Session 6C

Weed Control in Major Crops

Session Organisers	Mr M Lainsbury and Dr M Heath
Poster Papers	6C-1 to 6C-26

THE RELATIONSHIP BETWEEN HEIGHT REDUCTION, LODGING CONTROL AND YIELD IN WINTER BARLEY FOLLOWING USE OF TRINEXAPAC-ETHYL

J A TATNELL
Ciba Agriculture, Whittlesford, Cambridge CB2 4QT

ABSTRACT

The plant growth regulator, CGA163935 (trinexapac-ethyl), was tested on winter barley for the control of lodging. There was no significant crop phytotoxicity and in the absence of lodging CGA163935 did not affect yield or grain quality. Severe lodging occurred, and a direct relationship was established between the degree of height reduction and control of lodging. This resulted in improved yield in comparison to the untreated and standard treatments. Given the consistent relationship between height reduction by CGA163935 and lodging control, height reduction induced at unlodged sites could be used as a reliable indicator of the degree of lodging protection afforded.

INTRODUCTION

CGA163935, a cyclohexanedione compound first described by Kerber et al. (1989), represents a potent new chemical class of plant growth regulators. CGA163935 is taken up via the foliage, hydrolysed to its active form CGA179500, and translocated to the shoot meristem where it inhibits post GA12-aldehyde reactions in the biosynthesis of the plant growth hormone gibberellic acid. This inhibition results in a reduction in the length of those internodes that elongate after application, and therefore a shorter more sturdy plant (Kerber et al. 1989 and Adams et al 1991 a.b).

MATERIALS AND METHODS

CGA163935 was field tested in 4 small plot trials on commercial crops. The trials were of a randomised complete block design with four replicates. The plot size was 3m x 12m and a 3m untreated guard strip was left between each replicate. Fertiliser application, disease, pest and weed control were carried out by the farmer on site, with regard to soil type, variety and good agricultural practice. Test applications were made using a CO_2 - pressurised Ciba small plot sprayer fitted with six Lurmark 02 - F110 nozzles and calibrated to deliver 200 l/ha at 207 kPa and a forward walking speed of 1 m/second. CGA163935 was tested as an emulsifiable concentrate formulation (250 EC = 250 g ai/l). A range of rates were tested to ensure efficacy comparisons with standard treatments given the difficulty of predicting lodging events. Applications were made as close as possible to two timings in line with agricultural practice:

- Timing 1 (T1): GSZ 30-32 as recommended for Chlormequat chloride+choline chloride. To shorten and strengthen the lower two internodes of the stem and increase lodging resistance.

- Timing 2 (T2): GSZ 37-39 as recommended for Mepiquat chloride+ethephon for maximum activity. To reduce the length of and strengthen the upper internodes and stem overall, increasing lodging resistance.

Development stages were taken from the growth stages key by Zadoks (Tottman 1987). Crop phytotoxicity was monitored at intervals after application up to ear emergence on a percentage scale where 0% = no damage, 100% = crop death and above 10% = unacceptable damage.

Growth regulation was monitored by six *in situ* height measurements per plot at the end of flowering. The degree of lodging was assessed on a 0-100 scale where 0 = stems erect and 100 = stems horizontal (completely lodged). The Lodging index was then calculated according to Bolton and Adam (1987): Lodging Index = (% area of plot lodged x degree of lodging) / 100.

The trials were harvested when the untreated plots were mature using a `Sampo' small plot combine harvester, with a 2.0m cut. In each case a single cut was taken from the centre of each plot. Seed yields were corrected to 15% moisture and converted to t/ha. Statistical analysis of variance was performed on crop height, seed yield and 1000 grain weight measurements for individual trials data using Tukeys t-test. Dry Base Nitrogen analysis (DBN) was carried out on barley seed from selected treatments to determine if treatment affected grain quality. Test treatments are listed below.

Treatment	Dose (g ai/ha)	Timing
1. Untreated	-	-
2. CGA163935	75	T1
3. CGA163935	100	T1
4. CGA163935	200	T1
5. CGA163935	75	T2
6. CGA163935	100	T2
7. CGA163935	150	T2
8. CGA163935	200	T2
9. CGA163935	300	T2
10. Chlormequat chloride+choline chloride	1613	T1 standard
11. Mepiquat chloride+ethephon +Agral 90 (40ml/100 l spray equivalent)	610+310	T2 standard

RESULTS

No treatment caused any significant crop phytotoxicity. At the highest rate of 300 gai/ha, CGA163935 gave a maximum average of 1.25% burning at application. Table 1 details the meaned results of height, lodging index, yield, 1000 grain weight and DBN. Results are presented as a percentage of the untreated. Figures 1 and 2 show the relationship between height reduction and lodging control with CGA163935 and standard treatments from applications at T1 and T2 respectively.

Table 1. % height, lodging Index, yield, 1000 grain weight and DBN analysis vs untreated.

		PARAMETER (Av. 4 trials vs unt.)				
Treatment	Dose g a.i./ha	% Height (cm)	% Lodging Index	% Yield (t/ha)	1000 grain wt.	DBN analysis
1. untreated		(105.0 cm)	(64.2)	(7.1 t/ha)	(36.3g)	(1.82)
2. CGA163935	75	93.0	34.4	110.3	99.7	100
3. CGA163935	100	89.2	5.6	117.2	101.1	93.4
4. CGA163935	200	80.7	0.8	116.4	102.1	-
5. CGA163935	75	87.9	52.0	108.7	103.5	98.9
6. CGA163935	100	87.9	40.2	115.0	107.7	98.9
7. CGA163935	150	85.6	18.2	114.8	102.5	102.7
8. CGA163935	200	78.2	9.0	118.0	106.5	-
9. CGA163935	300	73.1	0.8	121.3	106.0	-
10. CC+CC*	1613	96.6	82.9	96.0	98.3	101.6
11. MC+E(+Ag)**	920	83.9	9.0	116.5	104.3	98.4

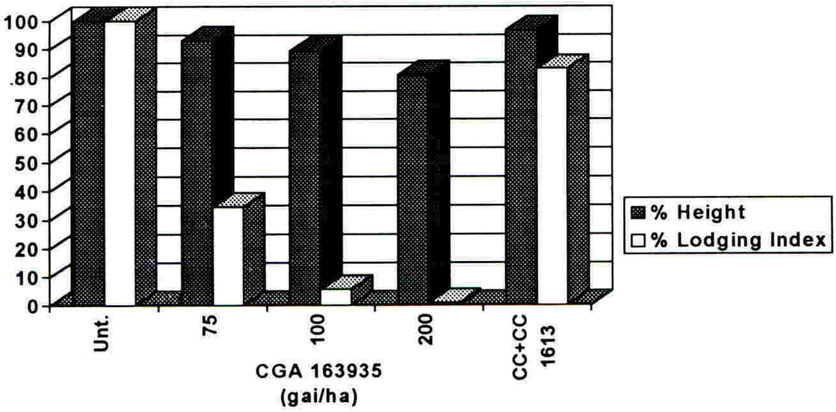
* = Chlormequat chloride+choline chloride.

** = Mepiquat chloride+ethephon+Agral 90

Figures 1 and 2 show a dose response for height reduction from CGA163935 at T1 and T2. Lodging occurred at all sites and lodging control was directly related to height reduction. At T1 (Figure 1), CGA163935 reduced height and lodging at all rates. Crop height reduced linearly with dose, with a corresponding reduction in lodging. 100 gai/ha, CGA163935 produced an 11% height reduction resulting in 94% control of lodging. Chlormequat chloride+choline chloride gave only a 3% height reduction, and only reduced lodging by 17%. The performance of the standard treatment was unacceptable given this level of lodging.

Figure 1 : Winter Barley

Height vs Lodging at T1



At T2 (Figure 2), height reduction by CGA163935 was again dose related, and the same direct relationship between height reduction and lodging control was apparent. 150-200 gai/ha CGA163935 gave lodging control equivalent to Mepiquat chloride+ethephon+Agral 90 at the full rate, and 300 gai/ha controlled lodging almost completely.

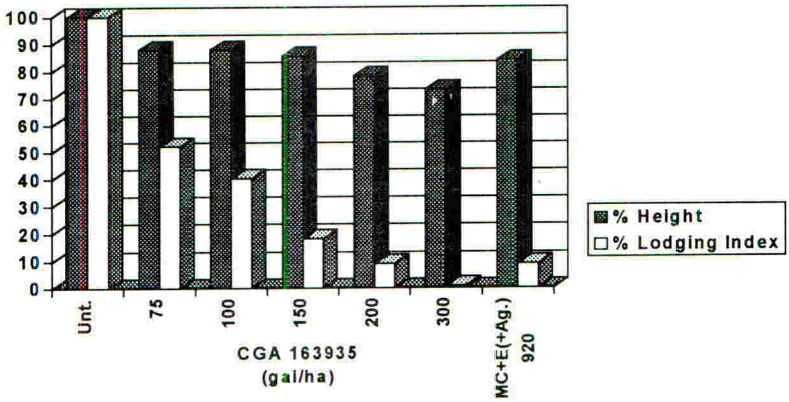


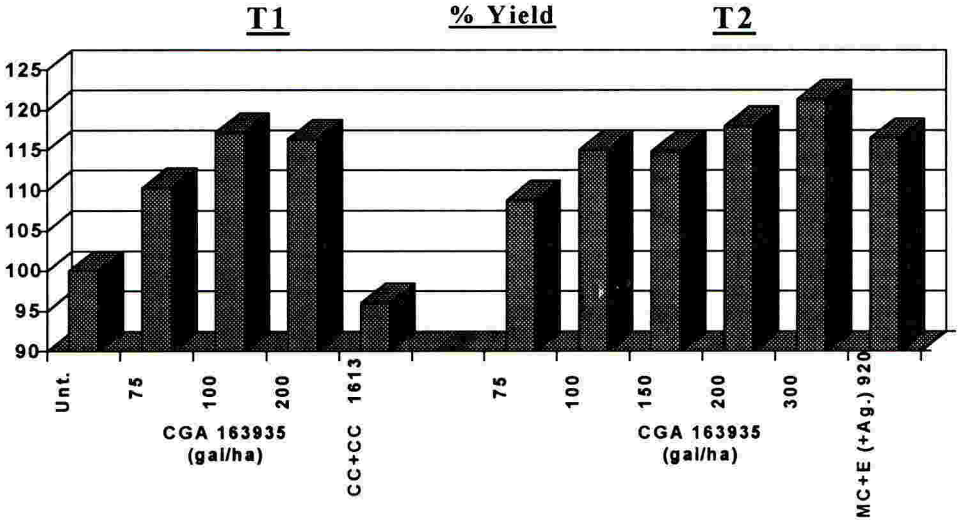
Figure 2 : Winter Barley

Height vs Lodging at T2

T1 applications resulted in shortening and strengthening of the lower two internodes, although compensatory growth in subsequent internodes can reduce final effects on height. Table 1 shows that although applications of CGA163935 at T1 and T2 both result in a dose dependant height reduction, for a given dose final height reduction is slightly greater from T2 applications. At T2 the upper internodes are shortened offering no possibility for compensatory regrowth. However applications at both timings reduce lodging effectively, CGA163935 appearing more active in this respect at T1 despite the smaller overall height reduction (see fig. 1 and 2). This indicates that lower stem strength is important in determining lodging susceptibility and counterbalances any compensatory growth in the upper internodes. Thus the correlation between dose, height reduction and lodging control remains the same for both application timings. The unpredictable nature of lodging is a problem when choosing sites but the relationship between height reduction and lodging control was very clear in these trials. Therefore under conditions of high lodging risk, height reductions can be used to indicate the degree of lodging protection conferred by plant growth regulators, regardless of application timing, even if lodging does not occur.

Figure 3 shows the effects of applications of CGA163935 and standard treatments at T1 and T2 on yield. Yield response was directly related to lodging control. Lodging was not fully controlled at all sites and thus comparison with the performance of the standards was critical. At T1, Chlormequat chloride + choline chloride had little effect on lodging and gave a yield similar to the untreated. By comparison 100 g a.i./ha CGA163935 gave almost full lodging control resulting in a 17% greater yield than the untreated. 75g CGA163935 reduced lodging by two thirds giving a 10% yield advantage. At T2, Mepiquat chloride + ethephon gave almost full control of lodging and 150 g a.i./ha CGA163935 gave slightly reduced control. This was reflected in the plot yields with a 15-16% yield advantage. 300 g a.i./ha CGA163935 gave a 21% yield saving illustrating the disastrous effects lodging has on recoverable yield. No treatment caused any significant changes in 1000 grain weight, and DBN analysis indicated no effects on grain quality from CGA163935 or standard treatments.

Figure 3 : W.Barley



DISCUSSION

The results presented herein indicate that CGA163935 had no adverse phytotoxic or grain quality effects up to the highest rates tested. CGA163935 also caused a consistent rate related height reduction at both application timings giving it a greater flexibility of use than the standard treatments. Lodging control and consequent yield protection by CGA163935 depended directly upon the degree of height reduction. Therefore at sites which are at a high risk of lodging but at which lodging has not yet occurred, height reduction can be used to predict the degree of lodging protection conferred by a plant growth regulator application. CGA163935 gave superior lodging control to chlormequat chloride + choline chloride at 1613 g ai/ha (T1), and near identical control to Mepiquat chloride + ethephon at 920 g ai/ha + Agral 90 (T2), at the 100/150 g ai/ha rates. This is a significant reduction in active ingredient inputs and affords the best yield protection allowing the full yield potential of the crop to be expressed.

Field testing of plant growth regulators is demanding since lodging is not a consistent phenomenon. Lodging affects yield and consequent financial returns and in its absence other means of interpreting trials data must be found to compare growth regulator performance. In Ciba trials where lodging did occur a link was established between height reduction and lodging/yield protection. Height reduction is a consistent effect of growth regulators and given the link described above can be used as an indication of lodging/yield protection afforded even in the absence of lodging. Independent evidence to support this link was accumulated by Easson et al (1992). They concluded that lodging was a result of the interplay between stem and root/soil factors as influenced by the weather, and that lodging occurred when a critical loading was generated by the aerial shoot which the root/soil system or lower stem was unable to resist. Critical loading depends on the crop, weather and the soil. The loading generated by the aerial stem is increased by greater deflection and this is increased by several factors including thinner and longer stems, stems with a higher fresh weight, higher ear fresh weight, greater surface area of the plant for rain retention (increasing weight), and wind action. Plant growth regulators affect plant growth and reduce the length and surface area of plant stems and leaves reducing the loading potential of the shoot and increasing the severity of weather events needed to produce a critical loading. Height reductions can therefore be used reliably to indicate the likely effectiveness of plant growth regulator treatments before, or in the absence of lodging.

Lodging prevention ensures maximum yield recovery and quality and prevents potentially large financial losses. A crop that is standing at harvest will be harvested more easily, rapidly and completely than a lodged crop reducing time and energy inputs. A lodged crop is likely to dry more slowly and grain will therefore have a higher moisture content at harvest resulting in the need for more expensive post harvest drying. Additionally lodged crops are more susceptible to fungal infection due to higher moisture levels, and also to pest/bird attack. The data presented herein shows that CGA163935 provides effective protection against lodging at a lower application rate and across a wider application window than current standard treatments.

ACKNOWLEDGEMENTS

Thank you to Pat Ryan for his help in producing this paper, and to my departmental colleagues for their help in the collection of field data.

REFERENCES

Adams, R; Kerber, E; Pfister, K; Weiler, E W (1991a) Studies on the action of a new plant growth retardant CGA163935. *11th International Conference on Plant Growth Substances, Amsterdam*. (In Press).

Adams, R; Kerber, E; Pfister, K; Weiler, E W (1991b) Studies on the action of a new plant growth retardant CGA163935. *Brighton Crop Protection Conference - Weeds 1991.* (In Press).

Bolton, B J G; Adam, N M (1987) Growth regulation of winter oilseed rape with RSW 0411. *Proceedings of Crop Protection in Northern Britain 1987*, 214-219.

Easson, D L; White, E M; Pickles S J (1992) A study of lodging in cereals. *HGCA report No. 52.*

Kerber, E; Leypoldt, G; Seiler, A (1989) CGA163935 a new plant growth regulator for small grain cereals rape and turf. *Brighton Crop Protection Conference - Weeds 1989,* **1**, 83-88.

Tottman, D R (1987) The decimal Key for the growth stages of cereals with illustrations. *Ann. Appl. Biol.* (1987), 110, 441 - 454.

COMPARING WEED CONTROL STRATEGIES IN ORGANIC AND CONVENTIONALLY GROWN WINTER WHEAT

A B DAVIES, M T F TURNER, R JOICE AND L NOBLE

Rhône-Poulenc Agriculture Ltd, Fyfield Road, Ongar, Essex, CM5 0HW.

ABSTRACT

The weed control strategy for the organically grown winter wheat crops in the Rhône-Poulenc Farm Management Study was a high seed rate (250 kg/ha), the use of a harrowcomb weeder and a fertility building crop rotation. On the conventionally managed study area, weeds were controlled using the full range of herbicides. Weed species and their frequency of occurrence were recorded over this initial three year period. The harrowcomb weeder was effective in reducing the frequency of occurrence of broad-leaved weed species such as *Stellaria* and *Veronica*. Generally, there was no impact on the number of species present and the perennials such as *Phleum pratense* and *Poa trivialis* increased. Autumn use of the harrowcomb was ineffective. Herbicides consistently controlled weeds in the conventional study crops. In view of the lack of control over perennial weeds by the harrowcomb, the effects of the rotation are discussed along with its possible use in Integrated Crop Management systems.

INTRODUCTION

In 1989 a study to monitor the effects of an organic and conventional arable system was initiated at the Boarded Barns Farm, Ongar. This paper focuses on the weed control strategies utilised within the winter wheat crops. Both areas were made up of five fields. The areas were judged to be of similar soils. Both study areas were chalky bolder clays (Wright, 1990).

ORGANIC SYSTEM

The organic system is run under United Kingdom Register of Organic Food Standards . Each field under went a two-year grass ley conversion. This conversion was phased across the five fields. One field entering the two-year conversion in 1989, two in 1990 and the final two in 1991. (UKROFS) rules (Anon., 1991).

In all but one case, winter wheat was the first crop planted after the two-year grass ley. Oats, beans and a grass or clover ley completed the proposed rotation.

The first organic winter wheat cultivar sown in autumn 1991 was Mercia. Under UKROFS rules, since both systems were present on the same holding different varieties had to be grown on the two systems. After a shallow ploughing in (10 - 15 cm) of the conversion ley and creation of a seed bed, this crop was sown at a rate of 250 kg/ha.

No fertiliser was applied until March 1993 when as the crop was looking patchy, a liquid feed derived from soya bean and amino acids was applied. Later that month, an application of pelleted organic fertiliser was used at a rate of 48 kg N/ha.

Mercia was also the variety sown in autumn 1993 on the two fields that had completed their conversion to the organic system. Cultivation and establishment practices were kept the same as in 1992, however, no fertiliser was used on the crops. In 1994 the only factor that was varied was that of variety which was change to Hereward.

Weed control strategy

Under UKROFS rules the use of herbicides is not allowed. Only cultural and physical methods are open to the farmer to utilise. In practice, this meant that the sowing rate was increased from 170 kg/ha to 250 kg/ha to allow the crop to out compete weeds during the establishment phase and to compensate for losses during germination. Weekly inspections of the crop were carried out. When required, a harrowcomb weeder was used to remove weeds. The harrowcomb weeder is a cultivation implement with thin metal tines at 15 cm centres. Covering some 12 metres at a pass and being 1.5 metres wide, only strongly rooted plants can resist its passage through the establishing crop. The angle of the tines can be adjusted to match soil and the crop rooting conditions. As can be appreciated, some crop plants as well as weeds are removed during this practice. One to two passes were carried out each season, depending on weed numbers. Rasmussen (1991) also found this number of passes to be enough under the right soil conditions.

Weed numbers were assessed by identifying the species present and recording the number per square metre every ten metres along two diagonal transects within the fields. Weed levels were then expressed as a frequency of occurrence.

1991/92 season

In the 1991/1992 season the crop was harrowcombed once in the autumn (28-11-91) and once in the spring (24-4-92) to remove weed plants. The effect of these cultivations on weeds species and numbers are shown in Table 1.

Table 1. The main species present on an organically-managed winter wheat field during 1991/92, and their frequencies of occurrence (no/square metre) following autumn and spring use of a harrowcomb weeder.

DATE OF ASSESSMENT	27/11/91	05/03/92	03/04/92	21/05/92	31/07/92
SPECIES	Before harrowing	After harrowing	Before harrowing	After harrowing	Prior to harvest
Stellaria media	43	31	32	26	0
Trifolium repens	40	44	43	39	0
Sinapsis arvensis	30	9	15	9	0
Veronica persica	14	19	19	12	0
Matricaria spp.	10	6	40	7	0
Poa annua	9	16	36	14	0
Polygonum aviculare	0	4	31	17	0
Phleum pratense	0	0	8	9	27
Veronica arvensis	0	0	18	2	0
Polygonum persicaria	0	0	25	0	0
No. of other species:	3	12	19	20	5
Total number species	9	19	29	29	6
Mean Frequency of all weeds:	17	14	13	7	8

Autumn cultivations with the harrowcomb did very little to control weed numbers or the species present. It is possible that the passage of the harrowcomb encouraged a flush of germination. It is now well established that cultivations must be carried out in early spring when weed plants are still small (Schmid & Steiner, 1987; Bräutigam, 1990; Böhrnsen & Bräutigam, 1990). Following this lack of weed control and the body of supporting data, the use of autumn harrowcombing has been discontinued.

Spring cultivations with the harrowcomb proved more successful in reducing weed numbers. Broad leaved species such as Speedwells (*Veroncia sp*) and Chickweeds (*Stellaria media*) showed some degree of control. Perennials and, in particular, the grasses such as Timothy (*Phleum pretense*) were not affected.

CONVENTIONAL SYSTEM

Under UKROFS rules a farm with an organic and conventional system running side by side cannot grow the same crop varieties in the same year. To comply with the rules, Hereward winter wheat was drilled on the five study fields in 1991 and 1992. To evaluate the effect of species within the management system Mercia was drilled in 1993. Seed rate on all occasions was 180 kg/ha with 'Panoctine' (guazatine) treated seed.

Weed Control Strategy

Weed control was carried out using the appropriate conventional herbicides. The strategy was that used by heavy land UK cereal growers, of an autumn application of 2,500 g/ha of isoproturon plus diflufenican. In the spring, fluroxypyr was used where necessary on the crop margins.

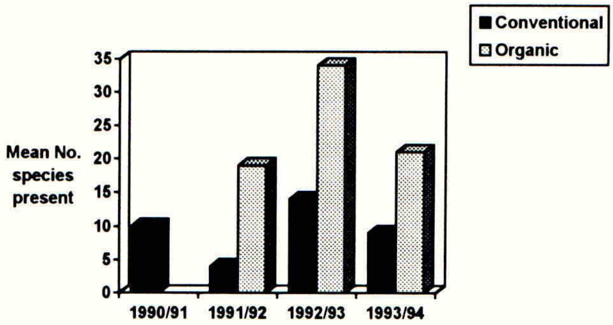
The effectiveness of the weed control programme was reflected in the lower number of weed species present after spraying (Table 2). 1991 had an initial autumn flush of annual species. This flush was controlled by the herbicides. As the crop matured, the number of species present did not change markedly.

Table 2. The main species present on a conventionally-managed winter wheat field during 1991/92, and their frequencies of occurrence (no/square metre) and the effect of an autumn application of herbicides.

