June or July was assessed over the whole plot.

The weed cover estimates from these trials were fitted to the logistic response curve used by Streibig (1989), assuming parallel but displaced response curves for different herbicide combinations in the same trial. In Tables 2 and 3 are the fitted value of weed cover at one quarter of the recommended dose in each trial. Since not all herbicides were tested in all trials, the adjusted mean for each herbicide was calculated by least squares fitting. For comparison, we show the adjusted mean for the full dose.

RESULTS

In the winter cereal trials (Table 2), autumn diflufenican+isoproturon (DFF+IPU) alone at quarter dose achieved 5% weed cover or less in 11 of 13 trials, the exceptions being WW9002 where both *S. media* and *Fumaria officinalis* escaped control and WB9002 where only *S. media* escaped. Overall the two pendimethalin products gave control almost as good as DFF+IPU, but *S. media* escaped in WW9202 and WB9002. Isoxaben+IPU did not perform as well as the other three autumn herbicides either at quarter or full dose and was particularly weak on *S. media* and *Galeopsis tetrahit* in WW9103.

Following up with a quarter dose of mecoprop in the spring controlled all the weeds that escaped DFF+IPU but did not fully control *S. media* after pendimethalin in WW9002 or *S. media* and *G. tetrahit* after isoxaben+IPU in WW9103. Overall, the combinations of diflufenican or pendimethalin products followed by mecoprop, all at quarter dose were highly effective and much better than either autumn or spring herbicides used alone.

Spring only treatment with a quarter dose of mecoprop failed to reduce weeds to 5% ground cover in 6 of 11 trials with *S. media* escaping in WW9003, *S. media*, *Myosotis arvensis* and *Viola arvensis* in WW9101, *S. media* and *G. tetrahit* in WW9103, *S. media* and *M. arvensis* in WW9201, *V. arvensis* in WW9202 and *Capsella bursa-pastoris* in WW9203. Overall, the quarter dose of metsulfuron-methyl tank-mixed with mecoprop gave better control but *V. arvensis* and *F. officinalis* escaped in WW9002, *S. media* in WW9003, *Veronica persica* in WW9102, *S. media* and *F. officinalis* in WW9103, *M. arvensis* in WW9104 and *C. bursa-pastoris* in WW9203. Other spring-only treatments were tried in only a few trials but did not generally perform better than metsulfuron-methyl with mecoprop.

For spring barley (Table 3), metsulfuron-methyl and mecoprop, HBN+fluroxypyr or mestsulfuron-methyl+thifensulfuron-methyl and mecoprop all gave relatively good results at quarter dose and were better than dichlorprop+MCPA or clopyralid+cyanazine+MCPA.

Metsulfuron-methyl and mecoprop at quarter dose failed to achieve 5% weed cover in 7 out of 22 trials, HBN+fluroxypyr in 6 out of 14 and metsulfuron-methyl+difensulfuron-methyl and mecoprop in 3 out of 10. In SB9003, *S. media* and *V. arvensis* escaped. In SB9104, *G. tetrahit*, *Matricaria matricarioides*, *F. officinalis*, *V. arvensis* and *Polygonum aviculare* all escaped. In SB9105, *P. aviculare* and *V. arvensis* escaped and in SB9109, *S. media* and *Chenopodium album*.

TABLE 3. Ground cover by broad-leaved weeds in summer in spring barley trials at quarter dose of the herbicides specified.

	Trial code																									
	SB 90 01	SB 90 02	SB 90 03	SB 90 04	SB 90 05	SB 90 06	SB 90 07	SB 90 08	SB 91 01	SB 91 02	SB 91 03	SB 91 04	SB 91 05	SB 91 06	SB 91 07	SB 91 08	SB 91 09	SB 92 01	SB 92 02	SB 92 03	SB 92 04	SB 92 05	SB 92 06	SB 92 07	No of trials	Adjusted mean ground cover, % Quarter dose	Adjusted mean ground cover, % Full dose
	Ground cover at quarter dose, %																										
metsulf & mec	7	4	36	8	2	1	8	2	1		2	28		1	5	1	67	3	9	2	3	0	0	1	22	9.5	3.2
dichlor+MCPA	13	18	45	6	1	5			3	9	44	53	57		5	3	87		6				1	3	17	18.2	8.6
HBN+flu									4	7	4	51	36	0	3	1	48		6	2	7		0	0	14	9.7	2.8
clop+cyan & MCPA	14	24		18	3				5	5	21	70	34	0	4	3	86								13	18.5	9.0
met+thifen & mec	8	5	32	4	0	1	4			1			38							2					10	8.9	4.0
metsulf & HBN+flu									1		1			0			25			1	1				6	0.2	0
metsulf & cyan	6	1	43		2															3					5	10.1	3.1
dic+mec+MCPA	15	13		16	3	3																			5	16.1	7.0
clop+dichlor+MCPA											32	40		1			88								4	20.1	12.1
cyan & mec & MCPA											16	60		0			81								4	19.3	7.8
cyan+IPU		1				1					6	42													4	6.1	2.0
dic+mec														0			75								2	16.2	2.5
flu & mec																				3	3				2	7.6	2.1
HBN+ben & CMPP																				2	3				2	6.8	1.7

Notes: + denotes propietary mix; & denotes tank mix.

DISCUSSION

For convenience of summarising the results of many trials, we have used the efficacy of the quarter dose as an indicator of the suitability of the herbicide for use at low dose. This is only a convenience and in the field situation, other doses are often needed.

For winter cereals, autumn herbicides based on diflufenican or pendimethalin at quarter dose, control the autumn-germinating weeds in most Scottish situations and provide a robust starting point for a weed control programme. The quarter dose of autumn herbicide was all that was required for 75% of the time in our trials but we did take care to apply the autumn herbicide in good conditions when the weeds were small. In all but one of the situations where weeds did escape, they were easily controlled by a quarter dose of mecoprop. The only exception was in an uncompetitive crop of wheat in an exceptionally weedy field. In most trials, the weed control achievable with spring herbicide alone was well below that of a low dose sequence.

