In outdoor container experiments, resistance to chlorotoluron has been associated with cross-resistance to many other herbicides with differing modes of action (Moss, 1987). Some herbicides, however, such as ethofumesate, propyzamide and trifluralin, have been as effective on the Peldon population as on a standard susceptible stock.

This paper describes further studies into the distribution of resistant A. myosuroides and field experiments aimed at determining how best to control resistant populations.

TESTING SEED SAMPLES FOR RESISTANCE TO CHLOROTOLURON

Materials and methods

Seed samples were collected in July 1988 from winter cereal fields and tested either at ADAS, Cambridge, or at Long Ashton Research Station. The test procedure at both sites was that described by Moss and Orson (1988) in which seeds were sown in pots of soil and plants sprayed at the 2-leaf stage with 2.0-2.5 kg/ha (ADAS tests) or 3.5 kg/ha (LARS test) of chlorotoluron. This chemical was used as a representative of the substituted-urea group of herbicides which includes isoproturon. Three standard reference stocks were included in all tests: Rothamsted (susceptible); Faringdon (partially resistant); Peldon A1 (resistant). There were five replicates. The % reduction in foliage fresh weights was calculated by relating weights in treated and untreated pots for each stock.

ADAS samples

A total of 105 samples was tested. Seeds were collected from 20 fields, selected at random, surveyed as part of the ADAS Winter Wheat Disease Survey of England and Wales. A further 59 samples were collected as part of a Home-Grown Cereals Authority (H-GCA) funded random survey of fields within 50 miles of Peldon, Essex. In addition, 26 other samples were tested. These were collected either from ADAS trial sites or from fields where clients had requested a test for resistance.

Long Ashton samples

A total of 42 samples was tested. Fifteen of these were from fields at Peldon (7), South Essex A (5), Tiptree A (1) and Oxford A (2); areas where resistance had previously been detected (Moss & Orson, 1988). These were included to confirm resistance in these fields. Twenty-seven other samples were tested.

Results and discussion

The following arbitrary classification has been adopted to identify different degrees of resistance, based on a comparison with the % reduction values of the three standard stocks:

```
Rothamsted              Faringdon                              Peldon
  value                   value                                 value
s   |    s    |      *      |      **      |  ***  |  ****  |   *****
susceptible     need further    partially   ----- increasingly resistant --->
    |          |evaluation  |   resistant|         |        |
```

The mean % reductions in fresh weight for the three standard stocks were: Rothamsted 93%; Faringdon 78%; Peldon 33%. The mid point value between Rothamsted and Faringdon was used to separate those stocks deemed to be susceptible and those requiring further evaluation to determine whether they exhibit a low level of resistance. Similarly, the stocks in the Faringdon to Peldon range were separated into three categories. Populations were only termed 'resistant' (** or more) if they showed greater resistance than the Faringdon population, which has shown partial resistance to chlorotoluron, not only in many pot experiments, but also in simulated field conditions (Moss, 1987).

Results were analysed statistically but it was not thought appropriate to classify resistance groupings using statistical parameters. In a series of notionally identical tests, the standard errors will be influenced by variability, the level of herbicide activity, and the proportion of resistant to susceptible stocks included. Therefore the assignation of resistance groupings could change between tests. In addition, because resistance is of a quantitative nature, any dividing line placed across the continuum of varying response must be arbitrary.

TABLE 1. Results of 1988 seed collections by county (105 ADAS and 27 LARS samples collected for the first time in 1988).

County	Number of samples	S	*	**	***	****
				------ Resistant ------		
Bedfordshire	5	3	2	0	0	0
Buckinghamshire	3	2	0	0	0	1
Cambridgeshire	30	21	8	1	0	0
Essex	33	30	1	1	1	0
Hertfordshire	5	5	0	0	0	0
Lincolnshire	6	4	1	1	0	0
Norfolk	5	5	0	0	0	0
Oxfordshire	8	7	0	0	1	0
Suffolk	27	21	3	2	0	1
Warwickshire	1	0	0	1	0	0
Other	9	9	0	0	0	0
Total	132	107	15	6	2	2

Ten of the 132 populations, collected for the first time in 1988, showed resistance to chlorotoluron (** or more). These populations came from a wide geographical area (Table 1). Two of the populations, one from Buckinghamshire and one from Suffolk, showed pronounced resistance (****).

The results from the 79 ADAS random survey samples showed that 68 were in the S category (86%), 7 in * (9%), 3 in ** (4%) and 1 in **** (1%).

Resistance was confirmed in all the fields identified as containing resistant A. myosuroides in previous tests at LARS. The rating for these fields was: Peldon (****-*****); South Essex A (**-****); Oxford A (**-****); Tiptree A (**).

The "others" category in Table 1 comprised the counties of Berkshire, Gloucestershire, Hampshire, Northamptonshire, Wiltshire and Worcestershire. Only one or two samples were collected from each of these counties and all were in the susceptible (S) category. Samples, classed as *, showed small reductions in fresh weight which were usually significantly lower ($P \leqslant 0.05$) than the susceptible standard stock (Rothamsted). These marginal levels of resistance might result in reduced field performance, especially under adverse conditions for herbicide activity, and need further evaluation.

Since 1982, a total of 296 samples of A. myosuroides have been tested for resistance to chlorotoluron. Resistance has been detected in 33 fields on 20 farms in England. These farms are located in seven counties: Buckinghamshire (1 farm), Cambridgeshire (2), Essex (9), Lincolnshire (1), Oxfordshire (3), Suffolk (3), Warwickshire (1). The most severe cases of resistance occur at Peldon, Essex, but other populations, in Suffolk and Buckinghamshire, with a comparable degree of resistance were detected for the first time in 1988. We conclude that the occurrence of severe resistance is low, but the incidence of more marginal resistance is disturbing in view of the potential for further evolution.

FIELD TRIALS

Materials and methods

Since autumn 1985 three types of field experiment in winter wheat have been carried out by ADAS on two farms at Peldon. All experiments comprised randomised block designs with three replicates. Where applicable, herbicide treatments were applied with a modified van der Weij pressurised knapsack sprayer in 200 l water/ha using F80-02 nozzles at 200 kPa. The full treatment list of each trial is included in the results tables (2-4). Where shown growth stages refer to the size of weed.

Cultivation trial

The first two years results of the cultivation trial have been reported previously (Orson & Livingston, 1987). In autumn 1987 and 1988 the range of herbicide treatments were replaced by applying herbicide according to the normal farm practice to the entire 24 m x 18 m cultivation plots. This included sequences of at least three herbicides active against A. myosuroides (similar to the most intensive programme in the sequences trial).

Individual herbicide evaluation trials

Two herbicide evaluation trials (plot size 6 m x 3 m) were conducted to evaluate, in the field, single applications of herbicides which have shown promising results in experiments at LARS. Some of these treatments are not selective in wheat. The 1987/8 trial was conducted in the absence of any crop.

Sequences trials

The most useful herbicides selective in cereals from the individual herbicide evaluation trial were also included in two herbicide sequences trials (plot size 6 m x 3 m) at one pre-em. and two post-em. timings.

Results

Cultivation trial

The cultivation trial continued to show the benefit of ploughing (Table 2). Although in the second year the density of A. myosuroides after two years ploughing was similar to that after ploughing followed by minimum cultivation, the continued ploughing in the third and fourth years resulted in significant (P ⩽ 0.05) reductions in A. myosuroides head densities. It is suggested that the unexpectedly high figure on the annually ploughed treatment in 1987 was due to the return to the surface of seed buried by the first ploughing. In 1986 and 1987 herbicide performance was shown to be improved by ploughing (Orson & Livingston, 1987). This is also likely to have contributed to the benefit shown by ploughing in 1988 and 1989.

TABLE 2. Cultivation trial, Twitch Field, Peldon Hall.

Autumn treatments				A. myosuroides heads/m^2 (July)			
1985	1986	1987	1988	1986	1987	1988	1989
Plough 25 cm (P)	P	P	P	107	1280	44	10
Plough 25 cm	mc	mc	mc	107	1394	883	114
Mincult 5 cm (mc)	mc	mc	mc	915	3667	2162	378
	S.E.D. (6 d.f.) +/-			147.3	549.1	125.0	59.1

Note: 1986 and 1987 counts refer to untreated plots, 1988 and 1989 refer to treatment as farm practice.

Individual herbicide evaluation trials

The maximum control achieved in the herbicide evaluation trials (Table 3) was 75%. Trifluralin, ethofumesate, propyzamide, fluazifop-P-butyl, carbetamide and tri-allate gave the best levels of control. For the 1987/8 results, when there was no crop and for products which are non-selective in cereals (such as carbetamide, fluazifop-P-butyl, ethofumesate and propyzamide) level of control is hindered in these trials by lack of crop competition. For these treatments especially, % reduction of plant numbers is more likely to reflect their capabilities.

Sequences trials

In the herbicide sequences trials higher levels of control were achieved in 1988/9 than the previous year (Table 4). However despite the equivalent of using four chemical treatments the highest level of control was only 86% (pre-em. tri-allate followed by early post-em. isoproturon/trifluralin followed by isoproturon). Both years trials demonstrate the benefit of a pre-em. treatment. The 1987/8 trial demonstrated a benefit from applying tralkoxydim rather than isoproturon as the late post-em. spray, but this was not repeated in 1988/9.

TABLE 3. Individual herbicide evaluation trials.

	1987/88 Church Field Brickhouse Farm, Peldon		1988/89 Lower 16 Acre Peldon Hall	
Cultivation method	Ploughed		Minimum cultivated	
Kd (chlorotoluron)	5.3		5.3	
	% Reduction *A. myosuroides*		% Reduction *A. myosuroides*	
Herbicide (rate/ha)	Plants	Heads	Plants	Heads
Pre-emergence	20/10/87		30/9/88	
trifluralin (1.1 kg)	48	62	53	33
chlorsulfuron (15 g) + metsulfuron-methyl (5 g)	35	55	-	-
tri-allate (2.25 kg) (c)	42	39	68	33
pendimethalin (2.0 kg)	50	38	29	50
Early post-em. (GS 12/13)	14/12/87		24/10/88	
isoproturon (2.5 kg)	26	38	34	31
chlorotoluron (3.5 kg)	5	27	31	43
diclofop-methyl (1.14 kg)	19	35	25	29
tralkoxydim (200 g) (a)	1	31	32	38
SMY 1500 (1.6 kg) (b)	34	45	33	35
isoproturon (1.95 kg) + trifluralin (1.3 kg)	-	-	31	29
carbetamide (2.1 kg)	57	62	51	30
fluazifop-P-butyl (187 g) (a)	75	48	57	31
ethofumesate (2.0 kg)	70	62	55	22
propyzamide (700 kg)	69	53	65	24
barban (312 g)	46	57	-	-
Late post-em. (GS 25-29)	18/4/88			
fluazifop-P-butyl (187 g) (a)	34	53	-	-
tralkoxydim (350 g) (a)	7	23	-	-
S.E.D. +/-	19	18	13	13
d.f.	32	32	36	36
(Untreated population/m^2)	(20.3)	(362)	(958)	(1247)

(a) tank-mixed with 0.1% non-ionic wetter ('Agral')
(b) 4-amino-6-tert-butyl-3-ethylio-1,2,4-triazin-5(4H)-one in formulation UK 220.
(c) granular formulation

TABLE 4. Sequences trials.

1987/8 Twitch Field, Peldon Hall (minimum cultivated
Kd (chlorotoluron) 8.7)

Early post-em. 9/3/88 (GS 11/13)	Late post-em. 18/4/88 (GS 23/25)	Pre-em. applied 10/11/87 Nil	chlorsulf./m-methyl
		% *A. myosuroides* control (heads)	
IPU	IPU	21	25
IPU	IPU/tralkoxydim	19	12
IPU	tralkoxydim	35	45
IPU/tralkoxydim	IPU	0	18
IPU/tralkoxydim	IPU/tralkoxydim	0	26
IPU/tralkoxydim	tralkoxydim	20	39
tralkoxydim	IPU	0	24
tralkoxydim	IPU/tralkoxydim	20	19
tralkoxydim	tralkoxydim	21	31

S.E.D. +/- 12.5 (60 d.f.)
(Untreated population 1773 heads/m^2)

1988/9 Melondowns Field, Brickhouse Farm, Peldon (minimum cultivated
Kd (chlorotoluron) 11.4)

Early post-em. 2/11/88 (GS 11/13)	Late post-em. 24/1/89 (GS 22)	Pre-em. applied 14/10/88 Nil	trifluralin	tri-allate
		% *A. myosuroides* control (heads)		
IPU	IPU	56	60	79
IPU	tralkoxydim	51	69	69
IPU/trifluralin	IPU	55	77	86
IPU/trifluralin	tralkoxydim	73	72	81
IPU/tralkoxydim	IPU	64	78	74
IPU/tralkoxydim	tralkoxydim	47	78	77

S.E.D. +/- 13.4 (42 d.f.)
(Untreated population 2206 heads/m^2)

Abbreviations and rates of active ingredient/ha

IPU = isoproturon (2.5 kg except 1989 when 2.1 kg late post-em); tralkoxydim (200 g); chlorsulf./m-methyl = chlorsulfuron (15 g)/metsulfuron-methyl (5 g), trifluralin (1.1 kg); tri-allate granules (2.25 kg); Nil = no pre-em. herbicide applied.

Discussion

These field trials confirm the poor control achieved by herbicides alone. In any one season as the number or frequency of active ingredients applied increased, the level of control improved slightly. However, even sequences of four herbicides, costing at least £85/ha, were insufficient to achieve acceptable levels of control. More consistent was the effect of ploughing which gave more than ten fold reductions in A. myosuroides head number when compared with minimum cultivation. Some control can be achieved by the use of products which are not selective in cereals but this would mean a change of cropping. The most sensible strategy to control resistant A. myosuroides is likely to be a combination of ploughing and the inclusion in the arable rotation of crops on which fluazifop-P-butyl, propyzamide, ethofumesate or carbetamide can be used. Delayed drilling and growing spring or other crops which discourage A. myosuroides must also be considered.

The results from the tests on seed samples indicate that resistant A. myosuroides is more widespread than previously reported. With the increasing incidence of resistance, strategies are required to contain existing resistant stocks. The field trials indicate however, that despite the use of an integrated system, control of resistant A. myosuroides will be unreliable and expensive in winter cereal dominated rotations. Strategies need to be developed to prevent resistance evolving elsewhere.

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THE APPEARANCE OF PHENOXY-HERBICIDE RESISTANCE IN NEW ZEALAND PASTURE WEEDS

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ABSTRACT

Investigations into the appearance in New Zealand of MCPA-resistant *Ranunculus acris* and *Carduus nutans* in dairy and sheep pastures respectively are reviewed. Extreme differences in sensitivity between susceptible and resistant populations of *R. acris* and *C. nutans* of 4.9 and 6.7-fold respectively, render normal rates of MCPA ineffective for the control of the "resistant" populations. Populations with intermediate levels of sensitivity to MCPA occur in both species. Resistance in both species was correlated with historical exposure to phenoxys, supporting the hypothesis that it is the result of herbicide selection pressure. In *C. nutans*, cross resistance occurs between 2,4-D, MCPA and MCPB.

INTRODUCTION

The purpose of this paper is to review New Zealand research into MCPA-resistance in *Ranunculus acris* (giant buttercup) and *Carduus nutans* (nodding thistle). *R. acris* is a perennial weed of dairy pastures receiving high annual rainfall. It occurs widely in the North Island (NI) on land of high fertility (Tuckett, 1961) and is a problem in the South Island (SI) at Takaka and Karamea. *C. nutans* is a biennial occurring mainly in sheep pastures under low rainfall and is most common in summer-droughted high-fertility areas in Hawkes Bay (NI) and Canterbury (SI).

INITIAL EXPERIMENTS IN THE FIELD AND GLASSHOUSE

Field trials in the 1950s in Taranaki showed that MCPA and MCPB gave "very satisfactory" control of *R. acris* (Tuckett, 1961), but in the late 1970s there were reports of poor control from these herbicides. Genetically based resistance was not suspected and trials were conducted in the NI to improve on the previous recommendation (Popay *et al.*, 1984; Popay *et al.*, 1989). This work confirmed late winter applications of MCPA were effective but also revealed the level of control to be highly variable between populations 10 km to 160 km apart. Field trials with MCPA at Takaka from 1984 until 1988, detected differences in control between sites within a radius of 1 km (Bourdot, unpub.). The extremes of this variation occurred on the Jones and Silcock farms. The reduction in ground cover of the Jones population by MCPA at the usual field rate of 1.0 kg/ha, was 93%, but only 11% for the Silcock population. Both populations were treated and assessed under identical conditions. Both sites supported permanent pastures rotationally grazed by dairy cattle and there appeared to be no managerial or environmental differences between them that could explain such a large difference in the efficacy of MCPA. However to eliminate possible environmental effects, a comparison of seedling progeny of the Jones and Silcock populations, was made under uniform conditions in a glasshouse at Lincoln (Bourdot & Hurrell, 1988). For both populations, 128 plants with 6 to 7 expanded leaves were sprayed with a logarithmic series of doses of MCPA from 0.198 to 3.375 kg/ha. Probit curves fitted to the mortality data (Fig.1a) showed the LD_{50s} of the Silcock and Jones populations to be respectively 1.51 and 0.31 kg MCPA/ha. The Silcock population was 4.9 times more tolerant to MCPA than Jones, confirming the existence of a genetic basis for the observed field differences in response to MCPA.

In the late 1970s almost simultaneously with the *R. acris* reports, a sheep farmer from Argyll in Hawkes Bay, reported that 2,4-D no longer gave adequate control of *C. nutans*. In 1981 the susceptibility of *C. nutans* at Argyll was compared with that of another population on a farm at Matapiro, some 30 km further north where no control problems had been experienced (Harrington & Popay, 1987). Nearly 200 plants were sprayed at the two sites with 20 mg/plant of 2,4-D or MCPA. The mortalities of the Argyll and Matapiro populations with 2,4-D were respectively 19% and 90%, and 49% and 96% with MCPA. Seedling progeny from Argyll and Matapiro were subsequently compared in a glasshouse at

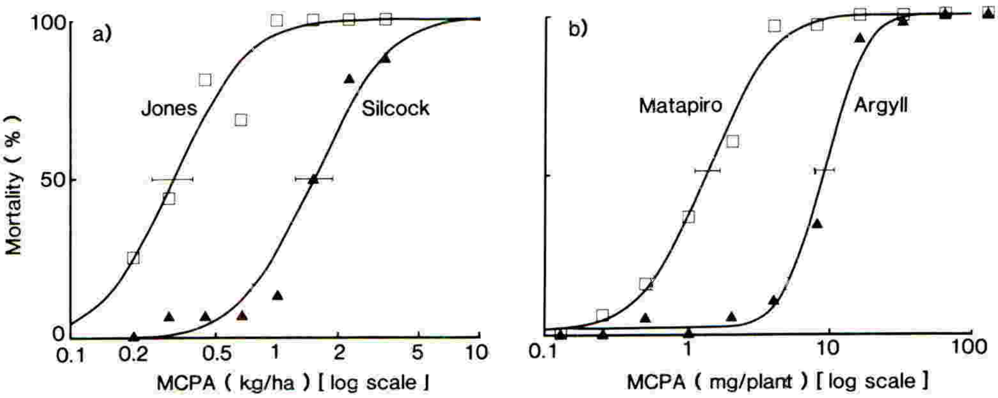

Fig. 1. Dose response curves for MCPA of susceptible and resistant populations of (a) *Ranunculus acris* (From Bourdot & Hurrell, 1988) and (b) *Carduus nutans* (From Harrington *et al.,* 1988). The 95% confidence intervals for the LD_{50}s are given as horizontal bars. The slopes of the probit curves were different (P=.05) for the two populations of *C. nutans,* but there was no evidence of this for *R. acris* for which the curves were constrained to be parallel.

Massey University. This confirmed an inherent difference in susceptibility and suggested the Argyll population could be as much as 30-times more tolerant of MCPA than the Matapiro population (Harrington & Popay, 1987). This first experiment used six rates of MCPA and 150 plants of each population. Comparisons were repeated another two times, and differences between the populations were found each time. In the second experiment only four rates of MCPA and 40 plants of each population were used and the results suggested the Argyll population was five times more tolerant than the Matapiro population (Harrington & Popay, 1987). The third glasshouse comparison used 12 dose rates of MCPA and a total of 260 plants, and this showed a 14-fold difference between the populations (Harrington *et al.,* 1988).

Glasshouse-grown *C. nutans* were stunted compared with field-grown plants, so to avoid the possibility that this may have influenced the results, the comparison of these two populations was repeated in the field. Several months after transplanting 354 Matapiro and 437 Argyll seedlings into a pasture at Massey University, a logarithmic series of doses of MCPA from 0.12 to 128 mg/plant was applied (Harrington *et al.,* 1988). Probit analyses showed 2% "natural" mortality occurred, and while the LD_{50} for the Argyll population was 9.08 mg/plant, the LD_{50} for the Matapiro plants was only 1.35 mg/plant (Fig.1b). Thus the Argyll population was 6.7-times more tolerant at the 50% level of mortality.

INTERMEDIATE LEVELS OF RESISTANCE AND CORRELATIONS WITH SPRAYING HISTORY

Once the existence of genetically-based resistance to MCPA had been confirmed in *R. acris* and *C. nutans*, investigations were begun with both species to find if such resistance occurred at other sites, and to determine if the resistances had resulted from herbicide selection pressure.

Seven populations of *R. acris* from Takaka dairy pastures and one from a roadside in Canterbury were compared in a glasshouse for susceptibility to MCPA. The LD_{50}s varied between the populations indicating intermediate levels of resistance existed. Information on the spraying history for each of these sites was collected by interviewing past and present land managers. The seven sites were ranked according to the intensity of historical spraying. The level of resistance as measured by the LD_{50}s, correlated well with this (Table 1). This suggests that past spraying of MCPA had caused a build-up of resistance in *R. acris.*

Seed from 28 populations of *C. nutans* was collected from various parts of Hawkes Bay, Waikato and Manawatu. The susceptibilities of these populations to MCPA were compared in a glasshouse by applying 3.0 mg MCPA/plant to 30 plants from each population. Differences in mortality were compared using an adjusted chi-square analysis (Harrington unpub; Harrington, 1989). Fourteen sites in Hawkes Bay and Waikato were located where *C. nutans* is more tolerant of MCPA than the Matapiro population. Spraying histories were obtained for seven of the most resistant and seven of the most susceptible populations. All sites had received herbicide in past years but resistance occurs only where 2,4-D has been used every year for many years (Table 2).

Table 1. Responses of the seedling progeny of 8 populations of *Ranunculus acris* to MCPA under uniform conditions in a glasshouse and corresponding MCPA exposure histories. LD_{50}s (kg MCPA/ha) are means of estimates from (n) dose-response experiments. Data from Bourdot & Hurrell (1988) and Bourdot unpub.

Population	Location	LD_{50}	rank[a]	Spraying history
Jones	Takaka	0.36 (3)	0	Not sprayed since 1958, possibly never sprayed with herbicide.
Saltwater Crk.	Canterbury	0.39 (1)	0	Never treated with herbicides.
Stratford	Takaka	0.52 (2)	1	Spot-sprayed rarely with MCPA from 1946 until 1974. Boom-sprayed with MCPB or MCPA occasionally from 1974 until 1984.
Langford t	Takaka	0.67 (1)	2	Sprayed with MCPA from 1946 until 1984 and often from 1979 until 1984.
Fellowes	Takaka	0.72 (2)	1	Occasionally spot-sprayed with MCPA from 1946 until 1984.
Langford b	Takaka	0.83 (1)	2	Sprayed with MCPA from 1946 until 1984 and often since 1979.
Reilly	Takaka	0.94 (1)	-	MCPA has been used but at unknown frequency.
Silcock	Takaka	1.30 (3)	3	Sprayed with MCPA triennially from 1955 until 1966, biennially from 1966 until 1981, annually from 1981 until 1984.

Correlation of "LD_{50}" and "rank"; $r = 0.845^{*}$

(a) Rankings of populations for historical exposure to MCPA based on the anecdotal information on application rates and frequencies. This information was supplied by the farmers in Takaka, and the Hurunui County Council for the Saltwater Creek population.

Table 2. Responses of the seedling progeny of 14 populations of *Carduus nutans* to 3 mg MCPA/plant, under uniform conditions in a glasshouse, and corresponding herbicide spray histories of the populations. Mortality data from Harrington (1989).

Population	Location	Control problem?	% kill[2]	Spraying history[1]
Maungatautari	Waikato	yes	0a	2,4-D annually for the last 15 yrs.
Waotu	Waikato	yes	0a	2,4-D ann. for the last 15 yrs.
Argyll	Hawkes Bay	yes	10ab	2,4-D ann. for the last 25 yrs.
Te Onepu	Hawkes Bay	yes	13ab	2,4-D ann. for the last 20 yrs.
Arohena	Waikato	yes	17b	2,4-D or MCPA ann. for the last 17 yrs.
Glenalvon	Hawkes Bay	yes	20b	2,4-D ann. for the last 30 yrs.
Kia Ora	Hawkes Bay	yes	23b	2,4-D ann. for the last 20 yrs.
Mason Ridge	Hawkes Bay	no	93c	2,4-D or MCPA infrequently for the last 30 yrs.
Limestone Downs	Waikato	no	93c	2,4-D infrequently for the last 10 yrs.
Maraekakaho	Hawkes Bay	no	95c	MCPA ann. for 20 yrs, then infrequently for last 15yrs.
Ohutu	Hawkes Bay	no	97c	2,4-D ann., then infrequently for the last 12 yrs.
Matapiro	Hawkes Bay	no	97c	2,4-D ann., then infrequently for the last 6 yrs.
Colyton	Manawatu	no	100c	2,4-D ann. for 10 yrs, then infrequently for the last 10 yrs.
Hickey Road	Hawkes Bay	no	100c	2,4-D ann. for 10 yrs, then infrequently for the last 8 yrs.

(1) Anecdotal information from farmers; for all populations herbicides may have been applied earlier than indicated, but confirmation was unavailable.

(2) Populations sharing the same letter do not differ in susceptibility (P=0.05).

Although it was resistance to MCPA that was detected in *C. nutans*, the selection pressure has been applied by 2,4-D on almost all farms (Table 2). The presence of cross-resistance in the Argyll population was examined further in a trial where plants from this and the Matapiro population were grown together at Massey University. The plants were grown in the field and received the recommended application rate of 12 commercial herbicide preparations (Harrington, 1989). Argyll plants were resistant to MCPA, MCPB and 2,4-D but not to picloram, clopyralid, dicamba, mecoprop or glyphosate. An unexpected result was a slight but significant (P=0.05) level of tolerance to the sulphonylurea herbicide DPX-L5300.

DISCUSSION

The experiments have shown that resistance to MCPA has developed within populations of both *R. acris* and *C. nutans* in New Zealand pastures. These resistances seem almost certain to have developed due to selection pressure exerted by phenoxy herbicides since for both species, the susceptibility of populations was correlated with their historical exposure to phenoxys.

Although some of the glasshouse experiments suggested very large differences in susceptibility between extreme populations of *C. nutans,* it seems that a 6 to 7-fold difference is the most realistic estimate. This is similar in magnitude to the 5-fold difference found in *R. acris,* and the 6-fold difference in susceptibility to mecoprop found in *Stellaria media* by Lutman and Snow (1987). It is a larger difference than found in *Tripleurospermum inodorum* by Ellis and Kay (1975) where populations never differed in susceptibility to MCPA by any more than 2.5-times. Five or 6-fold differences are not large compared to those reported for triazine herbicides (LeBaron & Gressel, 1982). They are large enough however, to render the least susceptible biotypes of *R. acris* and *C. nutans* "resistant" to MCPA applied at the normal application rate of 1.0 kg/ha.

Species taking many months to produce their first seeds may be more likely to develop resistance to non-persistent herbicides such as phenoxys, than annuals which seed within a short time from germination. Non-persistent herbicides will usually exert a low selection pressure on an annual species when, as is frequently the case, a new cohort of seedlings germinate, develop to maturity and seed after spraying in the same year. In this event both susceptible and resistant genotypes will set seed, thus slowing the build-up of resistance (Gressel & Segel, 1982). By contrast, in a species taking for example, 12 months to produce seed following germination, an application of a non-persistent herbicide needs only to be made once a year to remove all susceptible plants before they flower and seed, no matter when they germinate.