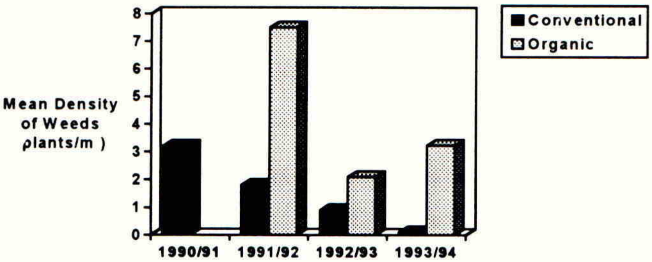
DATE OF ASSESSMENT	27/11/91	03/03/92	21/05/92	03/08/92
SPECIES	Before spraying	After spraying	Second assessment	Prior to harvest
Stellaria media	55	0	0	0
Veronica persica	57	1	1	0
Matricaria spp.	8	0	0	0
Poa annua	2	0	0	0
Veronica hederifolia	9	0	0	0
Number other species	5	3	5	4
Total number species	10	4	6	4
Mean frequency of occurrence	17	1	2	11

Three year trends

Between 1991 and 1994, the number of weed species recorded on the organic fields was consistently higher (10 to 20 species) than the conventional fields (Fig. 1a). Numbers of species have varied between years reflecting , it is thought, the prevailing weather conditions rather than the weed burden within each field.



b)



a)

Figure 1. The mean number of weed species present (a) and the density of weed species present (b) each year (1990 - 1994) on the conventional and organically managed winter wheat fields at the Rhône-Poulenc Farm Management Study site.

Although the cycle of the organic rotation, which includes fertility building leys, has not been completed yet, there are signs of a lack of control of perennial species. It remains to be seen if either the leys or the competitive effects of the crops, in particular oats, can suppress species such as creeping thistle (*Cirsium arvensis*) and docks (*Rumex sp*). There may be no alternative but to fallow the worst affected areas.

Weed densities have shown a progressive decline on the conventionally-managed fields (Fig. 1b). Whether this is coincidence or a genuine long-term trend will be shown as the trial progresses.

On the organic fields, the density of weeds was far higher, at least double the level found on the conventionally-managed fields (Fig. 1b). This differential is in keeping with those measured by Moreby *et al* (1994).

DISCUSSION AND CONCLUSION

Provided soil conditions are right, the harrowcomb, when used in the spring is effective at reducing the number of annual broad-leaved weeds present. Opportunities for using the machine exist in other farming systems. Where appropriate the harrowcomb will be used, particularly in the Integrated Crop Management part of the current Farm Management Study.

The most common annual weed on the organic fields was chickweed with mayweed frequently present. In surveying organic wheat crops in 1991, Yarham & Turner, (1992) also found these to be the most frequently occurring species. The perennial weed infestation on the organic fields is starting to pose a major challenge to the system. A creeping thistle (*Cirsium arvense*) problem, in one field in particular, has caused the proposed crop rotation to be changed to include a bare fallow period. The effects on soil nutrient status and structure as well as the financial effects will be monitored.

To date, there has been no evidence of any difference in weed populations in relation to wheat varieties grown. Similarly, it has not been possible to relate weed infestations to crop yields. By the 1996 harvest, yield monitoring equipment will have been fitted to the farm combine. This will facilitate the comparison of weed distribution data with the associated yield data.

REFERENCES

Anon. (1991) UKROFS , Standards for organic food production. London. UK Register of Organic Food Standards, Food from Britain.

Böhrnsen, A & Bräutigam, V (1990) Mechanische Unkrautbekämpfung mit Striegel und Netzegge in Winterweizen. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz. Sonderheft*, **12**, 463-472.

Bräutigam, V (1990) Mechanische Beikrautregulierung im Getreide mit Striegel und Netzegge nach verschiedener Grundbodenbearbeitung. *Veröffentlichungen der Bundesanstalt für Agrarbiologie Linz/Donau,* **20**, 65-78.

Moreby, S J; Aebischer, N J; Southway, S E; Sotherton N W (1994) A comparison of the flora and arthropod fauna of organically and conventionally grown winter wheat in southern England. *Annals of Applied Biology* **125**, 13-27.

Rasmussen, J (1991) Optimising the intensity of harrowing for mechanical weed control in winter wheat. *Brighton Crop Protection Conference*. Weeds. **3B**.177-184.

Schmid, O & Steiner, N (1987):Erfahrungen mit der mechanischen Unkrautregulierung im Getreide auf Betrieben des biologischen Landbau. *Alternative Konzepte*, **58**, 65-81.

Wright, P S (1990) Soils of the Boarded Barns Farm Project, Soil Survey and Land Research Centre report.

Yarham, D. & Turner, J. (1992) ADAS organic wheat survey. New Farmer and Grower **34**: 31-33.

EFFECT OF STRAW DISPOSAL METHOD AND EFFICACY OF HERBICIDES ON GRASS WEEDS

P BOWERMAN
ADAS Boxworth, Boxworth, Cambridgeshire, CB3 8NN, UK

ABSTRACT

Straw disposal by burning or incorporation by non-inversion cultivation commenced at ADAS Boxworth on a chalky boulder clay site in 1983. The effects on the efficacy of sequences of tri-allate/metoxuron or cyanazine/cyanazine with isoproturon were studied in 1989-1994. Control of grass weeds was frequently poorer where the straw was burnt compared with unburnt. There was an indication that herbicide activity was reduced after eight years of continuous straw incorporation with discs and tines. *Alopecurus myosuroides* appeared to be more competitive than *Bromus sterilis*.

INTRODUCTION

The widespread practice of straw burning on farms in England and Wales provoked public protest and a ban on burning was introduced after 1 July 1993. In 1984, 1.04 M ha (60 per cent) of the straw from the total wheat area, or over 6 million tonnes of straw, was burnt in fields. By 1992, this figure had fallen to about 2 million tonnes on 275 000 ha (14 per cent of the total wheat area) (Anon., 1992).

The change from burning to incorporation of straw could lead to changes in the physical, chemical and biological conditions of soil which would be expected to modify the need for fertiliser and pesticide applications (Prew, 1988). The carbon in burnt straw residues is highly adsorptive to herbicides, and can substantially reduce herbicide performance if such residues are retained close to the soil surface. Straw itself is much less adsorptive, although it may form a physical barrier and prevent herbicides reaching the soil (Cussans & Moss, 1988).

A study to investigate the long term effects of continuous burning or incorporation of straw upon the efficacy of herbicides commenced at ADAS Boxworth in autumn 1983 and ended at harvest 1994. This paper presents data from the last 6 years with sequences of herbicides of tri-allate plus metoxuron and cyanazine plus isoproturon. Rule (1991) reported on the data from the first 5 years when the herbicide treatments were different.

MATERIALS AND METHODS

Various straw disposal methods commenced at the site in autumn 1983.

Treatments

Main treatments:
1. Straw burning after spreading,
2. Straw chopped and incorporated.

The primary cultivation for both main plot treatments was one or two passes with a tine/disc combination implement to a depth of 10-15 cm within 24 hours of burning. Secondary cultivations were with a flexi-tine or power harrow and the plots were harrowed after drilling.

Sub-treatments 1989-94:
1. No grass weed herbicide,
2. Tri-allate as granules at 2.5 kg a.i. pre-emergence followed by metoxuron at 4.37 kg a.i. post-emergence,
3. Cyanazine at 2.25 kg a.i. pre-emergence followed by a tank-mix of cyanazine at 0.875 kg a.i. and isoproturon at 1.1 kg a.i. post-emergence.

Design

The experiment was a spilt plot design with three replications. The main plots were divided into two. The sub-treatments were applied to each half of the main plots in alternate years, i.e. straw disposal remained the same on both halves each year and herbicide treatments were applied to one half of the main plot in alternate years. No grass weed herbicides were applied in the "rest" years. The whole plots were 24 m x 20 m and the split-plots were 24 m x 4 m.

Assessments

Soil samples were taken with a trowel from the top 2.5 cm of soil of nil herbicide treated areas in autumn or spring for the determination of Kd for chlorotoluron values. Grass weed panicles were counted in five quadrats sited at random, each measuring 0.14 m^2, in late June.

RESULTS

Table 1. Dates of drilling and herbicide applications.

	Date of drilling	Date of herbicide application	
		Pre-emergence	Post-emergence
1988/89	9 October	31 October	7 December
1989/90	22 September	2 October	15 November
1990/91	25 October	21 November	17 December
1991/92	4 October	14 October	27 November
1992/93	13 October	22 October	4 January
1993/94	21 October	2 November	25 January

Date of drilling (Table 1) did not have a consistent effect on grass weed establishment; drilling was early in two years (22 September 1989 and 4 October 1991) and late in two years (25 October 1990 and 21 October 1993).

Soil Kd values (chlorotoluron) from the top 2.5 cm of soil are presented in Table 2. After the first six years of the different straw disposal systems, the Kd values appeared to be greater with the straw burnt treatment at each sampling date from September 1989.

Table 2. Soil Kd values (chlorotoluron).

Date sampled Straw treatment	September 1989	December 1990	January 1992	April 1993	December 1993
Spread/burnt	3.9	3.2	6.7	6.1	6.9
Chopped/incorp.	3.2	2.5	4.5	3.9	4.2

In the absence of herbicides, *Alopecurus myosuroides* dominated over *Bromus sterilis* and *Bromus commutatis* every year except 1991/92 when there was a population explosion of *Bromus sterilis* in the straw incorporated area (Table 3). The effect upon *Alopecurus myosuroides* populations of burning was not consistent from year to year but both *Bromus* species were always greatly reduced by burning.

Table 3. Populations of grass weed panicles with no herbicides and straw incorporated or burnt.

	Alopecurus myosuroides Panicles m^{-2}		*Bromus sterilis* Panicles m^{-2}		*Bromus commutatus* Panicles m^{-2}	
	Incorp.	Burnt	Incorp.	Burnt	Incorp.	Burnt
1988/89	1407	986	101	<1	1	0
1989/90	773	935	111	3	29	<1
1990/91	240	216	227	<1	1	0
1991/92	5	328	2449	114	269	7
1992/93	362	818	71	<1	3	0
1993/94	601	949	30	4	6	3

The percentage control with the two herbicide sequences of *Alopecurus myosuroides* (with both straw treatments) and of *Bromus sterilis* (from straw incorporation) are given in Table 4. The percentage control of *Bromus* species with herbicides on the burnt straw treatment is not presented as the populations were low on the nil herbicide treatments. The level of control of *Alopecurus myosuroides* was less with straw burning with both herbicide sequences each year except for 1992/93 with tri-allate/metoxuron. The mean levels of control in the last three years compared with the previous three years tended to be less and this was most marked with the *Bromus sterilis* control with both herbicide sequences.

Table 4. Percent control of grass weeds with herbicide sequences.

		Alopecurus myosuroides % control Incorp.	 Burnt	*Bromus sterilis* % control Incorp.
Tri-allate +	1988/89	99	83	90
metoxuron	1989/90	79	63	70
	1990/91	88	70	43
	1991/92	100	67	32
	1992/93	40	55	17
	1993/94	91	70	58
Cyanazine +	1988/89	94	71	83
cyanazine +	1989/90	80	78	58
isoproturon	1990/91	95	87	68
	1991/92	100	42	0
	1992/93	77	72	0
	1993/94	87	72	90

DISCUSSION

Straw treatments commenced in 1983/84 and the potential levels of infestation of *Alopecurus myosuroides* were high in 1988/89 as result of poor conditions for effective burning in the autumns of both 1987 and 1988. Paraquat was applied at 0.84 kg a.i. on 28 October 1988 (before crop emergence) to kill off an early flush of *Alopercurus myosuroides* but there was still a very large population of the grass weed in the crop. Good burns were achieved in the remaining years but burning did not reduce the populations of *Alopecurus myosuroides* consistently whereas those of *Bromus sterilis* were reduced consistently and there appeared to be a reduction of *Bromus commutatis.*

The herbicides selected for this study were applied either pre-emergence or early post emergence. Herbicides applied pre-emergence must enter the plants from the soil and so their activity might be affected by the presence of straw or ash. The site of uptake and/or action for thiocarbamates, such as tri-allate, has been shown to be the coleoptile (Nalewaja, 1968). Most activity of isoproturon on a range of grasses is the result of entry through the soil (Richardson *et al.*, 1977). Similarly the mode of uptake of metoxuron and cyanazine is through the roots (Richardson & Parker, 1978).

In 11 out of 12 comparisons, the percentage control of *Alopecurus myosuroides* with the herbicide sequences was less where the straw was burnt. The efficacy of the herbicides may have been affected by the presence of ash as the values for Kd in the last three seasons with straw burning were sufficiently high to expect poor activity of chlorotoluron and related herbicides such as isoproturon (Cussans *et al.*, 1982). Where the straw was incorporated, the levels of control of *Bromus sterilis* tended to be less in the last three years compared with the previous three years. This may indicate that a build up of straw residues does have an effect upon herbicide activity.

The data on panicle numbers of the three grass weeds in the unsprayed crops following straw incorporation show that there appeared to be some inter-species competition effect. In the three years that there was poor control of *Alopecurus myosuroides* (1988/89, 1989/90, 1993/94), the panicle numbers of *Bromus sterilis* were low. In 1992, there were very few panicles of *Alopecurus myosuroides* but a very large population of *Bromus sterilis*; with the intermediate levels of *Alopecurus myosuroides* in 1990/91 and 1992/93, the populations of *Bromus sterilis* were at an intermediate level in 1990/91 but at a relatively low level in 1992/93.

In long-term straw incorporation studies at four ADAS Research Centres, *Bromus* species became a problem where straw was incorporated with tines and discs but not where ploughed in or burnt (Bowerman *et al.*, 1993). Orson (1995) reported that date of ploughing in the autumn did not influence the populations of *Bromus* species in the subsequent crop but the quality of ploughing may have a profound effect. He noted that with non-plough tillage, it is best to cultivate as soon as possible after harvest to encourage germination and/or seed loss where straw is removed but where chopped straw provides an effective cover to the soil, delaying cultivations may provide an even larger reduction in infestation.

The ban on burning has resulted in a potential increase in the incidence of grass weeds which would require control measures in break crops and set-aside, the growing of less profitable spring sown cereals, or more frequent ploughing. This study has shown that burning had more effect on Bromus species than *Alopecurus myosuroides.* In autumn 1994, a study started at ADAS Boxworth to evaluate the effects of the frequency of ploughing in a rotation and date of drilling of winter wheat on grass weed populations. The results in the first year of this study and five years of the Integrated Farming Systems study have shown that cultivation method has had a greater effect on grass weed populations than date of drilling.

ACKNOWLEDGEMENTS

The author is grateful to many colleagues at ADAS Boxworth for their help. Financial support for this work from the Ministry of Agriculture, Fisheries and Food (MAFF) is gratefully acknowledged.

REFERENCES

Anon. (1992) Straw disposal survey 1992 - England and Wales. *Report of Government Statistical Service.* MAFF.

Bowerman, P; Davies, D B; Jones, A E (1993) The long-term effects of straw incorporation on winter wheat yields. In: *Soil Management in Sustainable Agriculture.* H F Cook & H C Lee (eds). Third International Conference On Sustainable Agriculture, Wye College, University of London, pp. 448-452.

Cussans, G W; Moss S R; Hance, R J; Embling, S J; Caverly, D; Marks, T G; Palmer, J J (1982) The effect of tillage method and soil factors on the performance of chlortoluron and isoproturon. *British Crop Protection Conference 1982- Weeds,* **1**, pp. 153-160.

Cussans, G W; Moss, S R (1988) Weeds. In: *Changing Straw Disposal Practices.* R D Prew & B D Smith (eds). HGCA Research Review No. 11, pp. 29-32.

Nalewaja, J D (1968) Uptake and translocation of diallate in wheat, barley, flax and wild oat. *Weed Science*, **16**, 309-312.

Orson, J H (1995) Rationalising herbicide use. In: *Fifth Cereals R&D Conference 1995.* Home- Grown Cereals Authority, pp. 10.1-10.20.

Prew, R D (1988) Introduction. In: *Changing Straw Disposal Practices.* R D Prew & B D Smith (eds). HGCA Research Review No. 11, pp. 3-6.

Richardson, W G; Dean M L; Parker, C (1977) The activity and selectivity of the herbicides: ethofumesate, Ru 12709 and isoproturon. *Technical Report Agricultural Research Council Weed Research Organization,* **44**, pp. 1-39.

Richardson, W G; Parker, C (1978) The activity and selectivity of the herbicides methabenzthiazuron, metoxuron, chlortoluron and cyanazine. *Technical Report Agricultural Research Council Weed Research Organization,* **51**, pp. 1-40.

Rule, J S (1991) The effect of straw disposal method on weed populations and the efficacy of herbicides on *Alopecurus myosuroides, Bromus sterilis* and *Bromus commutatis* in winter wheat crops. *Brighton Crop Protection Conference 1991- Weeds,* **2**, pp. 799-806.

THE EFFECT OF DIFFERENT TYPES OF PHYSICAL DAMAGE TO FOUR WEED SPECIES

P A JONES, A M BLAIR
ADAS Boxworth, Boxworth, Cambs., CB3 8NN, UK

J H ORSON
ADAS Cambridge, Brooklands Avenue, Cambridge, CB2 2BL, UK

ABSTRACT

Stellaria media, Papaver rhoeas, Poa annua and *Poa trivialis* grown in pots were subjected to a range of cutting and burial treatments to simulate mechanical damage. Burial to 1 cm depth was the most effective treatment, closely followed by cutting at the soil surface. Results are discussed in the context of currently used mechanical weeding techniques.

INTRODUCTION

The current move towards reducing herbicide inputs has led to increasing interest in the use of mechanical weeders. Much of the work in this area has been done in Scandinavia, where strict limits on pesticide use have already been introduced (Oleson *et al.*, 1994). There is already a limited requirement for reduction of chemical inputs in the UK in Environmentally Sensitive Areas, and voluntary reductions on organic farms. There is, however, a possibility that in the future these restrictions may be extended to include conventionally farmed arable areas. Mechanical weeders, alone or in combination with low rates of herbicide, are a potential alternative to full rate herbicide treatments. A weeder needs to remove weeds whilst leaving the crop relatively unaffected; hence, most types of weeder are designed for widely spaced row crops such as vegetables and maize, where the weeder can disturb the soil between the rows, and throw it across the rows to bury any weeds within the row whilst not adversely affecting the growth of the crop. Harrows and hoes can both be used as weeders in cereals (Rasmussen, 1993) where the gaps between the rows are much smaller, and there is less space for the weeder to work in if it is to avoid damaging the crop. This requires the weeder to have an element of selectivity (Rasmussen, 1990) between the crop and the weed. Lambain *et al.* (1993) observed that a harrow will not necessarily control a weed directly, but will impede its development, whilst a hoe will reduce weed numbers. Weeders used in cereals are usually of the harrow type and rely mainly on the burial of weeds, rather than on more physical types of damage such as uprooting and cutting. This paper describes experiments which aim to identify those types of physical damage which are most effective for weed control.

MATERIALS AND METHODS

Four species of weed were chosen for their different root and growth habits, *Stellaria media* (a fibrous rooting broad-leaved weed with a prostrate habit), *Papaver rhoeas* (a tap rooted broad-leaved weed with a compact habit), *Poa annua* (a prostrate annual grass weed), and *Poa trivialis* (an upright annual grass weed).

Seed from each of the chosen four species was distributed on the surface of a five litre pot filled with John Innes No. 2 potting compost on 1 February 1994 (Experiment 1) and 30 May 1994 (Experiment 2). The compost was chosen because of its high soil content, but with sufficient organic content to prevent water logging. Pots in Experiment 1 were kept in a cool glasshouse (set to 10 °C) until 9 March 1994, when they were transferred to an open ended poly tunnel; all plants in Experiment 2 were raised in a poly tunnel. Pots were watered daily to maintain them at field capacity. Plants were thinned so that at the time of treatment, 20 March 1994 in Experiment 1, and 27 June 1994 in Experiment 2, there were either five *S. media* or six plants of the other three species per pot.

The broad-leaved weeds had six leaves at the time of treatment, and the grasses had three leaves. There were five replicates of each treatment, and pots were placed in a randomised block arrangement, within each species.

The physical damage treatments evaluated in Experiment 1 were;

1. Carefully pull out weeds, with roots intact, and leave on soil surface.
2. Cut all stems at soil surface.
3. Cut through roots below soil surface at approximately 1cm, and leave cut plant in soil.
4. Cut stems and/or leaves approximately 1cm above soil surface.
5. Leave plants in soil, but flatten across the soil surface and totally bury with 2cm potting compost.
6. Partially bury plants with 2cm potting compost, but leave growing point visible, and allow plants to remain upright.
7. Carefully pull out weeds, place on soil surface, and totally bury with 2cm potting compost.
8. Carefully pull out and then re-bury roots with 1cm potting compost.
9. No damage.

The treatments in Experiment 2 were very similar except that the total burial treatments were reduced to 1cm. A new treatment of removing all the leaves by cutting them off was also included after observations made on weeds in the field after a pass of a mechanical weeder.

After treatment, pots were moved to a netted poly tunnel until harvest on 14 April 1994 (Experiment 1) and 12 July 1994 (Experiment 2) for *S. media* and *P. rhoeas*, and on 29 April 1994 and 12 July 1994 for *P. trivialis*, and on 29 April 1994 and 27 July 1994 for *P. annua*. After treatment, the pots were watered daily up to field capacity.

The *P. annua* in Experiment 2 was harvested late because of an infestation of aphids which was controlled with an application of 140 g ha^{-1} pirimicarb applied through an Oxford Precision sprayer on 13 July 1994.

All above-ground live material was harvested, put in an oven at 102°C for 24 hours, and dry weighted at the conclusion of each experiment.

RESULTS

All treatments caused a significant reduction in the dry weight of *S. media* compared with an untreated control (Table 1). In Experiment 1, the complete burial treatments (Treatments 5 and 7) were totally successful at killing the weeds. Cutting and pulling up treatments were partially successful, but live plants still remained three weeks after treatment. Visual assessments made at harvest indicated that these surviving plants would probably have developed given good conditions.

Table 1. The effect of different physical damage treatments on the dry weight (g) of *S. media* plants in two experiments, and the percentage control (%) which that weight represents.

Treatment	Experiment 1 Dry Weight	Experiment 1 %	Experiment 2 Dry Weight	Experiment 2 %
1. Pulled out and left on surface	0.221	47.3	0.263	75.0
2. Cut at surface	0.098	76.6	0.000	100.0
3. Cut 1cm below surface	0.164	60.7	0.285	72.9
4. Cut 1cm above surface	0.156	62.7	0.145	86.2
5. Buried	0.000	100.0	0.040	96.2
6. Partially buried	0.237	43.4	0.761	27.6
7. Pulled up and buried	0.000	100.0	0.015	98.5
8. Pulled up and roots buried	0.302	27.8	0.027	97.4
9. Strip leaves	n/a	n/a	0.231	78.0
10 .Untreated	0.418		1.051	
SEM	0.0289	(32df)	0.0758	(34df)

Most of the treatments gave better levels of control in Experiment 2. The burial treatments were again very effective, although the shallower covering did allow some slight re-growth. Cutting at the surface (Treatment 2) and pulling up and burying the roots (Treatment 8), also resulted in good control, whilst partial burial of the plant (Treatment 6) was a poorer method of weed control, as in Experiment 1.

Treatment effects on *P. rhoeas* (Table 2) were very similar to those observed on *S. media* (Table 1). However, the cutting at and below the soil surface treatments were more successful, particularly in the first experiment. There was better control in the second experiment from pulling out treatments, and, as with the *S. media*, there was very poor control by partial burial.

Table 2. The effect of different physical damage treatments on the dry weight (g) of *P. rhoeas* plants in two experiments, and the percentage control (%) which that weight represents.

Treatment	Experiment 1 Dry Weight	Experiment 1 %	Experiment 2 Dry Weight	Experiment 2 %
1. Pulled out and left on surface	0.131	55.0	0.0106	97.3
2. Cut at surface	0.014	95.0	0.0001	100.0
3. Cut 1cm below surface	0.024	91.7	0.0194	95.0
4. Cut 1cm above surface	0.065	77.5	0.1079	72.2
5. Buried	0.000	100.0	0.0000	100.0
6. Partially buried	0.181	37.7	0.0873	77.5
7. Pulled up and buried	0.000	100.0	0.0007	99.8
8. Pulled up and roots buried	0.075	74.1	0.0003	99.9
9. Strip leaves	n/a	n/a	0.2950	24.0
10. Untreated	0.290		0.3880	
SEM	0.0263	(32df)	0.0206	(36df)

Table 3. The effect of different physical damage treatments on the dry weight (g) of *P. annua* plants in two experiments, and the percentage control (%) which that weight represents.

