SESSION 7D

HERBICIDES AND PLANT GROWTH REGULATORS IN AGRICULTURAL UPLAND AND AMENITY GRASSLAND

SESSION ORGANISER	DR D. M. HILL
POSTERS	7D-1 to 7D-6

MATAGOURI, HAWKWEED AND PURPLE FUZZWEED CONTROL WITH SHEEP, GOATS AND LEGUMES IN THE NEW ZEALAND TUSSOCK GRASSLAND

G.G. COSSENS, R.B. MITCHELL, G.S. CROSSAN

Invermay Agricultural Centre, Ministry of Agriculture and Fisheries,
Private Bag, Mosgiel, NEW ZEALAND.

ABSTRACT

Matagouri (Discaria toumatou), Mouse-ear Hawkweed (Pilosella officinarum) and Purple Fuzzweed (Vittadinia gracilis) are weeds of the South Island tussock grasslands, they are important because of their exclusion of forage species. Chemical methods of control whilst effective are doubtfully economic in such extensively grazed lands. Therefore alternative methods of control other than chemicals are increasingly attractive.

Work in Otago, New Zealand, has shown Matagouri can be controlled by promoting understory grasses, then burning followed by superphosphate topdressing, legume oversowing and grazing with sheep and goats. Sheep alone were less satisfactory. Hawkweed infestation was reduced in all but the driest regions (less than 400 mm rainfall) by topdressing and legume oversowing followed by strategic sheep grazing.

Purple Fuzzweed was the most difficult to eradicate. Occurring in the semi-arid zone and unpalatable to both sheep and goats it was suppressed by oversowing and topdressing provided the grazing animal was excluded for at least three years.

INTRODUCTION

The tussock grasslands are a dominant feature of the South Island of New Zealand east of the Southern Alps. Covering 3.5 million ha they occupy almost one quarter of the island's land area and in order of importance are grazed by domestic sheep, cattle, deer and goats. Stocking rates are low, the average being about 2.5 stock units per hectare.

There are several constraints on pasture and animal production: environmental, as dryness and altitude; soil, as sulphur and molybdenum deficiency; and weeds as bracken, (Pteridium aquilinium) matagouri (Discaria toumatou) and gorse (Ulex europaeus). These three weeds are the dominant scrub weeds each being present and a problem in grazing management on over 1.2 million hectares of farmable land in the South Island. Matagouri is indigenous over most of the tussock lands. However, two other exotic species have become increasing weed problems over the past 25 years, these are Mouse-ear Hawkweed (Pilosella officinarum) on 1 million hectares and Purple Fuzzweed (Vittadinia gracilis) now present on over 20,000 hectares, whereas 20 years ago it was only a few hundred (Bascand and Jowett 1981).

Matagouri, Hawkweed and Fuzzweed are regarded as problems not so much because of their unpalatability to stock but because their ground form excludes other more palatable species and reduces the total feed available.

Herbicidal weed control is possible, nevertheless the tussock grasslands, except for the use of superphosphate, can be regarded as organically farmed and its products would be strongly supported by a world movement to alternative, more sustainable methods of agriculture. Therefore weed control by the grazing animal and suppression by plant competition provides an attractive alternative.

The objective of the work reported was to assess the practicality of a form of biological control of these weeds through the use of sheep, goats and legumes.

MATAGOURI [Discaria toumatou]

Ecology

Matagouri is a native spiny tree or shrub up to 5 m tall. It is very slow growing taking 20 - 30 years to develop and may live to 150 years. The leaves are deciduous, small, leathery and 1 to 3 cm long. Generally spanning an altitude range from 300 to 900 m it responds well to phosphate and sulphur and although not a legume is unusual in that it possesses root nodules fixing large amounts of atmospheric nitrogen. It can form dense thickets when topdressed and sheep in particular find matagouri hard to walk through, the twigs and spines downgrade the wool and entangled sheep may die, (Kerr 1986).

Matagouri Management

Burning is a favoured method of control on account of cheapness, however the plant is partially fire resistant and regrows rapidly following burning which then has to be repeated every 5 to 7 years at average tussock grassland stocking rates. Stocking rates of sheep need to be about 10 stock units/ha to effect any suppression within four to five years.

Chemical control is costly and uneconomic. 2,4,5-T and picloram - 2,4,5-T, were early chemicals used, the latter being particularly severe on clover and grass recovery. More recently triclopyr has been used with variable results.

Goats had not, up to 10 years ago, been farmed on a large commercial scale. In light of this they were therefore introduced into a sheep grazing system with the object of assessing their effect on matagouri control.

Experimental methods

A block of matagouri was closed to grazing for a year to accumulate understory fuel, burned and subdivided into 4 paddocks of 1.8 ha each. Sheep and yearling goats were introduced with nil, 7, 9 or 13 goats respectively in each paddock plus 18 sheep, approximately equal to 10,14,16,19 stock units/ha. The goats were resident on the trial and were weighed, the sheep were from the farmer's flock and were not weighed.

Matagouri density was measured by counting the number of plants along a 40 metre transect. The transects were replicated 10 times in each paddock and measured on six occasions during the life of the trial which ran from

August 1984 until March 1989. Herbage composition was measured on two occasions by cutting 10 quadrats 0.1 m^2 in each paddock.

Results and Discussion

At the high stocking rate of 18 sheep and 13 goats, matagouri crowns were reduced by 82% in 4 years after burning (Table 1). Matagouri regrowth was limited to the crowns, bushes were broken down and access was unrestricted between bushes. In the sheep-only block, access was confined to stock tracks between bushes and there was a 39% reduction in the number of crowns. The other two treatments were intermediate between these. There was a general trend towards a decline in the amount of cocksfoot and dead matter present and an increase in white clover with increasing goat numbers. The mean weight of the goats increased steadily from 19.7 to 35.6 kg between 1984 and 1987 even at the highest stocking rate of 18 sheep and 13 goats.

The work showed that a combination of sheep and goats at high stocking rates will suppress matagouri within 3 to 4 years. A continued goat presence will probably be required to maintain this.

TABLE 1. Number of live matagouri crowns at commencement and end of trial

Date	18 sheep 0 goats	18 sheep 6 goats	18 sheep 9 goats	18 sheep 13 goats
16-4-85	312	284	248	237
09-3-89	190	132	91	42
% Reduction	39	54	63	82

MOUSE-EAR HAWKWEED [*Pilosella officinarum*]

Ecology

The hawkweeds, adventives from Europe as seed contaminants, were recorded as early as the 1920s but did not become a problem until the marked decline of the rabbit in the 1950s. Several species of hawkweed inhabit the New Zealand tussock grassland but only mouse-ear hawkweed is a problem and to it is given the preferred common name of "hawkweed". Phenolic acids have been implicated in apparently allelopathic behaviour exhibited by hawkweed. Hawkweed spreads stoloniferously, readily invading open spaces and bare ground, displacing grass and tussocks and forming dense mats. It has small long-hairy leaves whose upper surface is silvery-grey. There is a single lemon-yellow flower and the plant is grazed by sheep.

Hawkweed Management

Both 2,4-D and mecoprop/MCPA/dicamba give acceptable but uneconomic herbicidal control of hawkweed (Meeklah et al., 1981).

Work in the MacKenzie basin of the South Island (Scott 1984) showed at least four years were required for a legume-grass sward to establish and reduce hawkweed cover. There, control of hawkweed was most effectively carried out by topdressing with superphosphate and overdrilling or oversowing white and red clover. However this technique although satisfactory where the rainfall is in excess of 450 mm annually, is unsuccessful in more droughty areas simply because clovers do not persist. Lucerne is the preferred, indeed, almost the only satisfactory legume currently available in this situation.

Further work reported here, summarises similar control measures in Central Otago over the years 1978 to 1984 and confirms the Mackenzie studies.

Experimental methods

There were 15 field trials aligned over 100 km in Central Otago. The average elevation was 400 m and annual rainfall 600 mm. Ten trials were oversown with red and white clover and five were direct drilled. Plot size varied but was usually 10 x 1.5 m. Treatments applied and rates/ha common to all trials were:

1. Control
2. 250kg sulphur superphosphate, 3kg white clover, 2kg red clover
3. as for 2 but plus 50 or 75kg N/year as nitrolime

Except for control all treatments had a basal dressing of 50gms/ha of molybdenum. Other treatments, not reported, included nitrogen rates up to a maximum of 300 kg N/ha/year. Trials were visually assessed about every 10 months and where possible herbage yield was measured using a sickle bar mower. Sheep were mob stocked onto trial plots to control pasture growth and assist hawkweed suppression.