Achieving the target of only 5% weed cover was much more difficult in spring barley and was not always possible even with the full dose of herbicide. Nevertheless, a tank mix of metsulfuron-methyl and mecoprop or a propietary mix of ioxynil, bromoxynil and fluroxypyr, both at quarter dose, were successful in about 65% of the situations represented by our trials. There is therefore scope for savings but only with careful choice of herbicide and dose. Fortunately, the yield loss resulting from a given weed cover is not so large for spring barley as for the winter cereals (Fisher *et al.*, 1993) so that the immediate penalty for misjudging the dose is small.

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LONGER-TERM EFFECTS OF REDUCED HERBICIDE STRATEGIES ON WEED POPULATIONS AND CROP YIELDS IN CEREAL ROTATIONS IN ENGLAND

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ABSTRACT

Four sites were established on ADAS farms in 1987-88 to examine the long-term effects of reduced herbicide inputs in cereal rotations. Routine application of prophylactic treatments kept weed and seedbank numbers lower over a 4-5 year period than threshold-based treatments, as did full rates compared with half rates. The most sustainable option for reducing herbicide usage without sacrificing yield or risking a rapid build-up of weed populations was the use of half-rate prophylactic treatments every year. Full-rate threshold treatments were triggered on 79% of possible occasions and so reduced herbicide usage to a much lesser extent. Half-rate threshold treatments, applied on 88% of possible occasions, resulted in the highest weed and seedbank populations, leading at one site to a reduction in cereal yield in the fifth year.

INTRODUCTION

Farmers are under both economic and environmental pressures to reduce their inputs of herbicides into cereal crops. They need to achieve this without affecting yield or harvesting efficiency in the current crop and without creating problems for future crops. Proven *et al.* (1991) reported on a series of field experiments across the United Kingdom in which various strategies for reducing herbicide usage in cereals are being evaluated over a six-year period. Their report concentrated on crop yields and economics over the first three years and showed that yield had been largely unaffected by intensity of herbicide usage to date. Herbicide treatments, where applied, had coped well with the weed populations encountered, other than at one site in Scotland. Information on the cumulative response of the weed flora over 4-5 years to a number of standard treatments applied at four Scottish sites has been presented by Davies *et al.* (1993). This paper examines the response to the same set of treatments applied at four English sites.

MATERIALS AND METHODS

The experiments were established at ADAS experimental farms in autumn 1987 on fields with a history of arable rotation and regular herbicide usage. Plot size was 12 m by 50 m and there were three replicates of each treatment. Winter wheat was grown every year at most sites, but a break crop of fodder beet at Gleadthorpe in 1990 was followed by spring wheat in 1991 and winter barley in 1992. Winter field beans were grown at Drayton and Rosemaund in 1992.

Two standard herbicide regimes were tested at all sites:

Insurance - Grass and broad-leaved weeds were controlled prophylactically with broad-spectrum herbicides in autumn and/or spring every year.

Threshold - Weed control was either applied or not applied in autumn and/or spring, using fixed thresholds.

In both cases spray applications were made using either 100% or 50% of the commercially-recommended rate of the herbicides chosen. Full-rate Insurance treatment was taken as the standard against which the performance of reduced input treatments was assessed. Threshold spray decisions were based on the Crop Equivalent system developed at IACR Long Ashton (Cousens *et al.*, 1985). Emerged weeds were counted and identified, the total Crop Equivalent per square metre calculated and a spray treatment applied if the threshold was exceeded. Choice of herbicides was left to local managers.

Weed seedling counts were made at intervals in each crop (details in Proven *et al.*, 1991). Soil samples (21 cores each of 2.5 cm diameter by 20 cm depth) were collected from every plot at the start of each experiment and after the fourth crop for weed seedbank analysis (as described in Wilson & Lawson, 1992). Weed and seedbank data were subjected to analysis of variance after square root transformation and seedbank data collected after the fourth crop were co-varied on the original populations recorded on each plot. In the tables total seed counts do not equate exactly with the sum of individual species means because of the effect of co-variance. Crop yields were assessed by a combine width cut up the centre of each plot.

RESULTS

At least one Threshold treatment was triggered in every cereal crop grown in the first five years at these ADAS sites. Autumn treatments were required on 14 and 15 out of 16 occasions on full- and half-rate plots respectively, while equivalent records for spring treatments were 12 and 14 out of 17 occasions. Overall, spray applications were made on 79% and 88% of possible occasions on full- and half-rate Threshold plots respectively. This masks the fact that most of the non-treatment occurred in the first two years. Both treatments were required in all cereal crops thereafter, with the exception of an autumn application at Drayton in 1989 and a spring application at Gleadthorpe in 1992, both on full-rate plots.

Weed seedbank assessments made after the fourth crop showed overall drops in total populations since the start of the experiments at Drayton, Rosemaund and Bridget's (Table 1). However, numbers of *V. arvensis* had increased considerably on Threshold plots at Gleadthorpe, while those of *Poa* species had been maintained or were on the increase at Rosemaund. Analysis of data on individual or total species at each site showed few instances of significant differences between treatments. Nevertheless, Insurance treatments usually produced slightly lower seedbank totals than Threshold treatments, while more seeds were regularly recovered from half-rate than full-rate plots other than at Gleadthorpe. *S. arvensis*, *V. arvensis* and *Poa* species had more seeds after four years on Threshold plots than on Insurance plots at Drayton, Gleadthorpe and Rosemaund respectively. *Poa* species and *V. arvensis* were more numerous on half-rate than on full-rate plots at Rosemaund and Bridget's respectively.

TABLE 1. Seedbank assessment after four crops (principal species).