Treatment	Experiment 1 Dry Weight	Experiment 1 %	Experiment 2 Dry Weight	Experiment 2 %
1. Pulled out and left on surface	0.149	50.7	0.000	100.0
2. Cut at surface	0.066	78.0	0.002	99.8
3. Cut 1cm below surface	0.119	60.5	0.005	95.4
4. Cut 1cm above surface	0.095	68.4	0.040	81.9
5. Buried	0.003	98.9	0.000	100.0
6. Partially buried	0.133	55.8	0.028	87.5
7. Pulled up and buried	0.000	100.0	0.003	98.6
8. Pulled up and roots buried	0.170	43.7	0.000	100.0
9. Strip leaves	n/a	n/a	0.052	76.9
10. Untreated	0.302		0.224	
SEM	0.0138	(32df)	0.0265	(36df)

Table 4. The effect of different physical damage treatments on the dry weight (g) of *P. trivialis* plants in two experiments, and the percentage control (%) which that weight represents.

Treatment	Experiment 1 Dry Weight	Experiment 1 %	Experiment 2 Dry Weight	Experiment 2 %
1. Pulled out and left on surface	0.121	27.7	0.000	100.0
2. Cut at surface	0.041	75.2	0.002	97.7
3. Cut 1cm below surface	0.101	39.3	0.021	69.9
4. Cut 1cm above surface	0.076	54.3	0.013	81.0
5. Buried	0.004	97.7	0.000	100.0
6. Partially buried	0.174	0.0	0.029	58.9
7. Pulled up and buried	0.000	100.0	0.001	99.0
8. Pulled up and roots buried	0.125	25.0	0.000	100.0
9. Strip leaves	n/a	n/a	0.035	49.3
10. Untreated	0.167		0.070	
SEM	0.0187	(32df)	0.0057	(35df)

In Experiment 1, *P. annua* followed a similar pattern of control to *S. media*, with only the total burial treatments showing very high levels of control (Table 3). Although the apparent level of control was greater than 50 percent in most other treatments, visual observations made at harvest indicated that these plants were healthy, and would have grown on. The treated plants in Experiment 2 were infested with aphids, a factor which may go some way to explaining the higher levels of control achieved by all treatments. As in the broad-leaved weeds, in this experiment, it was the cutting above the surface, partial burial, and stripped leaf treatments which performed poorest.

The effect of treatments on *P. trivialis* also followed similar trends to those of the other weeds, with the second experiment showing much higher levels of control than the first one (Table 4). Once again, it was the burial treatments which showed the best level of control.

DISCUSSION

Environmental control of the growing conditions was impossible, and hence there was a wide variation between the first and second experiment. The first experiment was done during the spring, with average daily temperatures of around 7°C whilst the second one was carried out during the summer with mean daily temperatures of about 18°C. The high temperatures (maximum temperature 28.8°C) to which the second experiment was exposed, led to the surface of the soil drying out rapidly despite daily watering whereas in the spring, the soil surface remained moist between watering, aiding the recovery of the plants. Of the various treatments investigated, the most effective was burial with partial burial being less reliable; this supports the principles behind the most widely used weeders. There may, therefore, be very little difference between a burial treatment which is sufficient to give good levels of control, and another which does not quite give the same depth of burial, and leads to very poor control. However, in these experiments there was no competition from a crop which could influence eventual control of partially buried plants.

Part of the rationale behind choosing the four types of weed was their different types of growth habits but there are no obvious trends to be drawn from these initial experiments. The growth stage of the weeds in these experiments was more advanced than would ideally be weeded in the field. Further studies are currently under way to investigate the competitive aspect, the effect of growth stage, and the importance of moisture on the effectiveness of the treatments. The results to date suggest that given poor conditions for weed recovery, there is a much wider scope for severely damaging weeds than if conditions are good for recovery when burial is required. It may be necessary to consider altering the current practice of sowing rows of cereals close together, and move towards wider rows, or a narrow and wide row combination to allow more robust weeding between rows.

There are obvious environmental benefits from introducing mechanical weeding at the expense of conventional herbicide treatments; however, there may also be detrimental side effects such as damaging beetles, other soil fauna, and nesting birds. The other major draw back to using a harrow type mechanical weeder is that on a heavy clay soil it may not be very effective at moving the soil, and at times when best weed control is possible (small weeds), then it may be impossible to get onto the land due to wet conditions.

ACKNOWLEDGEMENT

We thank the Ministry of Agriculture Fisheries and Food (MAFF) for funding this work.

REFERENCES

Lambain, J; Falisse A; Monfort B; Poelert J (1993) Weeding in Organic Agriculture - Results of Trials From 1988-1992. In: *Communications of the Fourth International Conference I.F.O.A.M.* pp. 243-248.

Olesen, J E: Andreasen F; Andreasen L (1994) A Computer Aided Integrated Crop Management System in Winter Wheat. *Aspects of Applied Biology* **40 (1)**, 93-96.

Rasmussen, J (1990) Selectivity - An Important Parameter on Establishing The Optimum Harrowing Technique for Weed Control in Growing Cereals. In: *Proceedings of the EWRS Symposium 1990,* pp. 197-204.

Rasmussen, J (1993) Mechanical weed control in cereals - a part of the future plant production. In: *Danish Institute of Plant and Soil Sciences Annual Report 1993,* pp. 58-61.

EFFICACY OF MON 37588 IN WESTERN EUROPEAN SOFT WHEAT

J P EULER, S K PARRISH, S HEWITT, W VOEGLER, H H RASMUSSEN, C STRIDE
Ceregen, Monsanto Europe S.A.
Technical Center Europe
Rue Laid Burniat
B-1348 Louvain-la-Neuve, Belgium

ABSTRACT

MON 37588 is a new herbicide for the selective control of annual and perennial grasses and annual broadleaf weeds in soft wheat. The product is applied postemergence of the crop and weeds in spring at rates varying between 10 and 20 g a.i./ha. The use of a surfactant is recommended. The weed spectrum of MON 37588 includes *Agropyron repens*, *Apera spica-venti*, *Bromus* species, *Galium aparine*, *Matricaria* species and *Stellaria media*.

INTRODUCTION

Since ancient times, common couch (*Agropyron repens*) has been the most important perennial grass weed in European wheat production. Because it is highly competitive to cereals (Harvey and Potts, 1978), no economical threshhold level for this species could be established until today. The introduction of Roundup® herbicide represented a decisive progress in controlling this troublesome weed.

MON 37500, a new sulfonyl urea herbicide, was discovered by Takeda Chemical Industries Limited and is developed by Monsanto Company through its Ceregen unit. During the early testing of the compound, activity on *Agropyron repens* was observed, which is novel for a wheat selective herbicide. Can MON 37500 provide a commercially acceptable level of couch control and what is its weed spectrum? This paper presents results from field trials carried out by Ceregen in France, Germany, United Kingdom, Denmark, Belgium and Switzerland in the years 1993 and 1994.

MATERIAL AND METHODS

Field applications of MON 37588 (an 80% WG formulation of MON 37500) were made postemergent to winter and spring soft wheat in March and April of the years 1993 and 1994. The experimental design was a completely randomized block with three to four replications. The plot size used was 10-24 m^2. All applications were made with small plot sprayers (flat fan nozzles) at spray volumes ranging from 200-250 l/ha and a spray pressure around 2 bar. Some treatments contained surfactant (tallowamine) at concentrations of 0.2-0.25% of the spray volume. Assessments were done visually as percent control (evaluation of % green biomass compared to the untreated control, where 0% means no difference to untreated and 100% means the complete absence of living plants in the plot). All data on *Agropyron repens* refer to the last incrop evaluation in wheat.

RESULTS

Selectivity

MON 37588 displayed an excellent selectivity on all tested soft wheat varieties. In some cases, a slight growth retardation of the crop was observed; however, this effect disappeared rapidly. No yield depression could be detected after the application of rates up to 60-80g a.i./ha (3 - 4 times the maximum use rate) on 12 winter wheat cultivars throughout Europe.

In earlier experiments it was shown that MON 37588 is not safe on barley or oats. The selectivity in rye, triticale and potatoes is currently under investigation.

Efficacy

TABLE 1. Percentage control with MON 37588 against annual and perennial weeds in winter wheat (Europe, 1993-94). All rates in grams active ingredient/ha.

Species	MON 37588 (+surf.)		Isoproturon	Amidosulfuron
	10	20	1200-1250	30
Agropyron repens	68 (9)	79 (40)	-	-
Apera spica-venti	100 (4)	96 (12)	83 (12)	-
Bromus commutatus	94 (4)	99 (5)	23 (1)	-
Bromus sterilis	70 (4)	78 (9)	43 (1)	-
Galium aparine	76 (16)	90 (48)	0 (5)	95 (29)
Matricaria inodora	90 (10)	94 (18)	99 (5)	88 (4)
Stellaria media	88 (9)	96 (21)	79 (12)	74 (12)

( ) = number of trials

After the application of MON 37588, couch plants developed symptoms like changing colour to dark green, severe stunting of the shoots and death of the youngest leaves. Couch was left as a green carpet, well below canopy level, so reducing crop competition.

Spray timing is important for the couch efficacy of MON 37588. The results of the later applications in April were generally better than the earlier timings in March.

The level of *Agropyron repens* control provided by MON 37588 was sufficient to increase the wheat yield:

TABLE 2. Winter wheat yields after the application of MON 37588 at two couch infested fields in the UK (1994). Results in metric tonnes/ha.

Trial location	Untreated	MON 37588	
		10g a.i/ha	20g a.i/ha
Yearsley (150 shoots/m^2)	4.90 (0%)	6.80*(79%)	7.55*(93%)
Miserden (121 shoots/m^2)	4.20 (0%)	5.60 (60%)	7.30*(91%)

* significantly different to untreated (P=.05, Newman-Keuls)
( ) = percent of *Agropyron repens* control

On silky bentgrass (*Apera spica-venti*), MON 37588 outperformed the standard isoproturon, especially at later, suboptimum application timings. Wild oat (*Avena fatua*) and blackgrass (*Alopecurus myosuroides*) could be controlled by MON 37588 if it was applied onto young and rapidly growing plants. Under the environmental conditions of Western Europe, however, the efficacy on these two species was insufficient in most cases. The control achieved on meadow brome (*Bromus commutatus*) and the suppression of barren brome (*Bromus sterilis*) is another interesting aspect of the product. Currently there is no commercial herbicide for the selective control of meadow brome.

The performance on cleavers (*Galium aparine*), scentless mayweed (*Matricaria inodora*) and common chickweed (*Stellaria media*) was good. Field chamomile (*Anthemis arvensis*), deadnettle (*Lamium* spp.), common poppy (*Papaver rhoeas*), and speedwell (*Veronica spp*). showed low suseptibility to MON 37588.

The addition of a surfactant or the use of liquid fertilizer as spray carrier increased generally the herbicide efficacy of MON 37588.

DISCUSSION

MON 37588 offers some very interesting features to the European wheat grower: excellent crop safety is combined with a high unit activity. For the first time, *Agropyron repens* can be controlled selectively in wheat, so that yield losses can be reduced already in the season of application. The performance on *Apera spica-venti* is outstanding, which means a higher flexibility with regard to application timing. Problem grasses like bromes are supressed or controlled. An additional benefit is the efficacy on some broadleaves like *Galium aparine*, *Matricaria inodora* or *Stellaria media.*

REFERENCES

Harvey, J J; Potts M J (1978) A cost effective approach to the control of *Agropyron repens* in cereal stubbles with glyphosate. *Proceedings British Crop Protection Conference - Weeds* pp. 49-55.

FIRST RESULTS OF TRIALS WITH NEW HERBICIDE MON37532

J DOBROVODSKY

Central Supervisory and Testing Institute of Agriculture Pesticide and Pest Control Method (SKZUZ), Zemedelska 1a, 658 37 Brno, Czech Republic.

ABSTRACT

MON 37500 is a new herbicide for the selective control of annual and perennial grasses and annual broad-leaved weeds in soft wheat. The product was applied post-emergence to winter wheat, in spring, at rates of 2.5-30 g A.I./ha.The effect of adding surfactant was also tested. The weed spectrum of MON 37500 included *Agropyron repens, Apera spica-venti, Galium aparine, Matricaria spp.* and *Stellaria media.*

INTRODUCTION

Agropyron repens, Galium aparine and *Apera spica-venti* are the most competitive weeds in cereals, especially in wheat. In Czech conditions, despite regular use of herbicides, increasing weed infestation has been observed. Various methods and pesticides, often in tank-mixture, have been used to control these weeds. However, no single product has been available, until now, which controls perennial and annual grasses together with annual broadleaves in cereals. MON 37500 is the first product claiming such broad efficacy and selectivity in soft wheat.

This paper presents results of official testing in Czech Republic

MATERIALS AND METHODS

Randomised small plot trials ($25m^2$ per plot with 4 replicates) were established post-emergence in winter wheat, in March and April 1993, using MON 37532, a 75% WG formulation. All applications were made using a small plot sprayer (nozzles TeeJet 30011) at spray volumes of 300-400 l/ha. Dose rates of 2.5-20 g A.I./ha without surfactant and 2.5-30 g A.I./ha with tallow-amine surfactant (as "Hyspray") were applied in 300-400 l/ha spray volume.

Applications were made in early spring at winter wheat GS 13-20 (Zadoks) and in late spring at GS 23-40.

Assessments were done visually as EWRC scores, where EWRC 9 represents no difference to the untreated control and EWRC 1 represents 100% control.

RESULTS

Selectivity

In only one trial, among the 19 carried out, a 10cm retardation of wheat growth was detected at the 30 g/ha dose rate.

Efficacy

Results are presented as means of EWRC scores obtained from up to 7 trials, the number of trials comprising the mean being given in parentheses.

Efficacy on *Agropyron repens* (Table 1) was sufficient to very good (5.2-1.7 EWRC) at dose rates of 10-30 g/ha of MON 37533 with surfactant. Best efficacy in *Agropyron* was observed following application at GS 12-15 of the weed. Efficacy was reduced by earlier application (weed GS 11-12) or later application (weed GS >40).

The effect of MON 37533 observed on *Agropyron* was one of severe retardation. Plants treated at GS 12-15 with 10 g A.I./ha, with surfactant, exhibited interruption of growth and either slowly died, or survived at a retarded stage of development. Surviving plants were not competitive with the wheat crop.

Efficacy on *Apera spica-venti* (Table 2) was very good to excellent (2.1-1 EWRC) at all dose rates, application at weed GS 12-20 being superior to the later timing, weed GS 20-40. Plants were severely retarded at dose rates as low as 2.5 g A.I./ha.

Efficacy on *Galium aparine* (Table 3) was approximately sufficient (6.8-4.2 EWRC) without any distinct influence of application timing. There was some variation between trials; incomplete control at low rates resulted in some regrowth and flowering.

Efficacy on DICAN (*Matricaria spp.*, *Stellaria* and others) was sufficient to excellent (Tables 4 and 5), in most cases, depending on application timing and dose rate. In Czech conditions, *Matricaria spp.* were particularly sensitive, especially *M. maritima*, being severely retarded by rates of 2.5 g A.I./ha and, thereafter, either remaining alive but not growing or competitive, or dying.

Efficacy was increased by 1-2 points on the EWRC scale by addition of the surfactant (Tables 1-5).

TABLE 1. Efficacy of MON 37532 on *Agropyron repens* (AGRRE)

Application rate of MON 37532 (g A.I./ha)	Growth stage (GS) and efficacy [EWRC scores]					
	GS 11 - 12		GS 12 - 15		GS <40	
2.5	-		8.1	(2)		-
5	-		5.9	(2)		-
10	7.4	(2)	5.2	(4)	6.7	(2)
20	5.8	(2)	5.1	(2)	5.2	(2)
2.5 + Hyspray 0.5%	-		8.0	(2)		-
5 + Hyspray 0.5%	-		4.2	(2)	4.7	(1)
10 + Hyspray 0.5%	5.2	(2)	3.8	(7)	4.7	(3)
20 + Hyspray 0.5%	5.0	(2)	3.4	(5)	4.5	(3)
30 + Hyspray 0.5%	-		1.7	(3)	3.5	(3)

TABLE 2. Efficacy of MON37532 on *Apera spica-venti* (APESV)

Application rate of MON 37532 (g A.I./ha)	Growth stage (GS) and efficacy [EWRC scores]			
	GS 15 - 20		GS 20 - 40	
2.5	2.1	(2)	5.6	(3)
5	1.5	(2)	2.8	(3)
10	1.0	(2)	1.7	(3)
2.5 + Hyspray 0.5%	1.5	(2)	3.3	(3)
5 + Hyspray 0.5%	2.2	(3)	2.2	(4)
10 + Hyspray 0.5%	1.8	(3)	1.4	(4)
20 + Hyspray 0.5%	1.8	(1)	1.2	(1)
30 + Hyspray 0.5%	1.0	(1)	1.0	(1)

TABLE 3. Efficacy of MON 37532 on *Galium aparine* (GALAP)

Application rate of MON 37532 (g A.I./ha)	Efficacy [EWRC scores]	
10	6.8	(4)
20	6.4	(4)
10 + Hyspray 0.5%	5.4	(5)
20 + Hyspray 0.5%	4.2	(5)
30 + Hyspray 0.5%	4.2	(3)

TABLE 4. Efficacy on MON 37532 on *Matricaria* ssp. (MATXX)

Application rate of MON37532 (g A.I./ha)	Timing and Efficacy [EWRC scores]			
	early spring		late spring	
2.5	1.3	(2)	1	(2)
5	1.7	(2)	1	(2)
10	1.8	(2)	1.2	(2)
2.5 + Hyspray 0.5%	1.3	(2)	1.2	(2)
5 + Hyspray 0.5%	1.7	(2)	1.6	(2)
10 + Hyspray 0.5%	1.5	(2)	2.3	(4)
20 + Hyspray 0.5%	1.5	(1)	2.7	(1)
30 + Hyspray 0.5%	-		2.7	(1)

TABLE 5. Efficacy of MON 37532 on *Stellaria media* (STEME)

Application rate of MON 37532 (g A.I./ha)	Timing and efficacy [EWRC scores]			
	early spring		late spring	
2.5	2.3	(2)		-
5	2	(2)		-
10	1.3	(2)	2.8	(1)
20	1.7	(1)	2.5	(1)
2.5 + Hyspray 0.5%	1.8	(2)	3.3	(1)
5 + Hyspray 0.5%	1.3	(3)	1.5	(2)
10 + Hyspray 0.5%	1.4	(3)	1.7	(3)
20 + Hyspray 0.5%	1.5	(2)	1.8	(3)
30 + Hyspray 0.5%	1.3	(1)	1.0	(1)

DISCUSSION

MON37532 looks a very promising wheat herbicide, with exceptionally wide range, covering the most important wheat weeds (*Apera, Galium;* control of *Agropyron repens* in winter wheat post-emergence is unique), good efficacy, very high unit activity and safety for wheat. Under present experience, this herbicide fits very well to Czech and Central European agriculture.

REFERENCES

EPPO (1986) Guideline for the biological evaluation of herbicides - weeds in cereals. *OEPP/EPPO bulletin*, **16**, 151-167.

Tottman, D.R. and Broad, H (1987) The decimal code for the growth stages of cereals, with illustrations. *Annals of Applied Biology*, **110**, 441-454.

FIELD, GLASSHOUSE AND LABORATORY INVESTIGATIONS INTO THE RATE OF DEGRADATION OF MON 37500 IN EUROPEAN SOILS.

S K PARRISH, J P EULER, R GROGNA, M SPIRLET
Monsanto, The Agricultural Group Louvain-la-Neuve, Belgium

A WALKER, F H MACVICAR, J E CULLINGTON
Horticulture Research International, Wellesbourne, Warwick, CV35 9EF, UK

Greenhouse experiments indicate that sugarbeet, winter oil seed rape, sunflower, pea and barley are sensitive to MON 37500. Field trials established to characterize the safety of these rotational crops found a possible concern with sugarbeet. Greenhouse bioassays of selected field soils were conducted to determine a relative half life (mean DT_{50} 47 days). Additional laboratory degradation studies with chemical analysis of MON 37500, were conducted on 77 European soils (mean DT_{50}, 61.5 days). Field soil dissipation studies gave DT_{50}'s between 14 and 47 days. The field trials, the soil bioassays, the laboratory degradation studies and field dissipation staudies all suggest that MON 37500 has an average soil DT_{50} in the range of 20-60 days. There was a trend towards slower degradation at higher soil pH.

INTRODUCTION

MON 37500 is a wheat safe, grass active experimental sulfonylurea herbicide. Sulfonylurea herbicides have historically demonstrated an injury concern to following rotational crops. (Duffy, et al). Several studies were initiated to characterize any potential rotational crop injury concerns with MON 37500.

MATERIALS AND METHODS

Determination of DT_{50} from Laboratory and Field Samples

Freshly collected soil samples were treated with MON 37500 and triasulfuron to concentrations of 4.0 mg/kg dry soil. Water content was then adjusted and maintained at the 33 kPa percentage. Soil-herbicide samples were incubated at 10°, 20° and 30°C. Samples were taken 1 day after treatment (DAT) and at several intervals for the next 56-70 days. The original study contained eight soil samples and compared MON 37500 to triasulfuron. The herbicides were extracted with methanol : water : acetic acid (90 : 9 : 1) (Walker and Welch). Herbicide concentrations were determined directly using an HPLC. This technique was also used to survey soils from 77 European locations in subsequent studies. Soil from the Monsanto farm at Franc-Waret, Belgium was used as an internal standard in all studies.

Large plot (10m X 50m) field studies were established in Northern Europe in 1992-93 and 1993-94. Treatments were made to winter wheat at 15, 30, 60 and 120g ai/ha (Spring 93) and 20, 40 and 80g ai/ha (Spring 94). Wheat was harvested in August. Normal cultivation followed. Each location was then sown to winter barley, winter oil seed rape, sugarbeet or sunflowers and peas at the appropriate times. Soil was sampled 1 DAT and at several following intervals. These samples were then bioassayed with pea and sunflower. Untreated soil from each location was treated with MON 37500 at 0.5,1,2,4,8,16 and 32ppb pea and sunflower were grown to create standard curves.

Determination of Rotational Crop Sensitivity

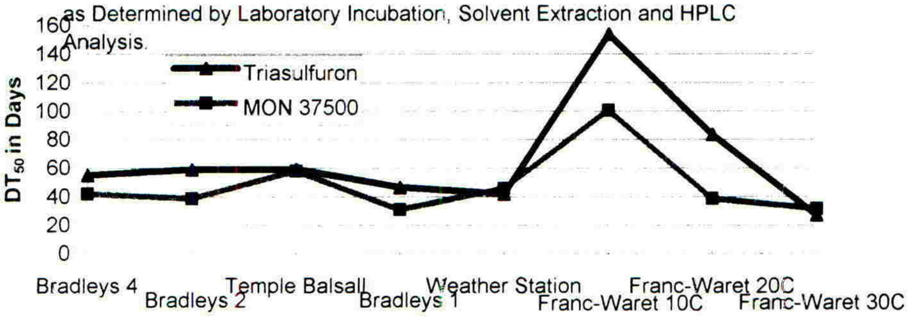
Soil from Franc-Waret Belgium was treated with 1,2,4,8,16 and 32g ai/ha of MON 37500 thoroughly mixed to a depth of 6cm, then placed in 20X10X6 cm trays. An empty 5cm pot was placed in the center of each tray to allow sub-irrigation within the closed tray system. Trays were then planted and placed in a growth room (17°/11°C, Day/Night). Assessments were made 30 days after planting.