Results and Discussion

Hawkweed was reduced in three years from 58% of ground cover to 2% by superphosphate topdressing and oversowing or overdrilling clovers (Table 2). Total dry matter yield was increased by 340%, most of the increase coming from the legume component (Table 3).

In general nitrogen increased grass yield and hawkweed vigour; it tended to depress clover density but not its vigour and hawkweed habit became more erect; it delayed flowering of the clovers, grasses and hawkweed. Superphosphate at rates equivalent to 30 kg P/ha and 36 kg S/ha each year dramatically improved clover vigour, density and yield. It had little effect on grasses and only slightly improved their growth. A combination of superphosphate and nitrogen was only slightly superior to superphosphate alone. Nitrogen would be uneconomic even at low rates in the tussock grasslands. Soil pH was depressed slightly in the presence of hawkweed as suggested by Scott (1984).

Overdrilled or oversown hawkweed areas should be left ungrazed for at least 12 months after sowing and the first grazing should occur whilst hawkweed is in flower (November - early December). If drought occurs, the second grazing should be delayed until sown species have made 10 - 15 cm of growth.

TABLE 2. Mean % ground cover of total area (Grass-G, Clover-Cl, Hawkweed-H)

Months of treatment	0			20			40		
Species	G	Cl	H	G	Cl	H	G	Cl	H
Control	4	3	58	22	12	50	29	22	32
Super + seed	4	3	58	26	47	8	30	59	2
Super + N + seed	4	3	58	32	45	8	37	57	4

TABLE 3. Mean Herbage yield (d.m. kg/ha) and 0-10cm soil pH (1978-84).

	Grasses	Clovers	Hawkweed	Total	pH
Control	310	30	340	940	5.26
Super + seed	210	2380	300	3220	5.28
Super + N + seed	450	3060	330	4290	5.31

PURPLE FUZZWEED [Vittadinia gracilis]

Ecology

A native of Australia, purple fuzzweed is a small twiggy herb-like bush up to 40 cms tall. It has small green leaves and purplish flowers and occurs dominantly in areas where the rainfall is less than 450 mm and the altitude less than 500 m. Commonly associated with thyme in Central Otago, it can form dense stands on northerly aspects, particularly those with a high proportion of bare ground. It is unpalatable to sheep and does not compete well with adventitious grasses (Williams 1981).

Purple Fuzzweed Management

The plant is reported to be tolerant of bromacil, otherwise there were no known control management systems. Like hawkweed the spread of purple fuzzweed has been attributed to severe depletion of the tussock grasslands by rabbits exposing soil and to a series of droughts after the elimination of rabbits in the 1950s. Field trials commenced in 1980 and continued to 1989, considered either the exclusion of all grazing as a means of control of fuzzweed, or the use of goats.

Experimental methods

Two goats were tethered on each of four 50 m running lines and held on fuzzweed for four months with plant counts made at the beginning and end of each period. A second area was closed to grazing from domestic stock,(but not rabbits) and cover estimates were made either visually or photovisually. In the latter, four fixed $1m^2$ quadrats where photographed and plant cover estimated by three observers of the projected images. There were eight replicates of four treatments on 6 x 6 m plots including control, superphosphate and nitrogen fertilisers, and grazing.

Results and Discussion

Nitrogen significantly increased fuzzweed cover density by about 48%; superphosphate alone by 33% (non significant) and nitrogen plus superphosphate by 63%. Where goats were grazed the animals steadily lost weight. Goats would only eat purple fuzzweed if no other herbage was available and the fuzzweed recovered rapidly as both mowing or grazing stimulated growth and flowering. Its growth habit and drought tolerance were very similar to lucerne.

When grazing was excluded, competition from grasses reduced purple fuzzweed cover slowly, a 50% reduction of fuzzweed density occurring over 30 months (Table 4). Suppression of purple fuzzweed by competition appears the only suitable method available for its control.

TABLE 4. Purple Fuzzweed. Mean % ground cover of total area.

	Purple fuzzweed	Grasses	Bare Ground	Haresfoot trefoil
12.09.80	41.0	28.0	31.0	nil
21.03.83	20.5	34.5	12.0	33.0
04.12.86	0.9	93.0	-	-
22.09.88	Plots Burnt			
09.07.89	11.1	71.0	11.1	Trace

ACKNOWLEDGEMENTS

The authors wish to thank the many farmers on whose land the work was conducted and also F.A. Meeklah, retired of Invermay, who initiated the Matagouri project.

REFERENCES

Bascand, L.D.; Jowett, G.H. (1981) Scrubweed cover of South Island agricultural and pastoral land 2. New Zealand Journal of Experimental Agriculture, 10, 455-491.

Kerr, I.G.C. (1986) Matagouri Management. Journal of the Tussock Grasslands and Mountain Lands Institute. Review, 43, 129-145.

Meeklah, F.A.; Mitchell, R.B.; McMillan, H. (1981) Chemical control of mouse-ear hawkweed. Proceedings 34th New Zealand Weed and Pest Control Conference, 132-136.

Scott, D. (1984) Hawkweeds in run country. Journal of the Tussock Grasslands and Mountain Lands Institute, Review 44, 33-48.

Williams, P.A. (1981) Vittadinia triloba and Rumex acetosella communities in the semi-arid regions of the South Island. New Zealand Journal of Ecology, 3, 13-22.

RESPONSE OF RUMEX OBTUSIFOLIUS, CIRSIUM ARVENSE AND PERENNIAL RYE-GRASS TO SOME SULFONYLUREA HERBICIDES

T.M. WEST

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

ABSTRACT

In outdoor pot experiments some sulfonylurea herbicides were tested for their activity on established *Rumex obtusifolius* (broad-leaved dock) and *Cirsium arvense* (creeping thistle), and also to determine their effect on Perennial rye-grass (Lolium perenne). DPX-M6316 and metsulfuron-methyl were effective in preventing regrowth of *R. obtusifolius*, at low doses. A tank mixture of these two herbicides was more active than the single components. *C. arvense* recovered after initial growth inhibition from all the sulfonylurea herbicides tested. Perennial rye-grass recovered fully, after a slight initial check, from DPX-M6316, DPX-L5300, DPX-M6316 + DPX-L5300 and chlorsulfuron + metsulfuron-methyl. The higher doses of metsulfuron-methyl applied alone caused more lasting damage to Perennial rye-grass. The potential of sulfonylurea herbicides to control *R. obtusifolius* and *C. arvense* in grassland is discussed.

INTRODUCTION

R. obtusifolius and *C. arvense* are intractable perennial weeds of grassland (Peel & Hopkins, 1980). Although herbicides are available for their control, e.g. asulam and triclopyr + clopyralid, improved treatments are being investigated. Previous work (Oswald *et al*, 1982) has shown the sulfonylurea herbicide, chlorsulfuron, to be effective against *R. obtusifolius* causing only slight transitory damage to grass species. Some new sulfonylurea herbicides damaged *R. obtusifolius* and *C. arvense* at early stages of growth (Richardson & West, 1986; West, 1988). Several grass species were unaffected, indicating a potential use in grassland. Research has continued at Long Ashton Research Station to investigate these herbicides as alternative treatments for the control of *R. obtusifolius* and *C. arvense*.

This paper presents data from outdoor pot experiments conducted in 1985, 1987 and 1988, on established plants of *R. obtusifolius*, *C. arvense* and Perennial rye-grass to determine the activity of sulfonylurea herbicides.

MATERIALS AND METHODS

Plant material

R. obtusifolius and Perennial rye-grass (cv. Melle) seeds were sown, 0.5 cm deep, into trays of Levington compost in February and early April, respectively. Root fragments from C. arvense stock pots were cut into 3 cm pieces, and planted into trays of Levington compost in March. Trays were kept in a heated glasshouse and watered gently overhead. Three plants per pot of R. obtusifolius and C. arvense, and 40 of Perennial rye-grass were transplanted at about the 1-2 leaf stage into 23 cm diameter pots containing a soil/peat/sand mixture (3:2:1) plus fertilizer, Osmocote 18.11.10 at 3.3 g/litre of soil. Plants were hardened off in a guaze sided glasshouse before being put outdoors, usually in late April. Pots were watered using trickle irrigation pipes and nutrient added as necessary.