Site and herbicide regime	Dose	Live seeds recovered /m² (to 20 cm depth)*		
Drayton		*Aethusa cynapium*	*Sinapis arvensis*	Total seeds
Insurance	Full	971 (1.16)	665 (1.02)	2057 (1.56)
	Half	835 (1.10)	707 (1.04)	2282 (1.63)
Threshold	Full	749 (1.06)	1341 (1.31)	2249 (1.68)
	Half	757 (1.06)	1502 (1.37)	2937 (1.82)
S.E. mean ± (d.f. 13)		(0.124)	(0.162)	(0.161)
Pre-trial mean		5150	6240	14405
Gleadthorpe		*Viola arvensis*	*Stellaria media*	Total seeds
Insurance	Full	314 (0.83)	218 (0.77)	1613 (1.41)
	Half	399 (0.88)	348 (0.85)	1488 (1.35)
Threshold	Full	1213 (1.26)	365 (0.86)	2121 (1.58)
	Half	948 (1.15)	314 (0.83)	1997 (1.54)
S.E. mean ± (d.f. 13)		(0.193)	(0.144)	(0.250)
Pre-trial mean		222	417	1952
Rosemaund		*Poa* species	*Chenopodium album*	Total seeds
Insurance	Full	2829 (1.79)	218 (0.77)	4509 (2.21)
	Half	3951 (2.08)	265 (0.80)	5054 (2.33)
Threshold	Full	3545 (1.98)	233 (0.78)	3993 (2.09)
	Half	5433 (2.41)	74 (0.67)	5443 (2.41)
S.E. mean ± (d.f. 13)		(0.266)	(0.095)	(0.301)
Pre-trial mean		3084	1444	9445
Bridget's		*Viola arvensis*	*Veronica* species	Total seeds
Insurance	Full	5385 (2.40)	188 (0.75)	5195 (2.36)
	Half	7862 (2.87)	74 (0.67)	8745 (3.02)
Threshold	Full	5481 (2.42)	61 (0.66)	5628 (2.45)
	Half	8387 (2.96)	203 (0.76)	8806 (3.03)
S.E. mean ± (d.f. 13)		(0.339)	(0.098)	(0.306)
Pre-trial mean		38300		40079

* Figures in parentheses are numbers of seeds recovered per 200 ml soil sub-sample, after transformation $\sqrt{(x+0.375)}$ and co-variance on pre-trial records.

Weed counts made in late spring in the fourth crop at each site, on quadrats protected from herbicide treatments in that year, also demonstrated cumulative effects of treatment in previous crops (Table 2). Again, differences were not often statistically significant, but in most cases weed counts were consistently higher with Threshold than with Insurance treatments and on full-rate than on half-rate plots. The main species occurring in these counts were also those of greatest frequency in the seedbank, with the

TABLE 2. Weed counts on protected areas in the fourth crops (principal species).

Site and herbicide regime	Dose	Number of annual weeds/m²*		
Drayton		*Aethusa cynapium*	*Sinapis arvensis*	Total seeds
Insurance	Full	72 (8.5)	7 (2.7)	102 (10.1)
	Half	96 (9.8)	11 (3.4)	137 (11.7)
Threshold	Full	92 (9.6)	10 (3.2)	127 (11.3)
	Half	104 (10.2)	17 (4.2)	144 (12.0)
S.E. mean ± (d.f. 14)		(0.73)	(0.62)	(1.07)
Gleadthorpe		*Viola arvensis*	*Stellaria media*	Total weeds
Insurance	Full	39 (6.3)	19 (4.4)	82 (9.1)
	Half	60 (7.8)	23 (4.8)	112 (10.6)
Threshold	Full	42 (6.5)	32 (5.7)	110 (10.5)
	Half	70 (8.4)	48 (6.9)	154 (12.4)
S.E. mean ± (d.f. 14)		(1.82)	(0.73)	(1.33)
Rosemaund		*Poa* species	*Lolium multiflorum*	Total weeds
Insurance	Full	48 (6.9)	13 (3.7)	72 (8.5)
	Half	59 (7.7)	23 (4.8)	97 (9.9)
Threshold	Full	61 (7.8)	20 (4.5)	95 (9.8)
	Half	55 (7.4)	20 (4.5)	86 (9.3)
S.E. mean ± (d.f. 14)		(0.39)	(0.44)	(0.48)
Bridget's		*Viola arvensis*	*Veronica* species	Total weeds
Insurance	Full	121 (11.0)	4 (2.0)	131 (11.5)
	Half	151 (12.3)	4 (2.0)	163 (12.8)
Threshold	Full	163 (12.8)	1 (1.3)	170 (13.1)
	Half	247 (15.7)	5 (2.3)	258 (16.1)
S.E. mean ± (d.f. 14)		(0.75)	(0.57)	(0.63)

* Figures in parentheses were analysed after transformation - $\sqrt{(x+0.375)}$.

exception of *L. multiflorum*, only occasional seeds of which had been recovered in soil samples from Rosemaund over the years.

Grain yields were unaffected by herbicide regime or dose in the first four years of the series (Proven *et al.*, 1991 and personal communication). Only two sites had cereal crops in 1992. Winter wheat at Bridget's recorded the first significant reduction in yield in response to weed control management at these ADAS sites (Table 3). This occurred on the half-rate Threshold plots despite both autumn and spring herbicide application. Counts of weeds surviving herbicide treatments at this site indicated that Threshold applications were having difficulty in coping with the weed numbers, especially

TABLE 3. Cereal yields and residual annual weed counts - 1992.

Site and herbicide regime	Dose	Yield of grain t/ha at 85% d.m.	Weeds surviving herbicide treatment - nos./m² (June)*	
Bridget's		Winter wheat	*Viola arvensis*	Total weeds
Insurance	Full	7.86	0.2 (0.76)	0.4 (0.88)
	Half	7.57	0.1 (0.69)	6 (2.48)
Threshold	Full	7.72	49 (7.02)	54 (7.36)
	Half	7.29	146 (12.11)	151 (12.32)
S.E. mean ± (d.f. 14)		0.163	(0.371)	(0.476)
Gleadthorpe		Winter barley	*Viola arvensis*	Total weeds
Insurance	Full	5.53	5 (2.23)	8 (2.92)
	Half	5.72	2 (1.57)	11 (3.34)
Threshold	Full	5.97	5 (2.29)	6 (2.49)
	Half	6.25	4 (2.12)	8 (2.84)
S.E. mean ± (d.f. 14)		0.266	(0.658)	(0.658)

* Figures in parentheses were analysed after transformation - $\sqrt{(x+0.375)}$.

of *V. arvensis*, encountered on these plots. At Gleadthorpe, by contrast, weed numbers surviving treatment were low and both they and grain yield records showed no differences between herbicide regimes or dose which could be attributed to weed control strategy.