RESULTS AND DISCUSSION

Laboratory Studies on the DT_{50} of MON 37500

The average laboratory DT_{50} for MON 37500 in the eight soil samples in the original study was 48.2 days 26.6% shorter than the average DT_{50} (65.7) of triasulfuron in the same soils (Figure 1). As has been seen with other sulfonylurea herbicides the rate of degradation of MON 37500 decreased with cooler soil temperatures (Figure 1). Triasulfuron rate of degradation was more affected by cool temperatures than treatments of MON 37500.

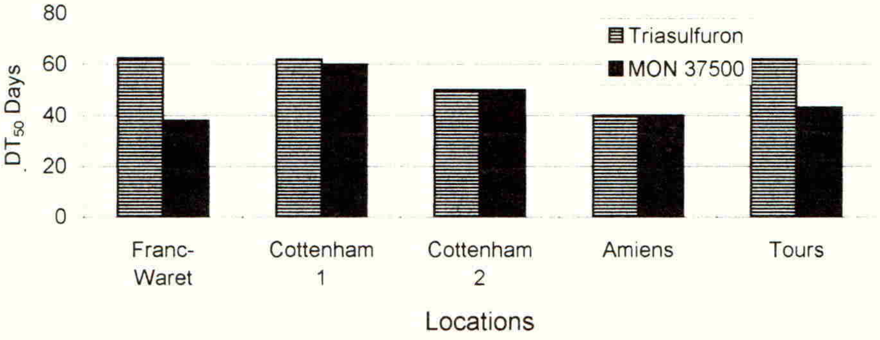
Figure 1. Relative DT_{50} of MON 37500 and Triasulfuron in Eight Soil Samples as Determined by Laboratory Incubation, Solvent Extraction and HPLC Analysis.



Field Studies on the DT_{50} of MON 37500

The DT_{50} of MON 37500 and triasulfuron were also determined by bioassay of the five 92-93 field rotational crop locations (Figure 2). Both compounds showed a similar degradation pattern at three of the five locations. Triasulfuron lasted substantial longer at two of the locations. The DT_{50}'s for MON 37500 as determined in the field bioassay were between 40 and 60 days and similar to the DT_{50}'s determined by the laboratory method. This indicates good translation between the laboratory and field methods.

Figure 2. The DT$_{50}$ of MON 37500 and Triasulfuron as Determined by Sunflower Bioassay of Field Trials Established in 1993.



Rotational Crop Sensitivity to MON 37500.

The relative soil activity of MON 37500 on broadleaf rotational crops is about 2X lower than for triasulfuron and chlorsulfuron, as determined in the growth chamber study (Table 1). However, there are exceptions such as sunflower. The unique situation is with the grass rotational crops such as barley and oats. Both of these crops are sensitive to MON 37500 and could be a rotational concern.

Table 1. The Soil Concentration that gives a 20% Growth Reduction (EC20) to Potential Rotational Crops with MON 37500, Triasulfuron and Chlorsulfuron

	Concentration		
Crop	MON 37500	Triasulfuron	Chlorsulfuron
Sugarbeet	0.5 ppb	0.25 ppb	0.25 ppb
Oil Seed Rape	1 ppb	0.5 ppb	0.5 ppb
Sunflower	0.25 ppb	0.5 ppb	0.5 ppb
Potato	8 ppb	0.5 ppb	0.5 ppb
Soybeans	6 ppb	3 ppb	3 ppb
Barley	1.5 ppb	32 ppb	> 24 ppb
Maize	6 ppb	16 ppb	1 ppb
Oat	6 ppb	6 ppb	3 ppb
Sorghum	0.25 ppb	3 ppb	6 ppb

Field Results Rotational Crops Studies

In the 1992-93 crop rotation study injury was seen with MON 37500 on sugarbeet at 3 of 6 locations with an application rate of 30g ai/ha (Table 2). It was similar to the injury seen with triasulfuron. However, triasulfuron caused injury at 4 of 6 locations. The two Cottenham UK locations were only 200 meters apart. The Cottenham locations each had different soil types. The injury seen at this location may indicate a local climatic effect was the reason for increased rotational crop injury rather than soil type. The results of the 1993-94 project did not show any injury problem for either MON 37500 or triasulfuron on sugarbeet (Table 2).

Table 2. Injury of Sugarbeet and Winter Oil Seed Rape in Rotation with Winter Wheat Treated with a Spring Application of MON 37500.

		MON 37500 Sugarbeet			Triasulfuron Sugarbeet			MON37500 Oil Seed Rape			Triasulfuron Oil Seed Rape		
1993 Project	Country	30g*	40g	60g	30g	40g	60g	30g	40g	60g	30g	40g	60g
Franc-Waret	Belgium	0		0	0		0	3		0	5		33
Cottenham 1	UK	27		21	25		18	0		0	15		20
Cottenham 2	UK	17		9	19.8		10.8	8		1	15		30
Amiens	France	23		35	13		28						
Dijon	France	0		0	0		0	0		0	0		0
Tours	France	0		3	5		33	0		0	0		0
1994 Project	Country	20g	40g	80g	20g	40g	80g	20g	40g	80g	20g	40g	80g
Franc-Waret	Belgium	0	0		0		0	0	0	3	3	0	
Niederbipp	Swiss	0						0					
Rossleben	Germany	0	0	0	0		0	0	0	0	0		
Altenebstorf	Germany	0	0	0	0		0	0	0		0	0	
G. Luesewitz	Germany							0	0	0	0	0	
Fresnes	France	0	0	0	0		0	10	0	30	23	40	
Artenay	France	0	0	0	0		0	0	0	0	0	0	
Athee	France							0	0	0	0	0	
Sublaines	France							0	0	0	0	0	
Royston	UK							0	3	10	4	8	
Cottenham	UK							5	3	15	9	21	
Hoeskevej	DK	0	0										

*Rate gAI/ha

Autumn planted oil seed rape was shown to be more sensitive to rotational crop injury with triasulfuron than MON 37500 (Table 2). This was expected because oil seed rape is more sensitive to triasulfuron and triasulfuron has an average DT_{50} that is 20% longer than MON 37500.

Spring applications of MON 37500 in 1993 caused slight injury to winter barley planted in September 1993 at the two Cottenham locations (Table 3). These two locations appear to be vulnerable sites to sufonlyurea herbicide carryover. Slight barley injury was seen at one location with the 1994 applications (Table 3).

The relationship between the bioassay measured field degradation of MON 37500, the rate of degradation determined with chemical analysis and the rotational crop injury seen in the field trials indicated an opportunity to predict the rate of degradation of MON 37500 over a large number of soils in a short period of time. Hence, a study was started to survey soils (77 to date) from across Europe (Figure 3).

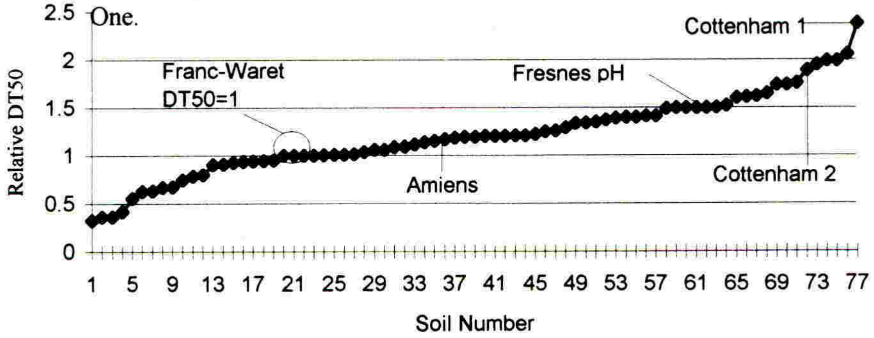
The survey was conducted in three experiments. In order to reduce variability between the DT_{50}'s from the different experiments the Franc-Waret soil was used as an internal standard in each group of incubations. The DT_{50} of the Franc-Waret sample in each experiment was set as "one standard DT_{50}". The other soils in each experiment were then related to the Franc-Waret standard DT_{50}. A soil with a DT_{50} of 2 had a relative DT_{50} 2X longer than the Franc-Waret standard. Knowing the rate of degradation (relative DT_{50}) and the relative crop sensitivity to MON 37500 allows a prediction as to whether there would be enough MON 37500 in the soil to cause injury to a particular rotational crop (Figure 4).

Table 3. Injury to Winter Barley as a Rotational Crop to a Spring Post-Emergence application of MON 37500.

		MON 37500 Barley					MON 37500 Barley		
1993 Project	Country	*30g	60g	120g		Country	30g	60g	120g
Franc-Waret	Belgium	0	0	0	Amiens	France	0	0	3
Cottenham 1	UK	8	30	55	Dijon	France	0	0	0
Cottenham 2	UK	10	20	26	Tours	France	0	0	0
1994 Project	Country	20g	40g	80g		Country	20g	40g	80g
Franc-Waret	Belgium	0	0	0	Fresnes	France	0	0	0
Niederbipp	Swiss	0	0	0	Artenay	France	0	0	0
Hunzenschwil	Swiss	0	0	0	Athee	France	0	0	0
Bleienbach	Swiss	0	0	0	Sublaines	France	0	0	0
Reisiswil	Swiss	0	0	0	Royston	UK	0	0	
Rossleben	Germany	0	0	0	Cottenham	UK	0	1	1
Altenebstorf	Germany	0	0	0	Boscombe	UK	0	0	0
G. Luesewitz	Germany	0	19	24	Miserden	UK	0	0	0
Blumberg	Germany	0			Daglingworth	UK	0	0	
Dijon	France	0	0	0	Yearsley	UK	3	2	
Luzille	France	0	0	0	Hoeskevej	DK	0	0	0
Tours	France	0	0	0	Mulstrup	DK	0	0	0
					Hammerbro	DK	0	0	0

*Rate g AI/ha

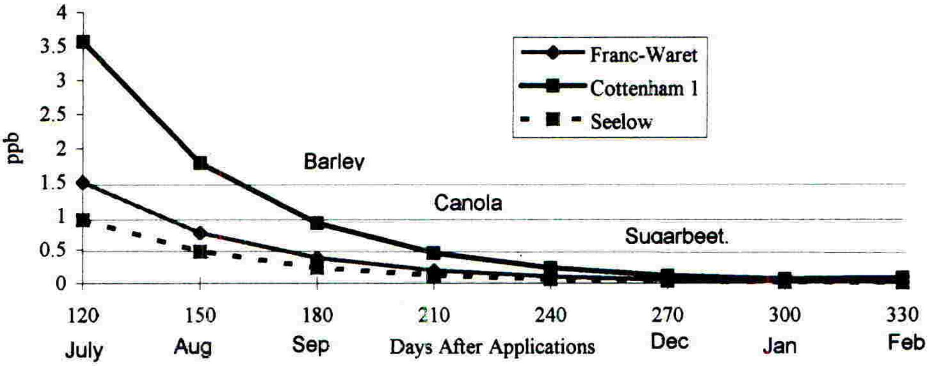
Figure 3. The Relative DT50 of MON 37500 in 77 Soils Sampled from Across Europe. Each DT50 is Set in Comparison with the Standard (Franc-Waret). The DT50 of the Franc-Waret Soil is set to One.



The degradation data from the laboratory study indicated a lower rate of loss with higher soil pH. A sample of the individual curves generated by the soil survey data is presented in Figure

4. The three soils shown are from Seelow Germany a rapid degradtion site, Franc-Waret Belgium the internal standard soil and Cottenham 1 the site with the most carryover injury and the longest relative DT_{50}. The residual levels predicted for the Cottenham 1 site is close to the EC20 for both barley and winter oil seed rape (Table 1) at the September sowing time.

Figure 4. The Predicted Degradation Curve of MON 37500 at Three Location. Also the Concentration which gave 20% Crop Injury in the Greenhouse.



This would indicate that a soil with a relative DT_{50} greater than two, is likely to be vulnerable to rotational crop injury at a 40g ai/ha (2X use rate). Hence, the data would predict most (98%) of the soils in Europe are safe at the 2X use rate. The soils on the European Continent should have no risk for rotational crop injury. The Cottenham 2 site is also predicted to have a potential for long residual activity (Figure 3). Therefore it is likely that the lab degradation curve has good utility as a predictor of field results.

CONCLUSION

The DT_{50} of MON 37500 averaged 40-60 days as determined by bioassay of field results and laboratory degradtion curves. Field dissipation studies show a DT_{50} between 14 and 47 days MON 37500 degrades at a rate about 20% faster than triasulfuron. Sunflowers and Sugarbeet are sensitive rotational crops. Damage has been seen with sugarbeets in 93-94 trials but not in the 94-95 trials. Winter oil seed rape and winter barley may be a concern but the data to date indicates 2X safety in most European situations. The laboratory method for determining the relative DT_{50} of MON 37500 appears to be a good predictor of potential rotation crop concerns with this herbicide.

REFERENCES

Duffy, M J; Hanafey M K; Linn D M; Russell M H; Peter C J (1987) Predicting sulfonylurea herbicide behaviour under field conditions. *Proceedings British Crop Protection Conference - Weeds*, 541-547

Walker A; Welch S J The relative movement and persistence in soil of chlorsulfuron, metsulfuron-methyl and triasulfuron *Weed Research,* 29, 281-287

RESPONSE OF WITLOOF CHICORY (*CICHORIUM INTYBUS* VAR. *FOLIOSUM*) AND SUGARBEET (*BETA VULGARIS* VAR. *SACCHARIFERA*) TO SOIL-APPLIED CEREAL SULFONYLUREAS

R. A.J. BULCKE and D. CALLENS
Laboratorium voor Herbologie, Centrum voor Onkruidonderzoek (I.W.O.N.L.),
Universiteit Gent, Coupure links 653, B-9000 Gent, Belgium

ABSTRACT

Certain sulfonylureas used in winter cereals have caused damage to succeeding crops like witloof chicory and sugarbeet, due to residue carryover under certain conditions. In bioassay studies ("small pot test" with herbicides preplant incorporated in a sandy loam soil; calculation of ED_{50} for foliage fresh matter accumulation over a two week growing period), witloof chicory and sugarbeet showed a differential response to several of the cereal sulfonylureas studied. Witloof chicory was clearly more susceptible than sugarbeet to metsulfuron methyl and triasulfuron but was clearly less susceptible than sugarbeet to chlorsulfuron, thifensulfuron methyl and especially tribenuron methyl. Both crops responded similarly to soil-applied amidosulfuron. The results of these short duration bioassays generally corresponded well with those of field persistence experiments.

INTRODUCTION

Cereal herbicides represent an important group within the sulfonylurea class. Their unprecedented herbicidal activity against certain weeds and crops not only enabled a dramatic fall in use rates but unfortunately also was responsible for injury to some extremely sensitive rotational crops like sugarbeet and witloof chicory, due to residue carryover occurring with some compounds (chlorsulfuron, triasulfuron) under certain conditions (Beyer et al., 1987; Brewster & Appleby, 1983; Marle, 1990; Nicholls et al., 1987).

In Western Europe, sugarbeet (*Beta vulgaris* ssp. *altissima* var. *saccharifera*) and chicory, either witloof chicory (*Cichorium intybus* var. *foliosum*) or large rooted chicory (*C. intybus* var. *sativum*), are frequently grown as rotational crops following winter cereals in which sulfonylurea herbicides may have been used. Further, in the event of failure of a cereal crop treated with a residual sulfonylurea, there is a need for information on suitable replacement crops. Consequently, it is useful to have information on the intrinsic sensitivity of potential rotational or replacement crops to cereal sulfonylurea herbicides.

With cereal sulfonylureas, various bioassay methods using different test species such as lettuce (Blair et al., 1989), beet (Iwanzik & Egli, 1989) and lentil (Strek et al., 1989) have been described and used for several purposes, mostly persistence and recropping studies. However, witloof chicory has not been used as a test species so that there is no information on its intrinsic sensitivity to these sulfonylureas.

The present study was conducted to examine the response of sugarbeet and witloof chicory, in bioassays as well as in field persistence experiments, to soil-applied sulfonylureas with selective uses in (winter) cereals.

MATERIALS AND METHODS

Bioassays

Greenhouse bioassay experiments were carried out using a small pot test method adapted from that described by Nyffeler et al. (1982). The sandy loam soil for the bioassays was collected from the upper 15 cm on field "KL" of the Experimental Farm, Faculty of Agricultural and Applied Biological Sciences, at Melle (province East-Flanders), sieved through a 2 mm mesh screen and allowed to dry in the air. The soil contained 1.82% organic matter, 34.9% sand (> 50 μm), 55.5% silt (2-50 μm) and 9.6% clay (0-2 μm) with a pH of 6.56 and a cation exchange capacity of 7.7 meq./100 g. The sulfonylureas were studied over an appropriate concentration range; the herbicides were applied in 100 ml of water to 1000 g air-dry sandy loam soil. The soil was then thoroughly mixed by hand. A nontreated control was also included.

Seeding densities for witloof chicory cv. Brussels laat and sugarbeet cv. Laser were 25 and 15 seeds per 6.5 cm pot respectively. Seeding depth was 0.5 cm for sugarbeet whereas witloof chicory seeds were scarcely covered with soil. Pots were watered by sub-irrigation when necessary. A detailed description of the growing conditions has been given by Desimpelaere (1993). Harvests were made fourteen days after seeding when untreated witloof chicory and sugarbeet plants had the first leaf expanded and their second leaf clearly visible. Foliage fresh weights were obtained by clipping the plants at the soil surface and weighing them.

In all bioassay experiments the experimental design was a randomized split-block with four replicates. Yield data from each concentration were expressed as a percentage compared to the yields of the corresponding untreated control. The responses to sulfonylurea concentrations were linearized by performing log transformations to herbicide concentrations and probit transformations to percentages. Data were subjected to analysis of variance and regression analysis. From the regression equations, ED_{50} values (herbicide concentration that causes 50 percent reduction) were calculated for each combination of crop species and sulfonylurea herbicide.

Field persistence experiments

Field persistence experiments were conducted over the 1980-1994 period on fields "KL", "N" and "R" of the Experimental Farm at Melle; the characteristics of the sandy loam soils on these fields were as follows: 7.2-13.5% clay (0-2 μm), 9.2-16.9% fine silt (2-20 μm), 36.5-52.4% coarse silt (20-50 μm) and 24.7-45.8% sand (> 50 μm); 1.57-2.59% organic matter; C.E.C.: 5.54-8.57 meq./100 g; pH: 5.64-6.27.

The sulfonylurea herbicides were applied, either in the fall (about mid-November) or in spring (about mid-March), on a bare soil under conditions simulating a prepared seedbed. Treated strips were 2.25-3.00 m wide and nearby untreated control strips were included. All treatments were replicated twice. At the end of April, approximately twenty and five weeks after fall and spring sulfonylurea applications respectively, sugarbeet and witloof chicory were planted in 1 m wide strips across the treated and control strips; seedbed preparation consisted of shallow (8-12 cm) non-inversion tillage operations. Herbicide applications were done with an air-pressurized knapsack sprayer (Azo Sprayers Veeze Ede), equipped with flat fan nozzles (Teejet DG11002), delivering 300 l/ha at 200 kPa pressure. For full experimental details reference is made to Callens et al. (1993, 1994, 1995), and Van Himme et al. (1982, 1983, 1984, 1987, 1988, 1989, 1990, 1991, 1992).

Visual estimations of crop injury (thinning, growth inhibition, chlorosis, necrosis...) caused by sulfonylurea herbicides were recorded at several times with the quasi-logarithmic 1-9 scale (1 = no injury; 9 = 100% injury), proposed by the "Committee on methods" of the European Weed Research Council. In addition to this, fresh matter yield of above- and belowground plant parts was determined at the normal harvest time. The response of both crops was translated into an A-F scale (see Table 2) by compounding visual injury estimations and yield data.

RESULTS AND DISCUSSION

Bioassays

A comparison on an ED_{50} basis of the responses of sugarbeet and witloof chicory to the various sulfonylureas tested demonstrates some interesting aspects (Table 1). Amidosulfuron is the only sulfonylurea that displayed more or less equal activity to both crops. Witloof chicory was clearly even more sensitive to metsulfuron methyl and triasulfuron than was sugarbeet (Table 1). Sugarbeet has been classified as sensitive to extremely sensitive to sulfonylureas like metsulfuron methyl and triasulfuron, yet there is only scarce information on its response under bioassay conditions. However, Iwanzik & Egli (1989), who used beet (type not mentioned) as a bioassay test species to quantify triasulfuron in soil samples, mentioned 0.1 g a.i./ha as the limit of detection; using their conversion factor of 1.4, this would correspond with 0.07 µg/kg

Table 1. Response of sugarbeet and witloof chicory to soil-applied cereal sulfonylurea herbicides in a greenhouse bioassay

Herbicide	ED_{50} (µg/kg air-dry soil) (with 95% confidence limits) for foliage fresh weight	
	Sugarbeet	Witloof chicory
amidosulfuron	6.75 (4.23-10.79)	6.59 (3.83-11.32)
chlorsulfuron	0.94 (0.62-1.41)	2.21 (extrapolated)
metsulfuron methyl	1.83 (1.22-2.74)	0.92 (0.78-1.10)
triasulfuron	1.68 (1.11-2.54	0.71 (0.57-0.88)
thifensulfuron methyl	4.88 (3.78-6.30)	19.09 (9.30-39.20)
tribenuron methyl	>22.50	»22.50

soil. A clearly lower sensitivity for witloof chicory than for sugarbeet was observed with the long-residual chlorsulfuron as well as with both short-residual sulfonylureas thifensulfuron methyl and tribenuron methyl (Desimpelaere, 1993). The extreme sensitivity of sugarbeet to chlorsulfuron has been reported repeatedly (Beyer et al., 1987; Brewster & Appleby, 1983). In persistence studies with tribenuron methyl, Kotoula-Syka et al. (1993) have demonstrated a much lower sensitivity of sunflower (*Helianthus annuus*), belonging like witloof chicory to the *Asteraceae* family, compared to sugarbeet.

Field persistence experiments

The results from the field persistence experiments reveal that, regardless of their time of application and, eventually, rate, sugarbeet is highly sensitive to all sulfonylureas studied; excepted for thifensulfuron methyl and tribenuron methyl, the same conclusion applies to witloof chicory (Table 2). Neither crop can replace a failing cereal crop that has been treated with one of the long-residual sulfonylureas; where one of the short-residual sulfonylureas (thifensulfuron or tribenuron) would have been used, sugarbeet should be excluded from the list of acceptable replacement crops.

Table 2. Response of witloof chicory and sugarbeet, sown in spring as replacement crops in field persistence experiments with simulated failure of a winter cereal crop treated in autumn or spring with a sulfonylurea herbicide

Sulfonylurea and time of application (A = autumn; S = spring)		Rate (g ai/ha)	Response (A-F)[1] of	
			Witloof chicory	Sugarbeet
amidosulfuron	S	30	**F** *(4)FFFF*[2]	**F** *(4)FFFF*[2]
chlorsulfuron	A	10	**C** *(1)C*	**F** *(1)F*
chlorsulfuron	A	12.5	**E** *(1)E*	**F** *(1)F*
chlorsulfuron	A	25	**F** *(2)EF*	**F** *(2)FF*
metsulfuron methyl	S	4	**F** *(5)EFEFF*	**F** *(5)EFEEF*
triasulfuron	S	10	**F** *(1)F*	**F** *(1)F*
triasulfuron	A	12.5	**F** *(3)FFF*	**F** *(3)FFF*
triasulfuron	S	12.5	**F** *(3)FFF*	**F** *(3)FFF*
tribenuron methyl	S	40	**B** *(4)AACB*	**E** *(4)DEDD*
thifensulfuron methyl	S	60	**C** *(4)ABCC*	**E** *(4)DEEC*

[1] **A** = tolerant crop : - no injury; normal yield
B = moderately sensitive crop: - slight injury, often temporary (up to 10%)
- sometimes low yield reduction (0-10%)
C = fairly sensitive crop : - permanent injury (10-15%); 10-20% yield reduction
- ploughing may (eventually) be necessary
D = sensitive crop : - clearly visible injury (15-35%); 20-40% yield reduction
E = very sensitive crop : - heavy injury (35-80%) and yield reduction (40-85%)
F = extremely sensitive crop : - very heavy injury (>80%) and yield reduction (>85%).