In New Zealand pastures, Popay and Kelly (1986) found that most seedlings of *C. nutans* emerge in late summer and autumn (February through May) and flower in the following summer months. They calculated that 98% of *C. nutans* plants that flower in summer are derived from autumn-germinated seedlings. Thus the usual late-autumn application of 2,4-D or MCPA made when the seedlings finish appearing (Matthews, 1975), will prevent all susceptible plants from flowering in that year. Applications made later in the year, but before seeding, would be similarly effective. The selection pressure on sprayed populations of *C. nutans* in pastures in New Zealand has thus probably been high despite the ephemeral nature of 2,4-D and MCPA.

The selection pressure exerted by MCPA on *R. acris* in New Zealand pastures may also be high. While a detailed demographic study has not been done on *R. acris* in New Zealand, it is likely that germination occurs mainly in autumn and in late winter as it does in the UK (Harper & Sagar, 1953). Field observations in Takaka certainly support this view, and also show seed production is confined to the summer months. Thus the recommended treatment with MCPA in late winter (August) (Popay *et al.*, 1984,1989), with or without additional later spring treatments of MCPA or MCPB (Matthews, 1975), would kill all susceptible plants emerging in a year.

Another factor that may have promoted the build-up of resistance in *C. nutans* and *R. acris* is a lack of genetic buffering. Many weeds produce persistent soil seed banks. The germination of such dormant seed produced by susceptible plants in years prior to the selection pressure being applied, or during years when the herbicide has not been applied, will depress the rate of build-up of resistance in a population (Gressel & Segel, 1982). In this respect the permanent pasture habitats of both species may be of considerable significance. Seeds are more likely to remain dormant if they are buried in the soil rather than left on the surface (Egley & Duke, 1985). Such burial is less likely to occur in a permanent pasture than in arable cropping soil, mitigating against the formation of a persistent seed bank. There will also be less return of any buried seed to the surface where it can germinate, than in cultivated soils.

No study has been made of the seed biology of *R. acris* in New Zealand but Sarukhan (1974) showed that only 1.5% of seeds of this species sown onto pasture in Wales remained viable after one year. While Grime *et al.* (1988) suggest the seeds of *R. acris* may persist in soil, others have failed to find evidence for a persistent seed bank under permanent pasture (Champness & Morris, 1948; Milton, 1936). The evidence indicates that *C. nutans* also may not form a persistent bank of seeds in the soil under a permanent pasture. Popay and Thompson (1979) working in New Zealand, found seeds of *C. nutans* sown within 20 mm of the soil surface disappeared quickly due to germination. As few as 3% remained after one year and none after three years. The seeds persisted only when buried. Similarly Kelly (pers.comm.) found only 7% of seeds of *C. nutans* sown on the soil surface under pasture persisted after one year and only 0.3% after 2 yrs.

Despite the probable existence of high selection pressures and a lack of genetic buffering in *R. acris* and *C. nutans,* it would seem, at least for *C. nutans,* that continued use of phenoxy herbicides over many years is needed to result in resistance in a population. The susceptible populations of *C. nutans* had all been sprayed in the past, but it was only where this pressure had continued every year that resistance occurs today (Table 2). It is possible that resistance had once occurred but disappeared in populations not treated in recent years, due to a fitness differential favouring the susceptible forms (Gressel & Segel 1982). However anecdotal evidence suggests that resistance never occurred at the sites not treated with herbicide in the last 10 to 15 years (Table 2). Studies are being done to determine if resistant forms of *C. nutans* and *R. acris* are less ecologically fit than susceptible forms.

Because phenoxy herbicides have been applied frequently enough to cause resistance to build up in *R. acris* and *C. nutans,* it is reasonable to expect resistance to phenoxys will appear in other pasture weeds in New Zealand. *Carduus pycnocephalus* is already suspected of having developed resistance at one of the farms on which a resistant population of *C. nutans* was found (Harrington, 1989). Preliminary experiments suggest that the resistance to MCPA is of similar magnitude to that in the Argyll *C. nutans* but further comparisons are required to confirm this.

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NEW DEVELOPMENTS IN TRIAZINE AND PARAQUAT RESISTANCE AND CO-RESISTANCE IN WEED SPECIES IN ENGLAND

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ABSTRACT

Biotypes of Epilobium ciliatum (American willowherb) and Poa annua (annual meadow grass) resistant to either paraquat or simazine have been recorded in fruit crops in England since 1982. Plants taken in 1988 from two hop gardens in Kent treated annually with paraquat and simazine for about 25 years were found to be resistant to these herbicides but showed unusual features. The P. annua biotypes were resistant to both herbicides, although the level of resistance to simazine was slight. An E. ciliatum biotype from one site was resistant to both paraquat and high doses of atrazine. At the same site triazine-resistant Chamomilla suaveolens was also found. These occurrences emphasise the need to use alternative herbicides in hops. Atrazine-resistant biotypes of Chenopodium album (fat hen) and Solanum nigrum (black nightshade) were discovered in forage maize areas in southwest England and south Wales.

INTRODUCTION

Triazine resistant weeds have been an increasing problem in fruit and ornamental crops in England for the last eight years. Species showing resistance have included Senecio vulgaris and Poa annua (Putwain, 1982), Epilobium ciliatum (Syn. E. adenocaulon) (Bailey et al.,1982), Erigeron canadensis (Clay & West, 1987) and Chamomilla suaveolens (Clay, 1987). Paraquat resistance was first documented for P. annua in 1982 (Putwain, 1982) and more recently for E. ciliatum (Bulcke et al., 1987; Clay, 1987). Control of many of these weeds with paraquat and simazine has become difficult in hop gardens in Kent where the herbicides have been used regularly for up to 25 years. The results of tests for resistance of these weeds are presented in this paper. Triazine resistant weeds of maize crops are common in the USA and Europe but none have been recorded previously in the UK. Recently, Solanum nigrum and Chenopodium album have become difficult to control with atrazine in some forage maize crops in SW. England and S. Wales. Results of tests of their response to atrazine are reported below.

MATERIALS AND METHODS

The locations and their herbicide history from which suspected resistant and susceptible biotypes were taken are shown in Table 1. Several plants of C. suaveolens, E. ciliatum and P. annua taken from two hop gardens near Maidstone, Kent (M1 and M2) in May 1988 were grown on in the glasshouse and their seed collected. Seed was obtained from other glasshouse-grown plants from biotypes selected from previous work as resistant to paraquat or simazine (Clay, 1987 and unpublished data). Seed of C. album and S. nigrum was taken from different parts of affected maize fields and, before use, was washed and soaked in 0.2% KNO_3 for 24 h. For tests of response to pre-emergence herbicides, seed was sown in sandy loam soil (12 per pot) and covered with 2 mm of soil.

TABLE 1. Sources of weed biotypes for testing of herbicide resistance.

Species	Biotype Code	Location	Crop	Herbicide history
C. suaveolens	M1	Maidstone district, Kent	Hops	c 25 yrs annual paraquat & simazine
	R	Luddington, Warks	Fruit	Annual simazine treatment c 10 yrs
	V	Luddington, Warks	None	None
E. ciliatum	E	E.Malling, Kent	Top Fruit	Paraquat c 27 yrs+ simazine c 17 yrs
	L	Long Ashton, Avon	Top Fruit	c 5 yrs annual simazine + paraquat 2-3 times a yr
	M1, M2	Maidstone district	Hops	c 25 yrs annual paraquat & simazine
	U	Luddington, Warks	Top Fruit	2 yrs paraquat
	W	Begbroke, Oxford	Bush Fruit	15 yrs simazine & occasional paraquat
Poa annua	B	Berkshire	None	None
	C	Chard, Somerset	Forest Nursery	c 10 yrs annual simazine
	M1, M2	Maidstone district	Hops	c 25 yrs annual paraquat & simazine
C. album	K	Keynsham, Avon	Forage Maize	5 yrs annual atrazine
	U	Usk, Gwent	Forage Maize	2 yrs annual atrazine
S. nigrum	B	Berkshire	None	None
	C	Chepstow, Gwent	Forage Maize	5 yrs annual atrazine
	E	Exeter district, Devon	Forage Maize	4 yrs annual atrazine
	U	Usk, Gwent	Forage Maize	No recent atrazine

For tests of post-emergence herbicides, seed was sown in trays of peat-based compost and the seedlings transplanted to 8 cm diameter pots of loam-based compost, five per pot for P. annua and C. suaveolens and one per pot for E. ciliatum. The herbicide formulations used were:- atrazine 50% a.i. 'Gesaprim 500FW', paraquat 20% a.i. as 'Gramoxone 100' and simazine 50% a.i. as 'Gesatop 500FW'. In post-emergence applications an adjuvant oil 'Actipron' was added to atrazine treatments at 2.5 l/ha.

Herbicides were applied using a laboratory track sprayer fitted with an 8002 flat fan nozzle giving a volume rate of 373 l/ha at 210 kPa. After spraying, pots were set out in the glasshouse in two to four randomised blocks. Plant condition was assessed at intervals after spraying and foliage fresh weight recorded three to six weeks after treatment.

The atrazine resistance of Solanum nigrum from three sites was also tested using the leaf disc flotation method devised by Hensley (1981). Discs, 4 mm diameter, were cut from the youngest expanded leaves of glasshouse-grown S. nigrum when the plants were 10-15 cm tall, and placed in tubes of buffer solution with 100 mg/l atrazine. Tubes were placed under vacuum until discs sunk, then illuminated and the number of discs floating counted after 15, 30, 45 and 60 min.

RESULTS

Poa annua

Atrazine applied post-emergence did not reduce the growth of the known triazine resistant biotype (C)(Table 2) but was very damaging to the susceptible type (B). The biotypes from the hop gardens (M1, M2) showed some degree of resistance to atrazine but were severely damaged by the highest dose. The only paraquat treatment not killing P. annua biotypes was the lowest dose on M1 and M2.

TABLE 2. Effect of atrazine + oil and of paraquat applied post-emergence to P. annua on 24/10/88[a].

Herbicide dose (kg a.i./ha)	Foliage fresh wt (% untreated) 23/11/88								Untreated fresh wt (g/pot)
	Atrazine				Paraquat				
	0.25	1.0	4.0	16.0	0.25	1.0	4.0	16.0	
Biotype C	77	72	112	101	0	0	0	0	12.9
B	6	22	4	0	0	0	0	0	29.4
M1	91	60	59	30	29	0	0	0	18.8
M2	60	51	44	40	27	0	0	0	18.8

[a] seed sown 25/8/88, soil surface watered, pots free draining.

TABLE 3. Effect of paraquat applied to P. annua biotypes on 13/1/89[a].

Paraquat dose (kg a.i./ha)	Foliage fresh wt (% untreated) 23/2/89									Untreated fresh wt (g/pot)
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40		
Biotype C	93	74	9	0	0	0	0	0	0	22.2
B	119	84	34	16	4	0	0	0	0	26.3
M1	100	87	86	75	77	60	36	32	18	23.1
M2	104	94	83	64	50	23	7	2	5	22.9

[a] seed sown 17/12/88, pots placed on capillary matting after spraying.

TABLE 4. Effect of simazine applied pre-em. to P. annua on 8/6/89[a].

Simazine dose (kg a.i./ha)	Foliage fresh wt (% untreated) 28/6/89 0.025	0.05	0.10	0.20	0.40	Untreated fresh wt (g/pot)
Biotype C	105	94	98	93	99	5.07
B	3	0	0	0	0	4.88
M1	42	4	0	0	0	3.06
M2	60	7	1	0	0	5.16

[a] Pots free draining, receiving light overhead watering.

In a dose-response experiment with paraquat a two to three times larger herbicide dose was required to give an equivalent degree of damage on the M1 and M2 biotypes compared with the standard susceptible type, B (Table 3); the C biotype was slightly more susceptible than the standard. Where simazine was applied pre-emergence the C biotype was not affected by the highest dose (0.4 kg/ha)(Table 4). The susceptible type (B) was virtually killed by the lowest dose (0.025 kg/ha). The doses required for > 95% weight reduction of the M1 biotype was 0.05 kg/ha and for M2 0.1 kg/ha.

Epilobium ciliatum

When atrazine and paraquat were sprayed post-emergence, plants from both hop-garden sites (M1, M2) were resistant to atrazine and that from one site (M1) was also resistant to paraquat as well (Table 5). The standard simazine-resistant biotype (W) showed no leaf damage from atrazine but was killed by all the paraquat doses. Growth of the standard paraquat-resistant biotype from East Malling was inhibited by the higher paraquat doses; the Long Ashton biotype (L) was more resistant. Both biotypes were killed by all atrazine doses. The Luddington biotype (U) was killed by all doses of both herbicides.

TABLE 5. Effect of atrazine + oil and paraquat applied post-emergence to C. suaveolens and E. ciliatum biotypes on 22/9/88[a]

Herbicide	Dose (kg a.i./ha)	Foliage fresh wt (% untreated) 28/10/88 C. suaveolens M1	R	V	E. ciliatum E	L	M1	M2	U	W
Atrazine	0.25	118	98	0	0	0	105	86	0	44
	1.0	100	104	0	0	0	73	115	0	70
	4.0	112	113	0	0	0	96	90	0	98
Paraquat	0.125	0	0	0	81	104	96	79	0	0
	0.5	0	0	0	66	86	62	0	0	0
	2.0	0	0	0	32	59	58	0	0	0
Untreated (actual value, g/pot)		7.4	8.1	9.2	12.8	5.4	4.3	5.7	10.1	8.3

[a] seed sown 25/8/88, soil surface watered, pots free draining.

Chamomilla suaveolens

The biotype from one of the hop gardens (M1) was resistant to the highest dose of atrazine (Table 5); one of the biotypes from Luddington (R) was completely resistant, the other (V) was susceptible.

Solanum nigrum

Most of the biotypes from the C, E and U maize sites were found to be relatively resistant to atrazine (Table 6), being unaffected by a dose of 0.4 kg/ha, whereas the susceptible biotype B was killed by the lowest dose (0.05 kg/ha).

TABLE 6. Effect of atrazine applied pre-emergence to S. nigrum biotypes on 8/6/89[a].

Atrazine dose (kg a.i./ha)	Foliage fresh wt (% untreated) 6/7/89 0.05	0.40	3.2	25.6	Untreated fresh wt (g/pot)
Biotype B	0	0	0	0	8.4
C	124	82	3	0	6.3
E	122	108	22	0.4	7.8
U	103	84	5	0.2	8.9

[a] pots free draining, receiving light overhead watering.

TABLE 7. Response of leaf discs of S. nigrum to atrazine (100 mg a.i./l).

Illumination time (min)	No. of leaf discs floating (% total present) 15	30	45
Biotype B	0	0	0
C	77	90	90
E	100	60	60
U	100	100	100

However, plants were killed or severely damaged by the higher atrazine doses and surviving plants showed typical triazine injury symptoms (leaf margin chlorosis and necrosis). These results were confirmed by the leaf disc test where the numbers of discs from the same C, E and U biotypes floating after treatment was 90-100% whereas none from the susceptible population (B) floated (Table 7).

Chenopodium album

Where atrazine was applied post-emergence one biotype (K) was found to be much more resistant to the herbicide than a biotype from another forage maize site (U) which was killed by 1 kg /ha of atrazine (Table 8).

TABLE 8. Effect of atrazine + oil applied post-emergence to C. album[a] at two dates.

Atrazine dose (kg a.i./ha)	Foliage fresh wt (% untreated) /3/89			Untreated fresh wt (g/pot)
	1.0	3.0	9.0	
Application 13/1/89[b]				
Biotype K	98[d]	69	41	4.13
U	0	0	0	4.59
Application 6/2/89[c]				
Biotype K	85[e]	90	82	14.5
U	0	0	0	17.1

[a] seed sown 7/12/88 [b] growth stage 1 or 2 pairs true leaves
[c] plants 9-13 cm tall. [d] 10/2/89 [e] 9/3/89

DISCUSSION

The P. annua from the hop garden sites (M1, M2) showed a degree of resistance to paraquat similar to that previously reported (Putwain, 1982), but clearly was susceptible to paraquat in certain conditions. Conditions in the glasshouse experiments were conducive to damage with low light levels, humid growing conditions and, in the second test, small plants. A feature of the response of the biotypes to paraquat in the field has been some foliar damage followed by recovery. This pattern was also found with paraquat resistant E. ciliatum (Clay, 1987). The level of triazine resistance in the hop garden biotypes of P. annua was much lower than that found with the Chard (C) biotype and also in earlier reports (Putwain, 1982). There was, however, a big difference in pre- and post-emergence susceptibility; doses of 0.1 kg/ha of simazine were lethal pre-emergence, while plants recovered from 16 kg/ha of atrazine post-emergence. The mechanism of resistance may, therefore, be different from that normally found in triazine resistant biotypes of this and other species where a modification of the thylakoid membrane binding site confers resistance (Le Baron & Gressel, 1982). With the hop garden biotypes resistance may be due to a detoxification mechanism reducing the amount of herbicide reaching the site of action comparable to that found with Alopecurus myosuroides resistance to chlorotoluron and other herbicides (Kemp et al., 1988). The only previous reports of paraquat and simazine co-resistance are with Erigeron species in Egypt and Hungary (Gressel, 1987; Polos et al, 1987). The failure of simazine to control P. annua in hop gardens even though the degree of resistance is small, may be due to its germination pattern. It is possible that spring-germinated P. annua are controlled, but that seedlings germinating after the hops are harvested in autumn are unaffected by the low levels of simazine remaining in the soil and these become large enough to survive spring-applied simazine and paraquat.

The occurrence in fruit and hop plantations of E. ciliatum biotypes resistant to either simazine or paraquat parallels that found previously in biotypes from fruit (Bulcke et al., 1987; Clay, 1987). A unique feature of the M1 biotype, however, was its resistance to both herbicides, paralleling that found with P. annua at both hop garden sites except that the level of triazine resistance in E. ciliatum was very much greater. The degree of paraquat resistance in M1 was relatively low, comparable to other E. ciliatum biotypes showing paraquat resistance and much less than that shown in paraquat- and triazine-resistant Erigeron species in Egypt and Hungary (Gressel, 1987; Polos et al., 1987). The M1 biotype is morphologically different from the others, being smaller with narrower leaves and branched shoots. However, Bulcke et al., (1987) found no correlation between leaf characteristics and paraquat or triazine resistance. Triazine-resistant C. suaveolens also found at the M1 site showed resistance at a high level similar to that found previously (Clay, 1987). The occurrence of at least three herbicide-resistant species at one hop garden site, two of which were resistant to simazine and paraquat, highlights the need to use herbicide programmes which may avoid such developments. Traditionally, simazine and paraquat have been the only herbicides used in hops along with dinoseb for controlling excess bine growth. After the withdrawal of dinoseb, which had appreciable post-emergence activity, weed problems have increased highlighting the need for alternative herbicides.

Triazine resistant C. album and S. nigrum have not been reported before in England although common overseas. The degree of resistance found in this work was comparable to that found elsewhere (Fuerst et al., 1986) but is less than in other triazine resistant species found in Britain (Clay, 1987). Doses of 3 kg/ha of atrazine on S. nigrum and 9 kg/ha on C. album caused typical triazine symptoms on leaves whereas no leaf symptoms occurred with atrazine at 4 kg/ha on C. suaveolens or E. ciliatum. Atrazine-resistance of S. nigrum was confirmed by the leaf disc flotation technique. This is a rapid and inexpensive method of identifying atrazine-resistant biotypes. The technique was used initially by Hensley (1981) on C. album and more recently on common simazine-resistant weeds in the UK, E. ciliatum, E. canadensis and Senecio vulgaris (Clay & Underwood, 1988).

As in maize overseas, resistant weeds generally occur where atrazine is used as the sole herbicide in a maize mono-culture. Surprisingly; S. nigrum at the Usk site, was resistant even though there had been no recent maize crops. However, the site was given dressings of farmyard manure deriving partly from maize silage from other parts of the farm probably containing S. nigrum seed. Since maize normally gets dressings of FYM from other cropped areas, rotating the sites where it is grown may not prevent resistance developing. Inclusion of effective S. nigrum herbicides in the spray programme is, therefore, essential.

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SESSION 4B

TREE CROPS: NEW PRODUCTION SYSTEMS AND THEIR IMPLICATIONS FOR WEED CONTROL

CHAIRMAN	DR J. D. QUINLAN	
SESSION ORGANISER	DR N. A. HIPPS	
INVITED PAPERS		4B-1 to 4B-3
RESEARCH REPORTS		4B-4 & 4B-5
POSTER		4B-6

EUROPEAN FORESTRY SYSTEMS

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ABSTRACT

Current forestry systems and their future development in Europe are a product of the historical development within an individual country and fiscal measures. In recent years financial aid linked to fiscal measures has been used to direct that development within individual countries and within the European Community.

Recent trends and forecasts for the near future can be grouped into Traditional, Urban and Farm Woodlands with Climatic Hazards straddling all three.

INTRODUCTION

The pattern of land use within the European Community is shown in Table 1. in order to provide background to the later explanation of changes in, and likely future developments in forests and woodlands. The Community is a net importer of wood and wood products and has surplus production on some agricultural products. As the climate throughout the Community is favourable for tree growth of a wide range of species it is a reasonable assumption that an expansion of the area of forest will take place. This is a very generalised statement and the following table illustrates national differences.

TABLE 1. Land Use. EC.

Country	Total Land Area (million ha)	Percentage of Total Area		
		Forestry	Agriculture	Urban and Other
United Kingdom	24.1	10	78	13
Belgium and Lux.	3.3	21	46	33
Denmark	4.2	12	67	21
France	54.6	27	57	16
West Germany	24.4	30	49	21
Greece	13.1	20	70	10
Iceland	6.9	5	83	12
Italy	29.4	22	59	20
Netherlands	3.4	9	60	32
Portugal	9.2	40	36	24
Spain	49.9	31	61	8
EEC Total	222.5	24	60	15
Sweden	41.2	64	9	27

Source UK. CSO Annual Abstract of Statistics 1988.
Elsewhere. F.A.O. Production Year Book Vol 40 1986.
From Forestry Commission Handbook 5 "Urban Forestry Practice" 1989.

rotation".

The phrase "Urban Woodland" could replace Arboriculture.

This is a high profile, high value industry. Bradshaw 1988 estimates the planting stock value at £121M per annum. In 1987/88 the Countryside Commission England/Wales gave £2.6M in grants and in Scotland £.26M was the equivalent sum. (Forestry Commission 1989.) The Department of transport plants over 1 million trees per annum. This is all at the smaller, amenity end of the scale.

On the larger scale two major initiatives have been launched this year. In Scotland the "Central Scotland Woodlands Trust" has been created to draw together public and private finance in order to create a woodland structure on 66,000 hectares of less favoured land in central Scotland between Edinburgh and Glasgow. This is a complex area of low grade agricultural land, derelict industrial sites, reclaimed mineral workings and with low population levels, but fringed by the very high density population zone of the central Scotland Industrial Belt.

In England and Wales a joint project by the Forestry Commission and Department of the Environment was launched in July 1989 "Forestry for the Community". A series of forests are planned in Urban areas to improve amenity and recreation areas. The launch was accompanied by a Forestry Commission Handbook (B Hibberd Ed 1989) that uses as its basis for weed control advice the very successful joint research work by the Forestry Commission and Department of the Environment (R J Davies 1987).

There are similar major schemes throughout Europe in Milan a scheme was started in 1967, "The Wood in the City". From the original small scheme 70 small woods have now been developed in Milan and surrounding villages (Luca Carra 1985).

The diversity of sites and species with the close proximity of man creates a considerable challange for the manager.

FARM FORESTRY

Woodlands

"We have received nearly 1000 applications to plant approximately 7000 ha of woodland over the first three years of the scheme and we expect 75% of this area to be broadleaved trees" (MAFF 1989).

This statement shows the farming response to a Government grant scheme to use trees to take some of the surplus land out of agricultural production. The other scheme "set aside" has not been as successful, as >1000 ha were proposed to go with woodland; 2-3% of the total set aside.

These schemes move higher quality land with easy vehicular access into forestry. Vigorous growth rates for a much wider spectrum of weeds, many of which have lain dormant in seed banks for a considerable number of years and are classed as "rare", are one of the penalties. On this high quality land very high productivity will be expected and great care will be needed to achieve good weed control in those early years. A resurgence of interest in Poplar has followed the availability of good quality land and Poplar is very sensitive to weed competition.

A wider range of tree species will be used, many for amenity or game improvement.

The European Commission published a Forestry Action Plan in the Official Journal of 15 June, seven regulations were adopted. They, amongst other things, increased grants and provided a new forestry premium for farmers in order to encourage farm land to go to forestry. It has brought no change in the UK as grants were in place, but is being considered in Ireland and a suggestion is made in the Timber Trade Journal that the annual planting rate will double to 30,000 ha by 1993. Not all European countries are interested in these schemes. Belgium, France and Germany have no such schemes to date and it will be interesting to see how the plan progresses.

Other possible farm forestry systems have not gone beyond the development stage. Short rotation coppice for energy purposes whilst achieving many headlines has never shown itself to be economical and has no grant support in the UK, but has in N Ireland. Of more interest is short rotation single stem growing of Poplar for use as industrial small roundwood as pulp or fibreboard. Demonstration areas of 250 ha are established in Belgium and a similar area is proposed in France.

Agro-Forestry

Trees can be grown in combination with either a pastoral or arable system and both are regularly used in parts of Europe. In the Po valley of Italy Poplar is grown at wide spacing with maize as an intercrop for 3-5 years of a 10 year rotation. Silvi-pastoral systems are successfully used in New Zealand with *Radiata* pine.

The arguments for agro-forestry as a method of reducing agricultural productivity were discussed and summarised S M Newman 1989. The one of interest to this Conference is that where a monoculture of a tree species that requires wide spacing is planted eg poplar, cricket bat willow and Walnut agro-forestry provide an alternative way (to use of herbicides) for managing the understorey.

Species used in the UK could well be fast growing broadleaves eg Poplar and *Nothofagus*, with the additional problem that grazing animals are expected to be present.

There is as yet no indication that these systems will be accepted for grant purposes in the UK or elsewhere in Europe.

Hazards

It is rather paradoxical that what is misfortune for some brings good fortune to others. I have mentioned the large restocking programme in East England as an aftermath to the 1987 gale damage, which also afflicted parts of Europe, particularly the Western sea board. A hazard much greater in magnitude is that of fires in the Mediterranean countries. The Daily Telegraph of Saturday 9 September 1988 gives the area damaged in France in 1988 as 170,000 ha, this is not journalistic licence as other EEC figures show a regular loss of 50,000 ha per annum. The afflicted countries may wish to use the Forestry Action Plan to replant these areas rather than plant up agricultural land.

Conclusion

The message that effective weed control is a necessity for quick establishment of trees still needs publicity. Forestry Commission Broadleaved Policy Review 1989 "The limited use of herbicides can be interpreted either as an indication of a lack of awareness, or money or long-term commitment on the part of the owner".

In France an investigation has been started into what has happened to the previously fire damaged areas. It is suspected that some is now covered by urban development and even golf courses. Whatever the land use, there appears to be a place for trees and therefore herbicides are needed for weed control.

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USE OF GENETICALLY IMPROVED FOREST TREES AND WEED CONTROL

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ABSTRACT

The tree improvement carried out by the Forestry Commission covers the wide range of coniferous and broadleaved species planted on the diverse sites available for forestry in the UK and managed under different silvicultural systems. The greatest effort is on Sitka spruce (*Picea sitchensis*), because of its commercial importance to the forest industry. A conventional tree breeding programme includes the identification of most suitable seed origins, establishment of clone banks and seed orchards, breeding new cultivars and field testing of progeny. Volume increments at harvest of >10% are confidently predicted from the use of improved stock of Sitka spruce. Increasing attention is being given to the use of vegetative propagation, including *in vitro* methods, which can offer substantial savings in making the genetically improved stock available earlier to the tree grower. The investment in genetically improved trees is likely to be wasted unless it is combined with sound silviculture including efficient weed control. The use of more sophisticated biotechnological methods can be expected in the future.

INTRODUCTION

The function of tree improvement is to provide seed and/or vegetatively propagated material of broadleaved and coniferous forest tree species of improved quality in terms of vigour, timber properties, disease and insect resistance and stability for use in commercial forestry. Commercial forests can be defined as individual scattered trees as in agroforestry, blocks of trees as in a shelter belt, or large areas of forest. In our tree improvement programme therefore we are covering a diverse group of species, forest systems and sites throughout the UK. The degree of effort varies with the species and generally reflects its economic importance or potential for forestry.

The tree improvement programme of the Forestry Commission for Sitka spruce (*Picea sitchensis*) will be briefly described as an example of a conventional tree breeding programme for forest trees. Since there is considerable and increasing interest in clonal forestry, some of the advantages and disadvantages of this will be noted. Both weed control and tree improvement have the common aims of increasing productivity, and profitability. These will be discussed in the general context of improvements in silvicultural methods and areas will be suggested where the two technologies may combine to provide further increases in profitability.