DISCUSSION

Proven *et al.* (1991) assessed the threshold approach in the first three years of this trial series in terms of efficacy, cost-effectiveness and practicality. They concluded that the annual costs of making detailed threshold assessments, together with the high incidence of spraying of Threshold plots, made this a less attractive strategy for reducing weed control inputs than one based on maintaining a prophylactic approach but at reduced rates of application. Our seedbank and weed assessments, plus the increased frequency of threshold triggering as the trials have continued, indicate that the latter strategy is also likely to be more sustainable over the longer term. Despite the relatively few occasions on which Threshold treatments were not applied, there was a clear trend by the fourth cropping year for there to be more weed seeds and more emerged weeds on Threshold plots than on Insurance plots. There were also more seeds and weeds on half-rate than on full-rate plots. The reduction in crop yield at Bridget's - the weediest site - in 1992, due to the inability of the half-rate Threshold treatment to cope with the large populations of *V. arvensis* on these plots, is a clear warning of the cumulative adverse effects of inadequate weed control. The full-rate Threshold treatment also failed to remove this species, but the surviving plants were not sufficiently competitive to cause yield loss. Both Insurance treatments dealt very adequately with the weeds present on their respective plots. At the less weedy Gleadthorpe site all herbicide treatments coped satisfactorily with the weed flora in 1992, despite earlier indications of increased populations on Threshold and half-rate plots.

The development of larger seedbank and emerged weed populations has also been found in response to Threshold as opposed to Insurance treatments at the four Scottish sites (Davies *et al.*, 1993) where a major increase in *S. media* forced the abandonment of both Threshold treatments at Smith's after two years. There was less evidence than at the English sites of the development of differences in the weed flora between full- and half-rate plots over a five year period. The overall results from the series demonstrate the need to take into account likely cumulative changes in weed and seedbank populations when strategies for reducing herbicide inputs are being considered. If winter crops are the main constituents of the rotation, particular attention should be paid to the autumn-germinating components of the seedbank, since species like *V. arvensis*, *S. media* and *P. annua* appear capable of exploiting reductions in intensity of weed control. Predominantly spring-germinating species declined steadily in seed numbers under winter cropping regardless of the herbicide strategy used, but would presumably have been encouraged by reduced herbicide usage in spring crops.

The evidence from these experiments favours cutting herbicide inputs by applying prophylactic treatments every year but at reduced rates, rather than by utilising the threshold approach tested. Half rates are not necessarily optimal in every situation and there is considerable potential for varying the treatments used to suit the weed populations encountered and for the use of simple threshold techniques to aid the choice of the most appropriate herbicide and dose. Careful selection of such treatments and the avoidance of continuous winter or spring cropping sequences could achieve substantial cuts in herbicide inputs without allowing weed populations to expand to the point where they create problems later in the rotation. Nevertheless, until more precise recommendations have been developed, the routine use of half-rate insurance treatments would appear to maximise savings with a minimum of risk.

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THE EFFECT OF WEED MANAGEMENT REGIME ON THE WEED POPULATION AND YIELD RESPONSE IN A CEREAL ROTATION IN N.IRELAND

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ABSTRACT

Weed population changes are described that reflect the accumulative effects, over six years, of a predominantly winter cropping system on an initial seedbank population dominated by spring germinating species. A general decline in seedbank numbers was combined with an increased incidence in both seedbed and seedbank of autumn germinating species. This was most evident on the unsprayed plots,but it was not until years five and six that seedbed seedling numbers and increased incidence of more competitive species, *Stellaria media, Brassica* spp. and *Galium aparine*, was reflected in decreased yields compared to the herbicide treatments.

Of these a full insurance herbicide regime gave the most effective control and, together with an Autumn Insurance approach, had reduced the residual seedbank by more than a Threshold or Grass Insurance regime. The use of a half rate regime reduced weed control by about 8% compared to the full rate but gave as good a yield response and was equally effective as the full rate herbicide regimes in preventing seedbank increase.

This confirms results from similar trials in both Scotland and England that the most cost effective weed control strategy is the adoption of a half rate prophylactic treatment on an annual basis.

INTRODUCTION

Economic and environmental pressures are inducing farmers to seek reduced rate strategies that will not jeopardise yields or harvesting efficiency or create more intractable longer term changes in their weed populations.

Comparative data on a range of strategies were gathered from sites throughout the UK, funded by the Home Grown Cereals Authority. The general cost effectiveness and benefits have been reported elsewhere (Proven *et al.* 1991) and (Davies *et al.* 1993b).

From the trial site in N.Ireland, six years data and the inclusion of an untreated control allows the key elements in weed population change, weed control, and yield response in response to cropping practice and herbicidal regimes to be identified.

METHODS AND MATERIALS

The trial was established in 1987 at Strangford, Co Down as a randomized block design with each treatment replicated three times. The treatments comprised: 1. Full Insurance,- prophylactic treatment of all weeds in autumn and/or spring in winter cereals and in the spring for spring crops. 2. Autumn Insurance,- control of all weeds in the autumn, with Threshold application in the spring. 3. Grass Insurance,- grass weed control in the autumn, with Threshold application in the spring. 4. Threshold Treatment,- application based on threshold levels in both autumn and spring.

The regimes were applied at full (treatments 1-4) or 50% (treatments 5-8) of commercially recommended rates with an untreated control (Treatment 9). Threshold decisions were based on the IACR Long Ashton crop equivalent (C.E.) system (Cousens *et al.*, 1985). The autumn herbicide treatments were diflufenican plus isoproturon (1,5) isoproturon/ioxynil/bromoxynil (2,6) or isoproturon alone (3,7). The spring and threshold treatments were based on metsulfuron-methyl alone, or bromoxynil ioxynil with fluroxypyr, or mecoprop or, in the spring wheat, with isoproturon. Plot size was 10m by 25m. Herbicides were applied by a hand held, knapsack, sprayer at 220 l/ha at 2 kpa.