Herbicide treatments

The formulations used were as follows:- asulam 400g a.i./litre a.c.; chlorsulfuron 20% a.i. W.G.; DPX-L5300 75% a.i. W.G.; DPX-M6316 75% a.i. W.G.; metsulfuron-methyl 20% a.i. W.G.; triasulfuron 20% a.i. W.G.; triclopyr + clopyralid 'Grazon 90' 240g + 60g/litre EC. DPX coded compounds are sulfonylurea herbicides from DuPont. The treatments (Tables 1-6) were applied using a laboratory track sprayer fitted with either a TeeJet, or Lurmark 8001 flat fan nozzle, at a pressure of 210 kPa to deliver 200-240 l/ha. A surfactant (Agral 90) was added to all spray solutions at 0.1% V/V. At the time of spraying, all plants had well established shoot and root systems. R. obtusifolius had 35-45 leaves/pot, were 20-25 cm long and had tap roots up to 30 cm long, most plants were not flowering although stem extension had started; C. arvense had 10-20 shoots/pot, was 40-50 cm high with roots 30-50 cm long, some flower buds were forming on the largest shoots; Perennial rye-grass had 10-12 tillers/plant and was 20-25 cm high. After spraying, pots were kept under cover for 24 h then watered overhead using a rose attached to a water line to simulate heavy rainfall. Pots were returned outdoors and set out in three randomised blocks.

Assessments

Plants were cut down to soil level 4-6 weeks after spraying, shoot fresh wts recorded and then allowed to regenerate for 9-13 weeks before harvesting again. Actual dates of assessments are given in Tables 1-6.

RESULTS

1985 Experiment (Table 1)

Application of metsulfuron-methyl, at 3.75 g a.i./ha, prevented regrowth of R. obtusifolius whereas C. arvense recovered from 15 g a.i./ha; both species suffered initial growth inhibition. Perennial rye-grass was recovering, after initial growth inhibition from metsulfuron-methyl, although shoot regrowth fresh wts were still appreciably reduced.

TABLE 1. Effects of metsulfuron-methyl on shoot fresh wts of *R. obtusifolius*, *C. arvense* and Perennial rye-grass. (Figures as % of untreated)

		R. obtusifolius		*C. arvense*		P. ryegrass	
	Date of treatment:	14 June 1985		28 June 1985		5 July 1985	
Herbicide	Dose	Assessed		Assessed		Assessed	
	(g a.i./ha)	27 Jul	27 Sep	5 Aug	18 Oct	18 Aug	25 Oct
Metsulfuron-methyl	3.75	34	0	49	118	60	57
	7.5	11	0	41	127	39	50
	15	13	0	38	104	29	38
Untreated	-	100	100	100	100	100	100
(mean value in g)		(136)	(51)	(154)	(34)	(102)	(30)
SED± (36 df)		8.0	26.1	13.6	20.6	6.2	7.2

1987 Experiments (Tables 2 and 3)

Applications of DPX-M6316, at 5, 10 and 15 g a.i./ha, and metsulfuron-methyl at 1.5 and 3 g a.i./ha, caused initial chlorosis of *R. obtusifolius* and reduced regrowth fresh wts by 81-99% whereas both plant species recovered, after initial chlorosis, from DPX-L5300 and triasulfuron treatments. Mixtures of DPX-M6316 + DPX-L5300 and metsulfuron-methyl + DPX-L5300 produced similar effects to the more active component applied alone. Triclopyr + clopyralid caused rapid epinasty and necrosis of *R. obtusifolius*, but only reduced fresh wt of regrowth by 42%.

TABLE 2. Effects of herbicides applied 8 June 1987 on *R. obtusifolius*, assessed 15 July and 1 October 1987. (Figures as % of untreated)

Herbicide	Dose (g a.i./ha)	1st assessment	2nd assessment
		Shoot fresh wt	
DPX-M6136	5	83	19
	10	83	12
	15	74	1
Metsulfuron-methyl	1.5	89	5
	3	86	1
DPX-L5300	15	88	109
	30	77	94
DPX-M6136 + DPX-L5300	10+15	78	3
	10+30	67	12
Metsulfuron-methyl + DPX-L5300	1.5+15	79	2
	1.5+30	69	1
Triasulfuron	15	119	94
	30	99	83
Triclopyr + clopyralid	720+180	24	58
Untreated	-	100	100
(mean value in g)		(123)	(85)
SED± (54 df)		13.0	18.5

Initially, C. arvense suffered considerable growth inhibition from metsulfuron-methyl and DPX-L5300, and moderate inhibition from DPX-M6316 and triasulfuron. However, recovery was vigorous from all these treatments and shoot wts exceeded those of untreated plants. Triclopyr + clopyralid treatments produced rapid necrosis and reduced regrowth wts by 72%.

TABLE 3. Effect of herbicides applied 8 June 1987 on C. arvense, assessed 15 July and 5 October 1987. (Figures as % of untreated)

Herbicide	Dose (g a.i./ha)	1st assessment	2nd assessment
		Shoot fresh wt	
DPX-M6136	30	83	145
Metsulfuron-methyl	3	51	145
DPX-L5300	15	49	173
	30	32	148
DPX-M6316	30+15	37	147
+ DPX-L5300	30+30	42	218
Metsulfuron-methyl	3+15	46	165
+ DPX-L5300	3+30	29	185
Triasulfuron	15	69	163
	30	65	178
Triclopyr + clopyralid	720+180	39	28
Untreated	-	100	100
(mean value in g)		(270)	(81)
SED± (48 df)		11.4	27.0

1988 Experiments (Tables 4-6)

TABLE 4. Effects of herbicides applied 30 June 1988 on R. obtusifolius, assessed 2 August and 18 October 1988. (Figures as % of untreated)

Herbicide	Dose (g a.i./ha)	1st assessment	2nd assessment
		Shoot fresh wt	
DPX-M6136	3	99	54
	6	79	63
	12	87	38
Metsulfuron-methyl	0.3	108	107
	0.6	106	53
	1.2	102	10
DPX-M6316 +	3+0.3	97	78
Metsulfuron-methyl	6+0.6	86	0
	12+1.2	113	0
Triclopyr + clopyralid	720+180	24	1
Asulam	1100	94	7
Untreated	-	100	100
(mean value in g)		(155)	(55)
SED± (54 df)		13.4	22.3

Applications of DPX-M6316 or metsulfuron-methyl caused considerable suppression of regrowth R. obtusifolius at low doses. Spraying with a mixture of DPX-M6316, at 6 g a.i./ha, with metsulfuron-methyl at 0.6 g a.i./ha, prevented regrowth of this species. Triclopyr + clopyralid and asulam caused severe suppression of regrowth.

C. arvense recovered vigorously after initial growth inhibition by treatments of DPX-L5300 and DPX-M6316. Triclopyr + clopyralid applications caused severe damage to sprayed foliage and prevented regrowth.

TABLE 5. Effects of herbicides applied 5 July 1988 on C. arvense assessed 2 August and 26 October 1988. (Figures as % of untreated).

Herbicide	Dose (g a.i./ha)	1st assessment	2nd assessment
		Shoot fresh wt	
DPX-M6136	30	114	122
	60	94	111
DPX-L5300	15	51	80
	30	78	135
DPX-M6136	30+15	68	109
+ DPX-L5300	60+30	85	136
Triclopyr + clopyralid	720+180	57	0
Untreated	-	100	100
(mean value in g)		(301)	(68)
SED± (56 df)		10.8	23.3

Perennial rye-grass suffered only a slight check to growth or some yellowing following application of all the herbicides tested, treated plants making a full recovery.

TABLE 6. Effects of herbicides applied 19 July 1988 on Perennial rye-grass, assessed 16 August and 14 November 1988. (Figures as % of untreated)

Herbicide	Dose (g a.i./ha)	1st assessment	2nd assessment
		Shoot fresh wt	
DPX-M6136	30	96	98
	60	102	108
	120	86	90
DPX-L5300	15	87	113
	30	79	97
	60	74	91
DPX-M6136	30+15	81	98
+ DPX-L5300	60+30	73	95
	120+60	78	84
Chlorsulfuron +	7.5+2.5	81	103
Metsulfuron-methyl	15+5	84	87
Asulam	1100	91	93
Triclopyr + clopyralid	480+120	89	83
	960+240	92	95
Untreated	-	100	100
(mean value in g)		(403)	(160)
SED± (56 df)		7.0	12.6

DISCUSSION

The herbicides recommended for use in grassland in the UK, gave effective control of R. obtusifolius and C. arvense, but had little effect on perennial rye-grass.