[2] **Aggregate result** / *(number of experiments)* / *individual results for all experiments*

Triasulfuron, at both rates and application times, metsulfuron methyl (4 g/ha in spring) and amidosulfuron (30 g/ha in spring) clearly were the most potent herbicides to both crops. The differential response of both crops to triasulfuron, recorded in the bioassays (Table 1), was not confirmed in the field. Here, the experimental conditions, especially herbicide rate and limited interval from application to planting, were such that triasulfuron residue levels at planting were still so high that both crops were more or less completely destroyed. Even under practical condictions in Northern France, Marle (1990) recorded injury to both witloof chicory and sugarbeet grown in 1990 as rotational crops on fields cropped previously with winter cereals treated in 1989 with triasulfuron. Exceptionally dry conditions in 1989 and other factors like high soil pH may have slowed down herbicide degradation.

The lower sensitivity to some sulfonylureas of witloof chicory compared to sugarbeet, recorded in the bioassays (Table 1), was confirmed in the field persistence experiments. (Table 2). Although for autumn applied chlorsulfuron, there were only results from a limited number of experiments, they demonstrate the lower sensitivity of witloof chicory with a clear dose-effect, compared to sugarbeet. However, it is for both short-residual herbicides, thifensulfuron methyl and tribenuron methyl, that the most striking differences were recorded. In field experiments conducted during the 1991, 1992, 1993 and 1994 experimental years, witloof chicory experienced only "slight" (tribenuron) to "just acceptable" (thifensulfuron) injury from residues resulting from herbicide applications made five weeks prior to seeding; sugarbeet, on the other hand, suffered from serious damage when exposed to identical residues (Table 2). A similar response of sugarbeet to tribenuron has been recorded by Verdier & Citron (1992). The present results clearly show that although thifensulfuron and especially tribenuron have been reported to undergo very rapid breakdown in soil (Beyer et al., 1987; Ferguson et al., 1985; Sionis et al., 1985), their soil persistence to different replacement crops may still differ considerably due to these important differences in intrinsic sensitivity.

ACKNOWLEDGEMENTS

This study was funded by the Institute for Encouragement of Scientific Research in Industry and Agriculture (I.W.O.N.L./I.R.S.I.A.).

REFERENCES

BEYER E.M; BROWN H.M.; DUFFY M.J. (1987) Sulfonyurea herbicide soil relations. *1987 British Crop Protection Conference - Weeds*, **2**, 531-547.

BLAIR A.M.; MARTIN T.D.; WALKER A.; WELCH S.J. (1989) Measurement and prediction of chlorsulfuron persistence in soil following autumn and spring application. *Brighton Crop Protection Conference - Weeds - 1989*, **3**, 1121-1126.

BREWSTER B.D.; APPLEBY A.P. (1983) Response of wheat (*Triticum aestivum*) and rotation crops to chlorsulfuron. *Weed Science*, **31**, 861-865.

CALLENS D.; VAN HIMME, M.; BULCKE R. (1993, 1994, 1995) Bespreking van de resultaten bereikt door het Centrum voor Onkruidonderzoek resp. tijdens het teeltjaar 1991-1992, 1992-1993 en 1993-1994. *Mededeling nrs. 58, 59 en 60 van het Centrum voor Onkruidonderzoek*, Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent, 154 pp., 164 pp., 193 pp.

DESIMPELAERE K. (1993) Biologische aktiviteit en werkingsduur van graansulfonylureumverbindingen ten aanzien van vervang- en volggewassen. *Afstudeerwerk Faculteit Landbouwkundige en Biologische Wetenschappen*, Universiteit Gent, Academiejaar 1992-1993, 88 pp.

FERGUSON D.T.; SCHEHL S.E.; HAGEMAN L.H.; LEPONE G.E.; CARRARO G.A. (1985) DPX-L5300 - A new cereal herbicide. *1985 British Crop Protection Conference - Weeds*, **1**, 43-48.

IWANZIK W., EGLI H. (1989) Comparison of bioassay and chemical analysis for triasulfuron quantification in soil samples. *Brighton Crop Protection Conference - Weeds - 1989*, **3**, 1145-1150.

KOTOULA-SYKA A.; ELEFTHEROHORINOS I.G.; GAGIANAS A.A.; SFICAS A.G. (1993) Persistence of preemergence applications of chlorsulfuron, metsulfuron, triasulfuron and tribenuron in three soils in Greece. *Weed Science*, **41**, 246-250.

MARLE M. (1990) Attention aux remanences des herbicides pour vos parcelles d'endives. *Bulletin de Liaison des Endiviers*, **N° 84**, 51-52.

NICHOLLS P.H.; EVANS A.A. (1987) The behaviour of chlorsulfuron and metsulfuron in soils in relation to incidents of injury to sugar beet. *1987 British Crop Protection Conference - Weeds*, **2**, 549-1144.

NYFFELER A.; GERBER H..R.; HURLE K.; PESTEMER W.; SCHMIDT R. (1982) Collaborative studies of dose-response curves obtained with different bioassay methods for soil-applied herbicides. *Weed Research*, **22**, 213-222.

SIONIS S.D.; DROBNY H.G.; LEFEBVRE P.; UPSTONE M.E. (1985) DPX-M6316 - A new sulfonyl cereal herbicide. *1985 British Crop Protection Conference-Weeds*, **1**, 49-54.

STREK H.J.; BURKHART D.C.; STRACHAN S.D.; PETER C.J.; RUGGIERO M.; WARNER R.W. (1989) Use of bioassays to characterize the risk of injury to follow crops by sulfonylurea herbicides. *Brighton Crop Protection Conference - Weeds - 1989*, **1**, 245-250.

VAN HIMME M.; STRYCKERS J.; BULCKE R. (1982, 1983, 1984, 1987, 1988, 1989, 1990, 1991, 1992) Bespreking van de resultaten bereikt door het Centrum voor Onkruidonderzoek resp. tijdens het teeltjaar 1980-1981, 1981-1982, 1982-1983, 1985-1986, 1986-1987, 1987-1988, 1988-1989, 1989-1990, 1990-1991. *Mededeling nrs. 36, 38, 40, 46, 48, 50, 52, 54, 56 van het Centrum voor Onkruidonderzoek*, Faculteit van de Landbouwwetenschappen, Universiteit Gent, 153 pp., 206 pp., 173 pp., 159 pp., 182 pp., 171 pp., 161 pp., 172 pp., 181 pp.

VERDIER J.L.; CITRON G. (1992) Persistance d'action des herbicides et remplacement de cultures. *ANPP - Quinzième Conférence COLUMA Journées Internationales sur la Lutte contre les Mauvaises Herbes Versailles - 2,3,4 Décembre 1992*, **II**, 657-664.

RESPONSE OF WEEDS TO LEVELS OF IRRIGATION, WEED CONTROL AND FERTILITY IN WHEAT

I S HOODA
Department of Agronomy, Haryana Agricultural University, Hisar-125004, India
S K AGARWAL
Department of Agronomy, Haryana Agricultural University, Hisar-125004, India

ABSTRACT

Response of wild canary grass to varying levels of irrigation, weed control and fertility was investigated at Research farm, Haryana Agricultural University, Hisar during the winter seasons of 1991-92 and 1992-93. Significantly higher dry matter production of wild canary grass was recorded following the applications of either 4 or 6 irrigations (at critical stagesof the wheat crop) or 120kg N + 60 kg P_2O_5/ ha fertilizer. The post-emergence application of either methabenthiazuron at 1.5 kg/ ha or isoproturon at 1.0 kg/ha significantly reduced the weed population and weed dry matter production compared with the weedy check in both the years.

INTRODUCTION

The higher nutrient and irrigation requirements of high yielding wheat varieties have caused a serious problem of increased weed infestation. The weed population in wheat crops consists of grass and broad-leaved weeds. The extensive use of phenoxy-acetic acid herbicides in wheat have reduced the problem of broad-leaved weeds. However, grass weeds, mainly wild canary grass and wild oat, have become a serious threat to wheat cultivation because both these are very similar to wheat. Practically no information is available on the response of wild canary grass to increased levels of essential inputs e.g. irrigation frequency, herbicide use and fertility levels. Therefore, field experiments were conducted to determine the control of grass weeds in relation to the above inputs.

MATERIALS AND METHODS

The field experiment was conducted at the Research Farm, Department of Agronomy, Haryana Agricultural University, Hisar. The soil was sandy loam in texture having pH 8.5, low in nitrogen, medium in phosphorus and high in available potash. The experiment was laid out in a split-plot design with four replicates. The main plot treatment consisted of a combination of (a) three irrigation levels viz. I_1 - Two irrigation (CRI, F), I_2 - four irrigation (CRI, T,F,M) and I_3 - Six irrigation (CRI = crown root initiation, T = Tillering, J = Jointing, F = Flowering, M = Milk stage and D = Dough stage)

(b) Three weed control treatment viz. W_1 - weedy check, W_2 - methabenzthiazuron at 1.5 kg/ha and W_3 - isoproturon (1.0 kg/ha) sprayed at 32 days after sowing (DAS) and sub-plot treatments (c) two fertility levels viz. F_1 - 60 kgN+30 kg P_2O_5/ha and F_1 - 120 kg N + 60 kg P_2O_5/ha. Wheat (cv. WH-157) was sown on 15th and 11th November in 1991-92 and 1992-93, respectively. Data were recorded at an interval of 30 days for population and dry matter of weeds.

RESULTS AND DISCUSSION

Maximum weed frequency (wild canary grass and wild oat) was noted during 10-40 days after sowing. Thereafter, the weed intensity remained constant upto 120 days. In general weeds matured earlier than the wheat crop. Post-emergence application of methabenzthiazuron and isoproturon reduced the intensity of wild canary grass significantly compared with the weedy check at 60, 90 and 120 DAS and at the harvest stage in both the seasons (Table I). This was due to the susceptibility of weed flora to phytotoxic action of these herbicides (Sharma *et al.*, 1987). At harvest, methabenzthiazuron and isoproturon gave 80.3 and 82.4 per cent control over weedy check of wild canary grass in 1991-92; respective values in second year were 82.5 and 86.4 per cent. Superiority of these herbicides over weedy check were also reported by Pandey & Mani (1982).

Table 1. Population of wild canary grass (weeds m^{-2}) as influenced by irrigation, weed control and fertility levels.

Treatments	Days after sowing									
	1991-93					1992-93				
	30	60	90	120	At harvest	30	60	90	120	At harvest
W_1	64.8	71.3	73.3	69.8	53.6	66.0	77.6	75.4	72.5	55.0
W_2	66.2	8.1	18.5	16.5	10.6	64.7	8.4	22.9	21.0	9.6
W_3	67.4	5.1	17.5	15.6	9.4	68.0	7.8	22.1	17.2	7.7
SEM±	2.5	1.7	1.6	1.6	1.4	2.9	1.8	1.5	1.7	1.1
CD at 5%	NS	5.1	4.8	4.8	4.1	NS	5.2	4.4	5.1	3.3

Dry matter yield of wild canary grass

Application of six irrigation produced significantly higher dry matter yields of wild canary grass (22.4 percent in 1991-92 and 6.8 percent in 1992-93) compared with two irrigations (Table 2). This was because of luxury uptake of moisture and nutrients resulting in

Table 2. Dry matter of wild canary grass (gm^{-2}) as influenced by irrigation, weed control and fertility levels.

Treatment	Days after sowing							
	1991-92				1992-93			
	60	90	120	At harvest	60	90	120	At harvest
<u>Irrigation levels</u>								
CRI, F	5.1	6.5	8.8	6.7	4.5	7.6	8.2	7.2
CRI, T,F,M	6.7	7.4	9.3	7.5	4.9	8.2	9.2	7.9
CRI, T,J,F,M,D	6.8	8.0	9.3	8.2	5.4	8.9	10.2	7.7
S.Em. ±	0.5	0.1	0.1	0.2	0.3	0.4	0.4	0.2
C.D. at 5%	1.6	0.4	0.5	0.6	0.9	1.3	1.3	0.7
<u>Weed control</u>								
Weedy check	9.0	11.3	11.7	9.2	7.7	9.9	9.4	8.3
Methabenzthiazuron 1.5 kg/ha	3.7	6.4	8.1	6.9	3.9	7.2	8.2	7.1
Isoproturon (Arelon) 1.0 kg/ha	3.4	6.5	7.5	6.3	2.9	7.1	8.0	7.4
S.Em. ±	0.5	0.1	0.1	0.2	0.3	0.4	0.4	0.2
C.D. at 5%	1.6	0.4	0.5	0.6	0.9	1.3	1.3	0.7
<u>Fertility levels (kg/ha)</u>								
60 N + 30 P_2O_5	5.0	6.7	8.9	7.2	4.2	7.3	8.3	7.2
120 N + 60 P_2O_5	6.8	7.9	9.3	7.7	4.9	8.3	9.0	7.9
S.Em. ±	0.4	0.1	0.1	0.1	0.2	0.2	0.1	0.1
C.D. at 5%	1.3	0.3	0.3	0.4	0.7	0.7	0.3	0.5

more vegetave growth and consequently higher dry matter levels of weeds. These findings confirm the results obtained by Wiese & Vandiver (1970).

The phytotoxic effect of methabenzthiazuron and isoproturon caused a considerable reduction in the dry matter of wild canary grass by decreasing their populations. The percent decrease in dry matter of wild canary grass was 60 and 25 by methabenzthiazuron and 63.2 and 32.2 by isoproturon when assessed at 60 days and at harvest, respectively in comparison with weedy check in 1991-92. The respective percent decrease in the second year was 49.5 and 15.1 by isoproturon. Similar reductions in dry matter were obtained by Balyan *et al.* (1987).

At harvest, significant increase in dry matter of wild canary grass (7.0 and 7.4 percent) were obtained by the application of F_2 treatment over F_1 in 1991-92 and 1992-93, respectively (Table 2). This may be accounted for by the greater availability of nutrients.

REFERENCES

Balyan, R S; Malik R K; Panwar R S; Bhan V M (1987) Evaluation of herbicides for weed control in wheat. *HAU Journal of Research.* **17,** 170-175.

Pandey, J; Mani V S (1982) Effect of herbicides and nitrogen on weed and yield of wheat. *Indian Journal of Agronomy.* **27**, 418.

Sharma, A K; Katyal S K; Malik R K; Panwar R S (1987) Studies on weed control in wheat with herbicides mixture. *HAU Journal of Research.* **17**, 341-345.

Wiese, A F; Vandiver C W (1970) soil moisture effect of competition ability of weeds. *Weed Science.* **18**, 518-519.

EFFICACY OF BROADLEAF CEREAL HERBICIDES AT THREE NATURAL CLIMATES

S K MATHIASSEN, P KUDSK, J L KRISTENSEN
Danish Institute of Plant and Soil Science, Department of Weed Control and Pesticide Ecology, Flakkebjerg, DK-4200 Slagelse, Denmark

ABSTRACT

The activity of six broadleaf herbicides was examined in climate simulators at three different climatic scenarios with natural diurnal fluctuations in temperature, air humidity and light intensity. Tribenuron and chlorsulfuron were most active at low temperature whereas air humidity was of greater importance than temperature to the efficacy of fluroxypyr and ioxynil. The performance of metsulfuron and clopyralid was influenced by temperature as well as humidity. In general, the efficacy was less influenced by climate than expected from previous studies.

INTRODUCTION

Previous investigations determining the influence of environment on herbicide efficacy have often been carried out in controlled environment chambers in which one climatic factor has been varied at a time while the others have been held constant. The climatic parameters have usually been examined at fixed levels although temperature, humidity and light intensity fluctuates in nature. Such experiments permit a ranking of climatic factors influencing on efficacy however it is difficult to transform the results into farmers recommendations.

The objective of our studies is to refine recommendations for the use of herbicides under different environmental conditions. Accordingly three climate simulator cabinets were build at our institute. In these cabinets temperature, water vapour deficit and light intensity can be varied accurately and natural cycling curves for temperature and relative humidity can be conducted. The facilities of the climate simulators have been described earlier by Kristensen, (1992).

This paper presents results on the influence of natural climatic conditions on the foliar activity of 6 herbicides.

MATERIAL AND METHODS

Plants were grown outdoors in 2 l pots in a soil/sand/peat mixture (2:1:1 wt/wt) containing all necessary macro and micro nutrients. The efficacy of the 3 sulfonylurea herbicides, tribenuron, chlorsulfuron and metsulfuron, was examined on *Lamium hybridum* whereas *Matricaria inodora, Stellaria media* and *Sinapis alba* were used as test plants for clopyralid, fluroxypyr and ioxynil, respectively. Prior to application the number of plants per pot was reduced to 6.

Herbicide efficacy was examined at 3 natural climatic scenarios. The climates were chosen to represent extreme Danish spring conditions. Temperature and humidity curves at the three climates are shown in Figure 1. Light intensity was 500 μE/m*s at all climates during a 16 hours photoperiod including 1.5 hours of dawn and sunset. The climatic scenarios are based on a simple model earlier described by Mathiassen *et al.*, 1994.

One day prior to spraying plants were transferred to the climate simulators. Herbicides were applied at the 2-4 leaf stage using a laboratory pot sprayer equipped with a boom fitted with two Hardi 4110-14 flat fan nozzles. The nozzles were delivering a spray volume of 150 l/ha. The sprayer was placed in close connection to the climate simulators. Commercial formulations of tribenuron, chlorsulfuron, metsulfuron, clopyralid, fluroxypyr and ioxynil were used in the trials. Tribenuron and chlorsulfuron were applied in admixture with 0.05% of a nonionic surfactant (83% linear alcohol polyethoxylate). Five doses representing the whole dose-response curve were applied and each treatment was replicated 3 times. Soil activity of the herbicides was avoided by sub-watering the plants, using a soil medium with a high organic content and covering the soil surface with gravel.

Plants were moved outdoors 5 days after application and harvested 2 weeks later. Fresh and dry shoot weights were collected.

Statistical Analysis

The results were analyzed using a nonlinear regression model. Dose-response curves were estimated using a logistic model describing fresh weight (U) as a function of dose (z):

$$U=C+\frac{D-C}{1+\exp(2*b*(\log(ED_{50})-\log(z)))}$$

The parameter D denotes the upper limit at zero dose, C the lower limit at large doses, b the slope and ED_{50} the dose required to reduce fresh and dry weight by 50%. The model can be reparameterized to include any ED value instead of ED_{50}. For each herbicide ED_{50}, ED_{70} and ED_{90} values were estimated. The goodness of fit was assessed by a F-test for lack of fit.

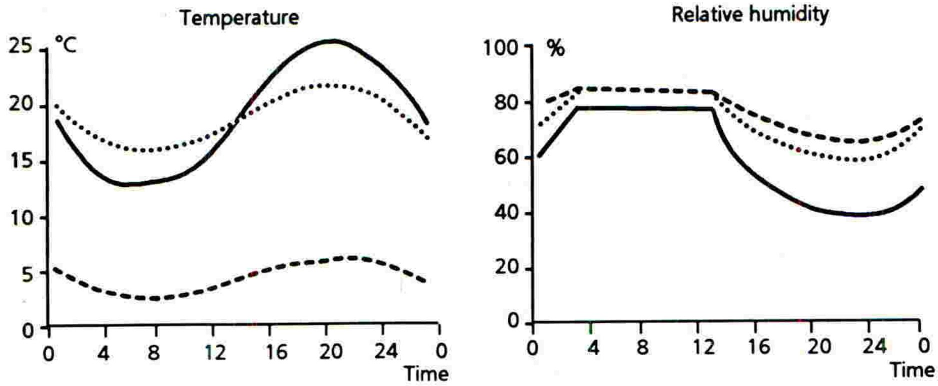


Figure 1. Climatic scenarios used in the experiments. Climate 1 (---) mean temperature 5°C and 80% relative humidity, climate 2 (•••••) mean temperature 20°C and 80% relative humidity and climate 3 (——) mean temperature 20°C and 63% relative humidity.

RESULTS AND DISCUSSION

Although plants were only placed under different climates for 6 days the fresh and dry weights of controls at the different environments were significantly different at harvest. Consequently the model was fitted separately for each climate. According to the F-test the model was accepted in all cases, but with fluroxypyr ED_{90} values could not be estimated because not even the highest dose produced a 90% effect.

In Figure 2 and 3 the estimated ED_{50}, ED_{70} and ED_{90} values of each herbicide and climate are shown.

The activity of tribenuron and chlorsulfuron was reduced with increasing temperature and no significant influence of humidity was found. The low impact of humidity on the efficacy of sulfonylurea herbicides applied in mixture with surfactants is in accordance with previous results obtained in controlled environment chambers (Thonke, 1984, Kudsk *et al.*, 1988). The negative effect of high temperature on tribenuron activity has been confirmed on other plant species as well in our climate simulators (Mathiassen *et al.*, 1994). Naleweja & Woznica (1985) also found a lower phytotoxicity of chlorsulfuron at high temperature compared to lower temperatures whereas the inverse relationship between temperature and activity of tribenuron and chlorsulfuron are inconsistent to the results of Thonke (1984). This discrepancy may be a result of different experimental designs *i.e.* when and how efficacies were measured.

Metsulfuron activity increased with increasing temperature and at the ED_{90} level the influence of air humidity was significant. It has previously been shown that the detrimental effect of low humidity can be overcomed by mixing herbicides with surfactants (Kudsk & Streibig, 1993). The higher susceptibility to humidity compared to tribenuron and chlorsulfuron could be due to the lack of surfactant in the spray solution.

With clopyralid an increased activity was obtained with increasing temperature and relative humidity. The significance of the two climatic factors was similar. No significant influence of temperature was observed on fluroxypyr activity but efficacy was significantly reduced at low humidity. The significant influence of humidity on fluroxypyr activity was surprising as fluroxypyr is formulated as an ester and humidity is generally considered not to be as crucial to the activity of lipophilic herbicides compared to hydrophilic herbicides like clopyralid (Kudsk & Kristensen, 1992).

The activity of ioxynil was not affected by temperature but significantly reduced at low compared to high humidity. This is in accordance to the results of Merritt (1984) who found that temperature only marginally influenced the activity of a salt formulation of ioxynil whereas humidity appeared to be a highly significant factor. Merritt also concluded that wide diurnal fluctuations in temperature and humidity could improve ioxynil activity by altering the water status and thereby inducing more chance of movement of ioxynil in plants. A comparison of the effect at climate 2 and 3 shows that this hypothesis was not supported in our experiments.