Weed seedling counts (fifty 25 x 25 cm^{-2} quadrats per plot) were made in the autumn and spring. The spray threshold adopted was normally 5.0 CE's m^{-2} except when cleavers occured when 1.0 CE m^{-2} level was adopted. Only in 1988/89 were thresholds not exceeded. Weed biomass (d.m. m^{-2}) was recorded prior to harvest from eight 50 x 50 cm^{-2} quadrats per plot and grain yields based on a combined swath. The seedbank was assessed on twenty one 2.5 cm cores taken to 20 cm depth, at the start of the experiment in 1987, and after 2 (1989) and 4 (1991) years.

Weed population change

TABLE 1. Species Composition of Soil Seedbank, (seeds/m^2) in the Top 20 cm of Soil.

Species	1987	1989	1991
Total	18,443	13,223	7,220
Stellaria media	111	0	780
Brassica sp.	0	222	1890
Anagallis arvensis	111	1333	780
Poa annua	3557	6114	1670
Polygonum persicaria	9223	4220	1440
Polygonum aviculare	555	444	333
Phleum pratense	3070	0	0

Seedbank numbers

The initial seedbank on untreated plots at this site was 18,434 m^{-2} in total comprising *Polygonum persicaria* (50%) and *Poa annua* (19%), *Phleum pratense* (17%) and small numbers of 26 other species. Total seed numbers declined to 13,223 m^{-2} in 1990 and 7,220 m^{-2} in 1991 due principally to loss of seeds of the three major species

[Table 1]. This masked an increase in populations of *S. media*, *Brassica* species and *Anagallis arvensis* which had featured as very minor components of the original seedbank. *Galium aparine,* although showing a significant increase in the seedbed numbers in later years, was not recorded in the seedbank.

In general, seedbank populations showed the same trends on herbicide treated plots with little difference between treatments in total or individual counts in samples taken in 1991. Fewer seeds were recovered from Full Insurance (3,650 m^{-2}) or Autumn Insurance (3,490 m^{-2}) plots compared to the Threshold (4,520 m^{-2}) or Grass insurance (6,110 m^{-2}) but differences between herbicide treatments or between them and untreated plots (7,078 m^{-2}) were not significant. Halving of doses also had no significant influence on seedbank numbers with 4,810 m^{-2} on the full rate and 4,070 m^{-2} on the half rate plots.

Seedbed numbers and CE values

Total seedbed numbers declined between 1987 and 1989, but rose steadily thereafter reaching a peak in December 1992 (Fig.2). Grass weeds dominated in the early years, but broadleaved species were responsible for most of the subsequent increase. The main contributors to this increase were *Brassica* spp., *Stellaria media* and *Galium aparine* (Fig.3).

These competitive species caused a considerable increase in the mean CE values of the population, mainly after the break crop of potatoes in 1991 (Fig.3). This change in competitiveness of the species was equally as important as the general increase in overall population numbers in determining the positive response to herbicide treatment which commenced in years five and six.

Weed control and crop yield response

The weed control data based on residual weed biomass are summarised in Table 2. The comparison of the herbicide regimes, over the five cereal crops of the trial, indicates that the Full Insurance option was the most effective treatment (82% control), followed by the Autumn (60%) and then the Grass Insurance (47% control) and Threshold options (45%).

The comparison of the half and full rate herbicide regimes shows that on average the half rate regimes were giving about 8% lower weed control based on the biomass data.

In years one to three, there was a very limited response in yield to weed control at either the full or half rates of herbicide. Only in years five and six do significant yield responses occur, with the half rate as good as the full rate in terms of yield response. The comparison of regimes showed no significant differences although the Full Insurance option gave the best results in both weed control and yield.

DISCUSSION

The initial weed seedling population numbers at this site were small and consisted mainly of grasses. Significant competitive changes in both population size and species composition and associated yield response to herbicide did not occur until years five and six. This is in agreement with the pattern observed in spring cereals (Courtney & Johnston, 1986) where positive yield benefits occurred in years three and four as weed threshold levels in spring barley exceeded 200 m^{-2}. In the current project a similar pattern has been observed at the Scottish sites (Davies *et al.* 1993a). It is also probable that the introduction of a winter cropping system onto a seedbank comprising