Results of our pot experiments have highlighted DPX-M6316 and metsulfuron-methyl as potential alternative herbicides for control of R. obtusifolius in grassland. The mixture of these two herbicides, at low doses, was also effective and appears a promising treatment. DPX-M6316 alone would probably be the most environmentally acceptable treatment. It has short soil persistence, low mammalian toxicity and is less damaging to Perennial rye-grass and other pasture grasses (Standell & West, 1989) than other herbicides tested. Also, at low doses, white clover may be less sensitive to DPX-M6316 than to other sulfonylurea herbicides (Standell & West, unpublished data). Control of C. arvense with sulfonylurea herbicides does not appear practicable unless treated at an early stage. Poor control of C. arvense in field experiments with DPX-L5300 and metsulfuron-methyl has been reported previously (Davies & Orson, 1987).

Further field experiments on DPX-M6316 to determine optimum dose, surfactant type and concentration, application timing (on weed and crop) and Perennial rye-grass variety tolerance, are essential to confirm the potential of this herbicide for control of R. obtusifolius in grassland.

ACKNOWLEDGEMENTS

Thanks are due to Mr R.J. Tutcher for technical assistance; to Mr R.F. Hughes and staff for practical assistance and to the manufacturers for the supply of herbicides used in these experiments.

REFERENCES

Davies, C.J.; Orson, J.H. (1987) The control of Cirsium arvense (Creeping Thistle) by sulfonylurea herbicides and a comparison of methods of assessing efficacy. Proceedings British Crop Protection Conference - Weeds, 2, 453-460.

Oswald, A.K.; West, T.M.; Richardson, W.G. (1982). The use of chlorsulfuron for the control of Rumex obtusifolius in grassland. Proceedings British Crop Protection Conference - Weeds, 1, 219-223.

Peel, S; Hopkins, A. (1980). The incidence of weeds in grassland. Proceedings British Crop Protection Conference - Weeds, 3, 877-890.

Richardson, W.G.; West, T.M. (1986). The activity and post-emergence selectivity of some recently developed herbicides: SMY1500, PPG884, PPG1259 and DPX-M6316. Technical Report Agricultural and Food Research Council, LARS, Weed Research Division, No.92, pp.42.

Standell, C.J.; West, T.M. (1989). Response of several pasture grass species to potential new herbicides for bracken control Proceedings Brighton Crop Protection Conference - Weeds (this volume).

West, T.M. (1988). The activity and post-emergence selectivity of some recently developed herbicides: Imazethapyr, BAS 51800H, DPX-L5300, Triasulfuron and DPX-A7881. Technical Report Agricultural and Food Research Council, LARS, Weed Research Department, No. 104, pp.58.

DPX-M 6316 - A NEW HERBICIDE FOR USE IN PASTURES

A. OSTERMEYER, B. MEIER

DU PONT DE NEMOURS (DEUTSCHLAND) GMBH, AGRICULTURAL PRODUCTS
DEPARTMENT, 6380 BAD HOMBURG, W.-GERMANY

ABSTRACT

A new sulfonylurea herbicide with the code number DPX-M 6316: Methyl 3-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)carbamoylsulfamoyl]-2-thenoate was tested over 3 years in W. Germany, Austria and Switzerland, for the control of weeds in grassland. The herbicide was applied either as a spot treatment using product in tablet form (3 tablets/0.135 g a.i. in 10 l of water), or as an overall treatment using a 75 % dry flowable formulation at a use rate of 22.5 g a.i./ha. Both methods of treatment showed very good efficacy on _Rumex spp._ plus some other important grassland weeds.

The overall spray was carried out at three different application timings. No significant differences in the efficacy at these application timings were observed, although in the case of early treatments, there was some growth of _Rumex spp._ from seeds germinating after the herbicide had been applied. DPX-M 6316 shows a high degree of selectivity to grasses and different species of clover.

INTRODUCTION

The agricultural area of W. Germany includes 4.5 Million hectares of grassland, which is 37 % of the total area. Due to the use of intensive grassland management systems, there has been a large increase of weeds throughout this area. Rumex species are wide spread and are difficult to control. In Central Europe Rumex is common in the Alpine area up as high as 1500 m, and is also common throughout Central and Northern Germany.

DPX-M 6316 was tested over several years for control of Rumex species and other weeds in grassland and is, or soon will be marketed under the trademark HARMONY* (75 % DF formulation) in Austria, W. Germany and Switzerland. A tablet formulation (one tablet contains 0.045 g a.i.) was introduced in Switzerland in 1989 as a spot treatment.

* Du Pont's registered trademark

DPX-M 6316 is a sulfonylurea herbicide, and the chemical and biological properties have previously been described (Ambach, R.M. 1984; Hutchinson, J.M. 1985; Sionis, S.D. 1985)

MATERIALS AND METHODS

DPX-M 6316 was tested in Germany in 9 Official trials in 1986 and in 10 in 1987. Additionally Du Pont trials have been carried out from 1985 till 1989.

For comparison the standard compounds asulam (1600 g a.i./ ha), dicamba + MCPA (240 g a.i./ha + 2720 g a.i./ha, fluroxypyr (360 g a.i./ha) and mecoprop (4480 g a.i./ha) were used.

The plot sizes were between 25 m with 4 reps and 250 m with 2 reps. Water quantity per ha was 400 l. In the Du Pont trials 11003 LP nozzles with 159 kPA were used.

The trials were carried out both on meadows and pastures, where Rumex spp. (predominantly Rumex obtusifolius, but also Rumex crispus), Cirsium vulgare, Achillea millefolium, Stellaria media or Ranunculus repens frequently appeared.

The applications were carried out at three different timings, during 1st growth (April/May), during 2nd growth (June/July) and during 3rd growth (Aug./Sept.), when the Rumex spp. was at the stage of rosette formation till beginning to flower.

The efficacy on weeds was rated as percentage control.

The effect on the desired grasses such as Lolium perenne, Festuca pratensis, Poa pratensis, and Phleum pratense was assessed for % growth depression and also by % thinning.

The safety to clover was rated as % growth depression, and 4 classes (0, < 10, > 30 and no observable effect) were made.

3 evaluations were made on average.

Parallel trial work was done by government officials and companies in both Austria and Switzerland.

RESULTS

Efficacy on weeds

In addition to Rumex species, DPX-M 6316 is also effective against some other important weeds of pastures. Table 1 shows the average percentage control against dicots in grassland, and summarizes all trials carried out in 1985-1989.

TABLE 1. Efficacy of DPX-M 6316 against weeds in grassland

Weed	n	% control 1. evaluation	% control 2. evaluation	% control 3. evaluation
Rumex ssp.	28	61-88*	91-97*	81-96*
Taraxacum officinale	12	14	15	18
Heracleum sphondylium	3	30	35	37
Cirsium arvense	5	67	89	78
Cirsium vulgare	3	76	97	
Achillea millefolium	5	21	69	78
Capsella bursa-pastoris	3	67	93	85
Cardamine pratensis	1	91	100	100
Lamium purpureum	4	78	86	75
Stellaria media	3	87	92	76
Ranunculus repens	8	65	95	80

(n) No. of sites weed present
1. evaluation = 2-3 weeks after application
2. evaluation = 6-8 weeks after application
3. evaluation = 1 year after application

* depending on application date (see table two)

Immediately after treatment all weed growth stops. About 7 to 10 days after treatment, Rumex spp. shows a clear, deep reddening, and about 1 month later weeds had died off completely.

Efficacy above 80 % is shown against Cirsium species and L. purpureum, and above 90 % against C. bursa-pastoris, G. pratensis, S. media and R. repens at the second evaluation (6-8 weeks after application). A. millefolium is still adequately controlled, whereas T. officinale and H. sphondylium are not sufficiently well controlled.

Efficacy against Rumex species at different application timings

Rumex spp. plants emerge during the whole vegetation period; particularly in bare places in the pasture following the first and second cut. Because DPX-M 6316 is mainly active when applied to the leaves, adequate growth of the weed is necessary at the time of treatment.

TABLE 2. Efficacy of DPX-M 6316 against Rumex ssp. at various application timings.