In general the responses to natural cycling temperature and humidity were lower compared to the results from controlled environment chambers (Merritt, 1984, Naleweja & Woznica, 1985). This probably reflects that in a natural climate the parameters interact and any benefits

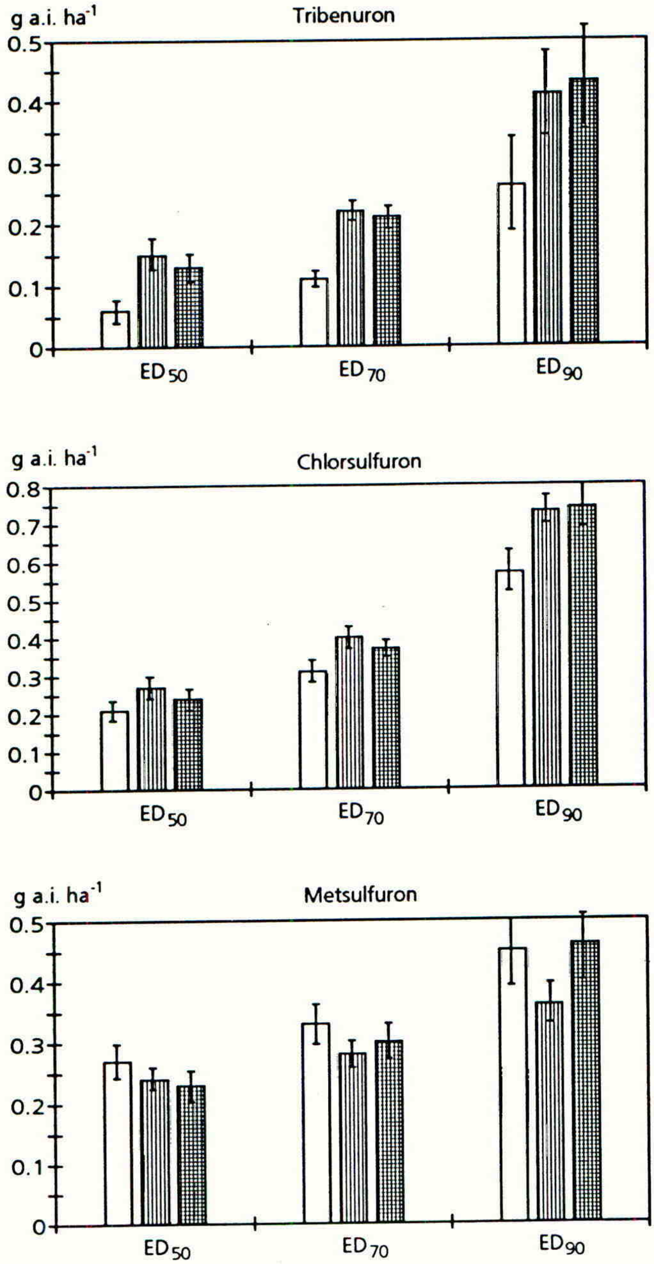


Figure 2. Estimated ED_{50}, ED_{70} and ED_{90} doses of tribenuron, chlorsulfuron and metsulfuron on *Lamium purpureum* at 3 natural climatic scenarios. Tribenuron and chlorsulfuron were applied in mixture with 0.05 % alcohol ethoxylate (83 %). 95 % confidence intervals are shown in parenthesis. Climate 1: □, climate 2: ▥ and climate 3: ▦. For climate regimes see fig. 1.

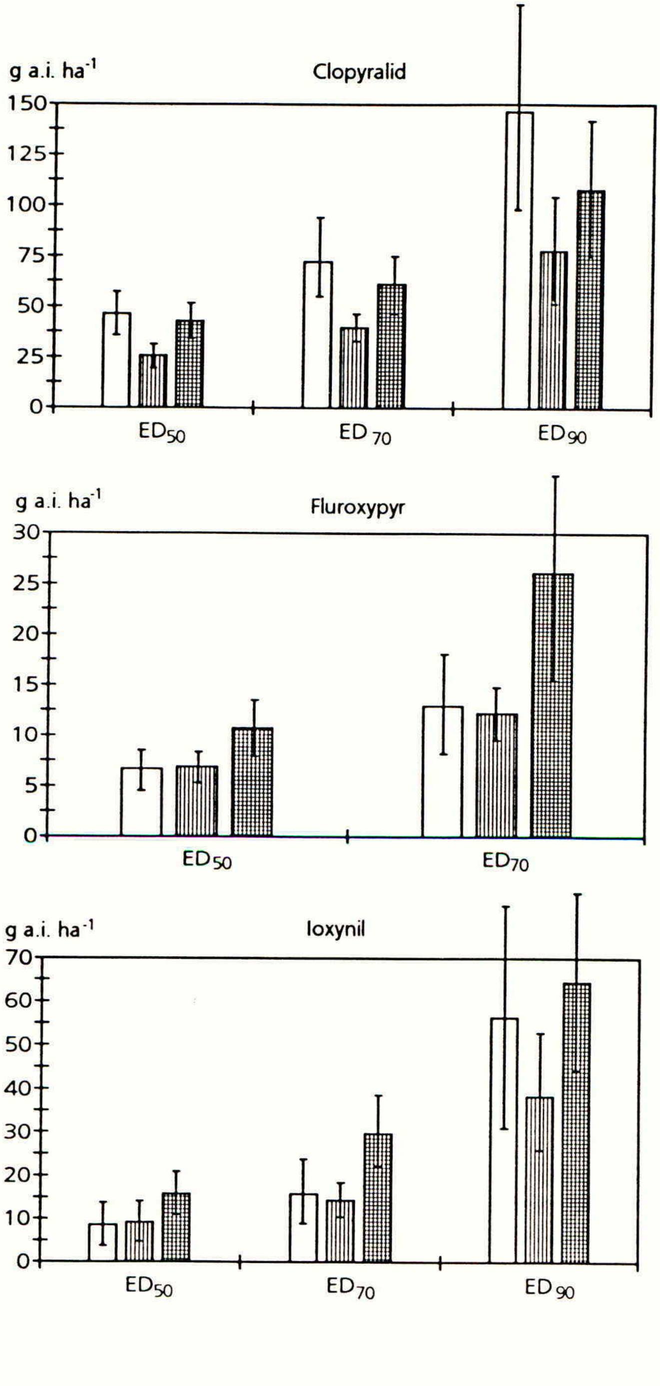


Figure 3. Estimated ED$_{50}$, ED$_{70}$ and ED$_{90}$ doses of clopyralid on *Matricaria inodora*, fluroxypyr on *Stellaria media* and ioxynil on *Sinapis alba* at 3 natural climatic scenarios. 95% confidence intervals are shown in parenthesis. Climate 1:□ , climate 2:▥ and climate 3: ▦ . For climate regimes see fig. 1.

of increasing temperatures may be counteracted by the adverse effect of the increased water vapour pressure deficit following a temperature rise. In addition wide differences in the climatic parameters between cabinets only prevail for short intervals. We believe that experiments performed in the climate simulator cabinets provide more reliable results to refinement of field doses in relation to climatic conditions compared to experiments carried out in controlled environment chambers. In addition to the natural climate we try to get as close as possible to natural conditions in the experiments by using outdoors grown weed species as test plants, applying the herbicides in a laboratory pot sprayer in a way comparable to field application and restrict the exposure to different climates to 6 days as this is the period that weather conditions can be forecasted reliable for the moment.

REFERENCES

Kristensen J L (1992) Research equipment for laboratory experiments with herbicides. *First International Weed Control Congress*, pp. 261-262.

Kudsk P; Streibig J C (1993) Formulations and adjuvants. In *Herbicide bioassays*, J C Streibig & P Kudsk (eds), CRC Press, Boca Raton, pp. 99-116.

Kudsk P; Olesen T (1988) The influence of temperature and humidity on the activity and rainfastness of DPX-L5300 applied alone and with a surfactant. *Proc. EWRS Symposium Factors affecting herbicidal activity and selectivity*, pp. 233-238.

Kudsk P; Kristensen J L (1992) Effect of environmental factors on herbicide performance. *Proc. 1. International Weed Control Congress*, **1** pp. 173-186.

Mathiassen S K; Kristensen J L; Kudsk P (1994) Climate simulators - one step closer to natural conditions. *Proc. SCI international symp. Comparing glasshouse and field pesticide performance II*, pp. 257-260.

Merritt C R (1984) Influence of environmental factors on the activity of ioxynil salt and ester applied to *Stellaria media*. *Weed Research*, **24**, pp.173-182.

Naleweja J D; Woznica Z (1985) Environment and chlorsulfuron phytotoxicity. *Weed Science*, **33**, pp. 395-399.

Thonke K E (1984) Temperaturen og luftfugtighedens indflydelse på 3 forskellige bladherbiciders effekt. *NJF Seminar*, **58**, 6.1-6.15.

BIOLOGY, DISTRIBUTION AND CONTROL OF *MILIUM VERNALE* M.B. IN GREECE

P G EFTHIMIADIS AND E A SKORDA
Agricultural University of Athens, Iera Odos 75, Athens, 11815, Greece

ABSTRACT

Milium vernale is a weed of increasing importance in northern and central Greece and has become a serious problem for winter cereals. An extensive survey of this weed in the major arable areas was carried out. The extent and density of infestation was recorded and showed the magnitude of the problem. The morphology, biology, crop competition and control of the weed were studied. The number of seeds per plant, germination period and other physiological characteristics were responsible for the rapidly increasing spread of the weed. This species competes with cereal crops and reduces their yield significantly (10-80%). In a series of trials, the biological efficiency, crop tolerance and application criteria were investigated for more than 10 herbicides against this and other weeds which were present in the same fields.

INTRODUCTION

Grasses have always been part of the arable weed flora in Greece. In the last two decades, populations of some species have increased considerably and now pose serious problems in crop production. In Northern Greece, and to a lesser extent in some central parts of the country, with a high percentage (more than 70%) of winter cereals, *Milium vernale* M.B. is considered a serious problem and it is increasing in intensity and geographic spread. Herbicides used by some farmers have not always given sufficient control due to unfavourable weather conditions during winter and spring or phytotoxicity to new cereal varieties (Skorda & Michailidis, 1980). In the 1960 s, *Millium Vernale* was observed only in some mountain and island regions, mainly on non arable land of Greece (Kavvadas, 1956; Damanakis & Economou, 1986). As a weed, it was found in the Valley of Pelasgonia, Prespa and Ohrid (Lazanovski *et al.*, 1973). In the early 1970's, *M. vernale* was found only in some cereal or alfalfa fields, especially in the field margins, in Greece. By 1978, *M. vernale* was present in 56% of surveyed fields (Skorda & Michailidis, 1981). In the mean time, farmers and advisers observed this weed in new areas of arable crops. Therefore, an extensive and quick survey in the major arable areas of northern and central parts of the country was undertaken to give a useful indication of the relative importance and distribution of this weed and the factors contributing to its occurrence. At the same time soil assessment, germination patterns in the field, morphological, phenological characteristics and herbicide effectiveness were studied.

MATERIALS AND METHODS

The method suggested by Scragg *et al.* (1976) was used for the *M. vernale* survey. *M. vernale* panicles in mid-April to mid-May are reddish to purple in colour and their height is

10 to 20 cm above wheat and barley plants which at that time are at the boot or an earlier stage. Therefore, it is very easy to detect *M. vernale* panicles in wheat or barley fields by careful scanning using bionoculars. Only fields in which a confident identification could be made were recorded as infested. No other weed at that time had the same appearance. Northern Greece and a central part were suitable for this method of surveying as it is well supplied with good public roads and most areas are cropped with winter cereals (70-80%). In order to survey a large number of fields as quickly as possible, it was decided to examine all wheat and barley fields adjacent to a series of public roads using a scale of 1-9 for proportion of fields infested and a scale of 1-5 for density of infestation. A separate field in each area was examined and the observation was made from different points of road margins, so it was possible to estimate a satisfactory number of infested fields. In a total of 710 km^2, 2420 winter cereal fields were examinined in Macedonia, Thrace and a part of Thessalia.

Soil samples were taken from the uppermost twenty centimetres. These samples were analysed. *M. vernale* seed germination was evaluated in fields of three regions under natural conditions. The emergence of *M. vernale* in each field was recorded monthly, always in the same randomly placed quadrat (25x25 cm) in four places of each plot and the emerged seedlings removed. The fields selected for this study were medium to heavily infested with *M. vernale.* Morphological characteristics of plants were recorded in ten randomly selected sample plots of 1 m^2 within each field. The fields were located throughout the surveyed area and can be assumed to reflect the *M. vernale* situation in Greece. Using the seed sampled from these fields, the morphologically distinct ecotypes were studied to confirm genetic and environmental variation. More than 10 herbicides were evaluated in heavily and medium infested fields in replicated experiments with plot size 30 m^2. Herbicides were applied pre or post-emergence. Weed species were counted and weighed (dry matter) close to the harvest time on an area of 1 m^2 for each plot. A central strip of 1.25 m down each plot was harvested by a harvester and yield recorded in kg/ha.

RESULTS

In Table 1, the results of the 1992-93 survey are given by districts. A high overall frequency of infestation was detected. The highest, medium to heavy infestations were in west

Table 1. Infected fields with *M. vernale* (% of field).

	Macedonia						Thrace		Th
	Gre*	Ko	Ka	Fl	The	Ka	Xa	Or	El
M. vernale not detected	33	38	12	33	36	58	52	56	60
Very light infestation	19	27	15	20	19	9	16	8	14
Light infestation	15	12	20	15	18	14	9	9	10
Medium infestation	13	11	21	14	19	9	15	20	12
Heavy infestation	20	12	32	18	8	10	8	7	4

* Gre= Grevena, Ko=Kozani, Ka=Kastoria, Fl= Florina, Th=Thessaloni, Ka=Kavala Xa= Xanthi, Or=Orestiada, El= Elassona,Th= Thessalia

Macedonia, the medium in Thrace and the lower in Thessalia. There were considerable differences between districts, ranging from 40% to 88%. The number of fields examined in West Macedonia was higher than in the other regions because there were more rotations in the latter than in the former. Also, it is clear that West Macedonia had the most serious infestation. Only in 12-38% of fields was *M. vernale* not detected, however, more than 28% of the area must be sprayed with effective herbicides to control the weed.

Soil properties

More than 80% of the fields infested with *M. vernale* had soils with medium to heavy texture, high contents of available P, K_2O and free $CaCO_3$, but they were very poor in organic matter. The clay content of soils was relatively high. Soil types with large ignition loss, be it organic or clay, are generally quite moist and frequently poorly drained.

Table 2. Emerged plants of *M. vernale* from September to March.

Month	Ptolemais	Florina	Grevena
September	19	25	68
October	165	53	105
November	88	326	153
December	27	40	49
January	4	11	5
February	3	68	3
March	187	220	165

Germination

M. vernale germinated mainly in autumn, sometimes starting in mid-August, given that the soil was wet, and continued until March (Table 2).The largest flush was in autumn and the smallest in spring. Therefore, the main flush occurred mainly in early-sown winter cereals which are the main crop in most areas of northern Greece. The later the sowing time, the less *M. vernale* occured (Table 3).

Table 3. Number of *M. vernale* (plants/m^2) at four and five sowing dates.

Galatia		Ardassa	
Sowing date	plants/m^2	Sowing date	plants/m^2
11 November	213c	22 October	170a
21 November	302b	1 November	78b
1 December	134d	11 November	42c
1 March	383a	21 November	76d
		11 February	40c

Seed production of *M. vernale* varied from 687 to 2,392 per plant in winter wheat, dependent mainly on the length of the vegetation period and number of tillers, which is strongly infuenced by crop competition. About 50% of produced seeds were shed to the soil about one month before harvesting.

Morphological variation

The *M. vernale* plants collected from all districts varied significantly in plant height, days to panicle emergence (Table 4), number of branches per panicle and per plant. All characteristics ranged widely and some tended to have a normal distribution for each parameter but not all.

Table 4. *M. vernale* and wheat heading time in seven districts.

	1977		1992	
District	*M. Vernale*	Wheat	*M. Vernale*	Wheat
Argos Oresticon	10-15/4	9-15/5	20-30/4	19-22/5
Neapoli	1-4/4	5-10/5	10-20/4	15-20/5
Grevena	5-10/4	5-10/5	15-26/4	12-25/5
Xirolimni	10-15/4	10-15/5	20-30/4	20-30/5
Kozani	10-15/5	12-17/5	20-30/4	20-30/5
Florina	10-20/4	12-22/5	20-30/4	20-30/5
Xylopoli	11-20/4	10-20/5	23-20/4	20-30/5

Chemical control

Most of the evaluated herbicides gave excellent control and high yield responses, while some gave less control and smaller yield responses (Table 5). Some of the herbicides caused temporary chlorosis or necrotic spots on the wheat plants. The phytotoxic symptoms and the high cost of herbicides discourage most farmers from using them.

DISCUSSION

Milium vernale continues to pose a serious problem especially in north-west Greece, where there is a high percentage of winter cereals and it is increasing on a relatively high acreage in southern regions of the country. Comparison of these results with the data available from Damanakis & Economou (1986) is difficult owing to differences in the surveying technique. It appears that the overall frequency of infestation is comparable to that given by Skorda & Michailidis (1981) and shows the maintainance of the frequencies of infestation of north-west Greece and the extension of the weed in eastern and southern areas of the country. There are no obvious reasons why the north-west part of the country should be more heavily infested with *M. vernale* than the remainder of Greece. The borders with Pelagonia, Prespa and Ohrid (Lazanovski & Vilarov, 1975) coupled with high rainfall almost every year and medium to

Table 5. Effect of herbicides on grain yield of cereals and plant number and dry matter of *M. vernale*.

Treatment	Dose (g AI/ha)	*M. Vernale* (plants/m^2)	Dry matter (g)	Grain yield % of control (kg/ha)
Control		14d	4.6ef	100g (628)
Imaz	400	37c	5.7e	457a
Dicl	720	1f	1.7	314de
Flam	325	14d	11.0d	314de
Flam+tria	325+14	34c	2.2f	361c
Flam+Sulf	325+14	57ab	54.4a	328cd
Flam+Chl	325+14	56b	12.8cd	441a
Flam+MCPA	325+150	55b	24.8b	471a
Flam	715	9e	2.4ef	327bf
Imaz+Sulf	400+14	50b	22.8b	402b
Imaz+Chl	400+14	33c	16.9c	318d

Imaz=Imazamethabenz, Dicl=Diclofop-methyl, Flam=Flamprop-methyl, Sulf=Sulfmethemeton-methyl, Chl=Chlorsulfuron, Tria=triasulfuron.

heavy texture soils would be some of the reasons. In addition, here a fairly intensive cereal cultivation is practised with either very infrequent or no rotation which is probably an important factor in encouraging this weed. The same is true for an area of Thessaloniki-Xylopoli. Spraying is now practised only on medium or heavily infested fields and may reduce the general level of infestation but is unlikely to have any effect on the frequency of light infestations, where treatment would probably be uneconomic. This is only true for Kozanis fields but not of other districts. The reason for this is both the high cost of herbicides and application because of small fields. All medium and heavily infested areas are associated with frequent cereal growing usually without any rotation.

Throughout the area, very light infestations are by far the most numerous. Comparing the 1978 and 1994 surveys, it seems that these are recent infestations which will progressively increase to higher levels or are infestations which were sprayed and controlled unsatisfactorily. A repeat of this survey in 8-10 years might give different results due to lower prices of cereal grain and higher cost of herbicides.

The ability of this weed to adapt to a relatively wide range of environmental conditions and its morphological and phenological characteristics would help it to increase in density and frequency. Due to short-strawed wheat varieties grown in the two last decades, the problem has increased in that time. The morphological and phenological variation in *M. vernale* observed from different districts and fields might be environmental or genetical. Therefore, seeds of the observed populations will be sown under uniform environmental conditions to find if this variation is genetical. Sokolovskaya & Probatova (1976) discovered races with *M. vernale* in isolated geographical areas of USSR with different chromosome numbers ($2n=10$, $2n=14$, $2n=18$). These differences in chromosome number would be reflected in morphological and phenological characters. The damage caused by *M. vernale* to cereals is very high. Control with effective herbicides can give double the yield compared with the unsprayed control, depending on factors like weed and crop density, sowing time and nitrogen level.

Delaying sowing time and taking advantage of the opportunity to control early emerged seedlings by seedbed preparation should reduce infestation. Furthermore, late drilling always has the risk of reduced yield. The general use of early sowing, where there is partially dormant seed (Lazanovski & Vilarov, 1975) with an ability to emerge in the field until March in low temperatures (optimum 6-8°C) will maintain and increase this weed.

The only means to control *M. vernale* is the use of effective herbicides. Several graminicides are registered in Greece. The herbicide and application cost may exceed yield benefits and the farmers are sceptical of their use. Also, the lower prices for agricultural produce in EC tend to discourage the use of expensive chemical control measures. As a consequence, the problem of *M. vernale* may be a threat to the development of agronomic systems which aim to minimize management inputs.

In conclusion, the principal reason advanced for the spread and maintainance of *M. vernale* is that this species is adapted to the niches created by the increased use of winter cereals and reduced tillage technique as well as its high competitive ability, its high rate of seed production, that it emerges from autumn to spring in low temperatures and the low usage of effective pre and post-emergence graminicides.

REFERENCES

Damanakis, M; Economou G (1986) The grasses of Greece. Records of occurrence and distribution. *Benaki Phytopathologhical Institue*, **1**, 1-326.

Kavvadas, D S (1956) Lexicon Botanic Illustrated (in Greek), **6**, 2632-2633, Athens.

Lazanovski, R; Antoski, S R; Natseva L; Svetievski, P (1973) Representation of grassy weeds in some weed communities in Macedonia and results of chemical control trials. *Symposium 3a Klasesti Pleveli, Makedonska Akademija na Naukite i Umetnostite Skopje*, 61-70.

Lazanovski, R J & Vilarov A (1975) *Milium vernale* M.B. an important grass weed in a part of Yugoslavia. *Proceedings European Weed Research Society Symposium Status, Biology and Control of Grassweeds in Europe,* **1**, 44-48.

Scragg E B; Kilgour D W; Carnegie H M (1976) A quick low cost survey of wild oats. *Proceedings 1976 British Crop Protection conference-Weeds,* **1**, 1-7.

Skorda E A; Michailidis B S (1980) Chemical control of *Milium vernale* M.B. on wheat. *Scientific bulletin of Cereal Institute* No. **69**, 1-15.

Skorda, E A; Michailidis B S (1981) Distribution and importance of *Milium vernale* M.B. in northern Greece. *Pan Hellenic Congress of Geotechnical Research*, **1,** 11-12.

Sokolovskaya A P; Probatova N S (1976) The Karyological characteristics of the genera Milium and Holms poaceal. *Botanicheskiizharnal (Lenigrad)*, **61** (Recd 1977) 969-973.

LONG-TERM EFFECTS OF REDUCED HERBICIDE USE ON WEED POPULATIONS AND CROP YIELD IN WHEAT

E A SKORDA, ADAMIDIS TH and P G EFTHIMIADIS
Agricultural University of Athens, Iera Odos 75, Athens, 11815, Greece

ABSTRACT

Since it is necessary to identify where there could be a reduced herbicide input without economic loss then more information is needed on the relation between weed competition and herbicide response particularly where the weed populations may be allowed to build up over successive years without herbicide use. A five-year experiment was begun in 1988 in a field with a dense natural infestation of wild oat (*A. ludoviciana* and *A. fatua*) and broad-leaved weeds (*Fallopia convolvulus, Bifora radians, Fumaria officinalis etc.*). Winter wheat had been grown for five seasons in the same plot and only in the first year of the experiment were herbicides applied. The effects of a range of herbicides against broad-leaved weeds or wild oat and mixtures of both on weed numbers, and their fate and yield were studied. In the absence of herbicide, some weed numbers progressively increased whilst others decreased over a period of three or four years. The same is true for weed seed production. On the contrary, following herbicide application most of the weeds decreased and this reduction continued for 2-3 years without herbicide treatments. The herbicides gave significant yield increases which appear to be attributable to factors other than weed control efficacy.

INTRODUCTION

In Greece, as in other countries, attempts are being made to optimise herbicide use not only for environmental implications, but also for economical considerations. As winter cereals in Greece are grown on dry and low fertility soils, grain yields are very small in comparison with the other EC countries. Therefore, with the shift of EC agricultural price policy, especially for cereals, Greek farmers estimated that weed control was an input item more amenable to reduction than fertilizers, or seeds, given that weed control is the only crop protection practice for winter cereals in Greece. They need to achieve this without affecting yield or harvesting efficiency in the current crop and without creating problems for future crops. The problem is more serious for farmers with small-sized fields (1-3 ha) who grow wheat without any rotation and where the cost of application is also quite high.

There is much information available about the efficacy of threshold and reduced applications for reducing weed control inputs (Clarke *et al.*, 1993; Fisher & Davies, 1993; Proven *et al.*, 1991). However, more information is needed on the relation between weed competition and herbicide response, particularly where the weed populations may be allowed to build up over successive years without herbicide use. An experiment was, therefore, begun in 1988 in a field with a dense natural infestation with wild oat (*Avena ludoviciana+A. fatua)* and broad-leaved weeds (*Fallopia convolvulus, Bifora radians, Fumaria officinalis etc*). In this experiment, winter wheat was grown for five seasons in the same plot and only in the first or fourth year were herbicides applied.