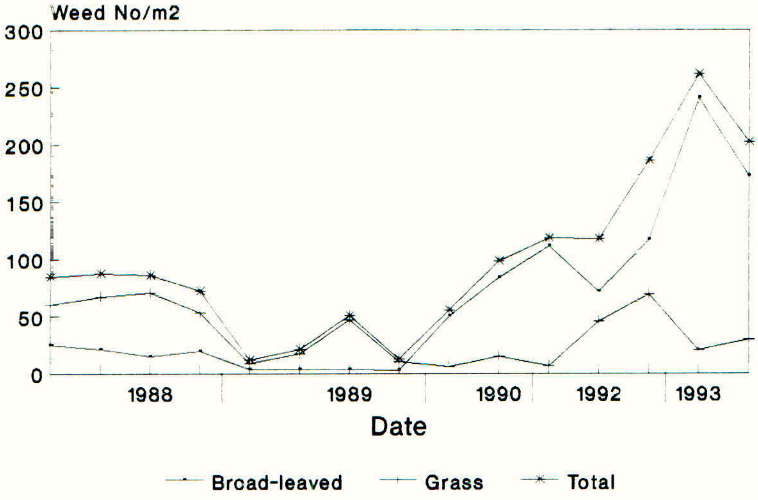

Figure 1.Total Weed Numbers in Untreated

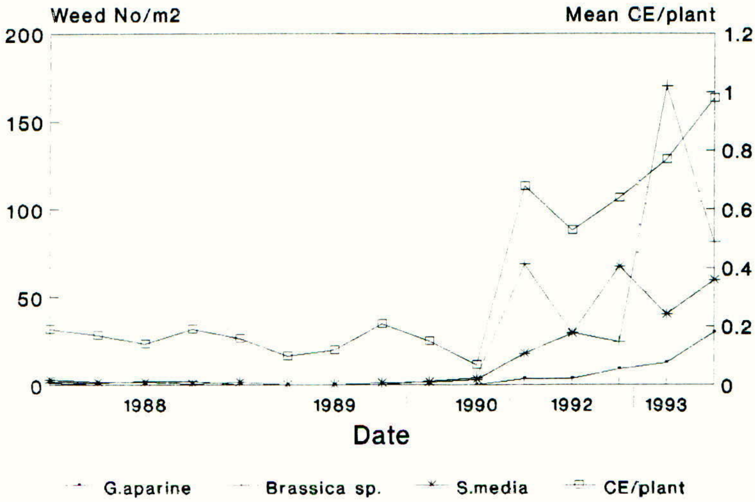

Figure 2.Key Species Numbers in Untreated

TABLE 2. Crop grain yield and total weed biomass

TREATMENT	1988 Winter Wheat Yield t/ha	1988 Winter Wheat Weed g/m^2	1989 Winter Wheat Yield t/ha	1989 Winter Wheat Weed g/m^2	1990 Spring Wheat Yield t/ha	1990 Spring Wheat Weed g/m^2	1992 Winter Wheat Yield t/ha	1992 Winter Wheat Weed g/m^2	1993 Winter Barley Yield t/ha	1993 Winter Barley Weed g/m^2	Mean Over Years Yield t/ha	Mean Over Years Weed g/m^2
Full Insurance	10.98	25.9	6.71	22.30	5.67	9.21	11.44	1.61	4.47	14.92	7.85	14.79
½ Ins	10.88	30.8	7.00	71.22	5.57	35.33	10.14	12.25	6.06	29.92	7.93	35.90
Autumn Ins	10.65	13.0	6.13	91.76	6.00	18.70	9.19	112.95	5.25	35.65	7.44	54.41
½ Autumn	9.92	36.7	7.92	78.44	5.91	21.20	10.10	113.92	5.06	65.49	7.78	63.15
Grass Ins	10.56	22.0	6.49	42.74	5.81	93.1	9.69	21.26	5.82	35.44	7.67	42.91
½ Grass	10.51	18.8	6.30	104.02	5.48	83.76	10.10	41.43	5.48	69.30	7.57	63.46
Threshold	10.82	35.5	6.00	122.54	6.14	16.85	9.57	131.79	4.90	99.23	7.49	81.18
½ Threshold	10.93	49.9	6.60	75.84	5.63	11.69	10.99	115.23	5.21	117.17	7.87	73.97
Untreated	10.55	60.0	6.25	118.98	5.66	124.6	7.54	161.25	4.16	242.76	6.83	141.52
Sig	NS	NS	NS	NS	NS	**	**	***	*	***	***	***
LSD (5%)	-	-	-	-	-	53.90	2.08	41.42	1.05	72.72	0.51	23.93

* - Nil Application, Ins - Insurance,

some 50% of spring germinating *Polygonum* species limited weed competition in the initial years.

The seedbank data illustrate that it was changes in the particular species, rather than total seedbank size, that were of importance in determining response to weed control; as suggested by Lawson (1993) in his interpretation of the seedbank data from other sites in this series. At this site the spring germinating component was replaced by *S. media*, and *Brassica* spp. both autumn germinating species. The increase in *Galium aparine* in the seedbed flora was not recorded in the seedbank samples taken in 1991 as this was before the main increase in incidence of this species. It was significant at this site that it was the increase of more competitive species with a consequent 5 x increase in the average CE value that was responsible for the increased weed competition and yield response more than the overall increase in weed numbers.

The weed control data confirm the potential for a reduced herbicide rate strategy in cereals. The cost effective comparisons for this HGCA series have been fully considered (Davies *et al.* 1993b) and they confirm that although there is a small penalty in terms of level of weed control, this does not appear to limit yield response. At this site the half rate regimes were as effective as the full rate in limiting seedbank build up although the data from all the sites (Lawson, 1993) suggests that there may be a small increase in the seedbank relative to the control. The data from this site in N Ireland confirm the overall conclusions from this series of trials (Davies *et al.* 1993b, Wright *et al.*, 1993) that a half rate prophylactic treatment applied on an annual basis provides a cost effective and environmentally sensitive approach to reducing herbicide inputs in cereals.

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SCARAB - THE IMPACT OF LESS INTENSIVE HERBICIDE USE ON THE DIVERSITY AND DISTRIBUTION OF WEED SPECIES IN THREE ARABLE ROTATIONS

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ABSTRACT

The impact of low input herbicide programmes on weed diversity and distribution is being evaluated in the SCARAB (Seeking Confirmation About Results At Boxworth) Project on three farms with different six-course crop rotations and soil types. Results are given for the first two years of the project. Over all three sites, a total of 12 species of grass weeds and 38 species of broad-leaved weeds were recorded. Many of the weeds were confined to the crop margin area, although at Gleadthorpe, a high proportion of broad-leaved weeds were also found in the crop. The efficiency of half-rate herbicide treatments was variable. Weed control was less effective in the broad-leaved oilseed rape and spring bean crops, compared with wheat or barley cereal crops.

INTRODUCTION

The SCARAB Project was designed to pursue the results and hypotheses developed from the Boxworth Project (1981-88) (Cooper, 1990; Greig-Smith et al., 1992). It is concerned with the effects of moderate and low input crop protection programmes on the flora and fauna within the crop canopy. The work involves six-course crop rotations of cereals and common break crops, and is carried out at three farms with very different soil conditions, rotations and farming practices (Cooper, 1990). The Project started in 1990 with a baseline year and will run over a period of seven years. The interim results reported here describe the effects of reducing herbicide inputs on the diversity and distribution of non-crop plant species in SCARAB for the first two cropping years, 1991 and 1992.

MATERIALS AND METHODS

Two contrasting pesticide regimes are compared. These are Current Farm Practice (CFP) and Reduced Input Approach (RIA). The intention on the CFP treatment is to apply such a programme of insecticides, fungicides and herbicides as would be judged necessary by a typical, technically-competant, financially-aware farmer, and is expected to be representative of general usage in comparable farming situations, as indicated in the most recent surveys of pesticide use. All pesticides are applied at normal rates as recommended on the product label for the cropping situation. The

RIA treatment is intended to contrast with CFP in its severity on non-target invertebrate populations. In particular, no insecticides are used except in crisis situations. RIA also involves the minimum use of fungicides and herbicides necessary to avoid more than 10% loss in yield or crop value. The intention is to apply a lower level of fungicides and herbicides in RIA than in CFP to each crop in the rotation. Treatments are applied to split fields. Plot areas for monitoring and assessments are superimposed, in the same place every year, onto conventionally drilled farm crops. Each pair of plots are located on a common field boundary and extends 150 m into the centre of the field. Plots are 84 m wide with a 36 m buffer zone between them. The experiment is being carried out at three ADAS Research Centres. These are High Mowthorpe (HM) in North Yorkshire, Drayton (DT) in Warwickshire and Gleadthorpe (GT) in Nottinghamshire. In all there are eight pairs of plots, two at Drayton and three at each of the other two sites.