Application Time	n	Efficacy in % 1.	2. evaluation	3.
Timing 1	8	88	91	84
Timing 2	13	76	92	81
Timing 3	9	61	97	96

(n) No. sites
1. evaluation = 2-3 weeks after the treatment
2. evaluation = 6-8 weeks after the treatment
3. evaluation = 1 year after the treatment

The quickest initial efficacy (evaluation date 1) is shown at the first application timing (April/May), the time with the most intensive growth of the Rumex. One to two months later the application of DPX-M 6316 has reached its optimal efficacy. Control of Rumex ssp. is commonly above 90 %. The most long lasting effect (evaluation 1 year after application) is achieved with applications during the third growth (August/September). When product is applied during the two earlier application timings, there is some new germination of Rumex seeds, thus decreasing the degree of efficacy.

Selectivity against grasses

The selectivity of DPX-M 6316 against grasses is shown in the following table. The first figures give average % growth depression and the second figure records % average thinning.

TABLE 3. Selectivity of DPX-M 6316 against grasses in grassland.

Application Time	n	Growth depression/thinning 1. evaluation	2.	3.
Timing 1	8	6/0	1/0	0/0
Timing 2	13	7/2	1/0	0/0
Timing 3	9	4/0	0/0	0/0

(n) No. sites
1. evaluation = 2-3 weeks after the treatment
2. evaluation = 6-8 weeks after the treatment
3. evaluation = 1 year after the treatment

DPX-M 6316 showed no damage to grasses or growth depression in 13 trials. In 10 trials a very slight and transient growth depression appeared at the first and second application timings. However, no long lasting depression or damage was observed on any of the grass species present (<u>L. perenne</u>, <u>F. pratensis</u>, <u>P. pratensis</u>, <u>P. pratense</u>).

TABLE 4. Number of trials with growth depression on clover species at varying application dates.

Application Time	n	Growth depression at the first rating 0	<10	>30 %	N.O.E.
Timing 1	11	1	1	2	7
Timing 2	10	1	1	1	7
Timing 3	18	9	5	0	4

(n) No. sites
N.O.E. = No observable effect

Due to the low number of observations at application dates I and II, significant conclusions with regard to the selectivity of DPX-M 6316 cannot be drawn. However, application date III (Aug./Sept.) shows good crop safety. The slight growth depression in the 5 trials (growth depression up to 10 %) was no longer evident at the time of the second evaluation.

REFERENCES

Ambach, R.M.; Toole, B.M.; Zadrorzny, S.A.; Johnson, K.D.; Ulrich, T.S.; Gorell, R.M.; Schell, S.E. (1984)
DPX-M 6316, A new herbicide for use in cereals, Proceedings North Central Weed Control Conference Winnipeg, Canada. 39, 120

Hutchinson, J.M.; Levitt, G; Hagemann, L.H.; Schell, S.E. (1985)
DPX-M 6316, A new selective postemergence herbicide for cereals - Meeting of Weed Science Society of America, Seattle, USA, 1985. 25, 10

Sionis, S.D.; Drobny, H.G.; Lefebvre, P.; Upstone, M.E. (1985)
DPX-M 6316 - A new sulfonylurea herbicide, Proceedings 1985
British Congress of Plant Protection - Weeds. 2, 49-54

RESPONSE OF BRACKEN AND EIGHT PASTURE GRASS SPECIES TO SOME SULFONYLUREA HERBICIDES

T.M. WEST, C.J. STANDELL

Department of Agricultural Sciences, University of Bristol, A.F.R.C.
Institute of Arable Crops Research, Long Ashton Research Station, Bristol,
BS18 9AF

ABSTRACT

Herbicides were tested in outdoor pot experiments for their activity against established bracken (Pteridium aquilinum) and, in glasshouse experiments, to determine the tolerance of eight common pasture grass species. DPX-L5300, DPX-L5300 + DPX-M6316, triasulfuron and chlorsulfuron + metsulfuron-methyl, applied to bracken in 1987, all severely inhibited frond regrowth and development of frond buds on the rhizomes during 1988. Asulam, chlorsulfuron + metsulfuron-methyl or DPX-L5300, sprayed in 1988, were most effective when applied at full frond emergence. However, earlier applications and those made at senescence in 1988 considerably reduced frond regeneration during 1989. Most grass species tested tolerated DPX-L5300 and DPX-M6316, applied alone or in mixture. Some species were more sensitive to chlorsulfuron + metsulfuron-methyl, and several species were sensitive to asulam. The potential of these herbicides for bracken control is discussed.

INTRODUCTION

Bracken (Pteridium aquilinum) has achieved notoriety as one of the world's most successful weeds. It is aggressive, competitive, harbours parasites, and generates toxins and carcinogens causing health risks to grazing animals and possibly humans (Taylor, 1989). Hill pastures of the U.K. are particularly vulnerable to bracken infestation, its spread being caused by reduction of grazing pressures and deforestation. The herbicide asulam can give effective control of bracken but damage to important pasture grasses may occur (Standell & West, 1989).

West & Richardson (1987) reported that bracken was susceptible to some new sulfonylurea herbicides, while grass weeds were tolerant. Research has continued at Long Ashton Research Station to investigate the potential of these herbicides as alternative treatments for bracken control in grassland.

This paper presents data from three pot experiments in which sulfonylurea herbicides were tested for activity on bracken at various growth stages and tolerance of common pasture grasses.

MATERIALS AND METHODS

Bracken experiments

Plant material

In April the year before treatment, rhizome fragments with viable frond buds were collected from a natural population near Long Ashton. Three 20 cm fragments were planted 8 cm deep in 25 cm diameter pots, containing a soil/sand/peat mixture (3:2:1) plus fertiliser, Osmocote 18.11.10, at 3.3 g/l. Pots were kept outdoors and watered using trickle irrigation pipes. During winter, pots were plunged into ashes to protect them from frost.

Herbicide treatments

The formulations used were as follows:- asulam 400 g a.i./l a.c.; chlorsulfuron 20% a.i. WG; DPX-L5300 75% a.i. WG; DPX-M6316 75% a.i. WG; metsulfuron-methyl 20% a.i. WG; triasulfuron 20% a.i. WG. DPX coded compounds are sulfonylurea herbicides from DuPont. The treatments (Tables 2 and 3) were applied using a laboratory track sprayer fitted with a Lurmark 80015 flat fan nozzle at a pressure of 210 kPa and giving a volume rate of 223 l/ha. A surfactant (Agral 90) was added to all spray solutions at 0.1% V/V. Growth stage at spraying in Experiment 1 was 6-8 fronds/pot, 60-80 cm high, vigorous rhizome system. Experiment 2 involved three series with 7-18 fronds/pot, each series being srayed at a different growth stage. These were (a) fronds up to 50 cm, 6 pinnae, none completely unfurled, (b) fronds up to 90 cm, 8-10 pinnae, all unfurled, and (c) fronds into senescence, most yellowed. All had vigorous rhizome systems. Pots were kept under cover for 24 h after spraying. Prior to removal outdoors, they were watered overhead using a rose attached to a water line to simulate heavy rainfall. Plants were then returned outdoors and set out in three randomised blocks.

Assessments

In August, the year after treatment, fronds were cut off at soil level and the fresh weight and number/pot recorded. Soil was removed and rhizome development assessed. The 'buds' referred to in the Results section are viable frond buds, i.e. those which could give rise to fronds in the following season. Rhizomes were then oven dried at 90°C for 48 h and dry weights recorded (Tables 2 & 3).

Pasture grasses experiment

Seeds were sown into seed trays of Levington compost, watered lightly and kept in the glasshouse. At the 1-2 leaf stage, 5 plants/pot were pricked out into 10 cm diameter pots containing a Mendip sandy clay loam plus Vitax Q4 fertiliser at 3.3 g/l. Pots were kept in a heated glasshouse, max. 25°C, min. 10°C, mean 16°C, with supplementary mercury vapour lighting giving 14 h photoperiods. Species tested and growth stages at spraying are described in Table 1.

Herbicide formulations were as those described for the bracken experiments. Herbicides were applied using the laboratory track sprayer fitted with a Lurmark 80015 flat fan nozzle at a pressure of 210 kPa and delivering 335 l/ha. Pots were set out in three randomised blocks, watered overhead 24 h after spraying, then as necessary.

Shoots were cut off 31 d and 69 d after spraying, oven dried at 90°C for 48 h and dry weights recorded (Table 4).