CONVENTIONAL TREE BREEDING PROGRAMME

Sitka spruce is the main forest species planted in Great Britain with current annual planting at 50 to 60% of the total forest area. The popularity of Sitka spruce is due to the tree's vigour, adaptability, form and timber quality (Holmes, 1987). It tolerates a wide variety of poor soils, a high degree of exposure and grows more rapidly than any other conifer in our oceanic climate to produce a timber very highly regarded for paper pulp and a good general purpose white sawn timber.

Sitka spruce is native to the west coast of North America and was introduced into Britain by David Douglas in 1831. Its native range is restricted to humid oceanic conditions from southern Alaska to northern California (Lines, 1987a). In a tree improvement programme the most immediate and greatest gains are obtained from identification and use of the best seed origins. Seed have been collected from throughout its range and experiments established to identify the best seed sources for Britain. The results from these trials form a solid data base allowing differences between seed origins in growth performance and habit to be quantified for our conditions. Queen Charlotte Islands origins were recognised early for the reliably, impressive growth and timber quality. More southern and northern origins are not as suitable, eg trees from California have an extended growing season and are susceptible to early frosts whereas trees from Alaska grow slowly and use only part of the growing season. The selection of provenance within the UK may also vary, ie trees of Washington origin are more suitable for south west England and parts of Wales. Generally for most economic traits, eg vigour, approximately 40% of the total variation is exhibited between origins and 60% of the variation is within an origin (Lee, 1989).

More intensive tree breeding programmes should only be initiated after the best seed origin has been identified. Tree breeding uses techniques of agricultural plant breeding but adjusted for plant size and generation time (Namkoong *et al.*, 1988). Forest crops however are more heterogeneous than agricultural ones and there is less control of the environment in forestry than in agriculture. The rate of improvement is largely controlled by the breeding cycle and by the time taken to obtain reliable data on progeny performances for the commercially important traits selected (Faulkner, 1987). Sitka spruce is selected for growth rate, stem form, branching habit and wood quality, including wood density.

The success of a tree breeding programme depends on the genetic variation in the trait to be selected for and on the effectiveness of choosing parents for breeding. Most tree breeding programmes start with the selection of superior phenotypes, ie trees appearing to have the desired attributes. These trees are chosen as the best individuals from the best stands on a variety of site types throughout the country. The phenotype of an individual is the result both of its genetical constitution or genotype and of the environment in which it was grown. By the end of 1986, 2700 superior phenotypes of Sitka spruce had been selected as potential breeding trees. The majority of these are of British Columbian origins with characteristics similar to those from Queen Charlotte Islands. Separate selections of Washington and Alaskan origins have also been made for southern sites and colder harsher sites respectively.

To determine how good these superior phenotypes really are, progenies of these trees, obtained from wind pollinations or crossing with pollen of known parentage, are grown in replicated experiments on at least three sites. If the progenies from a particular mother tree perform very well, the mother tree is used in future breeding work. Sitka spruce families are considered acceptable for inclusion in the breeding population if they exceed a Queen Charlotte Island control by 15% and the overall family mean by 7% for height at six years (Lee, 1986). Close correlations have been noted been between height at 6 years and height and diameters at 15 and 20 years (Faulkner, 1987). Of the 2700 Sitka spruce selected as superior phenotypes, approximately 2500 are currently being tested and the aim is to have a breeding population of 200 individuals. The best 40 individuals are being used to produce, in so called seed orchards, improved seed through open pollination or by controlled pollination with a mix of pollen from 20 superior parents. Progeny testing is costly to undertake as a range of distinct site types of sufficient uniformity are required to establish well replicated experiments. Preliminary assessments are available after 6 years, but some characters, eg wood density, can only be evaluated later. This requires a longer period of maintenance and also necessitates larger plot sizes with many more progeny. The true potential of a parent tree can only be judged from the results of such long-term and large scale field experimentation. With less than 10% of the original phenotypes providing superior genotypes, standards of selection are demanding.

Since the length of the breeding cycle is a major limitation to the rate of genetic improvement in forest trees, various attempts are being made to shorten it. For example, trees are being raised in large polythene houses and the plant growth regulators, gibberellins 4 and 7, are injected to enhance flowering (Philipson, 1987). Various artificial screening methods, eg frost tolerance (Rook *et al.*, 1980) are under review and efforts are continuing to improve juvenile/adult correlations.

Results from our present programme using seed from seed orchards and multiplying by vegetative propagation show that genetic gains in height growth at age 6 years of 15% have been attained; 10% increases in diameter growth at age 20 years, ie basal area increments of 21%, at age 20 have been measured and >10% increases in volume production at the end of the rotation are confidently predicted (Lee, 1989). Further significant gains from more intensive selections are anticipated, especially from tested specific crosses between known males and females.

HYBRIDS

As for some agricultural crops, the progenies of some interspecific crosses exhibit superior growth when compared to either parent. Interspecific hybrids are important in forestry. Poplar hybrids such as *Populus interamericana* are produced from seed then commercially made available to the grower as cuttings. A major programme is underway to develop improved F1 hybrids of European and Japanese larch (*Larix x eurolepis*). Research is investigating possible methods of multiplying the limited amount of hybrid larch seed by vegetative propagation.

There is also interest in hybrids between Sitka spruce and some of the other north American spruces, particularly *P. glauca*, to provide greater frost resistance and tolerance of drier sites.

IMPROVEMENT USING VEGETATIVE PROPAGATION

Clonal forestry has been practised with tsugi (*Cryptomeria japonica*) for centuries in Japan and for many decades in Europe with poplars (Toda, 1974; Libby, 1987). The gains in yield and greater uniformity of some tree crops have been most impressive, eg the volume of *Populus interamericana* "Unal", a new poplar cultivar, has been estimated as being almost three times that of *P. robusta* at age 9 years (Steenackers, 1984).

In future, vegetative propagation will be increasingly important in forestry, especially in intensively managed, short rotation plantations. The best individuals from a breeding population can be supplied to the forest industry more quickly than going through a conventional tree breeding programme employing seed orchards (Kleinschmit, 1987; Mason, 1989). This approach is also used when seed production is spasmodic and insufficient, due to poor flowering or insect and pathogen attack. Use of rooted cuttings may provide a constant source of material, although this may only be possible when cuttings are taken from physiologically young trees. Leakey and Ladipo (1987) claim for the west African hardwood, *Triplochiton scleroxylon*, that by their selection, multiplication and planting only high yielding clones, it is possible to achieve an 8 fold increase in yield. Improvements in other characters such as form and branching habit are claimed to be equally as impressive (Leakey and Ladipo, 1987). Similar approaches of selecting for branching characteristics are being used in this country for improving oak (Harmer, 1988).

Several *in vitro* propagation methods are being developed for forest tree species and they range from the relatively simple technique of micro-propagation to the more sophisticated techniques of somatic embryogenesis and production of transgenic plants (Hanover and Keathley, 1988). These methods are being developed to allow rapid multiplication of new genotypes (John and Mason, 1987) or manipulation of heritable variation to alter genetically individual trees (Hanover and Keathley, 1988). An example of particular interest is the introduction into poplar of a foreign gene, via the soil microorganism *Agrobacterium tumefaciens* as a vector, which confers tolerance to the herbicide glyphosate (Fillatti *et al.*, 1988).

Currently, the production of planting stock by *in vitro* propagation is substantially more costly than using rooted cuttings and considerably more than seedlings. In addition there are also dangers in using solely vegetative propagation as can be seen from experience with tsugi and poplars. Reduction of genetic variation needs careful consideration and there is a need for broadly based breeding populations to augment clonal forestry. Without variability there is no potential to improve or respond to changing requirements. The new biotechnologies being developed suggest immense gains but they should be seen as supplements to the improvements obtained via traditional breeding methods. Potential improvements obtained using new technologies will need to be thoroughly tested under field conditions.

TREE IMPROVEMENT AND WEED CONTROL

Any tree improvement programme costs money and improved seed can be several times the price of unimproved seed; these costs will be multiplied further if vegetative propagation methods are also employed. Justification for payment of these added costs are based on increased profitability from the gains in yield, improved quality or reduction of costs.

Economic analyses carried out on the use of improved stock emphasise that the greatest returns can be expected on the best sites. On this basis it is not possible to justify the use of improved stock for the poorer, exposed sites in this country (Mason, 1989).

Having made the decision to use improved stock it is important that the other aspects of silviculture are optimised as much as possible. The extra money paid for improved stock is wasted if proper measures are not taken to protect the trees after planting and to encourage rapid growth. McIntosh (1981) observed on experiments with Sitka spruce growing on mineral soils that weed control resulted in greater early height growth than fertilizer applications. In some experiments the trees only responded to P fertilizer applications in the absence of weeds.

It should be noted that the greater protection need not of necessity lead to greater establishment costs. Although the 15% increased height growth which has been measured for 10 year old Sitka spruce from progenies produced by our breeding programme will have tended to reduce the number of weedings required and number of years of protection from fences, the reductions in costs would have been negligible. A 20 to 30% gain in early height growth, ie 20 cm extra height at age 5, could however be important in reducing establishment costs. Positive selection for rapid early height growth on the other hand could downgrade timber quality to be saleable only at reduced prices.

The more common reforestation of forests in this country is providing problems where it might be economically justified to use the best genetical material. Many Sitka spruce stands on being felled regenerate a dense carpet of seedlings. Clearing the site is costly and improved planted stock may be difficult to distinguish from the regenerated seedlings - in addition to running the risk of being smothered by vigorous regeneration growth. In this example the availability of genetically improved Sitka spruce with tolerance to glyphosate or other appropriate herbicide would be a considerable advantage.

Looking further into the future, I presume we can expect the development of other generations of more efficient and selective herbicides or herbicide modes of action. Early screening for tolerance to herbicides of progenies from our breeding programmes could be relatively easily included.

Many trees exhibit allelopathy, ie suppression of germination or growth of neighbouring plants by chemicals which are leached, exuded or volatalised from the plant. Introduction of gene(s) to provide allelopathic control of competing neighbours is an obvious goal for those of us working on tree improvement and weed control. Regrettably it is probably a distant goal as, is the case in most of the new innovative biotechnology, advances are being hampered by the lack of knowledge of the basic physiology and biology of species important in forestry.

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WEED COMPETITION AND CONTROL IN NEW TREE PRODUCTION SYSTEMS

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ABSTRACT

The weed problems encountered in new tree plantings for timber, energy, conservation and amenity uses are reviewed with emphasis on perennial weeds. Weed competition is one of the most important factors leading to failure in establishment. Opportunities for using pre- and post-planting herbicide treatments, and non-chemical control methods, are discussed. There is a need to avoid over-dependence on one herbicide, glyphosate. Greater awareness of the potential benefits and difficulties of herbicide use is required, along with 'user friendly' systems of herbicide selection.

INTRODUCTION

Recent years have seen an upsurge in commercial and public interest in tree crops in the UK. This stems from a number of factors. There is increased public concern for the countryside and the health of the nation's woodlands. Food production is currently in surplus so alternative uses for agricultural land are needed. There is a demand for wood; the UK spends £4-5 billion annually on imported timber and timber products much of which could be supplied by home-grown timber. Wood from fast growing species such as poplar and willow may also be an alternative energy source. Tree planting for amenity and recreational purposes is also increasing, giving greater diversity in associated plant and animal species. These changes broadly determine the locations and characteristics of current tree plantings; surplus agricultural land is available both in upland and lowland areas. A greater variety of species is being planted, with emphasis on broad-leaved trees. Farm forestry normally involves planting in distinct blocks or strips and timber production may be less important than provision of conservation areas or game cover. Agroforestry systems, with either grass or arable intercropping are also being examined. The production of trees for uses other than timber - notably for energy or pulp - is also being tested; short rotation coppice of willow or poplar or single stem poplars are the most promising systems. Finally, there is the recently announced national commitment to urban forestry - development of woodlands on the fringes of major conurbations primarily for aesthetic and recreational reasons. With all these systems there is an overriding need for successful and rapid tree establishment - either to permit harvesting and, therefore, return on investment as early as possible, or to create the desired visual impact or game cover in minimum time. Weeds present one of the main obstacles to achieving these objectives - they threaten the survival or growth of newly planted trees in all systems and situations. The nature of this threat, the opportunities for overcoming it and the problems still awaiting resolution are reviewed in this paper.

THE WEED PROBLEMS OF NEW PRODUCTION SYSTEMS

The weed species causing problems are initially more likely to arise from characteristics of the sites than of the growing system. An example of this is the use of natural regeneration of trees to form new forests where the first and most difficult requirement is control of unwanted trees of the same species or habit. The main areas for new plantings are in low-grade agricultural land and perennial weeds will usually be the dominant problem both in upland and lowland areas. The extent and frequency of these weeds is often not apparent while land remains in pasture or arable crops, but removal of competition from a ground cover crop enables a rapid build-up of perennial weeds. In upland areas, perennial grasses, Pteridium aquilinum (bracken) and Cirsium arvense (creeping thistle) will dominate, while in lowland areas Convolvulus arvensis (field bindweed) and Equisetum arvense (field horsetail) present severe problems. The weed flora resulting from arable land will differ from that in pasture. Cirsium arvense, Convolvulus arvensis and Elymus repens (common couch) are frequent in the former but certain annuals, notably Polygonum species also cause particular difficulties because of their resistance to many residual herbicides. Where land has been under pasture, Cirsium arvense is the most common problem but Trifolium repens (clover) and Ranunculus species (buttercups) occur frequently. Maintenance of bare soil under trees with herbicides is the commonest weed control system practiced and in this situation, perennial weeds such as Cirsium arvense, Convolvulus arvensis and Elymus repens spread rapidly, patches can extend by several metres a year even when cut or sprayed with herbicides.

While the basic problems result from past history of the land planted, their severity depends greatly on the type of crop grown. The biomass crops poplar and willow are particularly vulnerable if grown from cuttings because they are rapidly smothered by uncontrolled weeds. The vegetation management system appropriate to urban fringe plantings may also be influenced by the problem of tree death, from vandalism and fire (Boylan, 1988); these problems can be mitigated by rapid establishment and canopy closure of high density plantings maintained with bare soil.

Agroforestry crops, particularly those grazed by stock, present problems of re-invasion of tree base areas from the reservoir of perennial weeds often present in the adjacent pasture. This will necessitate repeated treatment with herbicides during establishment. A particular problem of silvo-arable systems is tree damage from the herbicides applied to arable crops e.g. glyphosate applied to desiccate arable crops may drift onto trees which are particularly susceptible in late summer. With sylvo-pastoral systems an additional difficulty is restriction of stock access following application of certain herbicides.

In farm and urban fringe forestry, certain climbing weeds can quickly smother young trees (Hibberd, 1989). Species occurrence depends on soil type and condition but Tamus communis (black bryony), Calystegia sepium (hedge bindweed), Lonicera periclymenum (honeysuckle), Clematis vitalba (old man's beard) and Humulus lupulus (wild hop) occur commonly. However, in urban situations some of these species may be regarded as desirable.

WEED COMPETITION

The competitive effects of weeds and the need to weed have no doubt been recognised by careful growers since tree culture began, but documented evidence is comparatively recent and sparse. Davies (1985) reported results of Forestry Commission experiments carried out 60 years ago in which hoeing around young broadleaf trees improved growth considerably compared with repeated cutting of vegetation. The introduction of herbicides has allowed the effects of weed growth to be assessed in the absence of the soil disturbance and root damage inevitable with cultivations. White and Holloway (1967) demonstrated the competitiveness of annual weeds in tree fruit establishment while Atkinson and White (1976) showed the competitive effects of grassed alleys on growth of young fruit trees and that water was the main limiting factor. Davison and Bailey (1980) showed that growth of newly-planted _Acer platanoides_ was severely restricted by uncontrolled annual weeds, the main competitive period being May and June.

In forestry results of weed competition experiments have differed according to geographical area. Newly-planted conifers in upland areas of the UK have not generally shown major growth increases from complete weed removal particularly on deep or peaty soils (McIntosh, 1980; Tabbush, 1984) so cutting weeds that compete for light is often the only control measure. In some experiments growth increases were recorded only where fertilizer addition accompanied weed control, suggesting that, on infertile soils weeds will prevent trees benefitting from additional nutrients. Although experimental evidence of significant weed competition for water is lacking it is accepted that it can restrict growth in well drained soils in dry seasons.

In a range of sites in the English lowlands Davies (1985) clearly demonstrated the competitive effect of uncontrolled weed growth on newly planted broad-leaved trees. The work showed the greater inhibitory effect on tree growth of a mown grass sward compared with uncut grass due to greater water use by the mown grass. This has obvious implications for sylvo-pastoral agroforestry systems where a grazed sward will compete for moisture with the young trees. The size of the weed free area below young trees is also important for survival and growth. Forestry Commission experiments indicate that at least 1 m diameter is needed below transplants and 1.5 m diameter below standard trees (Davies, 1987).

How long is weed control needed after planting? Davison & Bailey (1980) found no growth reduction of _A. platanoides_ from annual weed growth in the second growing season, trees having been kept weed free in the planting year. However, Davies (1987) reported large increases in growth of 10 year old Ash trees once weed competition was removed. It is likely that tree species will differ in their ability to withstand weed competition but there is little published information on this aspect. The inhibitory effect of _Calluna vulgaris_ (Heather) on Sitka spruce root mycorhizae and consequent inhibition of nitrogen uptake is an extreme example of competition (Hendley, 1963) and also indicates the possibility of allelopathic effects of weeds on tree growth.

Weed competition also has severe effects in short rotation coppice where rapid even establishment is essential for productivity. Stott (1980) found that in willow uncontrolled weeds reduced willow stool survival by 50% in season after planting and shoot weight was reduced by 88%. Weed competition is unlikely to be severe after canopy closure but development of woody weeds, particularly _Rubus fruticosus_ (bramble) and _Rosa canina_ (dog-rose) can seriously interfere with harvesting.

The effects of uncontrolled weeds are most obvious in amenity plantings such as roadsides where it is accepted that up to 50% of trees planted will fail to establish (Patch, personal communication). The advantages of an effective weed control policy in urban planting have been demonstrated in Milton Keynes, where use of contact and residual herbicides and bark mulches has reduced the time for canopy closure from 10 years to 3-5 years (Salter & Darke, 1988).

WEED CONTROL OPPORTUNITIES

Pre-planting treatments

These are most useful where the perennial weeds present a good target for spraying. This, often, is prior to harvesting the previous crop e.g. where glyphosate is sprayed pre-harvest in cereals for control of E. repens, Cirsium arvense and Convolvulus arvensis (O'Keefe, 1980), spraying vigorous Cirsium arvense in pasture, and control of Rhododendron ponticum prior to felling trees, (Williamson & Mason, 1989). Where land is not ploughed, immediate pre-planting treatments are essential to aid rapid establishment. There is some evidence from sylvo-pastoral experiments that autumn spraying of glyphosate on swards is less satisfactory than spring spraying in that it allows more weed to develop during the growing season and leads to reduced tree growth (Sibbald, personal communication). Where perennial weeds are growing poorly in a preceding crop due to senescence, grazing or shielding by other weed growth, pre-planting use of glyphosate has given poor control. Thus the need to get perennial weeds into the right condition for spraying is paramount when their control in the subsequent crop is risky. Crops which may be at particular risk from herbicide damage include nursery transplant lines and cuttings. In these cases, a fallow may be justified in which annual weeds are controlled by a short-lived residual, herbicide and the perennial weeds sprayed during the growing season with the most effective translocated herbicide. Cultivated fallows are most successful for the control of E. repens and some perennial broad-leaved weeds if the growing season is dry, permitting the desiccation of rhizome fragments. Where the tree growing system permits use of translocated herbicides on perennial weeds after planting, e.g. trees in shelters, there may be no advantage in using a pre-planting herbicide treatment.

Post-planting herbicides

The use of soil-acting herbicides post-planting can provide effective season-long weed control, given the absence of perennial weeds. Traditionally, simazine or atrazine mixtures have been used on conifer crops, but there is a whole range of possible alternatives (Lawrie & Clay, 1989) which may be safer to broad-leaved crops and, in mixtures, effective on a wider range of weed species. Effective use of these herbicides is particularly important in poplar and willow cuttings and in small trees transplanted without tree shelters. These plantings are particularly vulnerable to spray damage if contact herbicides have to be used after planting. The use of soil-acting herbicides may have disadvantages. The unprotected soil surface is more vulnerable to erosion on sloping sites or poaching by stock in sylvo-pastoral situations. The herbicide itself may be leached laterally on sloping sites in heavy rain. Burrowing by vermin may also be a problem. As was found early on in fruit crops, using residual herbicides on such bare soil systems inevitably leads to a build-up of perennial weeds (Robinson, 1964) which, themselves, require treatment.

Foliar-acting herbicides become essential where annual weeds have not been controlled or where perennial weeds develop. Where tree shelters or unfeathered tree stems are present, herbicides such as glyphosate can be used successfully. There are certain weeds more susceptible to other herbicides, e.g. Equisetum arvense to amitrole (Davison and Bailey, 1982) and Trifolium species to triclopyr. Problems arise where foliar-acting herbicides have to be used near vulnerable trees, e.g. young poplar and willow plantings, where overspraying with glyphosate or paraquat can do severe damage, perhaps greater than that caused by the weed infestation itself. In such situations, careful choice of herbicides, spray timing and application methods is essential. With poplar and willow, clopyralid (effective on Cirsium arvense) appears appreciably safer than glyphosate (Clay et al., 1989); amitrole may also be relatively safe as a directed spray in willows early in the season. Dormant, cut down, stools of poplar and willow may also show sufficient tolerance to amitrole to permit overall spraying where weed growth would, otherwise, get out of control (Parfitt, 1989). Fluazifop-p-butyl is selective on broad-leaved crops and effective in suppressing E. repens (Ivens, 1989). Spot spraying, using tree guards, can also be effective for tree-base treatments.

For many situations, therefore, the annual use of a broad spectrum translocated herbicide, such as glyphosate, in early summer may be a preferable alternative to repeated use of soil-acting herbicides. The presence of dead vegetation can maintain good soil surface conditions and temporarily restrict weed growth as well as permitting vigorous tree growth. In some experiments using tree shelters there has been vigourous weed growth inside the tube but this has not appeared to inhibit tree growth (Sibbald, personal communication). A decision on the right herbicide programme will depend on all factors involved including economics - how quickly is a return on investment on trees required, and is optimising tree growth paramount?

Farm woodlands grown primarily for conservation purposes present special problems, and perhaps opportunities. While some tree-base weed control is essential for establishment, large scale use of broad-spectrum herbicides such as glyphosate is undesirable. With the knowledge now available on the selectivity of residual and foliar-acting herbicides, it should be possible to select those which suppress the most competitive, leaving a variety of 'desirable' species according to the properties of the herbicide used (Watt et al., 1988).

Non-chemical methods

Mulches have been used successfully for tree establishment. Since the value of black polythene mulch was demonstrated in fruit trees and bushes (Davison & Bailey, 1979), where it increased growth above that on weed-free soil plots, effective use has also been shown in trees (Davies, 1985; Potter, 1988), poplar and willow cuttings (Parfitt & Stott, 1984) and in silvo-arable systems (Wainright et al.,1989). In some circumstances, such mulches have disadvantages. Anaerobic conditions can develop on poorly drained sites and reduce growth (Davies, 1985) and they should not be used where perennial weeds occur as these may build up rapidly under mulch. Damage to plastic film also occurs from vermin, including voles and their predators. There have also been reports of damage to young trees after mulch removal, where an application of glyphosate has been taken up by the mass of roots near the soil surface (Pudwell, personal communication). A further drawback is the cost of polythene mulch; the material and laying can cost around £1.00 per tree which is, unacceptable for many types of planting. However it can give valuable long-term weed control in situations where regular herbicide use is not feasible or desirable.

Organic mulches such as straw, wood chip or bark have been used. Where straw was used to mulch willow and poplar cuttings, weed control and crop growth were as good as herbicide-treated bare soil, but growth was less than under polythene mulch (Parfitt & Stott, 1984). Soil temperatures in the growing season were lower under straw than bare soil but soil moisture levels were higher. Wood chip or bark mulches need to be thick to suppress annual weeds effectively, and perennial weeds are not controlled (Stimson, 1989). Both wood chip mulch and straw topped by farmyard manure effectively controlled all weeds in the year of planting in a recent sylvo-pastoral experiment at Long Ashton which was stocked with cattle. However, both these mulches were invaded by vigorous growth of perennial weeds (Cirsium arvense and P. aquilinum) in the second growing season. The possibility of tree growth inhibition due to toxins from fresh bark or nutrient deficiencies from use of organic mulches must also be considered (Davies, 1987).

UNRESOLVED PROBLEMS

The requirement for effective tree base weed control in most of the new production systems is clear, but certain problems likely to restrict progress require action from researchers, advisors, users and 'politicians'. The first is a research/advisory problem. The continuous and exclusive use of glyphosate in many growing systems is a recipe for the development of resistant weeds - either from build-up and spread of poorly controlled perennial weeds, such as Convolvulus arvensis or Trifolium repens, or the selection of resistant biotypes as has happened with the continuous use of triazine and paraquat herbicides in fruit and ornamental crops (Clay, 1989). Even if use lasts for only a few years, resistant types of weed species with wind-borne seed can be transferred to newly-treated areas and selection pressure for resistance is, thus, continued. Wherever possible, alternative treatments should be used in rotation. This underlines the need for new herbicides to be available as alternatives. When glyphosate is applied to weeds at the base of young trees, there is also a need to confirm that transfer of root-secreted herbicide from treated weeds to the trees, with consequent damage, is not a problem. Such damaging secretions have been demonstrated with high doses of glyphosate on herbaceous plants (Coupland & Lutman, 1982).

Secondly, there is a need for 'planners' and growers to be aware of the importance of weed control and its three vital elements: the choice of herbicide, the timing of treatment and careful, drift-free, application. Without these three components any system of tree establishment will fail. With some crops, such as poplar and willow grown from cuttings where infestation with perennial weeds is almost inevitable, there is a need for information on the capacity of the crops to recover from different degrees of overspraying with contact herbicides.

More detailed and easily accessible information is also needed on herbicide suitability in terms of crop tolerance, weed control spectrum, cost etc., than is currently available even from otherwise excellent publications such as 'The Use of Herbicides in the Forest' (Williamson & Lane, 1989.) Collated information from product leaflets such as is available on the 'Herbrex' computer database may be one answer (Lawson, 1989); this currently covers amenity plantings but not forestry.

Finally, anomalies in the implementation of the Control of Pesticides Regulations 1986 need to be resolved so that introduction of effective herbicide treatments in these forestry systems is not curtailed. Under the interim arrangements for minor crops, any Approved herbicide can be used on any non-edible crop coming within the "agriculture and horticulture" field of use but not in "forestry". This, therefore, permits use under trees in amenity areas, on roadsides and parks, but not in commercial forestry, farm woodlands or biomass plantings. For applications in such areas, "Off-label" approval is the only route to legalising use and it is not clear whose responsibility it is to obtain this. Manufacturers are, understandably, not often interested in obtaining label clearance for herbicide use in small market, high value crops, particularly where they may be used in areas accessible to the public with the risk of adverse reactions. This issue needs to be resolved to provide the range of treatments required for successful tree establishment. Without such treatments and their timely use, planting schemes will continue to fail as they have in the past, with detriment to the grower, the environment and waste of public money.

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TOLERANCE OF FORESTRY AND BIOMASS BROAD-LEAVED TREE SPECIES TO SOIL-ACTING HERBICIDES

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ABSTRACT

The tolerance of six broad-leaved forest tree species and five biomass species to eighteen herbicides was tested in pot experiments. Diphenamid, metamitron, napropamide, oxadiazon and pendimethalin were not phytotoxic to most species. Most other herbicides were not damaging at recommended doses but caused either initial damage or long-term growth reductions at higher doses. Imazapyr was very damaging to most species and diuron was damaging to all species except ash, oak and sycamore. Terbuthylazine was more damaging than simazine on many species. The results showed that there were a number of residual herbicides tolerated by the eleven species at relatively high doses and which could be effective components of herbicide programmes.

INTRODUCTION

With increasing interest in the UK in broad-leaved tree planting for timber, energy forestry (biomass) and agroforestry there is a need to find effective residual herbicides to prevent weed competition (Clay, 1989). Four pot experiments were carried out at Long Ashton Research Station (LARS) in 1987 and 1988 to evaluate the potential safety of soil-acting herbicides and mixtures on six broad-leaved forest tree species and five biomass species. The herbicides selected for trial were from those approved by MAFF in the UK for use in other crops and their weed control performance was well known.