Herbicide treatment decisions in 1991 and 1992 were based on routine crop walking which gave a visual assessment of weed species present, size and approximate numbers per square metre. Choice of herbicide (Table 1) also depended on weeds present in the previous crop, the most suitable treatment for the current crop, previous experience and discussion with the Technical Management Team of ADAS specialists.

Table 1. Site and herbicide treatment details

Site and field	Year	Crop	Herbicide	Herbicide rate CFP	RIA
High Mowthorpe					
Bugdale	1991	WOSR	Propyzamide	700 g/ha AI	348 g/ha AI
Old Type*	1991	S beans	Bentazone	1.44 kg/ha AI	0.72 kg/ha AI
			Glyphosate	1.08 kg/ha AI	0.54 kg/ha AI
Bugdale & Old Type*	1992	WW	Diflufenican + isoproturon	100 g/ha AI 1.0 kg/ha AI	50 g/ha AI 0.5 kg/ha AI
Drayton					
Field 1	1991	WW	Isoproturon	2.47 kg/ha AI	Nil
			Metsulfuron-methyl	6 g/ha AI	3 g/ha AI
			Fluroxypyr	200 g/ha AI	100 g/ha AI
Field 1 & Field 5	1992	WW	Diflufenican + isoproturon	100 g/ha AI 1.0 kg/ha AI	50 g/ha AI 0.5 kg/ha AI
			Metsulfuron-methyl	6 g/ha AI	3 g/ha AI
			Fluroxypyr	200 g/ha AI	100 g/ha AI
Gleadthorpe					
Near Kingston	1991	SB	Metsulfuron-methyl	6 g/ha AI	3 g/ha AI
	1992	WB	Diflufenican + isoproturon	100 g/ha AI 1.0 kg/ha AI	50 g/ha AI 0.5 kg/ha AI
Balkfield & Southfield	1992	SW	Metsulfuron-methyl	6 g/ha AI	3 g/ha AI

* Two pairs of plots in this field. (WOSR - winter oilseed rape, WW - winter wheat, SB - spring barley, WB - winter barley, SW - spring wheat)

Treatments were applied with conventional farm spraying equipment using standard water volumes, nozzles and pressures. Details for the sugar beet and potato crops at Gleadthorpe in 1991 and 1992 are not presented, as there were no differences in rates of herbicides applied to CFP and RIA. Similarly, no data are presented for the grass ley at Drayton in 1991 as no herbicides were applied. On each plot, non-crop plant species were monitored at three timings, early crop establishment, crop established but before canopy closure (usually after a herbicide had been applied) and pre-harvest. Assessments were done on three fixed transects into the crop, at right angles to the field boundary, down the centre of the plot and 24 m to each side. One 0.1 m^2 quadrat was assessed at each fixed sampling point at the crop margin (0 m) and 2.5 m, 10 m, 40 m, 80 m and 120 m along each transect. The number of plants of each weed species present was counted and the weed growth stage recorded where possible.

RESULTS

Diversity of weed species

The presence of each species found on either CFP or RIA, at all timings was recorded. There is insufficient space within this paper to detail differences in species diversity between treatments, although numbers of species were generally higher on RIA plots where weed control was less effective. The widest range of grass species was found at High Mowthorpe, but these occurred mostly in the crop margin area (Table 2).

Table 2. Occurrence and distribution of grass weed species

Grass species	Site HM	DT	GT	Grass species	Site HM	DT	GT
Agropyron repens	-	-	M	Hordeum sativum	M	-	MH
Alopecurus mysuroides	-	HF	-	Lolium multiflorum	M	-	MH
Arrhenatherum elatius	M	-	M	Poa annua	MHF	M	MHF
Avena fatua	M	H	M	Poa pratensis	M	-	-
Bromus sterilis	M	-	M	Poa trivialis	M	MHF	-
Festuca pratensis	M	-	-	Triticum aestivum	H	-	F

(M= margin of crop, H= 2.5 to 10 m into crop, F= 40 to 120 m into crop)

T. aestivum was found only in the headland and P. annua occurred in all three areas. Fewer grass weeds were found at Drayton. However, two species of economic importance, A. mysuroides and A. fatua, were found in the headland area (H) and A. mysuroides was also recorded in the field (F). A total of eight species was found at Gleadthorpe, again mostly in the crop margin area. H. sativum, L. multiflorum and P. annua were found on the headland, and T. aestivum and P. annua were found in the field.

A total of 38 broad-leaved weed species was found over the three sites (Table 3). As with the grass weeds, the highest number of species (28) was found at High Mowthorpe; 10 species were found in the crop margin area, 16 in the headland and 10 in the field. At Drayton, only 12 species of broad-leaved weeds were found and generally the weeds were not confined to the crop margin/headland area. There were 22 species of weeds at Gleadthorpe. The crop margin had a diverse flora of 19 species; fewer weeds were found in the headland area (12 species) but 18 species were found in the field. Stellaria media was the most widespread weed, occurring in the crop margin, headland and field areas at each site.