TABLE 1. Grass species and growth stages at spraying

Species	Common name	Mean ht (cm)	No. of tillers
Agrostis capillaris	Common bent	15	4-5
Cynosurus cristatus	Crested dogstail	11	4-6
Dactylis glomerata	Cocksfoot	25	3-4
Festuca ovina	Sheeps fescue	12	10-12
Festuca rubra	Red fescue	13	7-9
Holcus lanatus	Yorkshire fog	22	4-5
Lolium perenne	Perennial ryegrass	17	3-4
Poa pratensis	Smooth stalked meadowgrass	16	3-5

RESULTS

Effects on bracken growth the year after spraying

Experiment 1 (Table 2)

Chlorsulfuron + metsulfuron-methyl, at 15 + 5 g a.i./ha, reduced frond fresh weight by 98% and viable buds by 93%. DPX-L5300, at 10 g a.i./ha, reduced regrowth considerably, while 20 and 40 g a.i./ha reduced frond weight by 87% and 97% and viable buds by 89% and 88%, respectively. A mixture of DPX-L5300 + DPX-M6316, 20 + 40 g a.i./ha prevented frond regrowth and no viable buds remained. Triasulfuron reduced frond weights and viable buds up to 99%.

TABLE 2. Effects of herbicides applied 5 August, 1987, on bracken, assessed 19 August, 1988. (Figures expressed as % of untreated)

Herbicide	Dose	Fronds		Rhizome	
	(g a.i./ha)	Number	Fresh wt	No. buds	Dry wt
DPX-L5300	10	37	24	32	43
	20	13	13	11	29
	40	13	3	12	37
Triasulfuron	10	2	1	1	31
	20	35	15	26	30
	40	6	2	1	25
Chlorsulfuron +	7.5 + 2.5	35	9	10	34
metsulfuron-methyl	15 + 5	4	2	7	29
DPX-L5300 + DPX-M6316	20 + 40	0	0	0	38
Untreated	-	100	100	100	100
(Mean value)		(18)	(413 g)	(27)	(251 g)
SED ± (48 df)		5.9	10.6	11.3	10.7

Experiment 2 (Table 3)

Application at full frond emergence was effective for asulam and chlorsulfuron + metsulfuron-methyl, and DPX-L5300, at 30-60 g a.i./ha, all prevented regrowth and bud development. Activity of DPX-M6316 was moderate, and any synergistic effects of mixtures with DPX-L5300 were masked, as

DPX-L5300 was so active alone. Chlorsulfuron + metsulfuron-methyl was as effective, and asulam and DPX-L5300 were only slightly less effective, when applied at the earlier stage, still severely reducing or preventing regrowth and bud formation. Applications at frond senescence were the least effective, but still caused considerable regrowth reductions.

(In the summer of treatment, early application of sulfonylurea herbicides inhibited frond growth and no more emerged that season.)

TABLE 3. Effects of herbicides applied at three growth stages to bracken during 1988, assessed 22 August 1989. (Figures expressed as % of untreated)

Herbicide	Dose	Fronds		Rhizome	
	(g a.i./ha)	Number	Fresh wt	No. buds	Dry wt
Applied 26 May Fronds 50 cm - none completely unfurled					
Asulam	4400	3	1	1	34
Chlorsulfuron + metsulfuron-methyl	15 + 5	0	0	0	8
DPX-L5300	15	2	1	1	29
	30	6	1	0	26
	45	0	0	0	14
	60	1	1	0	25
Applied 12 July Fronds 90 cm - all completely unfurled					
Asulam	4400	0	0	0	83
Chlorsulfuron + metsulfuron-methyl	15 + 5	0	0	0	21
DPX-L5300	15	18	6	5	66
	30	0	0	0	35
	45	0	0	0	50
	60	0	0	0	30
DPX-M6316	30	144	73	73	60
	60	124	48	22	38
DPX-L5300 + DPX-M6316	15 + 30	4	3	1	30
	30 + 60	0	0	0	21
Applied 6 September Frond senescence starting					
Asulam	4400	13	4	6	57
Chlorsulfuron + metsulfuron-methyl	15 + 5	43	12	11	53
DPX-L5300	15	64	33	45	68
	30	36	17	9	61
	45	26	6	11	55
	60	9	3	5	50
Untreated control	-	100	100	100	100
(Mean value)		(49)	(937 g)	(103)	(438 g)
SED ± (54 df)		28.1	13.1	15.0	10.3

Experiment 3 (Effects on pasture grasses, Table 4)

Five grass species tested were tolerant to DPX-L5300 and DPX-M6316, alone or in mixture; growth of C. cristatus and L. perenne was inhibited initially and regrowth moderately reduced, and regrowth of *H. lanatus* was considerably reduced by DPX-L5300 at 30 g a.i./ha. Four species tolerated the chlorsulfuron + metsulfuron-methyl treatment, but *C. cristatus*, *L. perenne*, *H. lanatus* and *F. rubra* were sensitive. Only *D. glomerata* and *F. ovina* were tolerant to asulam; *L. perenne* and *P. pratensis* regrowth was moderately reduced, while regrowth of other species was severely inhibited.

TABLE 4. Effects of herbicides, applied 2 February 1988, on eight pasture grass species, harvested 31 d and 69 d after treatment. (Figures are shoot dry weights expressed as % of untreated)

Herbicide	Dose (g a.i./ha)	*Agrostis capillaris*		*Cynosurus cristatus*		*Dactylis glomerata*		*Festuca ovina*	
		31	69	31	69	31	69	31	69
DPX-L5300	15	109	142	56	130	118	134	125	139
	30	98	171	47	88	122	149	94	144
DPX-M6316	30	99	141	62	122	129	127	101	132
	60	115	134	44	63	153	132	121	135
DPX-L5300	15 + 30	96	120	55	61	123	143	115	141
+ DPX-M6316	30 + 60	107	132	51	40	80	115	93	115
Asulam	4400	23	2	69	1	125	147	47	104
Chlorsulf + Metsulf	15 + 5	73	116	42	10	68	132	67	99
Untreated	-	100	100	100	100	100	100	100	100
(Mean value in g)		(1.07)	(0.43)	(1.10)	(0.73)	(1.47)	(0.42)	(1.10)	(0.67)
SED ± (18 df)		15.6	12.1	11.4	22.2	23.4	24.1	9.5	11.7

TABLE 4. cont'd.

Herbicide	Dose (g a.i./ha)	*Festuca rubra*		*Holcus lanatus*		*Lolium perenne*		*Poa pratensis*	
		31	69	31	69	31	69	31	69
DPX-L5300	15	91	80	85	75	67	49	104	93
	30	98	86	70	24	77	70	94	132
DPX-M6316	30	77	62	105	116	75	67	108	92
	60	71	76	89	96	60	46	99	83
DPX-L5300	15 + 30	85	73	80	48	83	82	101	102
+ DPX-M6316	30 + 60	56	104	66	1	61	48	86	92
Asulam	4400	38	22	82	0	62	48	56	46
Chlorsulf + Metsulf	15 + 5	47	35	79	17	58	11	115	138
Untreated	-	100	100	100	100	100	100	100	100
(Mean value in g)		(1.23)	(0.98)	(1.36)	(0.77)	(1.53)	(0.98)	(1.31)	(0.74)
SED ± (18 df)		10.3	11.5	9.7	17.4	8.2	15.7	9.9	4.8

DISCUSSION

Asulam, chlorsulfuron + metsulfuron-methyl and DPX-L5300 have proved effective treatments for bracken control in our pot experiments. All showed maximum activity when applied at full frond emergence, but also caused considerable regrowth reductions when applied at an earlier stage or at frond senescence.

However, applying asulam early, before a full frond canopy has formed, could increase damage to underlying grasses. Chlorsulfuron has now been withdrawn from commercial use in the U.K. and previous work (Oswald *et al.*, 1985) showed higher doses of metsulfuron-methyl alone are needed for bracken control, reducing grass selectivity.

Our pot experiments have confirmed the earlier promise of DPX-L5300, alone or in mixture with DPX-M6316, for bracken control in grassland situations. The tolerance of grass species, together with low mammalian toxicity, short soil persistence and low dose rates associated with these herbicides (and the possibility of controlling bracken at an early stage) may make them environmentally acceptable treatments. However, soil leaching and effects on non-target plant species need investigating. Field experiments are now in progress to determine the potential of these herbicides for bracken control.

The way forward with bracken control in hill pastures is probably by containment and small-scale reclamation of useful and accessible land, rather than by eradication of vast areas, particularly as aerial application is likely to be severely restricted under new pesticide legislation. In the foreseeable future, a combination of herbicides and land management appears the only practical option available for control, especially as the development of biological control methods is still at an early stage.