MATERIALS AND METHODS

The experiment was conducted at the Agricultural Research Station of North-western Greece. The soil was silty-clay with pH 7.4. In the season prior to the experiment, the crop grown was wheat. The field of the experiment was naturally infested with a high population of wild-oat (*A. ludoviciana and A. fatua)* and broad-leaved weeds (*F. convolvulus, B. radians, F. officinalis* and some others). The wheat cultivar used was Dio (*Triticum aestivum)* and was representative of commercially available cultivars for the area. In each year of the experiment prior to drilling, the experimental area was ploughed to a depth of 10-15 cm and disced. Wild-oat and some broad-leaved weeds began to emerge with the wheat and emergence continued until early spring when the herbicides were applied. The broad-leaved weeds *B. radians, F. convolvulus and F. officialis,* which were the most dense, began to emerge in spring, before and after the herbicides were applied.

The experiments were of a completely randomized block design with four replicates and an individual plot size of 2.25x10m. Most herbicides were applied only in the first year using a plot-sprayer with a 2m boom and spray volume range 300-400 l/ha on April 12, 1989. Also, a plot was sprayed every year with half-dose of flamprop-M-methyl and fenoxaprop-P-ethyl. In the fourth year after the first application, two replicates were sprayed with imazamethabenz against dense wild-oat populations.

The climate is characterised by cold, rainy winters and hot, dry summers with much variation between years. The weather conditions in the third and fifth years of the experiments were generally favourable during the growing season and the crop cover was thick. Wild-oat regrowth occurred about two months after the herbicide applications in the first year. The second year was very dry and the overall wheat yields were very low.

Shortly before harvest and shedding, weed plants were collected from two random quadrats, each 0.5 m^2. The plants were hand-pulled, dried, weighed and counted. Grain and straw yield were taken using a plot combine harvester. From each plot, wild oat seeds were collected and counted from harvested grain and straw. Yields are quoted at 12% moisture content.

RESULTS

In the first year, a (relatively) high number of wild-oat *(Avena ludoviciana and A. fatua)* and broad-leaved weeds were present before spraying. The main species present were *Fallopia convolvulus (28 m^2), Chenopodium album (10 m^2), Bifora radians (14 m^2), Fumaria officinalis (17 m^2), Delfinium consolida (10 m^2)* and wild-oat (68 m^2). The number of broad-leaved weeds in the untreated plots decreased in the subsequent years. Where an effective herbicide had been used in the previous year, weed numbers were significantly lower than in the no herbicide plots. In the absence of herbicide against broad-leaved weeds and presence of herbicide against wild-oat, broad-leaved weed numbers were higher than in the unsprayed plots in the year of herbicide application but wild-oats were controlled (Table I). In the year of herbicide application, the panicles resulting from regrowth were small, immature or matured very close to harvest.

Table 1. Effect of herbicide treatment on number of wild-oat panicles and number of broad-leaved weeds in the 1989 (sprayed), 1990, 1991, 1993.

Treatment	Dose	Wild-oat (Panicles /$m^{2)}$)				Broad-leaved weeds (number /m^2)		
	(g AI/ha)	1989	1990	1991	1993	1989	1990	1991
Control		68bc	97a	58a	77a	79bc	24	7
Flam	175	54bf	38cf	50b	59cd	135a	9	9
Flam every year	175	54bf	12df	12de	37f	88b	12	11
Flam	324	51bg	17df	18de	42ef	88b	12	8
Flam+chl	175+1.5	65bd	9df	24de	53de	45de	23	9
Flam+trias	175+1.5	91a	61bc	36bd	67ab	27ef	3	9
Flam+Sulf	175+1.5	70b	15df	37bd	58cd	62cd	4	8
Flam+MCPA	175+150	50bg	72ab	43ac	60cd	80bc	15	9
Fen	48	39ei	99a	28cd	68a	81bc	6	8
Fen every year	48	39ei	39cf	9e	48de	81bc	6	11
Fen	96	20i	11df	15de	65ac	114a	8	8
Fen+chl	48+1.5	32fi	34cf	32cd	61cd	77bc	17	17
Fen+trias	48+1.5	37ei	27df	35bd	63cd	49de	1	11
Fen+Sulf	48+1.5	71ab	43cf	31cd	67ab	31ef	2	9

Flam=flamprop-M-methyl, chl=chlorsulfuron, trias=triasulfuron,
Sulf=sulfmethmeton-methyl, Fen=fenoxaprop-P-ethyl
Figures with a common letter do not differ significantly at $p<0.05$.

Flamprop-M-methyl applied at half-dose alone, as well as in mixture with broad-leaved herbicides, did not significantly reduce the number of wild-oat panicles (Table 1). Fenoxaprop-P-ethyl alone and with the broad-leaved herbicides significantly reduced the numbers of wild-oat panicles. The recommended dose gave higher control than the half-dose. In the following two seasons without herbicide use (1989-1990 and 1990-1991), wild-oat panicle numbers were significantly lower in the herbicide treated plots than in the untreated plots, except for the mixtures Flamprop-M-methyl+triasulfuron and MCPA. The highest reduction was in the herbicide at full rate and half every year. Wild-oat seed production was reduced after treatment with herbicides as a result of reduction in number of the plants or in number of seeds per panicle compared to untreated plots.

The fate of seeds during harvest

More than 50% of the total seeds produced had been shed naturally before harvest. The number of seeds as contaminants of grain was related to the degree of shedding at harvest and the number of seeds produced after different treatments. Highest numbers were shed to the soil, fewer were found in the grain and the fewest in the straw (Table 2).

Table 2. Number of wild-oat seeds collected from the grain and from the straw.

		1989			1990		
	Dose	Grain		Straw	Grain		Straw
	(g AI/ha)	(per kg)	(per m^2)	(per kg)	(per Kg)	(per m^2)	(Per kg)
Control		155a	31a	31a	74a	6.6ce	66ab
Flam-M	175	118b	25b	15bf	53bd	7.7ad	45df
Flam every year	175	118b	25b	15bf	23fh	5.1df	26fg
Flam	324	39cd	13c	15bf	29fh	4.6eg	31eg
Flam+chl	175+1.5	25gh	9eh	10fi	36dg	6.9be	38dg
Flam+trias	175+1.5	43c	11ce	5ik	60bc	8.3ac	44dg
Flam+sulf	175+1.5	24gh	7hi	11eh	61ac	8.4ac	53ad
Flam+MCPA	175+150	38ce	9eh	28a	39bd	6.1cf	69a
Fen	48	20hi	25b	18bc	55bd	6.8ce	37dg
Fen every year	48	20hi	5ik	19bc	29fh	4.8eg	38dg
Fen	96	10k	3l	17be	30eh	5.2df	28fg
Fen+chl	48+1.5	11jk	3l	17be	34df	5.2df	47bf
Fen+trias	48+1.5	16ik	6ij	4jk	51be	8.4ac	39cg
Fen+sulf	48+1.5	36ce	10dg	12dg	76a	9.7ab	61ac

Flam=flamprop-M-methyl, chl=chlorsulfuron, trias=triaslfuron, sulf=sulfmethmeton-methyl, Fen=fenoxaprop-P-ethyl
Figures with a common letter do not differ significantly at $p<0.05$

Grain yield

The overall effect of herbicide application was to increase grain yield not only in the year of application, but also in the following four years without any herbicide application (Table 3). In the first year when the herbicides were applied, the significant yield increases were 32% to 71% higher than that of the untreated control. The half-dose of Flamprop-M-methyl, Flamprop-M-methyl+MCPA gave grain yield increases of 13% and 19% but they were not significant. The tank-mix of Flam and with broad-leaved herbicides gave about the same yield as the full dose even though they gave lower control of wild oat, but they controlled most of the broad-leaved weeds. In the following years (no treatment), the yield increases tended to be greater following the herbicide treatments which gave the largest decrease in wild-oat without a difference between recommended and half-doses. In the following three years, the percent yield increases for the treated plots compared with untreated tended to be lower than the increases of the second year (Table 3).

DISCUSSION

The dramatic decline in wild-oat numbers which took place over the three years must be attributed to the herbicide treatments applied in the first year, but not for half-dose of flamprop-methyl and tank-mix with MCPA. This was the result of higher regrowth of wild-oat because of favorable growth conditions during the spring.

Table 3. Effect of herbicide on grain yield in 1989 (spray) 1990, 1991, 1992, 1993.

		Grain yield (kg/ha)				
Treatment	Dose (g AI/ha)	1989	1990	1991	1992	1993
Control		100h (1973)	100h (981)	100h (1346)	100dg (1440)	100e (1610)
Flam	175	113gh	144eg	143ad	128ae	130ac
Flam every year	175	113gh	186ad	145ab	138ac	148a
Flam	324	159ad	175af	140be	111bf	126ac
Flam+chl	175+1.5	166ad	194ab	142ae	139ac	118cd
Flam+trias	175+1.5	132eg	142g	129fg	142ab	137ab
Flam+sulf	175+1.5	149ce	143fg	142ae	106cg	138ab
Flam+MCPA	175+150	119fh	148eg	128fg	114be	116cd
Fen	48	139dg	164cg	121g	113bf	128ac
Fen every year	48	139dg	190ac	149ab	158a	148a
Fen	96	151be	186ad	142ae	156a	144a
Fen+chlor	48+1.5	157bd	178af	134df	95eg	120bd
Fen+trias	48+1.5	171a	179ae	134df	94eg	117cd
Fen+sulf	48+1.5	143dg	154dg	132ef	116be	132ac

Flam=flamprop-M-methyl, chl=chlorsulfuron, trias=triaslfuron, sulf=sulfmethmeton-methyl, Fen=fenoxaprop-P-ethyl
Figures with a common letter do not differ significantly at $p<0.05$

The higher decline in wild-oat numbers in the following two years than the year of herbicide applications was due to a reduction in wild-oat panicles and production of weed seed with low germination levels in the year of herbicide application. In the experiment with infestation of wild-oat and broad-leaved weeds, there was a clear and significant benefit to weed control with full rate of flamprop-M-methyl and with both half and full rates of the other herbicides. Half-dose of flamprop-M-methyl tank mixed with effective broad-leaved herbicides, as well as fenoxaprop-P-ethyl, had the same benefit.

As the cost of herbicide application in Greece, as well as in other countries with small sized fields, is high the posititon was generally optimized by reducing the frequency of herbicide use (once in three years) and using the full recommended herbicide rate for the most effective herbicides to against the weed population of the field. As a direct consequence, the most cost effective strategies were those which involved the least expenditure on herbicide and herbicide application, Proven *et al.* (1991) in continuous cereals has shown the benefit of reducing herbicide inputs on margins.

Furthermore, the use of reduced doses in very infested fields with weeds germinated for a long time as wild-oat (*A. ludoviciana+A. fatua*) and being in different growth stages at herbicide application, will give poor control. The full rate applied once in three years seems to be the most beneficial. This is logical because recommended rates include increments for reliable performance in adverse environmental conditions, for adequate performace against less susceptible weeds and to provide effective control even though the product is used alone rather than as part of a programme. Formal thresholds are not used because in small farms it is difficult to assess. Therefore the full rate, not every year, but once in three years gives the best performance. In that case, there seems to be a great need for better dose-response information on a wide range of commercial herbicides under field conditions. Broad-leaved weeds were present in high numbers in the year of herbicide application because most of them germinated in spring after herbicide application and, in that year, the weather conditions (humidity and temperature) favoured germination. Half-dose every year gave the same results as the full rate applied only in the first year of the experiment. In the following years, the low population of wild-oat allowed the wheat crop to be more competitive; this coupled with unfavourable spring conditions gave very low broad-leaved weeds numbers. The prime importance of wheat competition, in complementing herbicide activity in cereals has long been recognised (Skorda *et al.* 1991; Salone, 1992).

Reduced-doses of the herbicides tested controlled weeds without significant loss of yield. At the same time, it was possible to maintain a reasonable low weed population and weed seed production in the following two years with lower than the full rate and without significant loss of yield. In fact the full rate herbicides gave very much lower wild-oat seed production.

REFERENCES

Clarke J H; Bowerman P ; Young J E B; Cook S K; Jones A E; Grobes S J; Green M (1993) Effect of recommended and reduced rate herbicides on weed number yield and gross margin in TATISMAN. Report of the first two years. *British Crop Rotection Conference-Weeds*, **3**, 1009-1014.

Fisher N M; Davies D H K; Whytock GR (1993) Reliability of broad-leaved weed control in cereals using low doses of herbicides. *Brigton Crop Protection Conference-Weeds*, **3**, 1223-1228.

Proven M J; Courtney A D; Picton J; Davies D H K; Whiting A J (1991) Cost-effectiveness of weed control in cereal-systems based on thresholds and reduced rates. *Brighton Crop Protection Conference-Weeds*, **3**, 1201-1208.

Skorda E A; Efthimiadis P; Adamidis Th (1991) Wild seed fate affected by herbicides *Brighton Crop Protection-Weeds*, **3**, 929-936.

Salone J (1992) Yield responses of spring cereals to reduced herbicide doses. *Weed Research*, **32**, 493-500.

RISK EVALUATION OF THE LEACHING POTENTIAL OF SULFONYLUREA HERBICIDES

M H RUSSELL
DuPont Agricultural Products, Experimental Station, Wilmington, DE 19880-0402

T H CARSKI AND R A MCKELVEY
DuPont Agricultural Products, Stine-Haskell Research Center, Newark, DE 19714

ABSTRACT

A risk assessment was performed of the potential for low levels of sulfonylurea herbicides to leach to shallow ground water and impact either human health via drinking water or non-target plants via use of shallow ground water for irrigation. Exposure estimates of potential concentrations in shallow ground water were obtained using PRZM modeling and combined with hazard data derived from experimental data. The primary conclusion of the risk assessment was that sulfonylurea herbicides present a negligible risk to both human health and non-target terrestrial plants due to the low concentrations which may reach shallow ground water.

INTRODUCTION

Sulfonylurea (SU) herbicides have been developed for a wide range of agricultural crops including cereals, corn, sugarbeets and rice. The commercial success of this class of herbicide chemistry has led to increased scrutiny of various aspects of their environmental fate to ensure that wide-spread use remains environmentally sound. To evaluate the environmental impacts from the potential leaching of sulfonylureas, a risk assessment of the SU herbicides registered by DuPont Agricultural Products was conducted during the summer of 1992. The risk assessment was performed by evaluating the potential hazards resulting from the use of sulfonylurea herbicides, estimating potential exposures using modeling and then assessing the resulting risk of significant exposure to the defined hazards. The potential environmental risks resulting from the use of sulfonylurea herbicides for weed control in crops are presented in this paper.

OVERVIEW OF THE PROPERTIES OF SULFONYLUREA HERBICIDES

Seven different sulfonylurea herbicides were included in this leaching risk assessment: bensulfuron methyl, chlorimuron ethyl, chlorsulfuron, metsulfuron methyl, nicosulfuron, thifensulfuron methyl and tribenuron methyl.

One of the primary distinctive characteristics of sulfonylurea herbicides is the typical application rate required for weed control. In contrast to many conventional herbicides which require annual applications of one or more kilograms per hectare (kg/ha) sulfonylurea herbicides typically require less than 0.07 kg/ha. The low use rates of SUs are directly attributable to their mode of action which is to inhibit the plant enzyme acetolactate synthase (ALS).

Due to their low Koc values, most sulfonylureas are classified as having either high or very high mobility in soil (Figure 1). Because SUs have pKa values ranging from 3 to 5, the sorption of these molecules to soil varies as a function of pH with higher sorption at lower pH values. The SUs with pyrimidine heterocycles (e.g. chlorimuron ethyl and bensulfuron methyl) typically have higher Koc values than the triazine-based sulfonylureas.

Sulfonylurea herbicides have moderate to rapid dissipation rates in the field (Figure 2). One of the specific criteria used to select new SU herbicides has been shorter soil dissipation half-life. As a result, some of the newer SUs dissipate very rapidly in the field, with typical half-lives in soil of approximately ten days.

HAZARD ASSESSMENT OF SULFONYLUREA HERBICIDES

To support a leaching risk assessment, two water quality hazard end-points were selected: (1) US EPA lifetime Health Advisory Levels (HAL) and (2) concentrations in irrigation water which would potentially result in an initial inhibitory response in sensitive terrestrial plant species. Lifetime HAL values were estimated from the toxicology data for each SU with values ranging from 56 ppb for tribenuron methyl to 8750 ppb for nicosulfuron. The estimated range of sensitive plant response was determined from tests conducted in the grrenhouse to address regulatory requirements. These estimates were derived from data obtained from soil exposure of four monocotyledon and six dicotyledon plant species, many of which are known to be highly sensitive to SU herbicides. These studies were conducted in low organic matter, steam-pasteurized soil to maximize bioavailability and to eliminate microbial degradation of the herbicides. Due to these experimental conditions, the resulting levels of plant response were typically greater than would be observed in a field setting.

EXPOSURE ASSESSMENTS OF SULFONYLUREA HERBICIDES

The assessment of the potential exposure of ground water to sulfonylurea herbicides was performed using the Pesticide Root Zone Model (Carsel et al., 1984) using input parameters representative of "typical" product physical properties and "moderately vulnerable" environmental characteristics. Typical values of use rate, field dissipation half-life and adsorption coefficient were used for each compound (Wauchope et al., 1992). The environmental characteristics included the use of a low organic matter, sandy loam soil (1.5% in the top 30 cm, declining to 0.2% below 100 cm) and a moderate annual rate of ground water recharge (~170 mm/yr).

Estimated concentrations in shallow ground water were determined by calculating the cumulative mass flux past a specified depth over the period of a year following application and dividing this value by the annual recharge over the same time period. Using this approach, the predicted concentrations in shallow ground water were calculated for theoretical water tables located at both one and two meters depth, identified as PEC1 and PEC2. The resulting concentrations corresponded to an extremely shallow skimming well with a short screened interval.

LEACHING RISK ASSESSMENT OF SULFONYLUREA HERBICIDES

A leaching risk assessment was performed for each of the seven SUs under consideration. In each assessment, the predicted environmental concentrations (PEC) were compared with the concentrations required to present a potential hazard to either human health via drinking water or to non-target plants via irrigation water. As an assurance of minimal environmental risk, there should be a safety margin between the predicted levels of exposure and the levels of concern identified by the hazard end-points. For all of the sulfonylurea herbicides under consideration, a considerable margin of safety exists for both human health and sensitive non-target terrrestrial plants. Graphical illustrations of the risk assessments for the individual compounds are presented in Figures 3 to 5 for tribenuron methyl, metsulfuron methyl and chlorsulfuron, respectively.

DISCUSSION AND CONCLUSIONS

The exposure assessment procedure used in this evaluation incorporates a number of conservative assumptions including: permeable, low organic matter soils; extremely shallow ground water; drinking water and irrigation wells which skim the water table; and plant response estimates based on data generated under conditions that favor greater activity than would typically occur in a field setting. Many SU use sites have environmental and hydrologic characteristics that are much less vulnerable than those used in this evaluation.

Based on the results of this study, the following conclusions can be drawn concerning the risks presented by SUs to ground water used either as a source of either drinking water or irrigation water:

(1) Large margins of safety (from 500-fold to over 1,000,000-fold) exist between potential exposure concentrations of SUs in ground water and potential hazard concentrations for all sulfonylurea herbicides that were evaluated.

(2) Sulfonylurea herbicides do not pose a significant threat to human health via potential exposure in drinking water due to a combination of low predicted concentrations and relatively high lifetime Health Advisory Levels.

(3) Sulfonylurea herbicides do not present a significant threat to non-target terrestrial plants via leaching to shallow ground water and usage of this water for irrigation due to a combination of low exposure concentrations and moderate plant response concentrations.

In summary, the use of sulfonylurea herbicides is compatible with the protection of ground water quality in a manner that is protective of human health and helps ensure ecological safety.

REFERENCES

Carsel, R.F. *et al.* (1984). "Users Manual for the Pesticide Root Zone Model(PRZM)", Release 1, EPA-60013-84-109.

Wauchope, R.D. *et al.* (1992). "The SCS/ARS/CES Pesticide Properties Database for Environmental Decision-Making", *Reviews of Environmental Contamination and Toxicology*, **123**, Springer-Verlag.

FIGURE 1
Relative Mobility of Sulfonylurea Herbicides

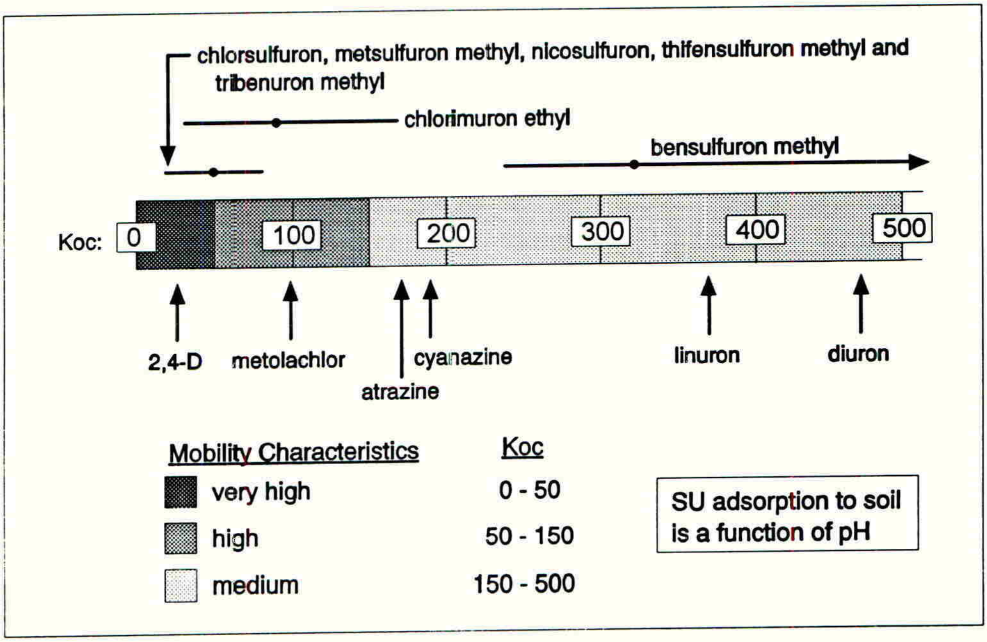


FIGURE 2
Field Dissipation Rates of Sulfonylurea Herbicides

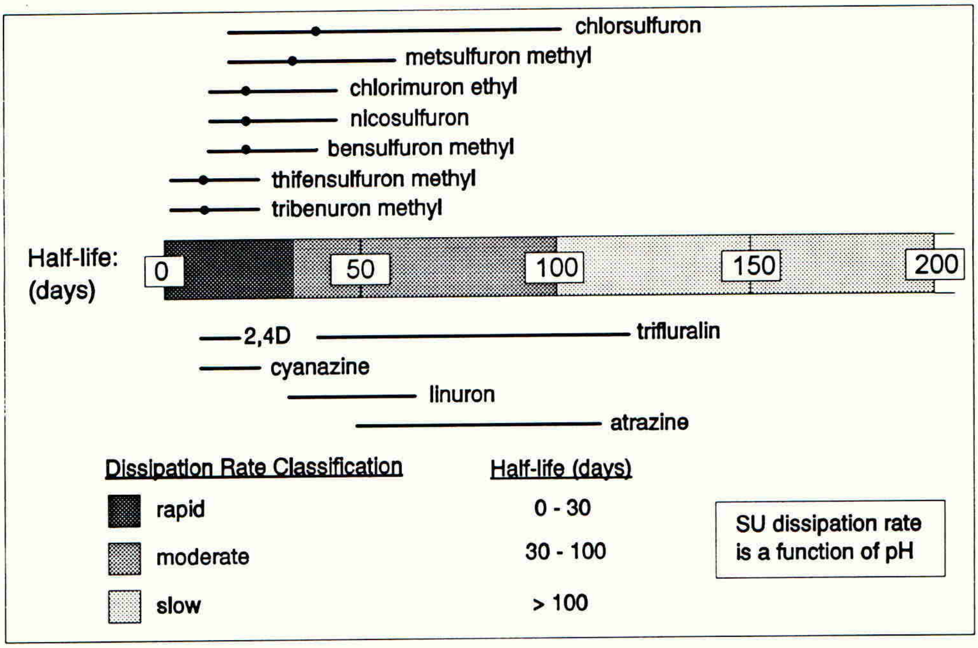


FIGURE 3
Risk Assessment of Potential Ground Water Concentrations of Tribenuron Methyl