Table 3. Occurrence and distribution of broad-leaved weed species

Broad-leaved species	Site HM	DT	GT	Broad-leaved species	Site HM	DT	GT
Aethusa cynapium	MH	MHF	-	Myosotis arvensis	F	-	-
Anagallis arvensis	-	MHF	-	Papaver rhoeas	HF	-	F
Anchusa arvensis	-	-	M	Polygonum aviculare	MH	HF	MHF
Anthriscus sylvestris	MH	-	-	Polygonum convolvulus	F	MH	MHF
Atriplex patula	-	-	MHF	Raphanus raphanistrum	H	-	MF
Brassica napus	H	-	HF	Rumex spp.	M	-	M
Capsella bursa-pastoris	H	-	MHF	Sonchus spp.	H	MHF	MF
Chenopodium album	F	-	MF	Senecio vulgaris	H	-	MHF
Cirsium arvense	-	HF	MF	Sinapis arvensis	F	F	-
Convolvulus arvensis	-	MF	-	Sisimbrium officinale	-	-	MF
Fumaria capreolata	F	-	-	Solanum tuberosum	HF	-	MHF
Galium aparine	M	MHF	MF	Stellaria media	MHF	MHF	MHF
Geranium spp.	-	-	M	Taraxacum officinale	H	-	-
Heracleum sphondylium	M	-	-	Torilis japonica	M	-	-
Lamium amplexicaule	HF	M	-	Urtica dioica	M	-	-
Lamium purpureum	HF	-	-	Urtica urens	M	-	MHF
Lamium album	M	-	-	Veronica persica	H	MF	-
Matricaria matricaroides	-	-	H	Vicia faba	HF	-	-
Matricaria perforata	-	-	MHF	Viola arvensis	-	-	MHF

(M= margin of crop, H= 2.5 to 10 m into crop, F= 40 to 120 m into crop)

Weed population distribution

Total numbers of weeds/m² have been meaned for the three transects in each plot for the pre and post-herbicide assessments only (Table 4). Data for the oilseed rape and bean crops at High Mowthorpe are presented separately. Data for the cereal crops are meaned for three crops at High Mowthorpe, three crops at Drayton and four crops at Gleadthorpe.

At High Mowthorpe, weed numbers in the oilseed rape crop were greatest in the headland area for both CFP and RIA, before and after treatment with full and half-rate propyzamide. There were more weeds, on the RIA plot in the spring, post-herbicide, but the difference was small. In the spring beans, bentazone was applied at full-rate on the CFP treatment and at half-rate in the RIA treatment, post-emergence of the crop. Weed numbers were high in the crop margin of CFP, but weed control was worse in the mid-field area of RIA. Half-rate bentazone applied to RIA gave only poor control of the major weeds, many of which were outside its spectrum of activity. In the wheat crops at High Mowthorpe, full and half-rate diflufenican plus isoproturon applied to CFP and RIA respectively gave good control of the weeds in early spring. Weed control remained good throughout the season in all three wheat crops in both treatments, although numbers of weeds increased in the crop margin area. It was not possible to estimate populations of some weeds in the crop margin area because of their high density. Weed ground cover was recorded, but the data are not presented here.

Populations of weeds were high in the wheat crops at Drayton, in the autumn before the herbicide treatments were applied, especially in the first wheat after grass in 1992. The crop margin and headland areas were the weediest. Weed control was variable and in general the half-rate RIA treatments resulted in poorer weed control. At Gleadthorpe, very high populations of weeds were found in the cereal crops, especially in the spring wheat crops after sugar beet and potatoes. There were fewer weeds in the barley crops. There was an average of over 300 plants/m² in the crop margin area for the four crops. Numbers of weeds were substantially reduced by both CFP and RIA herbicide treatments, although the RIA treatment was less effective in the mid-field area.

Table 4. Populations and distribution of weeds (numbers/m²)

Site, crop and distance from boundary (m)	Pre-herbicide		Post-herbicide	
	CFP	RIA	CFP	RIA
High Mowthorpe - W. oilseed rape				
0	43	17	0	0
2.5	227	190	113	147
10	100	87	50	60
40	7	63	7	13
80	33	90	20	30
120	70	33	33	13
High Mowthorpe - S. Beans				
0			135	48
2.5			22	58
10			56	54
40			30	236
80			23	186
120			31	42
High Mowthorpe - W. wheat (mean of 3 crops)				
0	8	13	36	30
2.5	73	73	1	4
10	20	38	0	2
40	22	12	0	4
80	16	18	0	2
120	31	30	1	5
Drayton - W. wheat (mean of 3 crops)				
0	82	146	1	27
2.5	47	51	19	29
10	11	3	18	18
40	18	5	28	19
80	4	14	14	31
120	2	12	7	33
Gleadthorpe - Cereals (mean of 4 crops*)				
0	149	302	43	27
2.5	73	51	11	18
10	28	38	23	14
40	46	27	12	24
80	31	18	8	27
120	12	20	14	30

* two spring wheat, one winter barley and one spring barley

DISCUSSION

Weed control is an important part of any crop protection programme and continuous reduction of inputs over a period of years could result in increased weed seed return to the soil and increasing weed problems in subsequent crops. While SCARAB is not primarily concerned with low inputs of herbicides it is important to monitor the effects which reductions in herbicide use have on weed diversity and distribution. Other studies within the project will determine how important the presence of weeds in the crop is to non-target beneficial invertebrates.

These interim results from SCARAB appear to mirror the results found at Boxworth, where plant diversity was shown to be greatest in the first metre of cultivated ground where both hedge and field species occurred. In addition, total weed density was highest at the field boundaries and declined from 5 m into the crop (Marshall, 1992). The major implication of the results from Boxworth is that most boundary plants do not constitute a threat as field weeds. Weed management should therefore aim to keep those few plant species such as cleavers and couch, which are capable of dispersing and becoming a problem under control, while encouraging the majority (Marshall, 1992). Many of the weed species found in the SCARAB plots were also confined to the crop margin area, although at Gleadthorpe a high proportion of broad-leaved weeds was also found in the crop.

The efficiency of the half-rate herbicide treatments varied from very effective to inadequate. Weed control was generally poorer in the broad-leaved oilseed rape and bean crops, where broad-leaved weeds predominated, and were often out of the range of the herbicides applied. Weed control in cereals was generally better and the differences between CFP and RIA were small. However, the residual levels of weeds left after treatment on both CFP and RIA are likely to increase weed seed return and future weed problems, especially in subsequent break crops. The impact of reduced herbicide programmes can be tolerated in the short-term, but the risk of creating longer term weed problems, which will require increased herbicide use in the future, must be considered.

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