ACKNOWLEDGEMENTS

Thanks are due to Mr R.J. Tutcher for technical assistance; to Mr R.F. Hughes and staff for practical assistance and to the manufacturers for the supply of herbicides used in these experiments.

REFERENCES

Oswald, A.K.; Richardson, W.G.; Flint, C.E. (1985) The effects of sulfonylurea herbicides on *Pteridium aquilinum* (bracken) in hill pasture. *Proceedings British Crop Protection Conference - Weeds*, *2*, 779-785.

Standell, C.J.; West, T.M. (1989) Response of several pasture grass species to potential new herbicides for bracken control. *Proceedings Brighton Crop Protection Conference - Weeds*. (In press.)

Taylor, J.A. (1989) Bracken toxicity and carcinogenicity as related to animal and human health. *International Bracken Group, Special Publication*. *Institute of Earth Studies, University College of Wales, Aberystwyth*, No. 44.

West, T.M.; Richardson, W.G. (1987) The activity of new herbicides on bracken and grass species. *Proceedings British Crop Protection Conference - Weeds*, *3*, 751-756.

RESPONSE OF SEVERAL PASTURE GRASS SPECIES TO POTENTIAL NEW HERBICIDES FOR BRACKEN CONTROL

C.J. STANDELL, T.M. WEST

Department of Agricultural Sciences, University of Bristol, A.F.R.C.
Institute of Arable Crops Research, Long Ashton Research Station,
Bristol, BS18 9AF

ABSTRACT

In glasshouse experiments, seven potential bracken (*Pteridium aquilinum*) herbicides were evaluated on a range of eight grass species.

In experiment 1, as expected, the total herbicide imazapyr was the most damaging. Asulam was the next most damaging, only three species (*Festuca ovina*, *Festuca rubra* and *Lolium perenne*) showing any regrowth two months after application. Of the sulfonylureas, chlorsulfuron and metsulfuron-methyl were more damaging than DPX-L5300 or DPX-M6316, although, with the exception of *Cynosurus cristatus*, *Holcus lanatus* and *L. perenne*, the grass species showed a reasonable level of tolerance. Triasulfuron showed a similar pattern of activity to DPX-L5300 and DPX-M6316, but most species were more sensitive at the higher doses.

Results from experiment 2 confirmed that, for *H. lanatus* and *L. perenne*, there were no differences in damage due to stage of growth at the time of application. However, *D. glomerata* was more tolerant to DPX-L5300, both alone and in mixture, at tillering than at earlier stages.

INTRODUCTION

Bracken is a widespread and invasive weed which is encroaching on upland grassland in England and Wales at a rate of 1-3% p.a. (Taylor, 1986). Traditionally, cultural management and asulam, sprayed intermittently and at some cost, have been relied on to halt bracken invasion of farm land. Asulam applied at full frond emergence, the only herbicide treatment recommended for bracken control in grassland in the U.K. (Soper, 1986), achieves a good level of control for up to four years (Veerasekaran *et al*., 1978). However, some pasture grasses commonly found in association with bracken are susceptible to asulam (Oswald *et al*., 1986; Soper, 1970; Williams, 1977), especially if there is inadequate bracken cover. Therefore, a herbicide treatment giving long-term control of bracken and improved safety on indigenous grasses is needed.

Two low-dose sulfonylurea herbicides, chlorsulfuron and metsulfuron-methyl, have potential for bracken control with improved grass safety (Davies & Williams, 1987; Oswald *et al*., 1985, 1986; West & Richardson, 1987). Similarly, several newer sulfonylurea herbicides have shown considerable promise (West & Richardson, 1987; West & Standell, 1989).

This paper presents data from two pot experiments examining these newer sulfonylurea herbicides for their safety on a range of pasture grass species at different growth stages.

MATERIALS AND METHODS

Plant raising

Seeds of all grass species (Table 1) were sown into seed trays and pricked out (two-leaf stage) at a density of five plants per 9 cm diameter pot. The potting medium used was unsterilised loam (Mendip silty clay) and sandy grit (5:1) plus 6.6 g Vitax Q4 per litre. In the second experiment, 12 seeds were sown directly into each pot and thinned to five plants per pot prior to spraying.

Herbicide treatments

The formulations used were: asulam 400 g a.i./ha a.c.; chlorsulfuron 20% a.i. W.G.; DPX-L5300 75% a.i. W.G.; DPX-M6316 75% a.i. W.G.; imazapyr 250 g a.i./l S.L.; metsulfuron-methyl 20% a.i. W.G. and triasulfuron 20% a.i. W.G. DPX coded compounds are sulfonylurea herbicides from DuPont. The treatments (Table 2) were applied using a track sprayer fitted with an 80015 flat fan Lurmark nozzle, at 45 cm above target height, giving a volume rate of 335 l/ha at a pressure of 210 kPa. A surfactant, Agral 90 (0.1% V/V), was used throughout and was also sprayed alone as a control treatment. Grass species and growth stages at spraying for experiments 1 and 2 are described in Table 1. Pots were watered from overhead with a fine rose 24 h after spraying and transferred to a heated glasshouse (15-25°C) with supplementary lighting (14 h/d). All species were laid out in three randomised blocks, then watered from above as required.

Assessments

In both experiments, regular visual scores of herbicide damage were taken to confirm dry matter (d.m.) assessments. All pots were harvested for total dry matter yields approximately 4 and 9 weeks (regrowth) after treatment. Herbage was cut 1 cm above soil level, weighed, oven dried at 100°C for 14 h and weighed.

TABLE 1. Grass species and growth stages at spraying.

Grass species (abbr.)	Experiment 1		Experiment 2			
	Height (cm)	Tiller no.	Height (cm)	Tiller no.	Height (cm)	Tiller no.
Agrostis capillaris (*A. cap.*)	13	2-3	-	-	-	-
Cynosurus cristatus (*C. cris.*)	14	3-4	-	-	-	-
Dactylis glomerata (*D. glom.*)	22	2-3	4.5	1	25	3-4
Festuca ovina (*F. ovi.*)	9	4-6	-	-	-	-
Festuca rubra (*F. rub.*)	14	4-5	-	-	-	-
Holcus lanatus (*H. lan.*)	18	2-3	10	1	22	8-10
Lolium perenne (*L. per.*)	15	1-2	10	1	13	3-4
Poa pratensis (*P. prat.*)	13	2-3	-	-	-	-

RESULTS

Experiment 1 (Table 2)

Asulam, at the field rate of 4.4 kg a.i./ha, prevented regrowth (9 weeks after spraying) in five out of eight species tested, and caused reductions in dry weights of 24, 59 and 88% for L. perenne, F. ovina and F. rubra respectively. At 1.1 kg a.i./ha, only L. perenne was unaffected at either harvest. However, there was no effect on regrowth with D. glomerata, F. ovina and P. pratensis and good recovery with F. rubra.

Chlorsulfuron and metsulfuron-methyl generally reduced dry matter yield at regrowth by less than 25% for five of the species. There was little or no regrowth from L. perenne, C. cristatus and H. lanatus. The tank mixture was more damaging than either of its components alone and caused considerable yield reductions in regrowth for A. capillaris, and F. rubra and, to a lesser extent, the other three species.

DPX-L5300, at doses up to 20 g a.i./ha, had no effect on six of the species and reduced C. cristatus shoot dry matter by only 22%. This reduction increased to 84% at double that dose. H. lanatus shoot growth was reduced by 70% at only 5 g a.i./ha.

DPX-M6316, at all doses, caused no more than 12% losses in regrowth dry matter for six of the species, L. perenne regrowth was reduced by 34% at the 40 g a.i./ha dose and that of C. cristatus, the most sensitive species, by around 40% at doses up to 20 g a.i./ha and nearly 80% at 40 g a.i./ha.

Triasulfuron was slightly more damaging than either DPX-L5300 or DPX-M6316, but doses up to 20 g a.i./ha were well tolerated by all but L. perenne and H. lanatus. C. cristatus was sensitive at all doses.

Imazapyr killed all species at doses above 30 g a.i./ha and on D. glomerata, the most tolerant grass, it caused a 39% reduction in shoot dry weight at 10 g a.i./ha.

Experiment 2 (Table 3)

In this experiment, three species were sprayed at both 3-4 leaf and tillering to test their sensitivity at different growth stages to the newer sulfonylurea herbicides and asulam. The species were chosen from those in experiment 1, as the most tolerant (D. glomerata), the most sensitive (H. lanatus) and the most important (L. perenne) which was also of intermediate sensitivity.