MATERIALS AND METHODS

In experiments 1 (1987) and 3 (1988) the six broad-leaved tree species tested were, ash (*Fraxinus excelsior*), beech (*Fagus sylvatica*), birch (*Betula pendula*), cherry (*Prunus avium*), oak (*Quercus robur*), all planted as 2-year-old trees and sycamore (*Acer pseudoplatanus*), as 1-year-old trees. In experiments 2 (1987) and 4 (1988) the biomass species used were red alder (*Alnus rubra*), as 1-year-old trees, two poplars (*Populus trichocarpa*), Fritzi pauley and (*P. trichocarpa*) Rap and two willows (*Salix burjatica*) Korso and (*S. viminalis*) Bowles Hybrid planted as 14 to 17 cm long cuttings in 1987 and 12 cm long in 1988.

Trees were potted up in March each year in 20 cm diameter pots in sandy clay loam + 15% V/V sand + 1.7 g l^{-1} Osmocote (1987) and sandy loam soil + 2 g l^{-1} Osmocote (1988). The biomass species were grown in the same soils but in 15 cm diameter pots. Cherries were cut back to 30 cm from the soil surface in 1988. The plants were put outside after potting and watered overhead and herbicides applied to moist soil 1 or 2 days later for forestry trees and one week for biomass species. Herbicide formulation and active ingredient content used were:- atrazine, 50% S.C.; cyanazine + atrazine, 50% S.C.; diphenamid, 50% WP; diuron, 80% WP; imazapyr, 25% a.c.; isoxaben, 50% S.C.; lenacil 80% WP; metamitron, 70% WP; metazachlor, 50% S.C.; metsulfuron-methyl, 20% WG; napropamide, 45% S.C.; oryzalin, 48% S.C.; oxadiazon, 25% EC; pendimethalin, 33% EC; propyzamide, 50% WP; simazine, 50% S.C.; terbuthylazine, 50% S.C.; terbuthylazine + atrazine, 40% + 10% S.C.

Herbicides were applied over three replicate pots of each species at the doses and on the dates shown in Tables 1-4, using a laboratory track sprayer fitted with an 8002E Teejet giving 425 l ha^{-1} at 175 kPa. Imazapyr was applied as a soil drench using 50 ml of solution per pot at the required concentration. After treatment, plants were placed outside in randomized blocks and watered by rain or trickle irrigation as required.

Plant condition was scored at intervals on a 0-7 scale, 0 = plants dead and 7 = healthiest untreated. At the end of the experiments shoot height and fresh weight were recorded.

RESULTS

Experiment 1

Diphenamid, lenacil, metamitron, napropamide and oxadiazon had little or no adverse effect at the recommended dose or at three times recommended dose on most of the six species (Table 1) and the diphenamid + lenacil mixture was not more phytotoxic than the individual components. Propyzamide damaged both cherry and sycamore but was only slightly phytotoxic to other species.

Oak, beech and birch were tolerant to most of the herbicides at nine times the recommended dose; these species were damaged by imazapyr but not as severely as other species. Isoxaben, oryzalin + diphenamid, terbuthylazine and terbuthylazine + atrazine caused growth reduction in most species mainly at the higher application rates. Atrazine and simazine caused growth reductions in ash, birch, cherry and sycamore; beech and oak were little affected. Atrazine was more phytotoxic than simazine.

Experiment 2

Diphenamid, metamitron, napropamide and oxadiazon were not damaging, or caused only a slight reduction in growth, on the five species at three times the recommended dose (Table 2) but there was greater reduction in growth when applied at the highest doses, particularly metamitron on alder. Oxadiazon at 18 kg ha^{-1} caused considerable leaf necrosis on shoots emerging after treatment but this was outgrown. The highest dose of isoxaben and lenacil reduced growth of most species and 9.0 kg ha^{-1} dose of propyzamide reduced growth of alder and willow (Korso). Simazine caused severe damage to all species at 3 kg ha^{-1} or more. Damage from atrazine and terbuthylazine was more severe than simazine particularly on poplars. All doses of imazapyr were very damaging to all species.

TABLE 1. Effects of residual herbicides on forestry species applied on 11 March 87 to ash, beech (Be), birch (Br), cherry (Ch), oak & sycamore (Sc) (Experiment 1)

Herbicide Doses (kg a.i. ha^{-1})	Total shoot fresh wt [a] (% of untreated), 13-14 January 88 Ash	Be	Br	Ch	Oak	Sc
Atrazine (1, 3, 9)[b]	59*	93	59*	98	126	59*
Diphenamid (4, 12, 36)	81	83	87	87	122	75
Imazapyr (0.2, 0.8, 3.2)	46*	116	94	23*	81	29*
Isoxaben (0.15, 0.45, 1.35)	44*	89	70	53*	97	76
Lenacil (1, 3, 9)	112	106	107	81	84	61*
Lenacil + Diph. (1+4, 3+12, 9+36)	107	124	104	67	94	83
Metamitron (3, 9, 27)	105	115	98	68	100	91
Napropamide (3, 9, 27)	110	108	95	108	71	73
Oryzalin (3, 9, 27)	80	96	92	77	107	59*
Oryzalin + Diph. (3+4, 9+12, 27+36)	99	122	76	60*	67	67
Oxadiazon (2, 6, 18)	101	107	96	91	98	74
Propyzamide (1, 3, 9)	94	121	106	65	102	68
Simazine (1, 3, 9)	80	89	79	87	143	71
Terbuthylazine (2, 6, 18)	58*	96	35*	26*	111	54*
Terbuth. + atra. (2, 6, 18)	78	96	60*	34*	94	39*
Untreated (fresh wt, g)	(43.9)	(23.9)	(56.2)	(35.8)	(30.4)	(7.42)
SED trt v untrt (df 98)	±18.0	19.7	17.2	17.9	19.8	19.2

* indicates values significantly lower than untreated at P = 0.05
[a] values represent means of the three doses
[b] generally lowest dose corresponds to recommended dose

TABLE 2. Effects of residual herbicides on biomass species applied on 16 March 87 to alder, poplar, Fritzi pauley (PF) Rap (PR) and willow, Korso (WA) and Bowles Hybrid (WB) (Experiment 2)

Herbicide Doses (kg a.i. ha^{-1})	Total shoot fresh wt [a] (% of untreated), harvested 22-30 September 1987 Alder	PF	PR	WA	WB
Atrazine (1, 3, 9)[b]	51*	15*	26*	49*	47*
Diphenamid (4, 12, 36)	74	108	103	82	100
Imazapyr (0.2, 0.8, 3.2)	25*	6*	0*	0*	20*
Isoxaben (0.15, 0.45, 1.35)	74	92	83	70*	90
Lenacil (1, 3, 9)	63*	102	73	40*	67*
Metamitron (3, 9, 27)	70*	94	94	78	96
Napropamide (2, 6, 18)	76	103	83	113	92
Oryzalin (3, 9, 27)	66*	73*	76	61*	74*
Oxadiazon (2, 6, 18)	88	115	88	106	103
Propyzamide (1, 3, 9)	56*	116	99	86	112
Simazine (1, 3, 9)	75	60*	66*	53*	54*
Terbuthylazine (2, 6, 18)	43*	17*	15*	23*	20*
Untreated (fresh wt, g)	(151)	(28)	(30)	(22)	(48)
SED trt v untrt (df 81)	±14.2	12.9	14.2	14.3	12.8

* indicates values significantly lower than untreated at P = 0.05
[a] values represent means of the three doses
[b] generally lowest dose corresponds to recommended dose

Experiment 3

Pendimethalin and simazine + propyzamide were not damaging in this experiment (Table 3). Cyanazine + atrazine also were relatively safe although some chlorosis occurred on birch three months after treatment with 6.0 kg ha^{-1}. Necrotic symptoms occurred with metazachlor on both beech and oak in the two months after treatment but this was outgrown. Metsulfuron-methyl initially appeared to be non-phytotoxic on all species but later scores and shoot weights indicated that some damage and reduction in growth occurred to both cherry and sycamore. Diuron was the most damaging herbicide in this experiment, the 3 kg ha^{-1} dose reduced growth of beech, birch and cherry. However, ash, oak and sycamore were unaffected.

TABLE 3 Effects of residual herbicides on forest species applied on 10 March 88 to ash, beech (Be), birch (Br), cherry (Ch), oak and sycamore (Sc) (Experiment 3)

Score of condition and total shoot fresh wt (% of untreated)

Herbicide	Dose ($kg\ a.i.\ ha^{-1}$)	Ash S	Ash W	Be S	Be W	Br S	Br W	Ch S	Ch W	Oak S	Oak W	Sc S	Sc W
Cyanazine +	2.0[a]	5.7	122	6.0	93	6.7	108	6.3	102	6.3	96	6.7	99
atrazine	6.0	5.3	81	7.0	162	7.0	130	6.3	104	7.0	121	5.7	154
Diuron	1.0	5.7	97	7.0	106	6.3	117	6.7	103	7.0	152	6.7	101
	3.0	5.7	112	2.7*	51	1.3*	13*	4.0*	57	7.0	139	6.3	144
Metazachlor	1.0	6.0	113	6.3	139	7.0	86	7.0	92	7.0	143	5.7	126
	3.0	6.7	113	5.3*	80	6.7	82	6.3	92	7.0	101	7.0	107
Metsulfuron	0.01	6.0	105	6.7	118	7.0	102	6.0	106	6.0	142	5.7	78
-methyl	0.03	6.7	127	6.7	118	7.0	93	5.3	73	7.0	136	6.0	80
Pendimethalin	2.0	5.7	101	6.7	152	6.7	109	6.7	109	7.0	150	6.0	132
	6.0	6.0	174	7.0	106	7.0	109	7.0	114	6.3	142	5.7	84
Simazine +	0.5+0.5	6.0	85	6.7	120	7.0	102	6.7	140	7.0	126	6.0	120
propyzamide	1.5+1.5	5.7	108	6.3	142	7.0	91	6.3	111	6.3	98	5.3	101
Untreated		6.2		6.6		7.0		6.4		6.3		6.2	
(actual value, g)			(15.4)		(8.4)		(32.4)		(40.5)		(7.1)		(16.6)
SED trt v trt	(df 30)	± 0.79		0.62		0.52		0.69		0.67		0.83	
trt v untrt		± 0.64	39.1	0.50	30.7	0.42	16.0	0.56	24.3	0.55	30.2	0.68	48.9

S = 0-7 score of condition 23 Sept 88; 0 = dead, 7 = healthy
W = total shoot fresh wt 8 Feb 89
* = indicates values significantly lower than untreated at P = 0.05
a = generally lower dose indicates recommended dose

TABLE 4 Effect of residual herbicides on biomass applied on 22 March 88 to alder, poplar Fritzi pauley (PF), Rap (PR) and willow Korso (WA) and Bowles Hybrid (WB) (Experiment 4)

Herbicide	Dose (kg a.i. ha^{-1})	Alder S	Alder W	PF S	PF W	PR S	PR W	WA S	WA W	WB S	WB W
		Score of condition and total shoot fresh wt (% of untreated)									
Atrazine	1[a]	5.0	111	2.3*	58	3.3*	62	4.0*	79	4.3*	94
	2	3.3*	41	1.3*	34	3.0*	60	1.3*	9*	2.7*	84
	4	0.3*	0	0*	0*	0.7*	0*	0.7*	0*	0.7*	14
Cyanazine + atrazine	1	5.7	115	4.3*	58	6.3	105	7.0	133	6.3	102
	2	6.3	167	1.7*	35	3.0*	71	3.7*	79	5.0*	119
	4	3.7*	70	0.7*	0	2.0*	49	1.7*	46	4.0*	113
Diuron	1	6.0	146	6.3	163	6.7	112	6.7	130	7.0	112
	2	5.0	32	2.7*	61	5.0	110	4.7	92	4.7*	109
	4	0.7*	16	1.0*	25	0.7*	3*	0.3*	0*	1.3*	17*
Metazachlor	2	4.7	102	4.3*	68	4.0*	102	5.0	118	4.3*	90
	4	4.3*	32	3.7*	67	4.3	140	4.3	97	4.3*	100
	8	3.7*	16	3.7*	84	3.3*	115	3.0*	61	3.3*	62*
Pendimethalin	1	6.0	114	7.0	135	7.5	189	6.7	120	7.0	112
	2	6.3	143	7.0	116	7.0	155	6.7	111	7.0	113
	4	5.7	95	7.0	142	5.7	149	6.3	120	7.0	111
Untreated (actual value, g)		5.8	(62)	6.9	(54)	6.3	(40)	6.3	(31)	6.6	(68)
SED trt v untrt (df 39)		± 0.65	49.0	0.71	35.3	1.13	44.8	1.02	34.6	0.41	16.0

S = 0-7 score of condition 3 June 88; 0 = dead, 7 = healthy
W = total shoot fresh wt 22-23 Aug 88
* = indicates values significantly lower than untreated at P = 0.05
[a] = generally lower dose indicates recommended dose

Experiment 4

Pendimethalin did not damage any of the five biomass species when applied at 2.0 or 4.0 kg ha^{-1} (Table 4). Metazachlor caused leaf necrosis and stunted shoots in spring but the plants recovered later in the season. The only appreciable growth reductions were at 8.0 kg ha^{-1} on willows and 4.0 and 8.0 kg ha^{-1} on alder.

All species except Fritzi pauley (PF) were unaffected by cyanazine + atrazine at 1 kg ha^{-1}, but higher doses caused damage, particularly to poplars and Korso (WA). Diuron applied at 4 kg ha^{-1} damaged all species, though on Rap (PR) and the willows the damage was short-term; no damage resulted from the 1 kg ha^{-1} dose. All doses of atrazine were damaging to all species except the lowest dose on alder.

DISCUSSION

The type of evaluation used in these experiments enables us to rank herbicides in order of tolerance, and this information can be used in planning subsequent field trials with mixtures. Currently, the only recommended herbicide for use in transplant lines in forestry is simazine, but for ornamental trees and shrubs other herbicides such as cyanazine + atrazine, diphenamid, diuron, napropamide, propyzamide and simazine have recommendations (Ivens, 1989), and their safety on many species has been confirmed in these experiments.

In the four experiments on the eleven species the results indicated that diphenamid, metamitron, napropamide, oxadiazon and pendimethalin are worth testing in field trials. These herbicides appear the safest of those tested, when applied to 'dormant' newly-planted trees and cuttings. However, there could be a risk of soil splash damage from oxadiazon as observed in the biomass experiment at early growth stages, although this was outgrown. Damage by oxadiazon on cherry and ash was also reported by Bentley and Greenfield (1987) but was attributed to spray contacting emerging foliage. Soil splash damage from oxadiazon has been observed on blackcurrants (Clay & Lawrie, 1987).

Cyanazine + atrazine, lenacil, lenacil + diphenamid and simazine + propyzamide were shown to be relatively safe on the forestry species. Earlier work on oak (Turner & Clipsham, 1984) and other species (Bentley & Greenfield, 1987) also showed that simazine + propyzamide mixture was safe. Propyzamide appeared relatively safe at the lower rates on most species.

Isoxaben, oryzalin, metazachlor and metsulfuron-methyl were generally well tolerated at lower doses by forest and biomass species; beech and oak were least damaged by these herbicides. The significance of short-term damage caused by metazachlor on several species requires further investigation. Metsulfuron-methyl caused growth reduction on cherry and sycamore, which could have been through foliar uptake since these species had started growth when sprayed. In conifers, at least, there is no evidence of damage from metsulfuron-methyl uptake by roots (Clay & Lawrie, unpublished data).

In general terbuthylazine, terbuthylazine + atrazine and atrazine were more damaging than simazine. This is unlikely to be due to contact with foliage except possibly cherry and sycamore. Williamson and Tabbush (1988) found that the mixture was particularly damaging to birch and cherry when applied pre-flush. Imazapyr may be useful as a pre-planting treatment, but there is a need to establish safe time intervals between spraying and planting because of possible root uptake.

These results confirm that some residual herbicides are potentially safe for use on newly-planted broad-leaved trees; mixtures of some of these herbicides could widen the spectrum of weed species controlled. This may also permit reduction of doses of individual components to reduce cost and possible phytotoxicity to the crop e.g. simazine + propyzamide. Further field work is needed to establish safe and effective programmes for the control of weeds amongst the different tree and biomass species.

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RESPONSE OF ESTABLISHED WILLOW STOOLS AT DIFFERENT GROWTH STAGES TO FOLIAR HERBICIDE APPLICATIONS

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ABSTRACT

To investigate the crop tolerance of established willow biomass stools to herbicides with potential for use against weeds of willow beds, six year-old stools were oversprayed with a range of herbicides at up to seven growth stages. Dormant stools were unaffected by paraquat, clopyralid, amitrole or glyphosate at recommended, or amitrole or glyphosate at double, dose rates. Stools with shoots up to 12 cm long were largely unaffected by paraquat or clopyralid: glyphosate was damaging. Amitrole, at recommended rates, damaged both 12 cm and 20 cm shoots. Use of double rate amitrole may be possible at early growth stages for very intractable weed problems.

INTRODUCTION

Short rotation coppice biomass (SRCB) is attracting more interest now as an alternative crop for the production of energy, pulp, or fibre-board. Work at Long Ashton has demonstrated both the value of effective weed control for this crop and the difficulty of achieving it (Stott *et al.*, 1989).

Weed control in established SRCB plantations requires herbicides, applied between the coppicing cycles, ideally when weeds are susceptible and stools are resistant. Past experience indicates that foliar-acting herbicides are required, but none of the candidate herbicides is completely selective. There is a need, therefore, to investigate the crop tolerance to foliar-acting herbicides known to be effective on the commonest weeds of SRCB (Clay *et al.*, 1989).

MATERIALS AND METHODS

The experiment was done on six year-old stools of *Salix burjatica* (syn. Aquatica Gigantea) Korso planted at 0.7 m between and 0.35 m within the rows, with a previous history of two annual cuts followed by one triennial cut and one annual cut. Plots consisted of two rows of five stools each (0.7 m x 3.5 m) in four completely randomised blocks.

Single applications of each herbicide treatment were applied by an Oxford Precision Sprayer using a single deflector nozzle at 1 bar pressure and a rate of 500 l ha^{-1}, to a 0.7 m swathe. Dose rates, dates and growth stages (mean length of the three longest shoots) at application are shown in Table 1. All treatments were oversprayed except the final amitrole (see Discussion).

At the end of the growing season, shoot fresh weights and numbers per stool were recorded. An additional count of the number of shoots per stool that exceeded the mean length in a block for unsprayed control plots was included as an indication of quality. No attempt was made to assess the effects of herbicides on weeds; few developed on any treated plots.

Because of the large range of treatment means for all analyses, data were transformed to give sufficient homogeneity. The transformations used were:-

LOG_e - Total weight and mean shoot weight.
Square root - Number of shoots per stool.
Angular transformation ($\sin^{-1}(\sqrt{\%})$) - % shoots exceeding control mean length.
Back transformed means are included in Tables in parentheses.
Analysis of variance was done on the transformed data and treatment interactions derived by Student's T-test.

Some treatments killed all the stools sprayed, leaving no measurable shoots. Others killed some stools or shoots, but at a later stage so that measurable, although dead, shoots remained. In each case, there were insufficient data for analysis. Where all stools were killed, tables are marked *; where some stools were killed, means are included in the tables (marked $^{+}$), but not included in statistical analyses. These means cannot be used for the statistical testing of differences between treatments.

RESULTS

Table 1 shows the percentage of dead stools combining both of the above categories. Stools were not killed by any treatments applied at the dormant stage, nor by paraquat or clopyralid at any growth stage. Glyphosate increasingly caused mortality from bud break onwards, killing most or all stools when applied to 6 cm shoots (recommended rate) or 3 cm shoots (double rate). Recommended rate amitrole did not cause stool deaths until applied to 12 cm shoots, killed all stools when applied to 20 cm shoots, but none when applied to 30 cm shoots. This pattern was repeated for the double rate from the 6 cm shoot stage.

TABLE 1. Effect of treatments on stool mortality: (percent). Nov. 1988.

Spray date Shoot length* Herbicide	 Dose (kg a.i. ha^{-1})	5/4 0	13/1 1	19/4 3	25/4 6	5/5 12	10/5 20	17/5 30
Amitrole	4.0	0	0	0	0	30	100	0
Amitrole	8.0	0	0	0	15	75	100	0
Glyphosate	2.25	0	15	20	80	100		
Glyphosate	4.5	0	5	85	80	100		
Paraquat	1.0	0	0	0	0	0		
Clopyralid	0.2	0	0	0	0	0		
Untreated control		0						

*(mean: 3 longest stool shoots: cm)

TABLE 2. Mean fresh weight (g) of shoots per stool (LOG_e transformed). Nov. 1988. Back transformed data in parentheses.

Spray date		5/4	13/1	19/4	25/4	5/5	10/5	17/5
Shoot length*		0	1	3	6	12	20	30
Herbicide	Dose (kg a.i. ha^{-1})							
Amitrole	4.0	5.62	5.40	4.94	4.99	4.70^{+}	*	5.20
		(276)	(221)	(140)	(146)	(109)		(182)
Amitrole	8.0	5.52	4.49	4.72	4.68	5.56^{+}	*	4.38
		(250)	(89)	(112)	(107)	(259)		(80)
Glyphosate	2.25	5.38	4.02	4.23^{+}	4.26^{+}	*		
		(217)	(56)	(69)	(71)			
Glyphosate	4.5	5.24	3.56	4.26^{+}	4.22^{+}	*		
		(189)	(35)	(71)	(68)			
Paraquat	1.0	5.63	5.37	5.46	5.14	4.98		
		(278)	(215)	(235)	(171)	(145)		
Clopyralid	0.2	5.59	5.15	5.41	5.39	5.04		
		(268)	(172)	(223)	(218)	(154)		
Untreated control		5.40						
		(220)						
SED		0.269 (treatments); 0.233 (control v. treatments) 76 df						

*(mean: 3 longest stool shoots: cm)

In all tables, * = all stools killed; + = too many stools killed for meaningful analysis.

TABLE 3. Mean number of shoots per stool (square root transformed). Nov. 1988. Back transformed data in parentheses.

Spray date		5/4	13/1	19/4	25/4	5/5	10/5	17/5
Shoot length*		0	1	3	6	12	20	30
Herbicide	Dose (kg a.i. ha^{-1})							
Amitrole	4.0	4.52	4.38	3.22	3.99	3.90^{+}	*	3.75
		(20.4)	(19.1)	(10.4)	(16.0)	(15.2)		(14.0)
Amitrole	8.0	4.20	3.29	3.65	3.34	5.05^{+}	*	3.04
		(17.6)	(10.8)	(13.4)	(11.2)	(25.5)		(9.2)
Glyphosate	2.25	4.22	3.26	3.44^{+}	3.87^{+}	*		
		(17.8)	(10.6)	(11.8)	(15.0)			
Glyphosate	4.5	4.16	3.34	4.12^{+}	3.90^{+}	*		
		(17.3)	(11.2)	(17.0)	(15.2)			
Paraquat	1.0	4.41	3.95	4.36	3.56	3.84		
		(19.5)	(15.6)	(19.0)	(12.7)	(14.7)		
Clopyralid	0.2	4.55	4.38	4.51	4.24	3.82		
		(20.7)	(19.2)	(20.3)	(18.0)	(14.6)		
Untreated control		4.38						
		(19.2)						
SED		0.333 (treatments) 0.289 (control v. treatments) 76 df						

*(mean: 3 longest stool shoots: cm)

The mean weight of shoots per stool (Table 2) harvested from treated plots was unaffected by any herbicide treatment sprayed on dormant stools, or by paraquat or clopyralid sprayed at any growth stage. Stools which survived recommended rate application of amitrole grew on to give yields not significantly different from the control. Double rate amitrole significantly reduced yield compared with control, paraquat and clopyralid treatments when sprayed at any stage after dormancy; glyphosate at either dose had the same effect, and double rate glyphosate reduced yield more than did the double rate amitrole.

The response to treatments expressed as the mean number of shoots per stool (Table 3) was very similar to that shown by mean weight per stool. Additionally, recommended rate amitrole applied to 3 cm or 30 cm shoots, and paraquat applied to 6 cm shoots significantly reduced shoot numbers compared with both the untreated control and the clopyralid sprayed at the same time.

Mean shoot weight, although responding similarly, differed significantly from the untreated control only where double rate amitrole was applied to 1 cm and 3 cm shoots, and where either rate of glyphosate was applied to 1 cm shoots (Table 4).

TABLE 4. Mean shoot weight (g) (LOG_e transformed). Nov. 1988.

Spray date		5/4	13/1	19/4	25/4	5/5	10/5	17/5
Shoot length*		0	1	3	6	12	20	30
Herbicide	Dose (kg a.i. ha^{-1})							
Amitrole	4.0	2.63	2.47	2.62	2.25	2.05^{+}	*	2.60
Amitrole	8.0	2.68	2.16	2.18	2.43	2.33^{+}	*	2.28
Glyphosate	2.25	2.52	1.69	1.78^{+}	1.57^{+}	*		
Glyphosate	4.5	2.42	1.28	1.43^{+}	1.51^{+}	*		
Paraquat	1.0	2.67	2.64	2.53	2.63	2.33		
Clopyralid	0.2	2.58	2.24	2.44	2.53	2.39		
Untreated control	2.47							
SED		0.165 (treatments)						
		0.143 (control v. treatments) 76 df						

For brevity, the back transformed data, which were derived from data in Tables 2 and 3, are not included.

*(mean: 3 longest stool shoots: cm)

Table 5 shows the percentage of stool shoots exceeding the mean length of each block's untreated control. By reducing shoot numbers or, possibly, weed competition, all treatments gave values greater than 50% (the control set value). For recommended rate amitrole, spraying shoots of 1 cm and 30 cm gave the highest values, which were significantly greater than the dormant or 12 cm shoots. At the double amitrole rate, spraying 6 cm shoots gave the highest value, significantly more than the dormant, 12 cm or 30 cm shoots: double rate amitrole gave significantly lower values than normal rate when applied to 1 cm and, particularly, 30 cm shoots.

TABLE 5. Percent stool shoots exceeding the control mean length (angular transformation). Nov. 1988. Original data in parentheses.

Spray date		5/4	13/1	19/4	25/4	5/5	10/5	17/5
Shoot length*		0	1	3	6	12	20	30
Herbicide	Dose (kg a.i. ha^{-1})							
Amitrole	4.0	61.4	70.9	68.6	65.8	58.5^{+}	*	71.1
		(77.1)	(89.2)	(86.7)	(83.2)	(72.6)		(89.5)
Amitrole	8.0	57.4	60.8	61.9	68.4	57.7^{+}	*	54.0
		(71.0)	(76.2)	(77.8)	(86.5)	(71.5)		(65.4)
Glyphosate	2.25	63.6	58.4	62.4^{+}	62.8^{+}	*		
		(80.2)	(72.5)	(78.6)	(79.0)			
Glyphosate	4.5	58.0	54.9	58.2^{+}	56.9^{+}	*		
		(71.9)	(66.9)	(72.3)	(70.2)			
Paraquat	1.0	64.2	69.2	72.1	71.7	66.9		
		(81.0)	(87.4)	(90.6)	(90.2)	(84.6)		
Clopyralid	0.2	64.0	63.6	68.8	63.1	66.2		
		(80.8)	(80.3)	(86.9)	(79.5)	(83.7)		
Untreated control not included in analysis (constant 50% original: 45° transformed)								
SED		4.53	69 df					

*(mean: 3 longest stool shoots: cm)

Analysis of the lengths of the three longest shoots per stool at the time of spraying showed significant difference only as time progressed: there were no differences between stools sprayed at the same time. Thus, herbicide response was not affected by differences in shoot length at any given spray date.

DISCUSSION

The results for the latest two amitrole treatments, where spraying 20 cm shoots killed all stools but spraying 30 cm shoots left the stools largely unaffected, may have been due to a necessary adaptation of the spraying method. To have oversprayed 30 cm shoots would have risked spray reaching the adjacent treatments. Thus, these were treated in a modified way by spraying shoots between the rows of stools, at the correct nozzle height above the ground and not the whole crop, so that only about 60% of the length of each shoot was sprayed.

Treatments which kill appreciable numbers of stools are obviously unacceptable. The risk of killing a few stools to control otherwise intractable, and perhaps localised, weeds may be worthwhile: double rate amitrole applied to 6 cm shoots or either rate of glyphosate applied to 1 cm shoots are examples of such treatments.