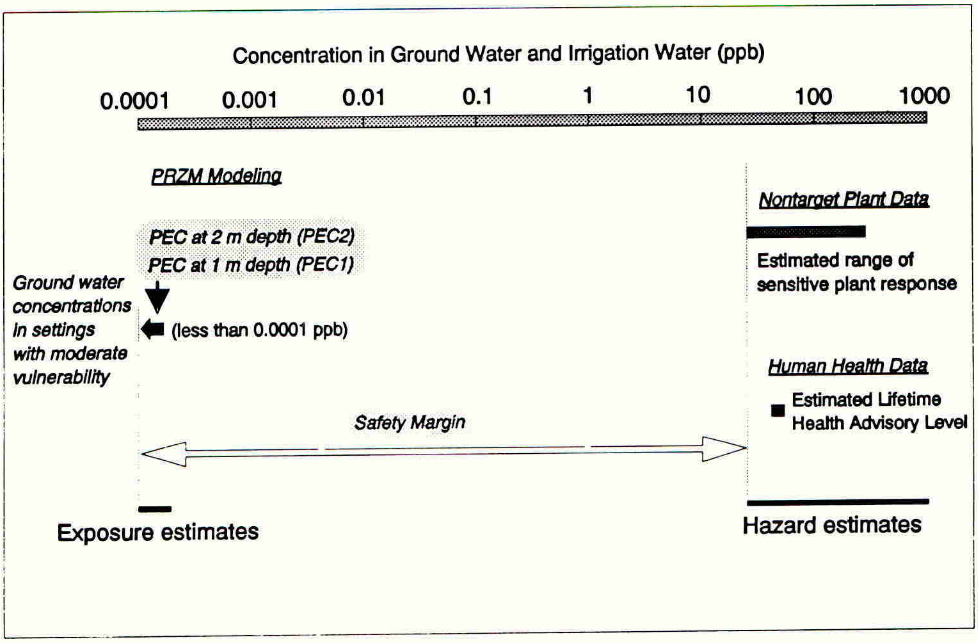


FIGURE 4

Risk Assessment of Potential Ground Water Concentrations of Metsulfuron Methyl

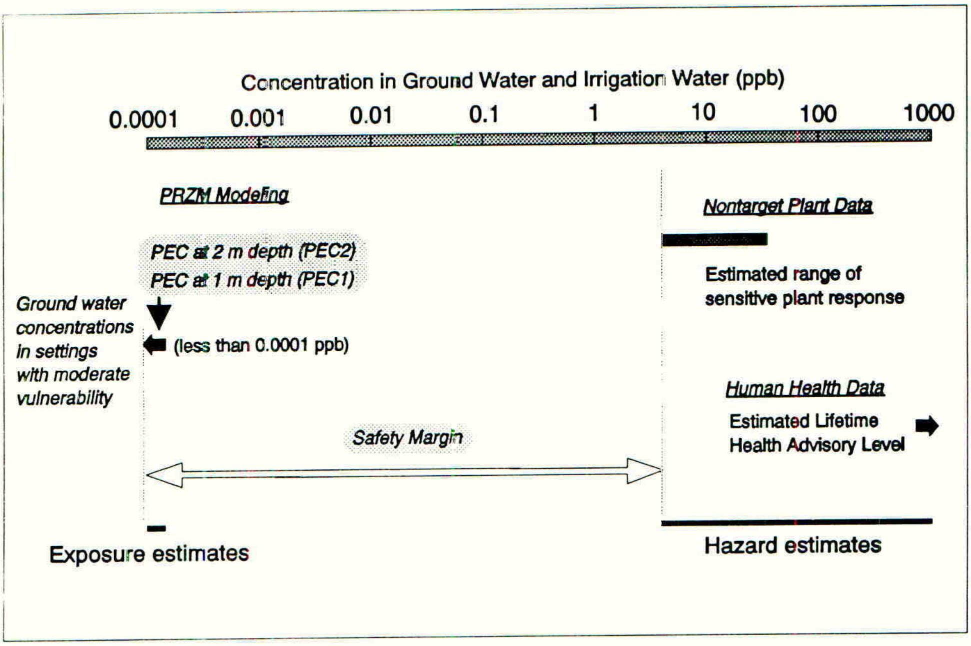
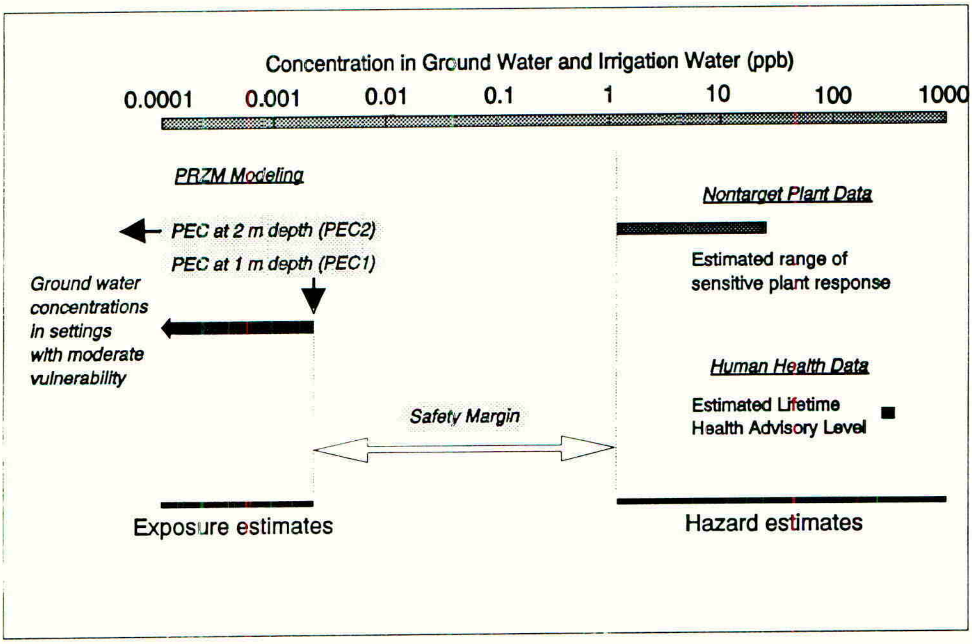


FIGURE 5

Risk Assessment of Potential Ground Water Concentrations of Chlorsulfuron



ANALYTICAL METHODS FOR SULFONYLUREAS IN ENVIRONMENTAL SAMPLES

A C BAREFOOT, J C STRAHAN, C R POWLEY, L M SHALABY
and F K KLEMENS

DuPont Agricultural Products, Experimental Station,
Wilmington, DE 19880-0402

ABSTRACT

The development of sulfonylurea herbicides applied at very low use rates presented analytical challenges that have been met by a variety of techniques. The purpose of the analysis, the matrix, the number of samples to be analyzed and the available instrumental technology all contribute to the choice of the method. During the past 15 years, we have developed methods which have been applied successfully to analysis of sulfonylureas in numerous crops and environmental matrices. The thermal lability and low vapor pressure of sulfonylureas have led us to rely on HPLC methods, both normal and reversed phase, for many analyses. The selectivity of the methods has been improved, when necessary, in several different ways including column switching and selective detectors. We have used LC/MS extensively for identification and quantitation of sulfonylureas and degradation products. We have developed immunoassays for many sulfonylureas to allow us to analyze numerous samples with minimum sample preparation. Each analytical technique has its place in meeting requirements for registration and use of sulfonylureas. Method performance criteria, regulatory requirements and analytical technology must be considered in choosing the appropriate method for analysis of sulfonylureas in environmental matrices.

INTRODUCTION

The determination of sulfonylureas in environmental samples requires methods suitable for estimating residues at concentrations much lower than high use rate agricultural chemicals. Whereas many herbicides may be applied at one or more kilograms/ha, sulfonylureas are applied at rates of less than 0.07 kg/ha. The sulfonylureas also are selective, and potential effects on sensitive rotational or non-target plants have required development of analytical methods capable of determining sulfonylureas at concentrations lower than for high use rate herbicides. The challenges for analytical chemists have come in all aspects of analysis. Sulfonylurea methods have required development of appropriate instrumental techniques, new extraction and analyte isolation procedures and sample handling methods that prevent contamination. The potential for false positives from matrix interferences or contamination increases as the concentration of the analyte in the sample decreases, and confirmatory methods and quality control have assumed greater importance in residue laboratories. Sulfonylurea methods using multiple chromatographic modes and mass spectrometry have become necessary for minimizing false positves and confirming identity of residues.

The choice of the procedures used in analytical methods depends on physical and chemical characteristics of the analyte, the purpose of the analysis, the degree of confirmation required, the instrumentation available and the desired method performance. The thermal lability and low volatility of sulfonylureas make impractical typical gas chromatographic methods and extraction methods requiring refluxing solvents. The commercialization of sulfonylurea herbicides in the 1980's coincided with significant developments in HPLC, LC/MS, immunoassay and supercritical fluid extraction, technologies which have been particularly useful for analysis of sulfonylureas (Peter et. al, 1989). In the same time period, increased scrutiny of the environmental fate of all agricultural chemicals and increasing interest in effects on non-target organisms have led to regulatory requirements for validated environmental chemistry methods (Marlow et al, 1995). The low use rate and sensitivity of some crops to sulfonylureas has required us to consider plant response for determining the method performance needed to meet the goals for environmental chemistry methods. For comparison of method performance with potential non-target plant effects, we have used the estimated range of sensitive plant response obtained from tests conducted in the greenhouse to address regulatory requirements. The estimates were obtained from four monocotyledonous and 6 dicotyledonous plant species, known to be sensitive to sulfonylureas, and exposed in low organic matter, steam sterilized sandy loam soil. Due to the experimental conditions, the resulting levels of plant response were typically greater than would be observed in a field setting.

ANALYTICAL METHODS USING HPLC

Early in the development of sulfonylurea herbicides, conventional soil residue methods were developed using organic solvent extraction followed by normal phase HPLC using a photoconductivity (PC) detector (Zahnow, 1982). The sensitivity of the PC detector and the selectivity of the chromatography gave limits of quantitation (LOQ) of about 0.2-1 µg/kg depending on the soil matrix. The method performance was comparable to the plant response data discussed by Beyer et al. (1987) and as shown in Figure 1-3 is comparable to the estimated range of plant response determined in regulatory studies .

The increasing popularity of reversed-phase HPLC, the use of aqueous extraction solvents and the ready availability of instrumentation with solvent and column switching capability led to new developments in sulfonylurea chromatographic methods. Increasing the selectivity of the chromatographic separation through eluent or column switching effectively automates the sample clean-up as part of the HPLC analyses and allows use of ultraviolet absorption for detection. An example outline of a column switching method is shown in Fig. 4. Column switching methods for sulfonylureas in crop matrices have been developed to support tolerances in agricultural commodities with quantitation limits of about 0.02- to 0.1 mg/kg. An eluent column switching method for metsulfuron methyl in soil gave a quantitation limit of 0.1 µg/kg using spiked control soils. The methods have continued to challenge the capabilities of instruments and analysts. For example, heart-cut methods specify electronically controlled switching values and peak collection within 0.4 minute time windows. Careful control of mobile phase composition, temperature and column conditions and sample clean-up are necessary for successful routine analyses, particularly as analyte concentrations approach 1 µg/kg.

Multiple separation modes used within one method increase the level of confidence in the qualitative identification of a chromatographic peak compared to single column methods. Within our laboratories, multianalyte eluent switching methods are under development to screen for sulfonylureas in soil and water. The method is based on HPLC with UV detection and uses a second chromatographic column to confirm the presence of a peak observed at the analyte retention time on the first column. The increased selectivity of the entire method allows minimal sample clean-up with quantitation limits of about 0.1 µg/l in water and 1 µg/kg in soil. The use of the second column reduces the possibility for false positives, but does not provide definitive proof for the identity of the analyte. When the analysis must confirm the identity of the chromatographic eluate, mass spectrometry supplemented as needed by infrared or NMR spectrometry must be employed.

LC/MS

The application of mass spectrometry to analysis of sulfonylureas has been reviewed previously (Shalaby, 1987). LC/MS methods take advantage of the selectivity of the detector to minimize the need for chromatographic separations and provide confirmation for the identity of the chromatographic eluate. The increased interest in multiresidue analysis has led us to apply LC/MS to determination of sulfonylureas in crops, soil and water. Methods have been reported for sulfometuron methyl and its sulfonamide metabolite in water with a quantitation limit of 0.4 µg/l (Shalaby, 1992a). LC/MS has been used successfully for determination of sulfometuron methyl, chlorsulfuron, bensulfuron methyl, nicosulfuron and rimsulfuron in soil (Shalaby et al., 1992a and 1992b). The methods use simple extraction and sample preparation procedures and illustrate the strength of mass selective detection in providing quantitation and confirmation of multiple analytes.

IMMUNOASSAY

Immunoassay based tests have seen increasing popularity because of the sensitivity, specificity and low cost and rapid turn around time of the assays. While several publications have emphasized the low detection limits which are possible (Peter et al., 1989; Sharp et al., 1989), the routine application of immunoassay with low detection limits to analysis of large numbers of samples is likely to result in many false positives from matrix components that interfere with antibody binding. Some of the cost and rapid turn around advantages of immunoassay are lost when special sample handling and control matrices are required to minimize matrix effects. The objective of the analysis must be considered to reach a compromise for the particular application. Although immunoassays offer selectivity useful for environmental analysis, confirmation by alternative methods is required when the presence of an analyte must be demonstrated unequivocally.

With the objective of analyzing large numbers of samples for more than one sulfonylurea at a time, we have developed multi-analyte enzyme linked immunoassay (MELISA). In the MELISA assay the microtiter plate is coated with a mixture of antigens to allow a number of different specific antibodies to be captured. Only one specific antibody is introduced into a portion of each sample and multiple aliquots of the sample, each with a different specific antibody, are analyzed on the same microtiter plate. The antibody that did not bind to the antigen in the sample will bind to the coating antigen. The second antibody enzyme conjugate and then an enzyme substrate are added to develop color which is measured by a microtiter plate reader. The MELISA format has been used to reduce the time needed to examine matrix effects from ten soils and six natural water matrices (Strahan et al., 1995). The analyses were completed in significantly less time than required by standard single analyte ELISA. The work showed that the matrix effects in undiluted soil extracts could give as much as 60% inhibition of the specific antibody. Dilution of the sample was required to reduce matrix effects to ± 10% for water and <15% for soil. The optimal dilution was determined by comparing the water and/or soil extract containing no analyte to a phosphate buffer control. Standards were prepared in the buffer for all analyses, which further reduced the sample analysis time. The limit of quantitation depends on the specific antibody and dilution required to minimize the matrix effects. Using the optimal dilution, the LOQs were in the range 0.1-1 µg/l for water and 0.5-2 µg/kg for soil.

CONCLUSIONS

Analytical methods for determining sulfonylureas in environmental samples have been developed with limits of quantitation in the range of or less than estimated plant response. Chromatographic methods require multiple modes of separation for successful analysis using UV detectors. Sample cleanup and chromatographic separations can be minimized by LC/MS with the additional benefit of confirming identity of the sulfonylurea. Practical, multi-analyte methods for screening large numbers of samples can be developed using MELISA with quantitation limits that meet the goals for environmental analysis of sulfonylureas.

REFERENCES

Beyer, E M; Duffy, M J; Hay, J V; Schlueter, D D (1987) Sulfonylureas. In: *Herbicides Chemistry, Degradation, and Mode of Action..* P C Kearny & D D Kaufman (eds.). Marcel Dekker, Inc., New York, pp. 117-189.

Peter, C J; Sharp, J K; Strahan, J C; Strek, H J; Shalaby, L M; Wheeler, J R; Carski, T H; Burkhart, D C; Zahnow, E W; Reiser, R W; Sherwood, G A (1989) Analytical Methods for Detecting Chlorsulfuron and Metsulfuron Methyl, The Brighton Crop Protection Conference - Weeds.

Marlow, D A; McDaniel, D D; Dupuy, A E; Leovey, E M (1995); U. S. EPA Pesticide Assessment Guidelines, Subdivisions N, E, and K; Data Reporting Guideline for Environmental Chemistry Methods, Federal Register.

Shalaby, L M (1987) On-line LC/MS as a Problem-solving Tool for the Analysis of Thermally Labile Herbicides. In: *Applications of New Mass Spectrometry Techniques in Pesticide Chemistry*, ed. J B Rosen (ed.), Wiley Interscience, pp. 161.

Shalaby, L M and George, S W (1992a) Liquid Chromatography/Mass spectrometry Multiresidue Methods for Thermally Labile Pesticides. In: *Emerging Strategies for Pesticide Analysis,* T Cairns & J Sherma, CRC Press, Boca Raton, pp. 292-307.

Shalaby, L M, Bramble, F Q and Lee, P W (1992b) Application of Thermospray LC/MS for Residue Analysis of Sulfonylurea Herbicides and Their Degradation Products, *Journal of Agricultural and Food Chemistry* , **40**, pp. 513-517.

Sharp, J K; Lueng, F S; O'Brien, D P; Carski, T H (1989) An ELISA Method for the Detection of Chlorsulfuron in Soil and Water. ACS National Meeting, 1989, Miami Beach, Fla.

Strahan, J C; Rankin, C; Gardner, T (1995) Applications of a Multi-analyte Enzyme Linked Immunosorbent Assay (MELISA), Immunochemistry Summit IV, August, 1995, Las Vegas, Nevada

Zahnow, E W (1982) Analysis of the Herbicide Chlorsulfuron in Soil by Liquid Chromatography, *Journal of Agricultural and Food Chemistry*, **30,** pp. 854-857.

Figure 1
Comparison of Chlorsulfuron Method Quantitation Limits to Estimated Plant Response

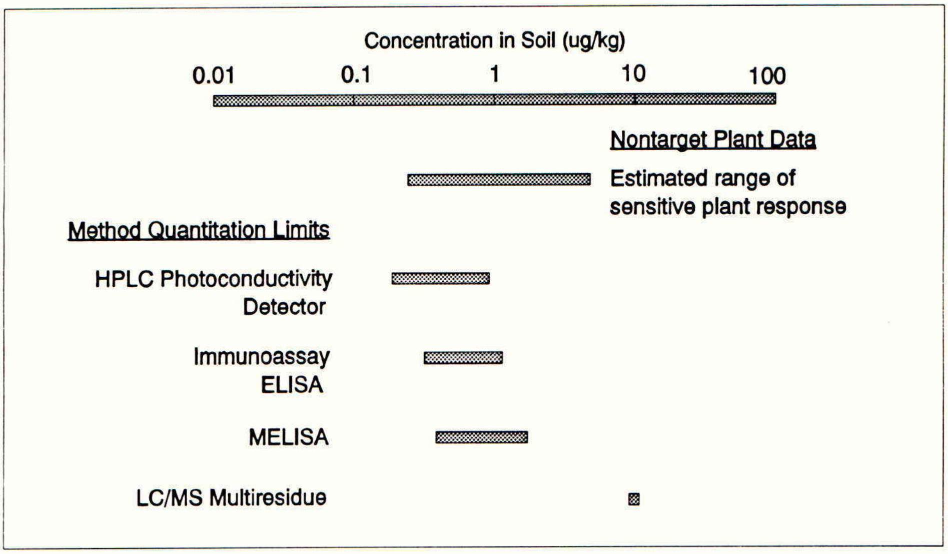


Figure 2
Comparison of Tribenuron Methyl Method Quantitation Limits to Estimated Plant Response

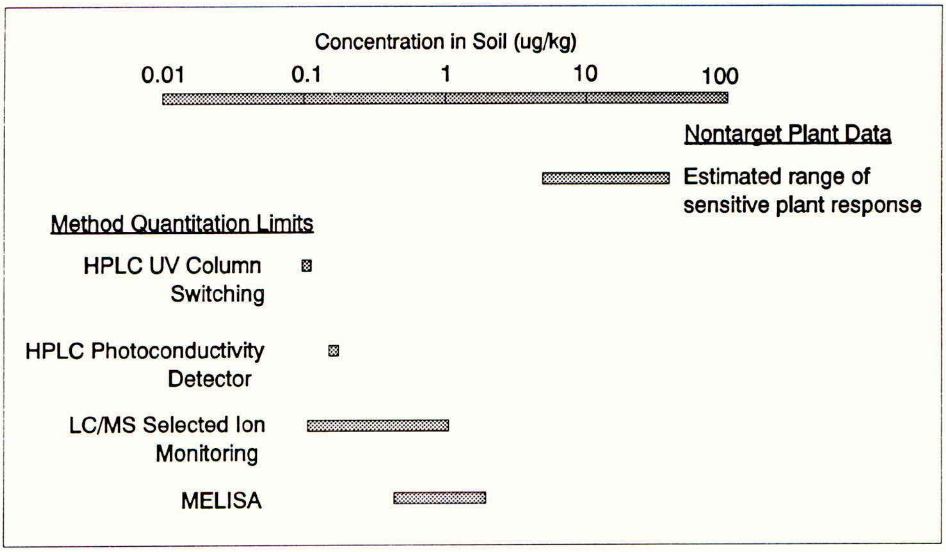


Figure 3

Comparison of Metsulfuron Methyl Method Quantitation Limits to Estimated Plant Response

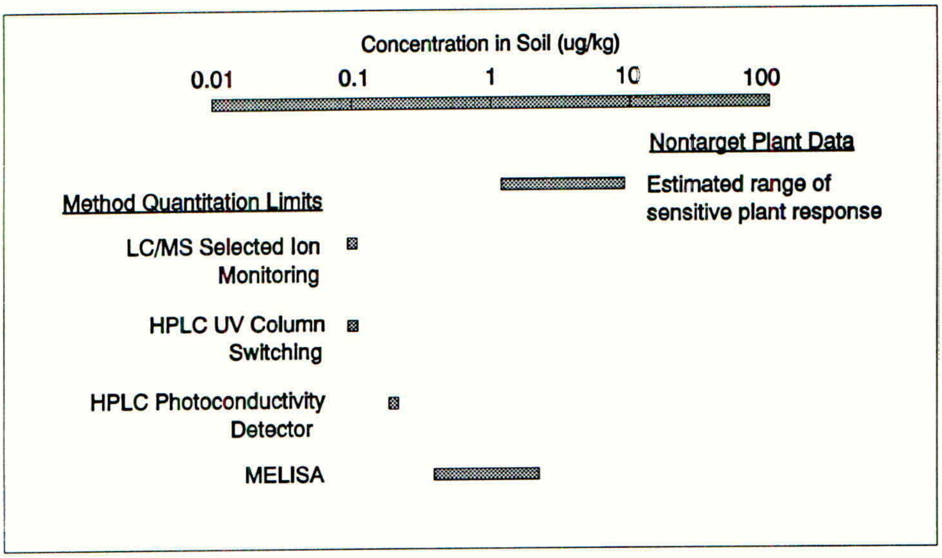


Figure 4
Outline of Sulfonylurea Plant Residue Column Switching Method

1) Extraction with aqueous buffer

2) Clean-up/Concentration using C18 Solid Phase Extraction

3) Analysis by HPLC
    a) Inject onto phenyl column with acidic mobile phase/high % organic modifier

    b) At one-half the retention time of the sulfonylurea on the phenyl column, switch eluent to pH 6-7/low % organic modifier

    c) Switch the sulfonylurea peak to the second column (C18) and elute with pH 6-7/low % organic modifier mobile phase.

    d) Detect by UV absorption.

    e) Clean chromatographic system with pH 6-7/high % organic modifier mobile phase