Numbers of shoots per stool, though markedly affected by treatments, are of practical significance only where annual harvests are considered, when all may contribute to yield. However, in the three-to-five year cutting cycles envisaged as optimal for biomass production, many of the initial shoots are shaded out, leaving only two to ten productive shoots, dependent on spacing, at harvest (Stott *et al.*, 1981). At the spacing used in this experiment, the lower figure applies. Thus, a reduction in shoot numbers may be advantageous, provided the surviving shoots grow well. No treatment reduced shoot numbers below these critical levels, and reference to mean shoot weight and percentage shoots exceeding the control mean length (Tables 4 & 5) shows that only double rate amitrole, at some growth stages, and either rate of glyphosate, post-dormancy, significantly reduced mean shoot weight, whilst all other treatments effectively increased shoot length. Notably, recommended rate amitrole applied to 3 cm shoots, or double rate to 6 cm shoots, whilst decreasing total weight or number of shoots per stool, had no effect on mean shoot weight.

Although it may be dangerous to base so critical an operation as herbicide application on experiments on only one cultivar in one season, these results support previous experience that dormant stools can be safely oversprayed with a wide range of herbicides. This safe period may be extended by delaying cutting to produce stools which, whilst not strictly dormant, at least have no expanding buds.

At later stages, paraquat or clopyralid may be used safely to control susceptible weeds (i.e. grasses, many annuals and thistle). More intractable weeds may be controlled, although at some risk, by early applications of glyphosate or later by amitrole at increased strength, particularly if sprayed between, rather than over, the crop rows.

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LONG-TERM STUDY OF HEXAZINONE EFFICACY IN PINE PLANTATIONS

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ABSTRACT

A trial was established in a young scots pine (Pinus silvestris) plantation in 1975. Treatment with hexazinone at rates of 1.8, 2.7 and 3.6 kg ha^{-1} was made in June 1976. No phytotoxicity on pine was observed at any rate used. Compared to an untreated hand-weeded control, deeper green colour of needles and increased radial growth was observed in the year following planting. By 1980 hexazinone at 1.8 kg ha^{-1} increased stem diameter by 46% and by more than 80% at 2.7 and 3.6 kg ha^{-1}. Hexazinone at 1.8, 2.7 and 3.6 kg ha^{-1} increased tree height by 15, 27 and 30% respectively. Measurements in 1982 showed smaller differences in growth, but trees treated with hexazinone were still taller than the untreated ones.

INTRODUCTION

Afforestation is considered one of the most important branches of forestry. New technologies and new methods of labour use are required, including the application of the most up-to-date chemicals to enhance productivity and lower costs.

MATERIALS AND METHODS

The experimental plots were at Chotoviny, in the Southern Bohemian State Forests. The area is flat and the forest contains a mixture of spruce and oak trees. The dominant weeds were Calamagrostis arundinacea and Calamagrostis epigejos, Carex brizoides, Juncus conglomeratus, Avenella flexuosa and Agrostis tenuis.

Scots pine seedlings were planted in 1975. The experiment had four plots each of 10 x 40 m with 2 m wide isolation zones. A CP3 knapsack sprayer with a Polijet red nozzle was used to spray hexazinone as a water soluble powder containing 90% a.i., on 10th June 1976. The weather was sunny.

The treatments were as follows:-

1. No chemical treatment, hand weeding only.
2. Hexazinone 1.8 kg a.i. in 300 l water ha^{-1}.
3. Hexazinone 2.7 kg a.i. in 300 l water ha^{-1}.
4. Hexazinone 3.6 kg a.i. in 300 l water ha^{-1}.

RESULTS

Application of the herbicide at an early stage of seedling development was beneficial. A large difference in height and radial growth was found between the untreated and all the treated plots, four years after planting (Table I). 1.8 kg ha^{-1} hexazinone increased stem diameter by 47% and at 2.7 and 3.6 kg ha^{-1} it increased stem diameter by 80%. Seedlings also grew significantly taller averaging 15% higher after treatment with either 2.7 or 3.6 kg ha^{-1} hexazinone.

Six years after planting differences in growth (relative to the untreated control) were smaller than after four years. However, the treated plots contained seedlings which were still substantially taller and which had larger stem diameters than those in the untreated plots.

Table 1. - The effect of hexazinone on height and stem diameter of scots pine seedlings planted in 1975, four and six years after spraying.

Year	1980			1982		
Hexazinone kg a.i. ha^{-1}	No. of trees	Av. height (m)	Av. d* (cm)	No. of trees	Av. height (m)	Av. d* (cm)
0	234	1.50	0.98	220	2.38	2.56
1.8	321	1.73	1.44	315	2.41	2.61
2.7	241	1.90	1.79	240	2.49	2.88
3.6	341	1.95	1.76	331	2.77	3.10

* d = breast height stem diameter

DISCUSSION

The tests results have shown quite clearly that the removal of competition by weeds at the early stages of development of scots pine seedlings improves growth. Seedlings planted in the plots treated with hexazinone have a greater access to moisture, soil nutrients and sunlight. Moreover, hexazinone has another benefit; the dead weeds turned into a protective mulch around the seedlings that helped to keep moisture in the soil. The degrading organic matter may also have played an important role in enhancing the effectiveness of treatment.

These tests clearly showed that 1.80 kg ha^{-1} hexazinone provided adequate protection for early stages of scots pine seedlings development. Although the higher doses resulted in greater growth, there is no point in over burdening the ecological system of the forest. Furthermore, the increased effect of the higher dose declined after several years.

ACKNOWLEDGEMENTS

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SESSION 4C

THE EVALUATION OF CROP TOLERANCE TO HERBICIDES AND MIXTURES IN CEREALS: METHODOLOGY AND RESULTS

SESSION ORGANISER MR M. A. LAINSBURY

POSTERS 4C-1 to 4C-8

SEQUENTIAL HERBICIDE PROGRAMMES 1987/88 TO PREVENT THE SPREAD OF *BROMUS STERILIS*.

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ABSTRACT

Wet conditions, late sowing and poor crop establishment at some sites and a difficult season for herbicide application, led to variable control of *Bromus sterilis* and other grass weeds which germinated throughout the winter and early spring of 1987/88. Few treatments achieved good enough control of *B. sterilis* to reduce populations in subsequent years. The most effective and least costly treatments were sequences of herbicides which started with pre-emergence application of triallate or cyanazine. Some high cost two-spray programmes based on isoproturon or metoxuron could be justified for *B. sterilis* where blackgrass or other grass weeds also needed to be controlled.

There was no evidence from limited observations on fixed quadrats of the regeneration of *B. sterilis* from below ground following earlier herbicide treatment.

INTRODUCTION

Bromus sterilis (Barren brome) has become an increasingly widespread and difficult weed to control in winter cereals, particularly in early sown crops in dry seasons, and where the weed seed burden cannot be reduced by effective straw burning.

Studies at Boxworth EHF and The Weed Research Organisation have shown that *Bromus* spp are more vulnerable to straw burning than blackgrass (*Alopecurus myosuroides*) or wild oats (*Avena fatua*) [Froud-Williams 1983]. Furthermore soil conditions after straw burning are often condusive to the germination of surviving grass weed seeds, allowing for their destruction prior to drilling [Moss 1980]. Consequently, herbicide treatments are required to deal with the increased grass weed risk where straw cannot be safely burnt and on headlands. Cultural control methods such as ploughing down *Bromus* seeds to below 12.5cm can be effective but requires careful ploughing which in practise is not always achieved. Delayed sowing can also be effective provided soil moisture is not lost with excessive cultivation or some degree of dormancy induced by dry conditions. Current investigations show that some stocks of *Bromus sterilis* have a greater tendency to dormancy than was previously thought [Peters 1989]. Thus the search for a cost effective herbicide or sequence of herbicides to deal with *B. sterilis* and other grass weeds is an important area of contemporary work.

MATERIALS AND METHODS

Site and application details.

Site	Boxworth EHF, Cambs.	Bridgets EHF, Hants.	Collingbourne Ducis, Wilts.	Kineton Warks.	Marton Lincs.	Worminghall Reading, Berks.
Soil	clay	silty loam	silty loam	clay	clay	silty clay
Drilling date :	5 Nov.	1 Oct.	4 Oct.	6 Nov.	14 Oct.	30 Oct.
Plot size, 3 reps.	4 x 12m	3 x 12m	2 x 12m	2 x 12m	2 x 12m	2 x 12m
Pre-em. a						
Date	7/8 Dec. 87	12 Oct. 87	7 Oct. 87	10 Nov. 87	23 Oct. 87	2 Nov. 87
Early post-em. b						
Date	12 Jan. 88	26 Oct. 87	2 Nov. 87	13 Jan. 88	8 Dec. 87	7 Jan. 88
Weed GS	GS 11/12	GS 11/12	GS 11/12	GS 11/12	GS 12	GS 11
Crop GS	GS 12	GS 11/12	GS 12	GS 12	GS 12	GS 13
Mid post-em. c						
Date	18 Feb. 88	10 Nov. 87	26 Nov. 87	22 Feb. 88	3 Feb. 88	7 Jan. 88
Weed GS	GS 12/13	GS 11/12	GS 13/14	GS 12/13	GS 13	GS 11
Crop GS	GS 14	GS 12/13	GS 14/21	GS 13	GS 14	GS 13
Late post em. d						
Date	9 Mar. 88	14 Apr. 88	11 Apr. 88	21 Mar. 88	17 Mar. 88	31 Mar. 88
Weed GS	GS 12-14	GS 24	GS 24	GS 23	GS 22	GS 22
Crop GS	GS 20-22	GS 30	GS 24-26	GS 24-26	GS 21-22	GS 24-26
Sprayer	OPS	AZO	OPS	AZO	AZO	AZO
Nozzle	flat fan F110/200 2 bars	02580 225 l 2 bars	OPS 80°/200 2 bars	Teejet 8002 225 l 2 bars	Teejet 8002 200 l 2 bars	8002 80°/200 2 bars

Treatments and timing

Timing =
- a pre-emergence
- b early post-emergence GS 12 crop. Brome 1-2 leaves
- c post-emergence GS 13 crop. Brome 2-3 leaves
- d late post-emergence in spring before GS 22. Brome ideally leaf 1-3

Treatments : sequences timed :-

	a	b	c	d	kg ai per ha	Product	rate/ha
1.	Triallate granular	-	-	-	2.25	Avadex BW	22.5kg
2.	"	-	+ isoproturon	-	2.50	*isopro-turon (IPU)	5.0 l
3.	"	-	+ isoproturon	-	2.50	"	"
			+ bromoxynil ioxynil	-	0.38	Deloxil	1.0 l
4.	"	-	isoproturon	-	2.00	Javelin	4 l
			+ diflufenican		0.25		
5.	"	-	chlorotoluron	-	3.50	Dicurane	7 l
6.	"	-	+ metoxuron	-	4.38	Dosaflo	8.75 l
7.	"	-	+ cyanazine	-	0.875	Fortrol	1.75 l
			+ isoproturon		1.0	IPU	5.0 l
10.	"	-	-	+ metoxuron	4.38	Dosaflo	8.75 l
11.	"	-	-	+ cyanazine	0.875	Fortrol	1.75 l
				+ isoproturon	1.0	IPU	5.0 l
16.	"	+ Avadex BW EC TM + isopro-turon	-	-	1.7	Avadex BW EC	4.25 l
					2.50	+ IPU	5 l
8.	Cyanazine	-			2.25	Fortrol	4.5 l
			cyanazine		0.875	Fortrol	1.75 l
			+ isoproturon	-	1.0	IPU	2.0 l
9.	Cyanazine				2.25	Fortrol	4.5 l
			cyanazine		0.875	Fortrol	1.75 l
			diflufenican IPU		0.1+1.0	Panther	2.0 l
15.	-	Cyanazine	-		1.25	Fortrol	2.5 l
				cyanazine	0.875	Fortrol	1.75 l
				+ isoproturon	1.00	IPU	2.0 l
12.	-	isoproturon	-	isoproturon	2.5 (each spray)	IPU	5 l
13.	-	isoproturon	-		2.5	IPU	5 l
				metoxuron	4.38	Dosaflo	8.75 l
14.	-	metoxuron	-	metoxuron	4.38 (each spray)	Dosaflo	8.75 l

17.]
18.] untreated controls
19.]

* Isoproturon : Hytane, Arelon or Tolkan

Results 1st year 1987/88 (Table 1.)

Control of Bromus sterilis by herbicide sequences based on pre-em. triallate was generally more effective at the westerly sites at Kineton and Collingbourne Ducis than at Boxworth and Marton in the east. When pre-em. triallate was used alone or followed by a late post-em. application of metoxuron or cyanazine + isoproturon in the following spring, consistently

Table 1.

Results 1987/88 1st year.

1. Barren brome heads/m² and percentage control compared with untreated.

Treatment and timing			Boxworth Cambs.		Collingbourne Ducis, Wilts.		Bridgets EHF, Hants.	Kineton Warks.		Marton Lincs.		Worminghall Oxon. *		Mean %
	SEDs Nil vs treated		± 82.1		± 47.68		± 18.4	± 5.14		± 59.6			± 14.8	± 11.29
	SEDs trtd. vs trtd.		± 100.6							± 48.7			± 17.74	
			per m²	%		%	%		%		%		%	
1.	a. Avadex BW		37.9	0	45	79	30	18.8	55	215	27	-	30	36.8
2.	a. Avadex BW	c. Hytane	153	30	176	17	68	1.3	97	123	58	-	73	57.2
3.	a. Avadex BW	c. Hytane + Deloxil	108	51	30	76	42	2.7	94	121	59	-	78	66.5
4.	a. Avadex BW	C. Javelin + IPU	199	9	46	78	83	2.2	95	94	68	-	73	67.7
5.	a. Avadex BW	c. Dicurane	107	51	16	92	[64]	9.3	78	145	51	-	63	66.3
6.	a. Avadex BW	c. Dosaflo	164	25	3	99	72	9.8	76	238	19	-	47	56.3
7.	a. Avadex BW	c. Fortrol + Hytane	179	18	26	88	78	7.0	83	93	68	-	75	68.3
8.	a. Fortrol	c. Fortrol + Hytane	19	91	61	71	63	8.7	79	76	74	-	85	77.2
9.	a. Fortrol	c. Fortrol + Panther	78	64		[81]	68	4.5	89	93	68	-	97	77.8
10.	a. Avadex BW	d. Dosaflo	151	31	153	27	43	17.3	58	169	43	-	33	39.2
11.	a. Avadex BW	d. Fortrol + Hytane	220	0	71	66	53	6.2	85	167	43	-	30	46.2
12.	b. Hytane	d. Hytane	137	37	20	90	52	2.3	94	47	84	-	70	71.2
13.	b. Hytane	d. Dosaflo	225	0	18	91	42	8.2	80	121	59	-	65	56.2
14.	b. Dosaflo	d. Dosaflo	49	78	20	90	55	9.2	78	145	50	-	33	64.0
15.	b. Fortrol	d. Fortrol + Hytane	69	68	166	21	30	6.2	85	125	57	-	30	48.5
16.	a. Avadex BW	b. Avadex emuls. + Hytane	335	0	20	90	60	0.0	100	43	85	-	72	67.8
17.	Mean of untreated controls		218	0	211	0	0	41.5	0	293	0	-	9*	
	SE		± 123.23		± 58.39			6.29		73.0			21.72	SE ± 19.55
	CV%		74.9		60.5		69.0	51.2		48.9			45.8	CV 32.3%

a = pre-emergence b = early post emergence c = delayed post-emergence d = spring, post-emergence

+ = tank mixed with.. [ ] = missing, computed value * = Estimate of percentage control on an area cover basis.

Table 2.

2. Additional grass weed control : weed heads/m² and percentage control compared with untreated.

	Boxworth Sterile brome		Meadow brome		Black-grass		Worminghall Sterile brome		Black-grass		Kineton Sterile brome		Black-grass		Wild Oats	
SED nil vs trtd.	± 82.11		± 252.1		± 453.0		± 14.48		± 14.60		± 5.14		± 26.52		± 10.36	
trtd. vs trtd.	± 100.6		± 308.8		± 554.5		± 17.74		± 18.10							
	per m²	%	per m²	%	per m²	%	per m²	%	per m²	%	per m²	%	per m²	%	per m²	%
1.		0	559	0	912	37		30		17	18.8	55		94		65
2.	153	30	948	0	479	67		73		67	1.3	97		100		98
3.	108	51	889	0	157	89		78		87	2.7	94		100		<100
4.	199	9	1273	0	135	91		73		90	2.2	95		100		99
5.	107	51	358	0	689	52		63		53	9.3	78		98		94
6.	164	25	536	0	572	60		47		47	9.8	76		100		89
7.	179	18	279	9	315	78		75		67	7.0	83		100		99
8.	19	91	98	68	142	90		85		97	8.7	79		100		81
9.	78	64	110	64	486	66		97		88	4.5	89		98		83
10.	151	31	392	0	721	50		33		30	17.3	58		98		86
11.	220	0	891	0	401	72		30		23	6.2	85		<100		91
12.	137	37	660	0	908	37		70		87	2.3	94		100		99
13.	225	0	508	0	986	31		65		57	8.2	80		100		99
14.	49	78	463	0	793	45		33		27	9.2	78		98		78
15.	69	68	512	0	311	78		30		13	6.2	85		100		88
16.	335	0	756	0	1240	14		72		87	0.0	100		100		<100
17.	218	0	305	0	1438	0	9	0	27	0	41.5	0	58.2	0	6.96	0
SE	± 123.2		± 378.2		± 679.6											
CV%	74.9		69.9		97.6		45.8		43.8		51.2		38.6		16.6	

Note : <100 control = 99.6 - 99.9%

poor results were obtained at all sites. However at Marton, a sequence based on pre-em. triallate followed by post-em. triallate emulsion + isoproturon tank mix gave very good control of B. sterilis. But for the poor result at Boxworth, this treatment would have been the best herbicide sequence in 1988. It also effectively reduced levels of blackgrass and wild oats at Worminghall and Kineton. Cyanazine pre-em. followed by a post-em. cyanazine + isoproturon or cyanazine + diflufenican (Panther) sequence of herbicides did well at most sites, notably at the eastern sites Boxworth and Marton. At Boxworth, these two cyanazine-based sequences were the only treatments which reduced levels of B. sterilis, Bromus commutatus and Alopecurus myosuroides (Table 2). Reducing the rate of cyanazine and applying it post-em., and delaying the follow-up spray of cyanazine + isoproturon until early spring was consistently ineffective at all sites. Of the two-spray programmes using isoproturon or metoxuron, two sprays of isoproturon, i.e. post-em. and in spring, were the best particularly at western sites, but in contrast two sprays of metoxuron timed similarly were particularly ineffective at Bridgets and Worminghall.

DISCUSSION

The rather variable results may be explained by the delayed or prolonged period of germination and development of grass weeds in the exceptionally wet and mild autumn and winter. At Boxworth, Bridgets and Collingbourne Ducis, B. sterilis and other grass weeds germinated throughout the winter, with a flush of emergence in January at Collingbourne Ducis. At Worminghall no emergence of B. sterilis occured within fixed quadrats until early April. At Kineton, three flushes of grass weeds were destroyed before late drilling but further germination took place throughout the winter. In contrast at Boxworth cultivations in wet conditions failed to kill germinated grass weeds before drilling, and there was no opportunity to spray with desiccant before emergence. Late drilling at Boxworth, Worminghall and Kineton meant that post-em. sprays were not applied until after Christmas. Although too much reliance on these results in a difficult grass weed year would be unwise, nevertheless some interesting observations were made :-

1. Variable and late germination of Bromus sterilis suggested that there was some seasonal factor associated with wet soils which prolonged or delayed the germination and development of the brome grass. In theory barren brome has been thought to have litle innate dormancy, but in practise is proving to be a difficult weed due to induced, or some degree of dormancy.

2. There has been no indication of regeneration of brome grass from below ground following control by herbicides (in fixed quadrat observations).

3. Sequences of herbicides may be necessary to deal with the variable germination and development of B. sterilis and other grass weeds that takes place particularly in mild open winters.

4. Sequences of herbicides were most effective when the follow-up treatment was not delayed too long following a pre-em. treatment.

5. Delayed applications of cyanazine at a reduced rate were markedly less effective than pre-em. full rate applications.

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FORMULATION VARIANTS OF CHLOROTOLURON/BIFENOX - EVALUATION OF CROP SAFETY

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ABSTRACT

Field testing of mixtures of chlorotoluron and bifenox took place over four seasons, progressing from evaluation of essentially a tank mixture, through a number of formulations, to a refined, effective and safe co-formulated product, SL344A. During this period a progression of trials was designed to investigate the impact of formulation, crop growth stage at application and insecticide tank mix partners on visual damage to both winter wheat and winter barley. On the basis of each year's results new formulations were developed and evaluated.

INTRODUCTION

Chlorotoluron, a phenylurea herbicide, has been used commercially for many years for the control of Alopecurus myosuroides and broad-leaved weeds. Bifenox is a nitrophenyl-ether herbicide which when added to chlorotoluron provides additional broad-leaved weed control. Dicurane Duo 495FW is a formulation containing 389g of chlorotoluron and 106g bifenox per litre and is recommended for the control of Alopecurus myosuroides (blackgrass), Avena spp. (wild oats), other annual grasses and many annual broad-leaved weeds including Veronica spp. (speedwells), Viola arvensis (field pansy) and Galium aparine (cleavers). It's use is at present restricted to Dicurane 500FW tolerant varieties of winter wheat.

A common phytotoxic effect from the bifenox component is a transient necrosis on the leaves which lasts for 4 to 6 weeks. Over the period 1984 to 1989 the formulation was progressively refined to improve crop safety, allow earlier post-emergence application to wheat, application to barley and tank-mixing with BYDV insecticides, whilst retaining the spectrum and efficacy of weed control.

MATERIALS AND METHODS

Sixty field trials were conducted on commercially grown cereal crops over the years 1984 to 1989 to investigate the efficacy and selectivity of various formulations of chlorotoluron + bifenox applied at 3500g + 954g ai/ha or 7000 + 1908g ai/ha respectively.

Treatments were made using a precision plot sprayer incorporating six Lurmark F11002 nozzles delivering 200 l/ha at 233kPa. Selectivity trials were located in weed free crops of winter wheat and winter barley. Applications were made at double the anticipated use rate and the plots were 3m x 12m replicated four times. Efficacy trials utilised areas of natural weed populations with plots of 3m x 8m replicated three times.

Crop safety was assessed visually taking observations such as discrete necrotic spotting and leaf discolouration attributable to the bifenox component into account. In addition eleven trials were harvested to determine effect on yield.

Weed control was evaluated throughout the season by plant counts or visual assessment.

RESULTS

1984

Field testing of formulations of chlorotoluron + bifenox began during the 1983/84 season. Two formulated products; SL279B and SL273B were compared with SL280, essentially a tank mixture of Dicurane 500FW + Mowdown 4F. Applications were made to both winter wheat and winter barley between GS 13-21 (Zadoks, 1974).

Applications in barley caused high visual phytotoxicity and unacceptable yield losses.

The results of post-emergence applications to wheat are shown in table 1. All treatments were more damaging than Dicurane 500FW but within the limits of acceptability. There were no significant effects on yield.

TABLE 1. 1983/84: Wheat, mean percent phytotoxicity (five trials)

Compound/Mixture	Rate (l/ha)	DAT 30	60	90	120
SL280	14 + 4	8	7	2	1
SL273B	20	7	7	3	1
SL279B	20	7	6	2	1
DICURANE 500FW	14	0	1	1	0

In the efficacy programme of 1984, all formulations gave high levels of control of broad-leaved weeds encountered. With respect to *Alopecurus myosuroides* however, SL279B was markedly less efficacious than SL273B or SL280 providing a mean control figure of 76%. In view of these results development efforts were concentrated on SL273B which was marketed as Dicurane Duo 495FW in the 1985/86 season.

1985

SL273B was modified such that the use rate was now 9 l/ha. Formulation variants differing in active ingredient particle size and surfactant content were tested during the 1985/86 season.

SL279B was again included in trials for use as a standard, and two variants on this formulation; SL279BF and SL279BC, incorporating different degrees of grinding of the active ingredients were tested for the first time.

Also in the first year of field testing were SL279C and SL334A, which differed in the type or quantity of surfactant.

Table 2 presents the data from the winter wheat selectivity trials. All applications were made post-emergence at GS 12-22.

TABLE 2. 1984/85: Wheat mean percent phytotoxicity (five trials)

Compound	Dose (l/ha)	DAT 14-35	46-54	82-85	190-230
SL 273B	18	3	4	3	2
SL 279B	18	6	5	3	2
SL 279BF	18	6	5	5	2
SL 279BC	18	4	6	4	2
SL 279C	18	12	12	12	3
SL 334A	18	2	2	2	0
DICURANE 500FW	14	2	2	0	0

SL279C stands alone as the most damaging treatment whilst SL279B, SL279BF and SL279BC were all very similar in the level of phytotoxicity induced. The least damaging formulation, producing levels similar to Dicurane 500FW alone and less than SL273B, was SL344A.

The difference between the safety of formulations was greatest from applications made at the 2 leaf stage with only SL273B, SL334A and Dicurane 500FW treatments giving acceptable levels of damage throughout the evaluation period.

With the exception of SL279BC and SL279C which gave significantly inferior control of A. myosuroides, all the formulations provided excellent control of the grassweed species in the trials. All formulations except SL279C gave excellent control of the broad-leaved weed species tested.

In view of these results further testing was initiated in 1986 to compare Dicurane Duo 495FW (SL273B) with the most promising new formulation (SL344A).

1986

In order to emphasise any differences in safety, application was made at the crop growth stages likely to show the greatest degree of sensitivity. Applications were made at GS 12 to wheat and with the potentially safe new formulation barley was reintroduced into the programme with applications made at GS 13. The data from these trials are presented in table 3.

TABLE 3. 1985/86: Mean percent phytotoxicity (ten trials)

Compound	Dose (l/ha)	Wheat GS 12 DAT 13-18	Wheat GS 12 DAT 42-45	Barley GS 13 DAT 15	Barley GS 13 DAT 44
DICURANE DUO 495FW	18	13	13	16	4
SL 334A	18	8	8	12	4
DICURANE 500FW	14	3	4	5	2

These results demonstrated the superior safety of SL344A compared to the present Dicurane Duo 495FW. The damage from Dicurane Duo 495FW which was higher than previously experienced can be attributed to the season's severe weather conditions. The phytotoxicity of SL334A is likely to have been similarly exaggerated.

Further studies evaluated differences between the two formulations when tank-mixed with BYDV insecticides. In Table 4 the results are expressed as the increase or decrease in percent phytotoxicity as compared to Dicurane Duo 495FW used alone. The results demonstrate the increased selectivity associated with SL334A when used in tank-mixes at double rates and applied at GS 13 in both winter wheat and winter barley.

TABLE 4. Mean percent maximum phytotoxicity: increase or decrease relative to Dicurane Duo 495FW 28 D.A.T. (ten trials)

Compound	Dose (l/ha)	Winter wheat	Winter barley
DICURANE DUO 495FW	18	-	-
" " + DECIS	18+0.4	-2	+4
" " + RIPCORD	18+0.5	0	+3
" " + AMBUSH C	18+0.5	+6	+4
SL 334A	18	-6	-12
" + DECIS	18+0.4	-8	-11
" + RIPCORD	18+0.5	-3	-10
" + AMBUSH C	18+0.5	-6	-10

During the 1985/86 season studies were extended to examine the performance of Dicurane Duo 495FW and SL334A at reduced rates; 7 l/ha and 5 l/ha. In line with previous years testing, there was no difference between the two formulations in the degree of weed control.

1989

SL334A was further evaluated during 1988/89 to determine if the earliest application timing in wheat could be reduced to GS 11 (Table 5).

The results indicate that this early timing may be possible in wheat although further testing would be required before such a recommendation could be made.

TABLE 5. Wheat (GS 11) 1988/89: mean percent phytotoxicity (five trials)

Compound	Rate (l/ha)	Mean % phytotoxicity 7 DAT	21 DAT	Spring regrowth	Ear emergence
SL 334A	18	3	2	2	0
DICURANE 500FW	14	0	0	2	0

WEED CONTROL

Data to support the comparable efficacy of SL334A and Dicurane Duo 495FW was gathered in the 1985/86 and 1988/89 field seasons and these results for both 9 l/ha and 7 l/ha are presented in table 6. All control values are within one percent with the exception of Galium aparine where control at 7 l/ha appears improved for SL334A.

TABLE 6. Comparison of the activity of SL334A and Dicurane Duo 495FW (Percent control; grassweeds 151-209 DAT by headcounts, broad-leaved weeds 145-202 DAT by visual observation)

Species	Growth stage at application (leaves)	No. of trials	SL 334A 9 l/ha	SL 334A 7 l/ha	DICURANE DUO 9 l/ha	DICURANE DUO 7 l/ha
Alopecurus myosuroides	1-3	5	99	97	99	99
Avena fatua	1-3	1	-	100	-	100
Lolium multiflorum	2-3	1	-	100	-	100
Lolium perenne	2-3	1	-	100	-	100
Poa annua	1-5	2	-	100	-	100
Poa trivialis	1-3	2	-	100	-	100
Aphanes arvensis	2-4	1	-	100	-	100
Capsella bursa-pastoris	2-4	2	-	100	-	100
Galium aparine	0-4	3	100	97	100	87
Lithospermum arvensis	2-4	1	100	-	100	-
Matricaria spp.	0-2	4	-	100	-	100
Myosotis arvensis	2	2	-	100	-	100
Papaver rhoeas	2-4	1	-	100	-	100
Senecio vulgaris	2-4	1	-	100	-	100
Sinapis arvensis	2	2	-	100	-	100
Stellaria media	2-12	7	-	100	-	100
Veronica hederifolia	0-4	6	100	99	100	99
Veronica persica	0-4	7	100	100	100	100
Viola arvensis	2-6	8	-	100	-	100
Volunteer beans	4-8	1	-	97	-	98
Volunteer rapeseed	2-8	1	100	-	100	-

DISCUSSION

The progression of field trials carried out over four seasons demonstrates that whilst physical compatability trials may be sufficient to evaluate some tank mixtures, biological field examination is essential where a product has shown a potential for crop damage. The trials also demonstrate the importance of modifying assessment methodology and timing so that field symptoms produced by a particular chemical, in this case discrete necrotic spotting produced by bifenox, are recorded. This allows accurate interpretation of the data obtained in order to arrive at reliable and safe label recommendations. In these trials significant variations in safety were noted between formulations differing only in active ingredient particle size or surfactant quantity or type. The difference that small changes in formulation can make to crop safety was demonstrated by the 1985 results. The formulations SL279C and SL334A which varied only in surfactant content were the most and least damaging respectively. Field testing was essential to determine such differences.

Having identified acceptable safe formulations, efficacy must be considered. In 1984, this separated SL279B and SL273B with the former being markedly less efficacious with respect to post emergence control of A. myosuroides. Similarly when a safer formulation has been identified, as in the case of SL334A, it is essential to prove by field testing that loss of efficacy and spectrum of control has not occurred. Table 6 shows the almost identically excellent control for SL334A and the present Dicurane Duo 495FW. As Barley yellow dwarf virus (BYDV) becomes a more widespread problem in both winter wheat and winter barley, the importance of controlling the aphid vector increases. The improved safety of SL334A against SL273B was carried through to the consideration of these two formulations in tank mix with BYDV insecticides. The identification of a safer formulation has also allowed the expansion of the timing spectrum for post-emergence application in wheat to as early as GS 11 and use on barley crops from GS 13. In yield trials there was no correlation between levels of visual damage observed and measured yield reductions, with unacceptable levels of visual damage not significantly effecting yield. If a threshold value exists above which visual damage causes unacceptable yield loss, this level was not reached in these trials. It is likely that much higher levels of phytotoxicity may be tolerated in the autumn/winter than in the spring without an effect on yield.

The employment of a methodical progression of formulation testing has led to the choice of the latest formulation SL334A where reduced phytotoxicity has allowed earlier application timing in wheat together with the addition of barley as a tolerant crop. BYDV insecticide tank mixes also show improved safety with the use of the new formulation whilst extensive efficacy trials show no loss of activity resulting from formulation change. This safer formulation with the same excellent record of efficacy will supersede the present Dicurane Duo 495FW when approval is granted.

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THE EVALUATION OF CEREAL TOLERANCE AND HERBICIDE EFFICACY UNDER GLASSHOUSE CONDITIONS

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ABSTRACT

The role of glasshouse studies relative to field trials is discussed. The opinion is forwarded that in addition to screening for selectivity in cereals and activity on weeds the glasshouse can be a valuable tool in determining herbicide characteristics before field trials are commenced.
The techniques of pot propagation are described as are the means of treatment application. Methods of assessment are described including a 0-9 visual assessment scale. The main use of these techniques is described including screening coded compounds, investigation of factors influencing cereal tolerance, the effects of formulation, the effects of soil and compatiblity testing.

INTRODUCTION

The evaluation of herbicides is a complex procedure involving assessment of effects on crop and weeds under a wide range of conditions. The progress of a new compound from synthesis through to marketing is both complex and time consuming (Allen, 1977). The procedure is complicated by registration formalities, economic considerations relative to toxicity, dose and market price (Finney, 1988) and the possibility that a novel herbicide may have unexpected effects not shown up by current trial methods which have developed from work with established herbicides and cropping systems. Problems of this nature have been encountered in some arable rotations with herbicide residues (Beyer et al 1987, Caverley, 1987) and with herbicide resistant weed species (Moss, 1987).

The general concept of herbicide development is that a very large number of test compounds are screened in primary and secondary screens leading to local or regional screens or field screens (Giles, 1989) followed by a comprehensive field trials programme.

Field trials are by their very nature of limited usefulness. Many variables cannot be properly tested in the field that have considerable influence on crop safety and herbicide efficacy. It is often preferable to evaluate as many variables as possible in the laboratory and glasshouse. By such an approach it is conceivable that a nearly complete profile of a herbicide's activity can be developed prior to field trials. In this circumstance the role of the field trial becomes one of confirmation of the characteristics of a herbicide rather than an investigation into them.

THE USE OF POT STUDIES WITH CEREAL HERBICIDES

Initial screening is primarily designed to determine gross activity or selectivity. Tests are carried out using relatively high dose rates. A new material may be classed as "positive for further screening if there is only 20% growth inhibition of the crop and more than 80% inhibition of one or several weeds (Gerber, 1977). Using pot grown material dose response curves can be drawn to cereals and weed species.

From these curves the margins of safety can be assessed.

Selectivity between a crop and a weed is determined primarily by physiological factors and secondly by physical and environmental factors, for example:

Physiological factors	-	biochemistry of the crop and weed, crop, variety, growth stage, 'hardness', weed resistance, etc.
Physical factors	-	dose, formulation, compatibility, application, retention by plant, solubility, volatility, stability, etc.
Environmental factors	-	temperature, light, moisture, rainfall, humidity, wind, soil type, soil condition, soil ph, soil organic matter, soil absorption, etc.

METHODS OF USE IN GLASSHOUSE STUDIES

The tests developed by Oxford Plant Sciences Ltd., were originally based on methods used by the Weed Research Organisation (Holly, 1965). Plants are usually raised in 9 cm diameter plastic pots; where cereals are to be grown to ear emergence or later 25 cm pots are used. The growing medium is normally a general purpose loam consisting of: 20% loam, 15% grit, 65% Irish Peat plus base 0.1% ground limestone and 0.2%, "Vitax Q4" Nutrient. Five cereal seeds are sown in 275 mls of growing medium per pot at a depth of 1 cm. Watering is generally by automatic overhead irrigation on a demand basis determined by weather and temperature. In suitable circumstances pots can be watered from below by placing them on capillary matting. In winter artifical lighting is provided by a battery of sodium lamps. Lighting assists growth but is also useful to extend the day length. Undressed seed is normally used and after emergence aphicides and fungicides are applied as necessary. In general, the aim is to avoid all chemical treatments other than those under test. In cereals there is normally 100% emergence after 7 days and 1.5 leaves emerging per week up to the 5 leaf fully unfolded stage. Most trials are planned to be sprayed by the 5 leaf stage, at which time growth and tillering become abnormal due to high light levels around individual pots and the effect of foliar nutrition. No nutrient is given for short term trials but for trials of more than 1 months duration a soluble foliar feed is applied at weekly intervals, as by this time cereal plants are essentially "pot-bound", and depend on applied nutrients for further growth. Herbicides are normally applied using a modified Azo Van der Weij sprayer operating at 2.0 kg/cm^2 (30 lb/in^2) pressure in 200 l/ha of water and moving at a constant speed of 2m/second, 45 cm above the plants. Different circumstances may require alternative means and conditions of application, e.g. CDA application.

Five main tests are carried out:

1. Post emergence to the foliage only, avoiding contact with the soil.
2. Post emergence to the foliage and soil.
3. Post emergence to the soil only as a drench avoiding foliage contact.
4. Pre-emergence to the soil surface.
5. Incorporated into the soil before planting.

A single pot represents one "plot" and six replicates are generally sprayed. Prior to spraying pots are assembled and graded for uniformity. After spraying plants from each replicate are randomly arranged on the benches to avoid any growth effects due to position in the glasshouse.

ASSESSMENT OF RESULTS

Depending on the nature of the test different assessment methods are used. Those most commonly used are as follows:

1. EMERGENCE.

In trials with pre-emergence and soil-incorporated herbicides the numbers of plants emerging are counted and percentage emergence is calculated. In some cases counts are repeated over a period of time to give a measure of the check to growth caused by a treatment. It is also necessary to assess emerging plants for vigour loss compared to the control and for any specific symptoms.

2. PLANT HEALTH.

In all types of test visual assessments of plant health are used as the main assessment tool. All pots are scored "blind" using a visual assessment key. This uses a 0-9 linear scale, as follows:

0-9 Visual assessment scale

0. Completely dead.
1. Moribund, but not all tissue dead.
2. Alive, with some green tissue, but unlikely to make much further growth.
3. Very stunted, with much dead tissue, but apparently still making some growth.
4. Considerable inhibition of growth with dead tissue starting to appear.
5. Readily distinguishable inhibition of growth with dead tissue starting to appear.
6. Reduced growth with initial signs that tissue is beginning to die.
7. Slight reduction in growth, epinasty and other morphological abnormalities. Heavy prostration.
8. Some detectable adverse effects compared with the control such as colour difference and slight prostration.
9. Indistinguishable from the control.

As a rule at least three visual assessments are carried out in the life of a trial. Up to six assessments may be made. In general effects on cereals are apparent up to 30 days after treatment. After this time, small differences between treatments tend to disappear.

3. FRESH WEIGHT.

This method of assessment consists of cutting all aerial growth from the cereal plants at soil level. All foliage from each pot is weighed and mean weights per pot per treatment are calculated. This method is particularly useful where visible differences are small but confirmation of growth differences need to be established. It is used frequently with perennial weeds especially *Elymus repens* (Common Couch).

4. HEIGHT MEASUREMENTS.

This method involves measuring the height of the main shoot above soil level. It is less useful in herbicide trials but is employed for certain growth regulators in grass species.

DATA RECORDING

All assessments are recorded on the PSION Organiser using the OAG Datalogger programme. This programme accepts full details of the trial layout at a set up stage and allows any variables to be entered when the experimenter examines the treated pots. Both scores and quantitative data can be entered. Having recorded all the assessments the programme de-randomises the data and assembles it in tabular form giving both totals and means. This is then printed out directly or loaded onto computer disc for further processing or preparation of tables suitable for a study report.

AREAS OF USE

Screening Coded Compounds.

At present, compounds submitted for evaluation have been accompanied by guide-lines on rates of use and selectivity. If the test species is not specified winter wheat and winter barley are screened plus a spread of common weeds e.g.

Alopecurus myosuroides; *Avena fatua*; *Poa annua*; *Stellaria media*; *Tripleurospermum maritimum*; *Chenopodium album*; *Capsella bursa-pastoris*; *Galium aparine*; *Veronica persica*; *Viola arvensis*.

Each species is planted in separate pots. The doses used, if not specified, would be on a logarithmic scale, e.g. 0.01gm/ha, 0.1gm/ha, 1.0gm/ha, 10gm/ha, 100gm/ha, 1000 gm/ha. Assessments would be appropriate to the timing of application and the nature of the response of each speices.

Physiological Factors.

A range of cereal varietal interractions with herbicides can be assessed using the techniques outlined above. Application timings later than the first node detectable stage have so far not been asked for.

The use of the glasshouse for evaluation of weed resistance is exemplified by work with *Alopecurus myosuroides* (Moss, S. 1987). Stocks of resistant, semi-resistant and tolerant strains are grown with candidate seed stocks and sprayed with chlortoluron and isoproturon at 0.25 - 28.0 kg/ha. From the results dose response curves are calculated and ED50 values determined. This technique has also proved satisfactory for assessing triazine resistant weed populations.

Physical Factors.

It is often only at a late stage of development that the effects of the formulation, compatibility or application on the activity of a herbicide are examined. Laboratory studies are used to determine basic physical characteristics but effects on herbicidal activity must be measured on plant material.

The glasshouse has proved most useful in the evaluation of biological compatibilities of herbicides, fungicides, insecticides and foliar fertilizers using single and double dose mixtures. This test is often carried out in parallel with physical compatibility tests. In some cases over a hundred tank mixtures have been evaluated based on a single herbicide. Under glasshouse conditions, this is both manageable and uniform but would not be so in the field.

Environmental Factors.

The use of growth cabinets for measuring the effect of temperature, light, moisture, humidity and rainfall is now well established. This is one area in which the glasshouse test is limited. Moisture can be controlled, but little else to any significant degree.

The glasshouse is very useful for investigating the effects of soil conditions. Soil type, pH, nutrient organic matter and moisture levels can be varied at will. Differing soils can be imported and comparative tests made. Cereals can then be grown in test soils and the effect of herbicides evaluated.

DISCUSSION

Whilst glasshouse bio-assay is a very versatile tool for studying herbicide tolerance in cereals there are clear limitations. The most obvious one is the application of data generated from such tests. Can the data be directly used for making a recommendation on farm? In our experience there are many situations where the data can be used directly in the field. This is particularly important in tolerance studies. Cereals grown under glass tend to be poorly waxed and unduly sensitive to herbicide damage. Our general conclusion over six years of this type of work is that the glasshouse study will give more pointers to potential areas of crop sensitivity than a comparable field trial. The true role of the glasshouse bio-assay is therefore to indicate circumstances where crop injury is possible.

In the glasshouse, assays are carried out at relatively early growth stages. We have found cereals are more susceptible at these younger growth stages. A positive result in the glasshouse at double recommended rates of use has proved to be directly applicable to later growth stages recommended in the field.

Once the limitations of glasshouse tests are appreciated the glasshouse enjoys the enormous advantage of both speed of execution and year-round availability. There is invariable only one time in a calender year a field trial can be laid down whereas the glasshouse trial can be started at anytime and be repeated as required. In our view, glasshouse studies will have a growing role to play as a problem solving tool and as a means of rationalising field trials.

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THE PERSISTENCE OF SULFONYLUREA HERBICIDES ALONE OR IN MIXTURES WITH GRAMINICIDES

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ABSTRACT

The response of lentils (*Lens culinaris* Medik.), pea (*Pisum sativum* L.), chickpea (*Cicer arientinum* L.), sunflowers (*Helianthus annuus* L.), onions (*Alium ceppa* L.), corn (*Zea mays* L.) and sugarbeet (*Beta vulgaris* L.) to soil residues 8 to 14 months after application of chlorsulfuron, triasulfuron and sulfmethmeton-methyl alone and mixtures with five wild oat herbicides was determined at five trials in Greece. All crops were significantly injured by chlorsulfuron at all rates 8 to 14 months after application, as determined by visual evaluations, number of plants/m^2, d.m.weight or grain yield. Lentils corn, and onion were the most sensitive while sunflower was the least sensitive.Injury of onion was less under dry conditions than under irrigation. Triasulfuron residues injured onion, corn and sugarbeet while chickpea, pea and lentils were tolerant. Corn and onion, when planted 8 months after herbicide application, were injured by sulfmethmeton-methyl;the other five crops were tolerant. All mixtures of sulfonylureas with graminicides caused less injury to crops than the sulfonylureas alone.Sugarbeet was very sensitive to imazamethabenz alone and in mixtures with sulfonylurea herbicides.

INTRODUCTION

Sulfonylurea herbicides are broad-spectrum herbicides which selectively control many annual weeds in autumn-sown small grains (Skorda,1982;Efthimiadis *et al.* 1986; Efthimiadis *et al.*,1987). However, several research workers have found injury to succeeding crops from chlorsulfuron residues in the soil and some growth inhibition from triasulfuron (Brewster and Appleby,1983;Peterson and Arnold,1985; Klingaman *et al.*,1986; Esau and Rumney, 1985).

Imazamethabenz is a post-emergence herbicide for the control of *Avena* spp., *Alopecurus myosuroides* Huds., and certain broad-leaved weeds in wheat and barley but sugarbeet was injured when sown 6-8 months after 0.4-1.1 kg/ha imazamethabenz applied in the autumn (Miller and Alleg, 1987).

Persistence of herbicides in soils is affected by soil type and environmental conditions. Chemical hydrolysis and microbial breakdown are the principal modes of degradation of sulfonylureas. Therefore field degradation of sulfonylureas has been found to be fastest in warm, moist, light textured, low pH soils, and slowest in cold, dry, heavy, high pH soils (Beyer *et al.*,1987; Anderson and Humburg,1986). Persistence of imazamethabenz residues varies with soil type (Allen and Caseley,1987).

Since crop rotation is a common practice in diversified farming areas herbicide residues in the soil are of concern. The objective of this study was to examine the potential for sulfonylureas and imazamethabenz alone and in mixtures with other herbicides to cause injury to seven rotational crops, commonly grown in Greece.

MATERIALS AND METHODS

Field experiments were conducted at three locations in Greece over a period of two years. The soils were clay and silty-clay with pH 7.4, 6.7 and 6.6. The climate is characterized by cold, rainy winters and hot,dry summers with much variation between years.

The rotational crops were sunflower (cv Hysan), corn (cv Aris), onions (cv wateronion), and sugarbeet (cv polybeta) under irrigation and lentils (cv M- 1956), pea (I.E.- 88603), and onion (local variety) under dry conditions.

Herbicides were applied in water using a plot-sprayer with a 2.5 m boom and the spray volume ranged 300 - 400 l/ha. All herbicide rates are expressed on an active ingredient basis and are presented in the result tables. All tillage operations were carried out to a depth of 15 cm.

The experiments were designed as randomized complete blocks with four replicates, individual plots being 4 by 15 m. Herbicides were applied at stage Zd 12-23 to wheat in March and the crop was harvested in July. The experimental area was ploughed in the autumn following herbicide application and rotational crops were planted in November or the following spring 8 to 14 months after herbicide applications.All crops were planted in rows 26-70 cm apart, according to the normal row spacing for each crop. Hand weeding was used to remove weeds from all rotational crops.

Crop injury was evaluated by visual ratings,dry matter and yield weights in a portion of the centre rows of each plot; corn and sunflower were only assessed by d.m. at the time of seed filling. Dry weight was determined by counting and clipping the plants at ground level. Analysis of variance was performed and the means were compared using Waller-Duncan k-ratio t-test.

RESULTS

Visual symptoms of injury began to appear in lentils, onion, corn and sugarbeet approximately 2 weeks after emergence. Severity of symptoms increased as the rate of herbicides increased. Lentils, onion, corn and sugarbeet plants were stunted with yellow to purple coloration of leaves. This coloration, which was almost similar to symptoms of phosphorus deficiency, disappeared later in the season but the plants remained stunted. Leaf purpling was not evident in the crops tolerant of treatment in the experiment.

1986-1987. The two experiments were in adjacent areas where the soil was clay, pH 7.4 and other conditions were very similar. These experiments examined the residual effects on the rotational crops (onion, chickpea and pea) of the three sulfonylurea herbicides alone at the rates 10, 15 and 20 g/ha or in mixtures with diclofop-methyl and imazamethabenz at the recommended rates (Table1).

Chlorsulfuron reduced onion yield and to some extent stand at the rates 10 to 20 g/ha, but the effects were lessened by mixture with diclofop-methyl or imazamethabenz. The same was true with triasulfuron at the rates 15 and 20 g/ha, but not when in mixture with imazamethabenz. Chlorsulfuron reduced pea yields at rates 10 and 15 g/ha but not in mixtures with diclofop-methyl. All three crops were tolerant to sulfmethmeton-methyl in both experiments.

1987-1988. Under dry conditions, two experiments evaluated the residual effects of the three sulfonylurea herbicides in mixtures, in one experiment with fenoxaprop-ethyl and tralkoxydim and in the other with flamprop-methyl at the label recommended rates on the crops lentils, chickpea, onion, and sunflower (Table 2). Chlorsulfuron + flamprop-methyl reduced lentil yields and d.m. weight while chlorsulfuron + fenoxaprop-ethyl reduced the yield of lentils, chickpea and onions. Chlorsulfuron + tralkoxydim mixtures

TABLE 1. Effect of sulfonylurea herbicides on three crops planted 8-10 months after application.

Treatment		Onion (Experiment 1)		Pea (Experiment 1)	Chickpea (Experiment 1)	Onion (Experiment 2)		Pea (Experiment 2)	Chickpea (Experiment 2)
		Yield kg/ha	Plant No/m^2	Yield kg/ha	Yield kg/ha	Plant No/m^2	Yield kg/ha	Yield No/m^2	Yield kg/ha
Control		13980a	24ac	2200a	2860	25.0ce	10410ac	1850ac	3260
Trias	10	12990ac	25ab	2370a	3070				
	15	10830d	16d	2060ab	2640	23.8cf	7930ce	2050ab	3270
	20					19.3g	7840de	1600ce	3160
Trias+dicl	10+720	12970ac	24ac	2150ab	2810				
	15+720	11310cd	27ab	2090ab	2870	20.0fg	9780ad	1930ac	2900
	20+720					19.8fg	8850bd	1640be	3120
Trias+imaz	10+400	13520ab	26ab	2320a	2950				
	15+400	13020ac	29a	1970ab	2650	27.3bc	8920bd	1950ac	3155
	20+400					21.5dg	9640ad	1620ce	3010
Chlor	10	7850e	17d	1580c	2440				
	15					21eg	6230e	1360e	2720
Chlor+dicl	10+720	11740bd	27ab	1960ab	2550				
	15+720					32.5a	7400de	1770ac	2655
Chlor+imaz	10+400	13190ac	27ab	1840bc	2610				
	15+400					29.5ab	10150ad	1820ad	2935
	20+400					26.3bc	8950bd	1430de	3100
Sulf	10					32.0a	11770a	1950ae	3540
Sulf+dicl	10+720	12930ac	24ac	2480ab	3000	25.8bd	11290ab	2120a	3065
+imaz	10+400					24.8ce	11780a	1950ac	3230
	15+400					19.5fg	10280ad	1769ae	3025
LSD p = 0.05					NS				NS

Trias = Triasulfuron, Dicl = Diclofop-methyl, Imaz = Imazamethabenz, Chlor = Chlorsulfuron, Sulfm = Sulfmethmeton-methyl.

reduced the yields of lentils and onions and the d.m. weight of sunflowers.

Lentils appear to be the most sensitive crop and mixtures of chlorsulfuron + + tralkoxydim appear more widely damaging than the other herbicide mixtures.

Experiment under irrigation. This experiment tested the crops most sensitive to sulfonylurea herbicides, that is sugarbeet, corn and onion (cv water-onion) and the less sensitive sunflower. Sugarbeet was very

TABLE 2. Effect of three sulfonylurea herbicides on four crops planted 10 to 12 months after application (experiments 3 and 4).

Treatment	Rate g/ha	Lentils d.m. kg/ha	Lentils yield kg/ha	Chickpea d.m. kg/ha	Chickpea yield kg/ha	Onion plant No/m^2	Onion yield kg/ha	Sunflower d.m. kg/ha
Experiment 3								
Control		5525be	950ad	3625a	805a	10.8a	10210a	9875a
Flam	715	5300df	953ad	4475a	925a	10.3a	10400a	9850a
Flam+chlor	715+10	4325g	768f	4300a	825a	10.8a	10651a	10450a
Flam+trias	715+10	6375a	1133a	4100a	808a	10.3a	9820ab	9875a
Flam+sulfm	715+10	6200ab	1085ab	4470a	798a	11.2a	10792a	10570a
Experiment 4								
Control		6075a	1148a	3800b	822ab	11.8ab	12130a	9550de
Fenox	180	5900a	1073ab	4050ab	1095ab	10.8ab	10100ce	11950ab
Fenox+chlor	180+10	4825b	820c	2750c	612c	9.8cd	8288fg	10351bd
Fenox+trias	180+10	6000a	1015ab	4150ab	908ab	10.8ad	10350cd	10780ad
Fenox+sulfm	180+10	6150a	993ab	4375ab	935ab	11.3ac	11893ab	10980ad
Tralk	300+10	5700a	1013ab	4275ab	880ab	11.0ad	9913ce	10400bd
Tralk+chlor	300+10	3525c	525d	4350ab	925ab	9.3d	7235g	8730e
Tralk+trias	300+10	6050a	1140a	4175ab	812ab	10.0bd	9945ce	12050a
Tralk+sulfm	300+10	6125a	1150a	3975b	828ab	9.3d	9700de	10180ce

Flam = Flamprop-methyl, Chlor = Chlorsulfuron, Trias = Triasulfuron, Sulfm = Sulfmethmeton-methyl, Fenox = Fenoxaprop-ethyl, Tralk = Tralkoxydim.

sensitive to chlorsulfuron, triasulfuron and imazamethabenz alone and in mixtures. The reduction of dry matter was greatest with the higher rates. Sugarbeet was tolerant to sulfmethmeton-methyl at the two rates tested (Table 3).

Onion was very sensitive to chlorsulfuron residues alone and in mixtures with very high reduction of the yield and the number of plants per m^2 but to sulfmethmeton-methyl only at a rate of 20 g/ha. The sulfunylurea residues alone or in mixtures reduced the dry matter weight of corn. Sunflower was tolerant of all tested herbicides.

Imazamethabenz alone and in mixtures with sulfonylureas caused severe injury to sugarbeet but all the other crops were tolerant.

DISCUSSION

Chlorsulfuron reduced the growth and yield of lentils, pea, chickpea, onion, corn and sugarbeet planted in the autumn or spring 8, 12 or 14 months after herbicide application to wheat. The reductions were least from the mixtures of chlorsulfuron and graminicide herbicides. Sunflower was the crop most tolerant of chlorsulfuron and, of the three experiments, in only one were slight reductions due to chlorsulfuron residues seen. Onion was tested in two soil types and two growing years, the one drier than the other. However, chlorsulfuron residues affected the crop in both years and soil types. The reduction of yield was greatest in the heavier soil, in earlier planted crops and in the dry year. Persistence of chlorsulfuron in soils is affected by soil type and environmental conditions (Beyer *et al.* 1987; Burkhart and Fay, 1985). Therefore, the herbicide residues in the soil may be of great concern to farmers in their rotation programmes.

TABLE 3. Effect of three sulfonylurea herbicides on four crops planted 13-14 months after application (experiment 5).

Treatment	Rate g/ha	Onion plant No/m^2	Onion yield kg/ha	Corn plant No/m^2	Corn yield kg/ha	Sunflower d.m. kg/ha	Sugarbeet d.m. kg/ha
Control		11.6b	9297ab	4.9ac	8900ab	5885ab	3360ab
Dicl	720	12.0ab	8682ac	5.4a	8530ac	5570ab	3210ab
Imaz	400	11.9ab	8840ac	5.1ab	9665a	5875ab	3120bc
Imaz	800	12.0ab	8920ac	5.1ab	8400ad	5830ab	1192ej
Trias	10	11.7ab	9227ab	4.9ac	7860be	4930bd	2525cd
Trias	20	11.9ab	9755ab	4.6be	7230cg	4980bd	2040cd
Trias+dicl	20+720	11.7ab	9897ab	4.7bd	7590bf	5405ac	3550a
Trias+imaz	10+400	11.8ab	9862ab	4.9ac	8000be	5170ad	1550fj
Trias+imaz	20+800	11.6b	8817ac	4.7ad	8480ad	5315ad	640hj
Sulfm	10	11.8ab	8655bc	4.1dg	7440cg	5440ac	3070ab
Sulfm	20	11.7ab	7642cd	3.3fh	6910eh	5325ad	3580a
Sulfm+dicl	20+720	12.8a	10055a	3.5fh	6950eh	5620ab	3147ab
Sulfm+imaz	10+400	11.1b	8917ac	3.6fh	7410cg	5735ab	1250ej
Sulfm+imaz	20+800	11.4b	9067ab	3.2hi	6280fh	5965a	2200ce
Chlor	20	7.5c	5600e	3.5gh	7090dh	5645ab	2385cd
Chlor+dicl	20+720	7.6c	6050e	2.9hi	7350ch	5860ab	2000cd
Chlor+imaz	10+400	8.4c	6445de	3.6fh	8100be	5915ab	1825fh
Chlor+imaz	20+400	6.4c	5405e	3.8eh	8420ad	6100a	42k

Dicl = Diclofop-methyl, Imaz = Imazamethabenz, Trias = Triasulfuron, Sulfm = Sulfmethmeton-methyl, Chlor = Chlorsulfuron.

Onion, corn and sugarbeet yields were reduced by residues of trialsulfuron.

All rotation crops but corn and onion were tolerant to sulfmethmeton-methyl. In only one experiment was onion affected by double the recommended rate of sulfmethmeton-methyl in a very dry and hot growing season. Kral and Ferguson (1987) reported that sulfmethmeton-methyl was rapidly inactivated in the soil allowing onion to be sown 60 days after application without injury. Probably the soil and climatic conditions were more favorable to degradation of the herbicide than the Greek conditions. Sulfmethmeton-methyl offers more rotational crop flexibility in dry, hot conditions than the other two, triasulfuron being between sulfmethmeton-methyl and chlorsulfuron.

Only sugarbeet was injured when sown 12-14 months after 0.4-0.8 kg/ha imazamethabenz applied in the spring on wheat with corn, onion, chickpea, lentils, pea and sunflower being tolerant. However the injury from imazamethabenz alone or with sulfonylureas mixtures was very high.

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REACTION OF WINTER WHEAT VARIETIES TO HERBICIDES

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ABSTRACT

The report presents the results of three series of experiments in which the reactions of 18 wheat varieties to recommended herbicides were evaluated during 1970-88. Varieties were classified as resistant, moderately sensitive (when morphological changes to growth occurred with no effect on yields) or sensitive (when yield reductions ranging 5-10% were found).

INTRODUCTION

Winter wheat producers frequently report symptoms of injury to crops after treatment with herbicides. This injury is often transient with no effect on final yields but in some instances yields may be affected. This is most likely if:

- the crop is weakened by disease or incorrect cultivations.
- applications are made outside the recommended growth stages.
- weather conditions are particularly inclement.
- there are errors in application.
- unsuitable herbicides have been used.

Moreover, the effects could be due to the greater sensitivity of some varieties to herbicide applications (Rola et al 1974, 1985; Krol 1971). This paper reports field experiments on the susceptibility of winter wheat varieties grown in Poland to recommended herbicides at various application times.

METHODS AND MATERIALS

Five series of experiments, each lasting three years, were conducted during the years 1970-88 on black soils (O.M. 3.4%, pH 6.9) in Poland. These soils were relatively weed free. Trial design was a randomised block split-plot with three or four replicates. Plot size was 25m^2 split by variety. Treatments, application times and varieties tested are listed in figures 1 and 2 which present yield results from 1984-88. Assessments of crop injury were made using the EWRS scales. Yields were corrected to 13% moisture and analysed using Tukey's multiple range test.

RESULTS AND DISCUSSION

1. Pre-emergence treatments: Applications to some varieties resulted in slower growth and slight crop thinning which was apparent the following spring. Pendimethalin at 1650 g ai/ha affected the varieties

Rota, Panda, Beta, Gama and Jawa while methabenzthiazuron only affected the variety Gama. These effects were transient and there was no effect on subsequent growth or final yield. Chlortoluron at 1600 g ai/ha caused yellowing and necrosis of leaves leading to plant losses. Yield reductions were observed on the varieties Alcedo (-6%) and Alba (-7%). Injury symptoms not resulting in yield losses were seen in cvs Grana, Jawa, Rota and Panda treated with pendimethalin, cv Gama treated with methabenzthiazuron and cvs Gama, Jawa and Rota treated with chlortoluron.

2. Early post-emergence treatments (GS 12-15): Treatments applied during the autumn and the spring sometimes caused a loss of turgidity, checks to growth and longitudinal rolling of leaves as well as yellowing and leaf tip necrosis. Metoxuron + simazine at 1800+200 g ai/ha caused a decrease in plant density and a 7% yield loss to cv Liwilla. Although injury symptoms were not apparent, cv Modra suffered an 8% yield loss when treated with metoxuron + simazine. Isoproturon at 1500 g ai/ha caused leaf tip necrosis and yellowing to cvs Beta, Liwilla and Modra but only Modra suffered a yield loss (-6%). Spring application of chlorsulfuron at 18.75 g ai/ha caused leaf yellowing to the cvs Gama, Jawa and Rota but there is no loss of yield.

3. Later post-emergence treatments (GS 21-29): Linuron + methabenzthiazuron + terbutryn (350+430+220 g ai/ha) caused leaf yellowing to cvs Alba and Weneda which persisted for 12 days. MCPA + dicamba at 715+785 g ai/ha applied during tillering to cv Beta resulted in a reduction in 1000 grain weight. MCPA + clopyralid at 1040+100 g ai/ha caused no crop injury symptoms but at harvest a 7% yield loss was recorded on cv Saga and a 6% loss on cv Salwa. Hormones, when applied during tillering caused ear deformation characterised by irregular distribution of the spikelets along the rachis but in most cases these symptoms did not adversely affect the yield. 2,4-D + dicamba at 1080+84 g ai/ha affected cvs Gama, Panda, Rota, Jawa, Beta, Emika and Jawa. 2,4-D + mecoprop at 705+465 g ai/ha caused symptoms to cv Polanka and Delta. All symptoms were transient, lasting for only 2-5 weeks. The most tolerant of the varieties to herbicide treatment generally were cvs Gama, Jana and Mironowska 25 (Rola et al 1974, 1985).

CONCLUSIONS

Although recommended for use in winter wheat crops in Poland, not all herbicides show similar selectivity to all varieties. Symptoms of crop injury frequently occur even when products are correctly applied but these do not necessarily result in significant yield losses.

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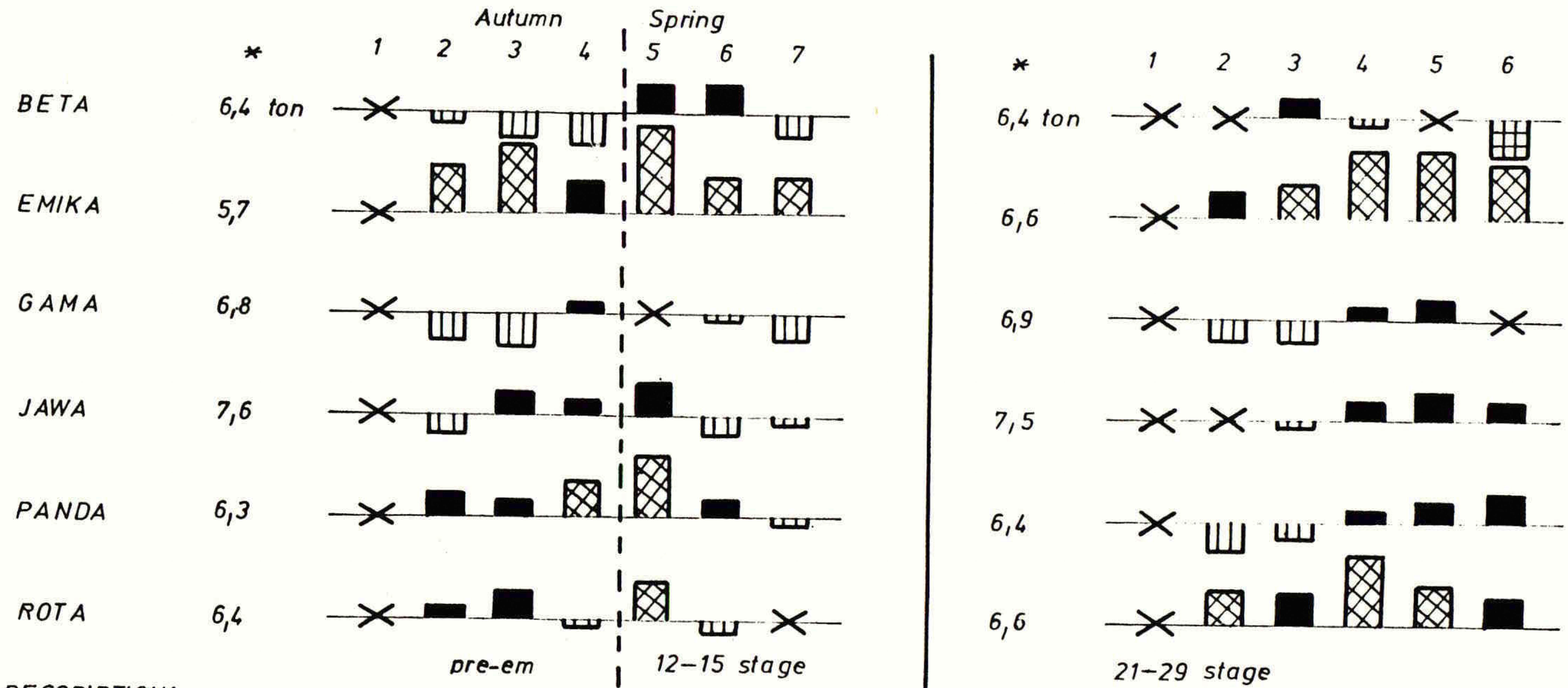
REACTION OF WINTER WHEAT VARIETES ON HERBICIDES (% OF YIELD)

FIGURE 1: ZECH-JUNG WROCŁAW 1984-86



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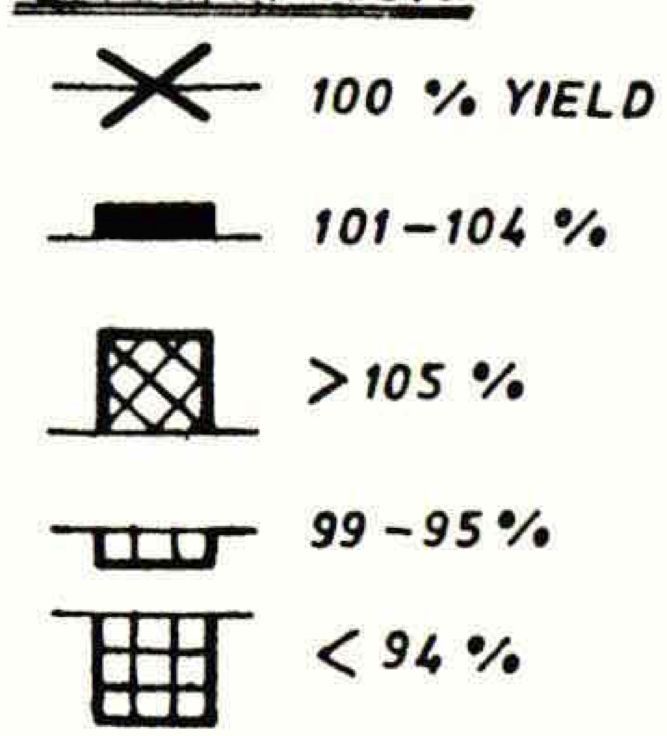


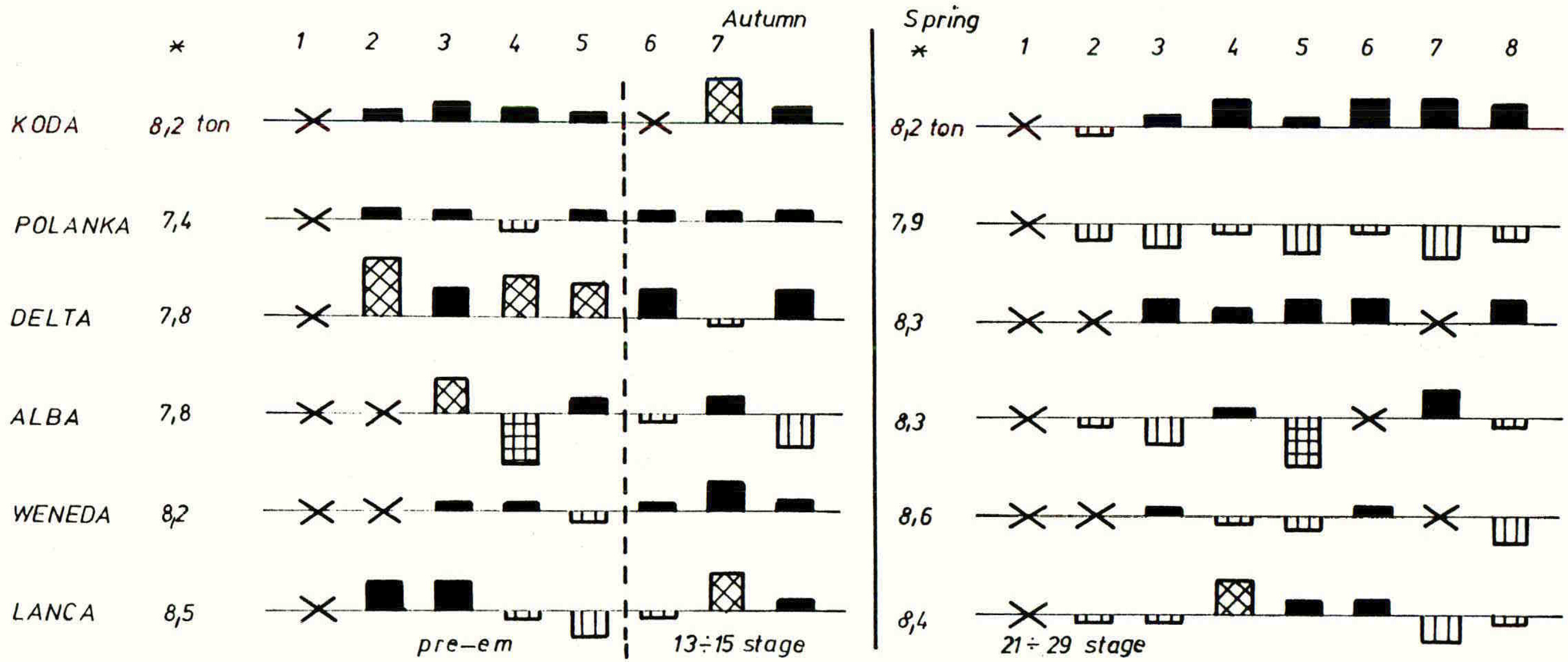
AUTUMN: * YIELD FROM CONTROL PLOTS
1. CONTROL
2. CHLORTOLURON 2000 g ai/ha
3. PENDIMETHALIN 1650 g ai/ha
4. METHABENZTHIAZURON 2100 g ai/ha

SPRING:
5. CHLORSULFURON 18.75 g ai/ha
6. METOXURON + SIMAZINE 1800+200 g ai/ha
7. ISOPROTURON 1500 g ai/ha

SPRING: * YIELD FROM CONTROL PLOTS
1. CONTROL
2. 2,4-D + DICAMBA 1080+84 g ai/ha
3. 2,4-D + DICHLORPROP 705+465 g ai/ha
4. MCPA + MECOPROP 450+500 g ai/ha
5. MCPA + DICAMBA 715+785 g ai/ha
6. MCPA + FLURENOL + DICAMBA 1050+200+100 g ai/ha

REACTION OF WINTER WHEAT VARIETES ON HERBICIDES
(% OF YIELD)

FIGURE 2: *ZECH – JUNG WROCŁAW 1987÷1988*



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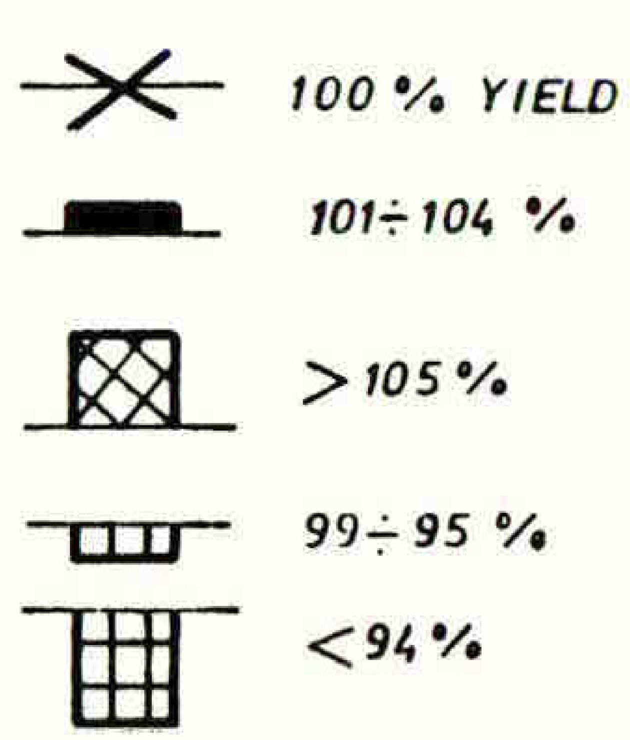

AUTUMN: * YIELD FROM CONTROL PLOTS

PRE-EM:
1. CONTROL
2. TRIFLURALIN + LINURON 1440 g ai/ha
3. LINURON + METHABENZTHIAZURON + TERBUTRYN 350+430+220 g ai/ha
4. CHLORTOLURON 1600 g ai/ha
5. CHLORSUFLURON 15 g ai/ha

POST-EM:

6. ISOPROTURON 1500 g ai/ha
7. CHLORSULFURON 15 g ai/ha
8. CHLORTOLURON 1600 g ai/ha

SPRING: * YIELD FROM CONTROL PLOTS
1. CONTROL
2. ISOPROTURON 1500 g ai/ha
3. LINURON + METHABENZTHIAZURON + TERBUTRYN 350+430+220 g ai/ha
4. CHLORSULFURON 15 g ai/ha
5. CHLORTOLURON 1600 g ai/ha
6. MCPA + FLURENOL + DICAMBA 1050+200+100 g ai/ha
7. 2,4-D – DICAMBA 1080+84 g ai/ha
8. 2,4-D – MECOPROP 705+465 g ai/ha

FIELD PERFORMANCE OF FENOXAPROP-ETHYL IN WHEAT IN NORTH AMERICA

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ABSTRACT

Comparative efficacy and crop tolerance of fenoxaprop-ethyl and HOE 7113 (fenoxaprop-ethyl + HOE 070542) is summarized from field trials executed from 1986-1989 in Canada and the United States. Tolerance of spring and winter wheat to fenoxaprop-ethyl was inadequate. A high degree of crop tolerance was achieved when fenoxaprop-ethyl was applied in the presence of HOE 070542. Control of Avena fatua and Setaria spp. by fenoxaprop-ethyl was rate dependant. Control of annual grass weeds was not adversely affected when fenoxaprop-ethyl was combined with HOE 070542.

INTRODUCTION

Fenoxaprop-ethyl (ethyl-2-[4-(6-chloro-2-benzoxazolyloxy)-phenoxy]-propanoate) (HOE 033171) and its resolved optical isomer fenoxaprop-p-ethyl (HOE 046360) were discovered by agricultural chemists at HOECHST AG in Frankfurt, West Germany (Bieringer *et al.*, 1982). HOE 046360 is considered to have the same herbicidal activity at half the dosage rate of HOE 033171 (Huff *et al.*, 1989a). In European tests, wheat has shown poor tolerance to fenoxprop-ethyl when applied at rates necessary to control annual grass weeds. The addition of an external modifier, HOE 070542, further augmented the difference in selectivity (Huff *et al.*, 1989b). Field trials were established to study efficacy associated with fenoxaprop-ethyl alone and in combination with HOE 070542 under North American conditions.

METHODS AND MATERIALS

All field trials were of a randomized complete block design, with a minimum of 3 replicates. Plot size was a minimum of 12 m^2. Applications were made with backpack or bicycle sprayers, pressurized by CO_2, at 275 kPa in a minimum of 100 l/ha of water via 80° or 110° flat fan nozzles. Crop phytotoxicity was assessed visually as % damage; weed control was assessed visually or via plant counts; yields were assessed via mechanical harvest by a small plot combine. All were compared to untreated check plots. Fenoxaprop-ethyl was applied as a 120 or 90 g a.i./L EC (emulsifiable concentrate). Fenoxaprop-p-ethyl was applied as a 75 g a.i./L EW (emulsifiable water-based formulation). HOE 6001 and HOE 7113 were applied as a 75 and 60 g a.i./L EW respectively.

RESULTS

Tolerance of hard red spring and durum wheat varieties (at Zadoks 14-22) to fenoxaprop-p-ethyl was evaluated in Canada in 1989. There did not appear to be tolerance differences between the 8 varieties of hard red spring wheat or the 3 varieties of durum wheat tested, therefore, results were averaged across varieties for each species and are summarized in Table 1. HOE 6001 at 100 or 200 g a.i./ha caused less phytotoxicity than equivalent rates of fenoxaprop-p-ethyl. Yields will be analyzed in the autumn of 1989.

Table 1. Tolerance of wheat to applications of fenoxaprop-p-ethyl, HOE 6001 and tralkoxydim, Canada (1989)

Treatment	Rate (g a.i./ha)	%Phytotoxicity (# of trials) Spring Wheat[1] 7-11 DAT	Spring Wheat[1] 16-22 DAT	Durum Wheat[2] 7-11 DAT	Durum Wheat[2] 16-22 DAT
fenoxaprop-p-ethyl	100	54.7 (11)	47.9 (11)	69.4 (3)	88.9 (3)
fenoxaprop-p-ethyl	200	66.2 (8)	56.6 (8)	73.6 (2)	83.4 (2)
HOE 6001	100	15.3 (11)	5.9 (11)	14.4 (3)	6.3 (3)
HOE 6001	200	12.8 (11)	5.8 (11)	11.9 (3)	6.3 (3)
tralkoxydim[3]	250	8.7 (11)	6.5 (11)	10.0 (3)	6.3 (3)
tralkoxydim	500	10.4 (8)	8.0 (8)	20.4 (2)	10.6 (2)

[1]Spring wheat varieties treated at Zadok's 12-22 were Columbus, Katepwa, Conway, Neepawa, Park, Hy320, Hy355 and Oslo
[2]Durum wheat varieties, treated at Zadok's 14-22 were Sceptre, Kyle and Wakooma
[3]Tralkoxydim was applied with crop oil concentrate at 0.5% v/v

In 1988, applications of fenoxaprop-p-ethyl and HOE 6001 were made to weed-free plots which included 8 hard red spring and 3 durum wheat varieties at two stages of plant growth (Zadoks 13-21 and 21-24) in the north central United States. Varieties within species responded similarly to treatment and results were averaged. Table 2 summarizes crop phytotoxicity at 21 DAT. Fenoxaprop-p-ethyl applied alone at 180 or 360 g a.i./ha caused 16-28% crop injury at early applications but only 5-10% at later applications. The crop was not notably injured by HOE 6001 at either growth stage when applied at the same rates. Durum wheat sustained greater injury than hard red spring upon application of fenoxaprop-p-ethyl. Phytotoxicity of HOE 6001 at 90 or 180 g a.i./ha never exceeded 14% on durum wheats.

In 1986, fenoxaprop-ethyl was applied at 180 and 360 g a.i./ha to hard red spring wheat in 6 weed-free locations in the north central United States. The relationship of phytotoxicity of wheat to crop yields is shown in Figure 1.

Yields with HOE 7113 were similar to the untreated check plots.

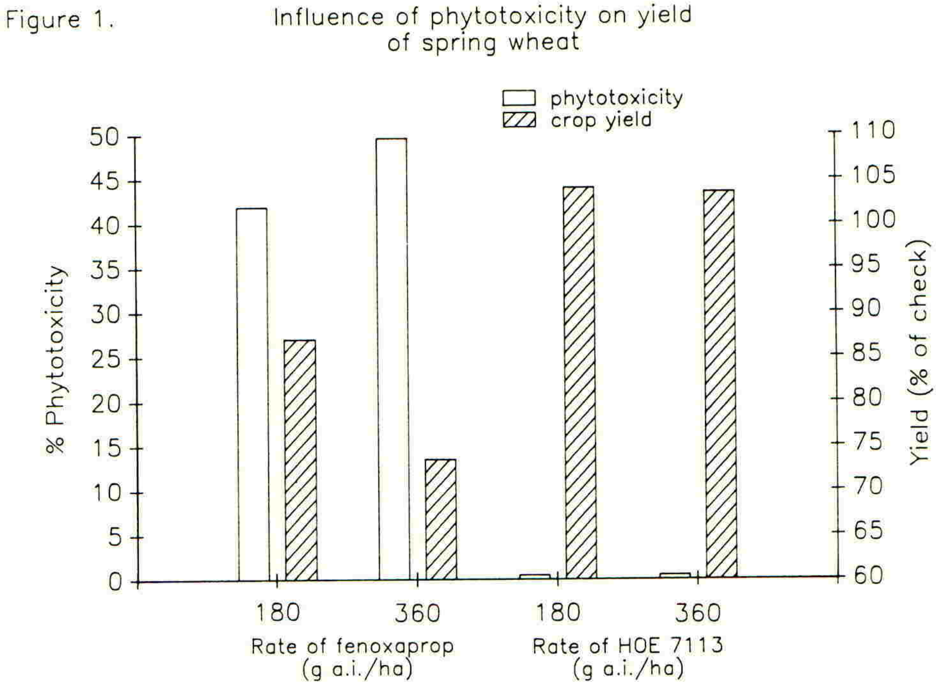


Table 2. Tolerance of wheat to applications of fenoxaprop-p-ethyl and HOE 6001, United States (1988)

Treatment	Rate (g a.i./ha)	% Phytotoxicity[1] Zadoks 13-21 HRS[2]	Zadoks 13-21 Durum[3]	Zadoks 21-24 HRS	Zadoks 21-24 Durum
fenoxaprop-p-ethyl	90	15.8	38.3	5.3	23.2
fenoxaprop-p-ethyl	180	27.7	53.3	10.2	64.7
HOE 6001	90	5.5	13.5	2.3	6.2
HOE 6001	180	3.4	11.2	1.2	4.6

[1]Phytotoxicity was rated in all plots at 21 DAT
[2]Hard red spring wheat varieties included Coteau, Butte 86, Telemark, Len, Alex, Pioneer 2369, Marshall and Stoa
[3]Durum wheat varieties included Vic, Ward and Rugby

Applications were made to wheat and grass weeds at two growth stages (Zadoks 13-21 and 21-24) in 1986. The data from these trials is summarized in Tables 3a (crop tolerance), 3b (<u>Avena fatua</u> control) and 3c (<u>Setaria</u> spp.control). Earlier applications of fenoxaprop-ethyl at 120 and 180 g a.i./ha injured wheat greater than later ones, although there was substantial phytotoxicity at each application stage. Crop tolerance to HOE 7113, diclofop-methyl and imazamethabenz was very good.

Table 3a. Phytotoxicity of fenoxaprop-ethyl and HOE 7113 on hard red spring wheat, United States and Canada (1986)

Treatment	Rate (g a.i./ha)	% Phytotoxicity (# of trials) Zadoks 13-21	Zadoks 21-24
fenoxaprop-ethyl	120	31.8 (14)	14.1 (13)
fenoxaprop-ethyl	180	35.4 (14)	22.8 (13)
HOE 7113	120	5.2 (14)	4.7 (13)
HOE 7113	180	4.1 (14)	4.2 (13)
diclofop-methyl[1]	1100	2.5 (10)	2.0 (7)
imazamethabenz	560	2.5 (5)	1.0 (4)

[1]Some treatments of diclofop-methyl were applied at 800 g a.i./ha and included bromoxynil at 280 g a.i./ha

Table 3b. Efficacy of fenoxaprop-ethyl and HOE 7113 to Avena fatua on spring wheat, Unites States and Canada (1986)

Treatment	Rate (g a.i./ha)	% Avena Control [Range] (# of trials) Zadoks 13-21	Zadoks 21-24
fenoxaprop-ethyl	120	74.6 [0-97] (13)	83.5 [9-98] (13)
fenoxaprop-ethyl	180	79.1 [37-98] (13)	90.7 [52-100](13)
HOE 7113	120	87.8 [50-100] (13)	88.6 [68-100](13)
HOE 7113	180	92.4 [75-100] (13)	96.7 [92-100](13)
diclofop-methyl*	1100	81.9 [48-97] (7)	77.2 [58-98] (8)
imazamethabenz	560	90.1 [81-97] (4)	91.4 [85-96] (4)

*Some treatments of diclofop-methyl were applied at 800 g a.i./ha and included bromoxynil at 280 g a.i./ha

Table 3c. Efficacy of fenoxaprop-ethyl and HOE 7113 to Setaria spp. on hard red spring wheat, Unites States and Canada (1986)

Treatment	Rate (g a.i./ha)	% Setaria Control [Range] (# of trials) Zadoks 13-21	Zadoks 21-24
fenoxaprop-ethyl	120	84.9 [31-100] (11)	93.3 [16-98] (11)
fenoxaprop-ethyl	180	81.0 [19-100] (11)	91.5 [48-100](11)
HOE 7113	120	82.7 [50-100] (11)	91.4 [57-100](11)
HOE 7113	180	91.0 [69-100] (11)	91.6 [84-100](11)
diclofop-methyl*	1100	85.6 [50-100] (6)	78.5 [40-97] (4)

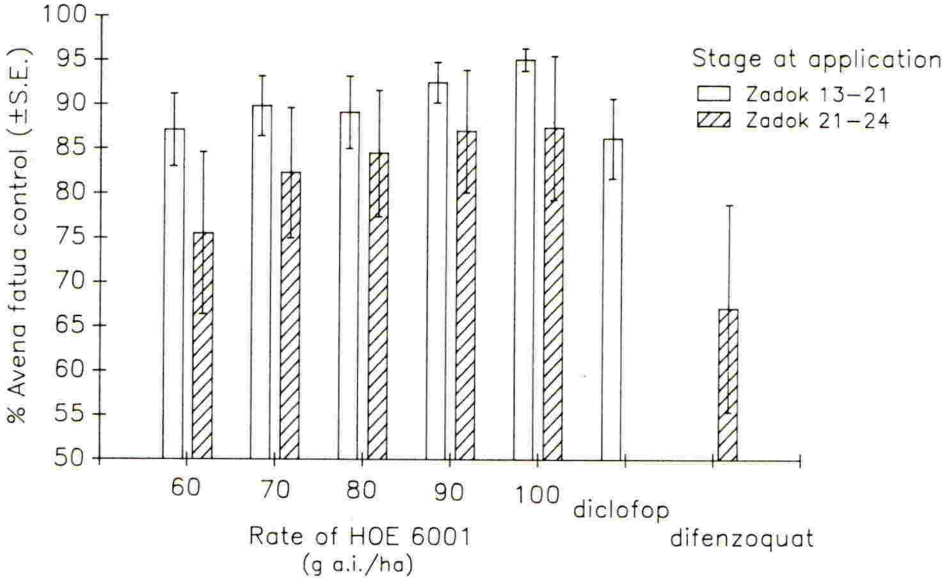
*Some treatments of diclofop-methyl were applied at 800 g a.i./ha and included bromoxynil at 280 g a.i./ha

Pre-tillering applications of fenoxaprop-ethyl at 120 and 180 g a.i./ha resulted in Avena fatua control of 75 and 79%, respectively while the same dosage rates of HOE 7113 improved

Avena fatua control to 88 and 92%. Differences were not as great at post-tillering (Table 3b). HOE 7113 at 180 g a.i./ha improved control of Setaria spp. by 10% over the same rate of fenoxaprop-ethyl in pre-tillered applications (Table 3c).

HOE 6001 was applied at 60, 70, 80, 90 and 100 g a.i./ha to spring and winter wheat in 1988 for the control of Avena fatua at two growth stages (Zadoks 13-21 and 21-24). The control achieved is illustrated in Figure 2.

Figure 2. Control of Avena fatua in wheat with HOE 6001



DISCUSSION

Application of fenoxaprop-ethyl to hard red spring, winter or durum wheat was extremely injurious. The magnitude of the damage was such that it often reduced yields under weed-free conditions. In these studies, the injury to wheat from these products was effectively mediated in the presence of HOE 070542. Doubling the dosage rate of HOE 7113 or HOE 6001 did not result in any additional phytotoxicity. Rather, crop damage was often further reduced at higher rates of HOE 6001 or HOE 7113, as the increased amount of HOE 070542 appeared to over-compensate for the increased amount of fenoxaprop-ethyl.

Within wheat species, durum was the least tolerant to applications of fenoxaprop-ethyl. Hard red spring and winter wheat varieties exhibited similar tolerance to these products. In the presence of HOE 070542 however, damage was so limited that no species separations were evident.

Generally, fenoxaprop-ethyl applied to pre-tillering crops was responsible for greater phytotoxicity than when applied to post-tillering crops. These differences in tolerance between crop growth stages were similar in nature with HOE 7113 and HOE 6001 but to a much lesser extent.

Avena fatua and Setaria spp., were very susceptible to applications of fenoxaprop-ethyl and fenoxaprop-p-ethyl. It appeared that control of these species was often improved in the presence of HOE 070542. It is apparent that the substantially improved crop tolerance associated with HOE 7113 and HOE 6001 allowed the crop to compete more effectively in preventing any possible weed regrowth and/or new germination, as there is no residual activity associated with these products. Average control of Avena fatua and Setaria spp. was most consistent with 180 g a.i./ha of HOE 7113. There was lower mean control as well as greater control variability when HOE 7113 was applied at 120 g a.i./ha. The rate of HOE 6001 was not as critical when applied to younger stages of Avena fatua. However, mean control improved and variability in control declined as the rate of HOE 6001 increased from 60 to 100 g a.i./ha. Rate of HOE 6001 was a more important factor in control when later applications were made to Avena fatua.

ACKNOWLEDGEMENTS

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EFFECT OF WHEAT SEED RATE ON *LOLIUM RIGIDUM* COMPETITION

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ABSTRACT

Over two years two wheat cultivars were grown at five seed rates with and without control of *Lolium rigidum* Gaud.(annual ryegrass). The herbicides used had no effect upon the crop. Results from both years showed that an increase in wheat seedrate reduced the number of ryegrass heads and dry matter weight/m^2 and increased grain yield. The effectiveness of the herbicide was similar in favourable and adverse conditions for weed growth at all seed rates but the lowest. The yield increase due to ryegrass control was higher with lower seedrates than with higher. The two cultivars did not respond similarly in the two years of experiments for all seedrates and ryegrass competition.

INTRODUCTION

Annual ryegrass (*Lolium rigidum* Gaud.) is a serious and widespread weed of cereal crops in Greece. In wheat crops about 80% of the emergence of ryegrass occurs during the autumn from October to December. Since most winter cereal crops are sown in November or December,crop and weed emergence often coincide. Therefore, as competition between ryegrass and wheat is mainly restricted to the pre-tillering period within 3-6 weeks of emergence (Reeves, 1976) the density of the crop is very important to its competitive ability. Medd *et al.* (1985) found that the effect of ryegrass was substantially reduced by increasing wheat cv Condor sowing density. However, the two wheat densities used were very low in comparison to recommended densities in Greece. Research was conducted to compare the effect of ryegrass competition on the relationship between seed rate, weed growth and grain yield of two wheat cultivars over two years.

MATERIALS AND METHODS

Two similar experiments were conducted over two years on alluvial soils typical of the wheat growing area. The soil was naturally infested with a high population of *Lolium rigidum*. The two wheat cultivars (*Triticum aestivum* L. em. Thell.) used, Aiges and Dio,represent commercially available cultivars for the area. Experimental design in both years was a split - split - plot arrangement of a randomized complete block with four replicates per treatment. Cultivars were the main treatment, seedrates and ryegrass control treatments being the sub-plots. Each sub-sub-plot consisted of 10 rows, 8.2 m long with 20 cm spacing. The wheat seedrates used were 120, 150, 180, 210 and 240 kg/ha. Sowing was done by hand in furrows opened by a small tractor. All emerged ryegrass and other plants were destroyed before sowing. Nitrogen (N) and phosphorus (P_2O_5) were applied at rates of 100 and 40 kg/ha, respectively, before sowing and 60 kg/ha of nitrogen was applied as top dressing at tillering. On the day of sowing the plots were rototilled and the fertilizer broadcast and incorporated.

Diplofop-methyl was used at the recommended rate of 800 g/ha applied at the two to three leaf stage to control ryegrass. Half of each seedrate plot was treated with the herbicide and the remaining plot was left to the natural infestation of ryegrass. Barriers constructed of plastic sheets were inserted at the sides of sprayed plots to prevent spray drift. All experimental plots were sprayed with 2.4-D in March for the control of broadleaved weeds. A propane-pressurized sprayer with a 2 m boom was used to apply the berbicides.

Seedling counds

Wheat seedlings were counted in two 0.5 m^2 quadrats, placed at random in each plot. The ryegrass seedlings emerging during and at the end of winter were counted in the same manner. Shortly before the wheat harvest ryegrass was collected from two random quadrats each 0.5 m^2. Ryegrass plants were hand pulled, dried, weighed and the number of heads counted. Both experiments were relatively free of broadleaved and other grass weeds, with only a very few wild oats being present.

Grain yield

When the wheat was ripe, yields were obtained by cutting a single swath of 1.25 m width from the centre of each plot with a small plot combine harvester. The grain from each plot was weighed and yields were adjusted to 12% moisture. The 1000- grain and hectolitre weights, sedimentation test (Zeleny, 1960), and protein content were determined to evaluate the effect of seedrate and ryegrass competition of the quality of grains. Data from both years were analyzed using analysis of variance.

RESULTS

Wheat established well at the five seedrates even though the second year was unusually dry. The average densities of the seedling populations are presented in Table 1.

TABLE 1. Number of wheat and ryegrass seedlings/m^2.

Seedrate kg/ha	Wheat seedlings/m^2		Ryegrass seedlings/m^2	
	Aiges	Dio	Aiges	Dio
120	311*e	329 e	67 a	76 a
150	369 d	398 d	66 a	67 b
180	427 c	455 c	46 b	44 c
210	497 b	520 b	48 b	48 c
240	548 a	563 a	41 b	44 c

*Figures with a common letter do not differ significantly at $p<0.05$.

Ryegrass density

The infestation of ryegrass was natural and the populations of both years were relatively dense. Seedlings emerged over a 2-month period but the majority of them, more than 80%, emerged in the autumn together with the wheat. The lower seedrates of both cultivars had the higher emerged ryegrass populations. At the other seedrates the numbers of ryegrass seedlings were similar (Table 1).

Diclofop-methyl had no effect upon the wheat but gave satisfactory control of ryegrass at all seedrates in both years (Tables 2 and 3).Ryegrass heads and ryegrass d.m. progressively reduced as wheat seed rates were increased.Application of diclofop-methyl gave > 96% reduction of ryegrass seedheads in year 1 and 83-94% reduction in the dry conditions of year 2.Dry matter reductions ranged 88-96% in year 1 but only 70-91% in year 2. The lowest reduction (70%) occured at the lowest seed rate of cv Dio while the greatest reduction (91%) occured at the highest seed rate of cv Aiges.

Grain yield

Grain yields varied between the years because of the differences in rainfall.The highest yield in plots with ryegrass control was 4640 and 4345 kg/ha in the first year for cv Aiges and Dio, respectively. In the second year it was 3056 and 2575 kg/ha. The highest yield of the ryegrass infested plots was 3645 and 3573 kg/ha in the first year and 2456 and 2221 kg/ha in the second for each cv respectively (Table 4).

Ryegrass control increased yields in the first year by 26-43% for cv Aiges and by 22-46% for cv Dio and in the second year by 10-30% and 14-19% respectively.The highest increases were associated with the lower seedrates. This was related to the higher densities of ryegrass at the lower seedrates.

After the control of ryegrass in year 1, only the lowest seedrates gave reduced yields. In year 2 yields increased with seed rate from 120-210 kg/ha for cv Aiges and at all increases in seed rate for cv Dio. Where ryegrass was not controlled, the lowest yields were achieved by the lowest seedrate (120 kg/ha) in both years. These low yields were generally associated with the higher values of ryegrass d.m./m^2. This suggests a high degree of competition from the weed and that grain yield was negatively correlated with ryegrass density (Figure 1).The failure of cv Aiges to maintain yield increases when sown at 240 kg/ha indicates the onset of intra-specific competition.

Increasing the seedrate had no effect on the baking quality of the grain from both cultivars with or without ryegrass competition, but after ryegrass control the quality was a little better than without control as shown by the results of the sedimentation test and protein content evaluation (Table 5).

DISCUSSION

The four seedrates, 150 to 240 kg/ha, studied in these experiments,were selected as representative of the range normally encountered in wheat growing areas of Greece. The seedrate 120 kg/ha is used by farmers in years with very favourable environmental conditions during autumn in fields with good seedbeds.

The results of these experiments show that the cultivars differ in their ability to compete with ryegrass. This difference had no effect on the number of ryegrass plants established by December-January each year, but a large effect on the number of heads developed. There was almost a

TABLE 2. Effect of seedrate on number of ryegrass heads/m^2.

		1st year					2nd year				
		Seedrate (kg/ha)					Seedrate (kg/ha)				
Cultivar	Treatment	120	150	180	210	240	120	150	180	210	240
Aiges	Unsprayed	860	648	533	555	371	202	137	100	73	34
	Sprayed	4	8	14	7	7	16	14	6	9	6
Dio	Unsprayed	473	419	334	308	279	114	106	110	76	40
	Sprayed	8	6	11	12	9	10	11	9	12	4

1st year LSD p=0.05, Seedrate 61, Treatment 123, Cultivar 39, T x C NS, T x SR 55, SR x C 87

2nd year LSD p=0.05, Seedrate 15, Treatment 31, Cultivar 9.8, T x C 22, T x SR NS, SR x C 22.

TABLE 3. Effect of seedrate on total dry weight of ryegrass (g/m^2).

		1st year					2nd year				
		Seedrate (kg/ha)					Seedrate (kg/ha)				
Cultivar	Treatment	120	150	180	210	240	120	150	180	210	240
Aiges	Unsprayed	1155	885	803	600	545	531	458	443	249	150
	Sprayed	59	68	72	63	21	85	49	47	31	13
Dio	Unsprayed	1060	640	509	543	423	616	489	433	314	175
	Sprayed	123	58	54	63	58	182	94	70	46	29

1st year LSD p=0.05, Seedrate 74, Treatment 149, Cultivar 47, T x C NS, T x SR 66, SR x C 105

2nd year LSD p=0.05, Seedrate 46, Treatment 92, Cultivar 29, T x C NS, T x SR NS, SR x C 65.

TABLE 4. Effect of seedrate on grain yield (kg/ha).

		1st year					2nd year				
		Seedrate (kg/ha)					Seedrate (kg/ha)				
Cultivar	Treatment	120	150	180	210	240	120	150	180	210	240
Aiges	Unsprayed	2813	3168	3625	3638	3645	1779	2231	2353	2456	2295
	Sprayed	4013	4103	4640	4593	4635	2314	2702	2948	3056	2524
Dio	Unsprayed	2843	3163	3568	3533	3573	1669	1664	1878	2009	2221
	Sprayed	4148	4278	4338	4325	4345	1963	1983	2148	2296	2575

1st year LSD p=0.05, Seedrate 255, Treatment 509, Cultivar NS, T x C NS, T x SR NS,SR x C NS

2nd year LSD p=0.05, Seedrate 238, Treatment 477, Cultivar 150, T x C 337, T x SR NS,SR x C NS.

two-fold difference in ryegrass head density between the two cultivars grown at the same original weed infestation level. Crop yields were also influenced by the different competitive abilities. The effects of competition varied between experiments.

TABLE 5. Effect of seedrate on sedimentation test and protein content.

		Sedimentation test						Protein content					
		Seedrate (kg/ha)						Seedrate (kg/ha)					
Cultivar	Treatment	120	150	180	210	240	Mean	120	150	180	210	240	Mean
Aiges	Unsprayed	20	22	21	19	19	20	12.35	12.39	12.25	12.02	13.06	12.41
	Sprayed	21	22	22	19	21	21	12.66	13.69	13.76	12.27	13.08	13.09
Dio	Unsprayed	13	15	13	17	16	15	11.30	11.96	11.08	12.77	12.36	11.89
	Sprayed	18	19	17	17	18	18	12.88	12.90	12.95	12.31	13.41	12.89

Sedimentation test LSD p=0.05, Cultivars 3.9, Treatment 0.9, All others NS
Protein content LSD p=0.05, Treatment 0.4, All others NS.

Wheat seed rate is usually considered to have relatively little influence on final crop yield. This view was not supported by the results of these experiments. There were significant differences in crop yield between the two lower and the higher crop seedrates used in the abcence of weed competition (in one cultivar in the first year and in both in the second). In the presence of ryegrass yields were also significantly higher at the higher crop seedrates for the two cultivars in both years. Also the number of ryegrass heads and d.m. declined as crop seedrate increased presumably due to greater crop competition. In the first year there were

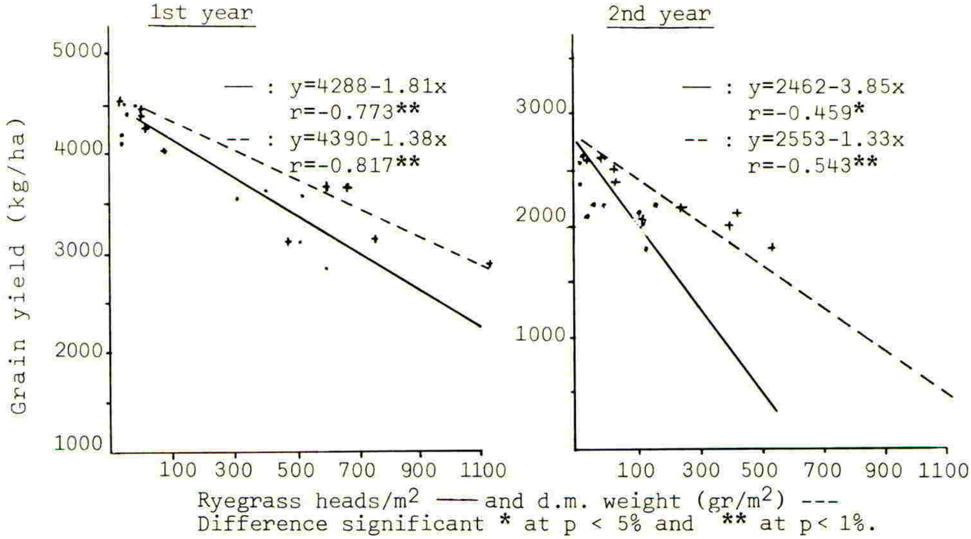

Fig.1. Relationship between ryegrass heads/m^2, d.m. weight (gr/m^2) and grain yield.

approximately half as many weed heads in the crop sown at the highest seedrate as in that sown at the lowest rate, while in the 2nd year these differences were even greater. The same was true for d.m. weight of ryegrass. Similar results have been found with ryegrass and other weeds in cereal crops (Moss,1987, Skorda and Efthimiadis,1985, Medd *et al.*,1985, Anderson, 1988).

Reductions of wheat yields due to ryegrass competition were greatest for both cvs at the lowest seedrate and similar at the three highest seedrates in the first year. In the second year, which was very dry, the reduction of cv Aiges yield was greatest at the first four rates and least at the highest seedrate. However, this seedrate (240 kg/ha) did not produce the optimum yield with or without ryegrass competition. High seedrates deplete soil moisture reserves more rapidly than low rates and this can result in lower yields when moisture supply is limiting (Pelton, 1969). In contrast, in cv Dio, in this dry year, the reduction of yield due to ryegrass was almost constant for all rates and the ryegrass number of heads/m^2 was relatively low. This may be because cv Dio plants can utilise the soil moisture reserves better than ryegrass. The two cultivars also differ in height and drought tolerance. Cultivar Dio is more drought resistant and 10 cm taller than Aiges. Appleby *et al.* (1976) also found that two short wheat cultivars were more sensitive to *Lolium multiflorum* competition than were two taller, varieties. However, as competition between ryegrass and wheat is mainly restricted to the pre-tillering period (Reeves, 1976), the better use of available moisture by cv Dio may contribute to its increased competitive ability.

It is concluded that use of a wheat seedrate of 180 to 210 kg/ha provides better control of ryegrass under semi-arid mediterranean conditions. Seedrates lower than 180 kg/ha are more sensitive to ryegrass competition and may therefore yield less grain. Such low wheat densities also exert a reduced level of competition on the ryegrass, allowing its plants to produce more seeds. The effect of wheat seedrate on other weed species that may be present could be similar.

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BIOASSAY OF TRIALLATE TOLERANCE FOR WHEAT VARIETIES

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ABSTRACT

Triallate tolerance of *Triticum aestivum* L. and *T. turgidum* L. cultivars can be quickly assessed under growth chamber conditions. Germinated wheat seeds with 2-3 mm coleoptiles were exposed to triallate concentrations between 0 and 1 ppm for two days; growth of the coleoptiles two days after the exposure, or length of the first leaf after one week is considered a quick indication of triallate tolerance with good correlation to field evaluations.
Among the 12 cultivars tested, wheat cv. Mexicali tolerated 4 times higher concentrations of triallate than the sensitive cv. Marius.

INTRODUCTION

Wild oat (*Avena* spp) is the main grass weed in Spanish cereals, with over 1 million Ha infested (García-Baudín, 1984).

The use of herbicides containing triallate is important in wheat and barley because they remove wild oats before they can compete with the crop. Some differences in tolerance to triallate among wheat cultivars have been reported (Norris and Lardelli, 1972; Schaat and Thill, 1984; Mascia et *al*., 1988).

In two field trials in Cadiz and Cuenca, under different climatic conditions, triallate applications pre-plant incorporated (outside label recommendations in wheat), also showed varietal differences; wheat cv. Marius was damaged by triallate 1.2 Kg a.i./Ha while wheat cv. Mexicali tolerated 3.6 Kg a.i./Ha of triallate pre-plant incorporated (Costa, personal communication).

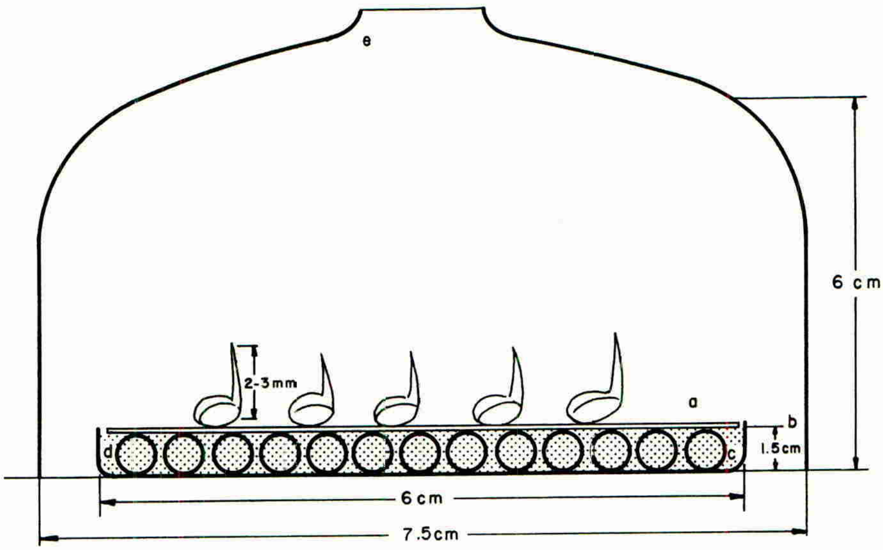
The objective of this work was to develop an easy method of assessment of varietal differences among wheat cultivars which are predictive of field tolerance to triallate.

MATERIALS AND METHODS

Seeds from 10 *Triticum aestivum* L. cultivars and 2 *T. turgidum* L. cultivars were germinated until coleoptiles were 2-3 mm long. Five germinated seeds of each variety were exposed to triallate solutions of 0, 0.25, and 0.50 ppm. The seeds were placed on filter paper within Petri dishes covered with a transparent plastic lid as indicated in Figure 1.

The Petri dishes, with a minimum of four replicates per treatment were placed in a growth chamber with a 16 h day at 25 +/- 1^{o}C and 8 h night at 15 +/- 1^{o}C under a 60 uEm^{-2}s^{-1} light.

FIGURE 1. Bioassay details; a) germinated wheat seeds, b) filter paper, c) hollow glass rods, d) triallate solution, and e) closed plastic lid.



Growth of the wheat, from the coleoptile base to the tip of the leaf, was measured 48 h following exposure to triallate.

A second experiment, comparing only Marius and Mexicali wheat cultivars was conducted with five replicates per treatment using the techniques described above. The triallate concentrations in this experiment were 0, 0.25, 0.50, and 1.00 ppm. Following the 48 h growth measurement, the five seedlings of each treatment were transplanted into 15 cm pots containing untreated soil and grown under the described growth chamber conditions. One week after transplanting the height of plants was measured from the base of the shoot to the tip of the first leaf.

RESULTS AND DISCUSSION

Growth results of the first experiment are shown in Table 1 in absolute length, and in Figure 2 as a percentage of the untreated plants of each variety.

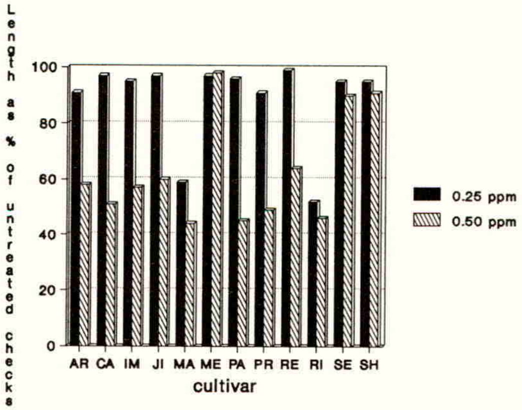
These results show that most cultivars do not differ significantly from the untreated checks following exposure to 0.25 ppm triallate, with the exceptions of cvs. Marius and Rinconada. At the higher 0.50 ppm triallate concentration most cultivars differ significantly from the untreated checks with the exception of cvs. Mexicali, Shasta and Sevillano.

The results of the second experiment are shown in Figure 3 as a percentage of untreated controls after 48 h exposure and in Figure 4 as a percentage of untreated controls one week after transplanting into untreated soil.

TABLE 1. Length in mm of wheat leaves of different cultivars following 48 h exposure to triallate. (ISED).

Cultivar	Triallate concentration (ppm)		
	0	0.25	0.50
Aragón 03 (AR)	58,64+/-5,31	58,36+/-3,21	34,00+/-4,66
Castan (CA)	41,90+/-2,76	40,45+/-3,01	21,45+/-0,81
Impeto (IM)	46,30+/-2,55	43,85+/-5,73	26,52+/-2,07
Jiloca (JI)	46,00+/-4,95	44,43+/-3,10	27,83+/-9,67
Marius (MA)	51,00+/-2,29	30,32+/-5,06	22,72+/-2,41
Mexicali (ME)	44,90+/-2,36	34,73+/-3,68	44,07+/-4,57
Pavon (PA)	46,80+/-4,15	44,75+/-2,93	21,24+/-0,57
Paramo (PR)	49,64+/-0,73	45,36+/-3,62	24,28+/-5,79
Recital (RE)	39,55+/-2,79	39,15+/-0,91	25,20+/-6,04
Rinconada (RI)	43,28+/-3,95	22,44+/-1,78	19,88+/-0,58
Sevillano (SE)	48,76+/-2,50	46,36+/-2,97	43,68+/-3,90
Shasta (SH)	51,12+/-1,31	48,52+/-1,91	46,60+/-3,30

FIGURE 2. Relative growth of wheat leaves following 48 h exposure to triallate.



The results confirm those found in the first experiment. Comparing growth response to different triallate concentrations, cv. Mexicali at 1.00 ppm was less inhibited than cv. Marius at 0.25 ppm.

Moreover, one week after transplanting into untreated soil, the differences between Mexicali and Marius were not reduced.

These results parallel field observations and indicate that the growth measurement after 48 h exposure is a valid method to screen cultivar tolerance to triallate.

FIGURE 3. Relative growth of Marius and Mexicali wheat cultivars following 48 h exposure to triallate.

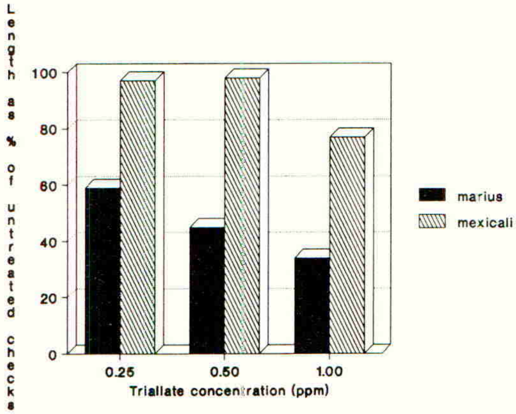
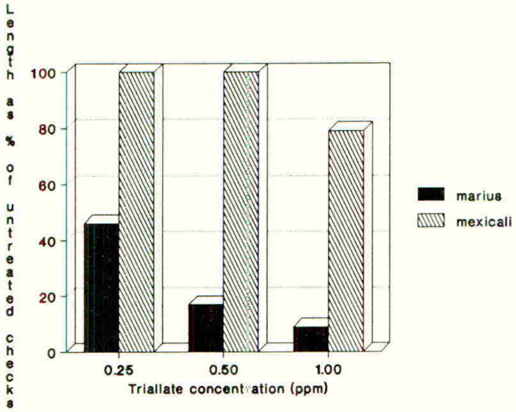


FIGURE 4. Relative growth of Marius and Mexicali wheat cultivars one week after transplanting.



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