Asulam gave similar results to those in experiment 1, although L. perenne was more sensitive than in experiment 1 even though the plants were of a similar size. As expected, the grasses at the seedling stage were more susceptible than at tillering.

Doses of the sulfonylurea herbicides were higher than those used in the previous experiment (rates currently being used in field experiments) and a mixture of DPX-L5300 and DPX-M6316 was included. Results for all herbicides were as expected, with D. glomerata at tillering being tolerant of DPX-L5300 and DPX-M6216, alone and in the mixture, with some tolerance at the seedling stage. H. lanatus was sensitive at both growth stages to DPX-L5300 and

TABLE 2. Effects of herbicides on shoot dry matter (expressed as % of unsprayed controls) harvested 30 and 63 days after treatment. (Experiment 1).

Herbicide	Dose	A. cap.		C. cris.		D. glom.		F. ovi.		F. rub.		H. lan.		L. per.		P.prat.	
	(g a.i./ha)	30	63	30	63	30	63	30	63	30	63	30	63	30	63	30	63
Asulam	1100	25	0	41	0	69	106	47	92	49	65	58	0	108	126	40	139
"	2200	23	0	49	0	50	17	36	52	45	56	71	0	55	97	46	55
"	4400	22	0	54	0	62	0	33	41	35	12	60	0	51	76	49	0
Chlorsulfuron	7.5	84	71	39	18	114	133	116	92	87	94	40	4	52	31	120	98
"	15	86	84	33	4	96	142	86	75	86	78	39	6	34	4	105	116
Metsulfuron-	2.5	66	104	45	25	88	114	122	111	126	122	32	10	54	59	115	92
methyl	5	57	80	38	5	74	103	77	67	79	60	29	1	50	13	74	84
Chlorsulfuron+	7.5+2.5	58	59	34	3	71	103	96	81	74	59	29	0	36	3	104	77
metsulfuron	15+5	51	61	32	1	73	71	69	59	44	36	33	0	31	2	74	72
DPX-L5300	5	114	100	55	79	88	124	118	119	111	104	38	30	84	92	125	88
"	10	94	103	50	115	91	149	119	100	103	109	39	1	84	122	116	120
"	20	99	101	49	78	107	119	105	104	128	110	32	0	70	100	112	113
"	40	114	90	26	16	94	121	87	84	75	115	28	0	60	75	63	72
DPX-M6316	5	116	83	50	65	98	108	109	89	114	99	75	119	79	95	116	106
"	10	131	99	50	63	94	126	107	96	88	110	62	89	76	99	115	119
"	20	125	107	31	58	110	101	105	99	80	112	47	107	50	89	113	108
"	40	110	106	35	26	102	122	104	96	91	109	42	88	47	66	116	119
Triasulfuron	5	114	91	45	43	77	90	105	84	126	117	78	115	84	86	102	98
"	10	96	83	23	11	74	93	101	92	112	122	67	82	67	49	104	111
"	20	103	94	23	3	79	71	87	88	95	91	32	14	57	34	82	98
"	40	73	77	32	1	60	63	76	45	78	64	32	9	41	3	65	70
Unsprayed controls (g per pot)		0.77	0.69	1.16	0.80	1.63	0.72	1.10	0.73	1.15	0.81	1.46	1.25	1.52	0.91	1.34	0.64
S.E.D.±		13.4	13.6	6.8	13.0	10.0	13.7	9.1	11.5	13.1	11.3	9.1	9.6	10.4	12.2	10.0	9.1

DPX-M6316. *L. perenne* was also more sensitive to the herbicides than in experiment 1.

TABLE 3. Effects of herbicides on seedling and tillered stages of 3 grasses, on shoot dry matter (expressed as % of unsprayed controls) harvested 28 and 63 days after treatment. (Experiment 2).

Herbicide	Dose (g a.i./ha)	*D. glom.*				*H. lan.*				*L. per.*			
		3-4 leaf		tiller		3-4 leaf		tiller		3-4 leaf		tiller	
		28	63	28	63	28	63	28	63	28	63	28	63
Asulam	4400	9	0	49	0	10	0	65	0	28	20	73	25
Metsulfuron-methyl	40	11	0	58	22	2	0	51	0	16	0	50	0
DPX-L5300	30	37	64	101	127	2	0	46	0	29	32	65	24
"	45	14	11	100	109	5	0	49	0	34	34	82	18
DPX-M6316	60	65	106	106	122	9	10	44	4	27	17	84	30
"	90	54	57	96	116	5	0	52	0	28	31	59	2
DPX-L5300	30+60	26	52	96	116	7	0	50	0	20	8	57	2
+DPX-M6316	60+90	42	55	81	118	5	0	54	0	26	6	41	0
Unsprayed controls (g per pot)		.19	.71	2.24	.25	.43	1.08	2.88	.67	.42	.96	1.77	.57
	S.E.D.±	9.9	10.5	15.2	20.9	8.5	8.0	6.6	13.3	8.5	12.1	7.7	17.0

DISCUSSION

Asulam, although giving good bracken control, can severely damage or kill a number of pasture grass species. Chlorsulfuron and metsulfuron-methyl alone, and in mixture, have shown acceptable selectivity (Oswald *et al.*, 1985). Chlorsulfuron has now been withdrawn from the market, but DPX-L5300, DPX-M6316 and triasulfuron have been shown to have potential both for bracken control at different growth stages and improved grass tolerance (West and Richardson, 1987; West and Standell, 1989).

This paper reports work on a wider range of grass species to confirm the initial results of crop tolerance. With the exception of imazapyr, the herbicides tested are likely to cause less damage to understorey grasses than asulam at the recommended field rate. These herbicides also reduce bracken frond numbers and rhizome viability, when applied at different growth stages, in pot experiments and they are currently being evaluated in field trials (Standell and West, unpublished data). This, together with their low mammalian toxicity and short soil persistence, suggests that these herbicides may contribute to improved management practices which could begin to halt the alarming spread of this serious and widespread weed.

ACKNOWLEDGEMENTS

The authors thank Mr G. Stone for technical assistance, Mr R.F. Hughes and staff for practical assistance and the manufacturers for the supply of herbicides used in these experiments.

REFERENCES

Davies, D.H.K.; Williams, G.H. (1987) Activity of sulfonyl-urea herbicides on Pteridium aquilinum in the south of Scotland. Proceedings Crop Protection in Northern Britain, 355-360.

Oswald, A.K.; Richardson, W.G.; Flint, C.E. (1985) The effects of sulfonylurea herbicides on Pteridium aquilinum (bracken) in hill pasture. Proceedings British Crop Protection Conference - Weeds, 2, 779-785.

Oswald, A.K.; Richardson, W.G.; West, T.M. (1986) The potential control of bracken by sulfonylurea herbicides. In: Bracken: Ecology, Land Use and Control Technology, R.T. Smith and J.A. Taylor (Eds), England, Parthenon Press, pp. 431-439.

Soper, D. (1970) The tolerance of pasture grasses to asulam. Proceedings 10th British Weed Control Conference, pp. 465-475.

Soper, D. (1986) Lessons from fifteen years of bracken control with asulam. In: Bracken: Ecology, Land Use and Control Technology, R.T. Smith and J.A. Taylor (Eds), England, Parthenon Press, pp. 351-357.

Taylor, J.A. (1986) The bracken problem: a local hazard and global issue. In: Bracken: Ecology, Land Use and Control Technology, R.T. Smith and J.A. Taylor (Eds), England, Parthenon Press, pp. 21-42.

Veerasekaran, P.; Kirkwood, R.C.; Fletcher, W.W. (1978) Studies on the mode of action of asulam in bracken (Pteridium aquilinum L. Kuhn). III. Long-term control of field bracken. Weed Research, 18, 315-319.

West, T.M.; Richardson, W.G. (1987) The activity of new herbicides on bracken and grass species. Proceedings British Crop Protection Conference - Weeds, 3, 751-756.

West, T.M.; Standell, C.J. (1989) Response of bracken and eight pasture grass species to some sulfonylurea herbicides. Proceedings Brighton Crop Protection Conference - Weeds, (in press)

Williams, G.H. (1977) Qualitative effects of asulam and glyphosate on swards dominated by bracken (Pteridium aquilinum (L.) Kuhn). Journal of the British Grassland Society, 32, 149-155.

FACTORS INFLUENCING THE EFFICACY OF GRASS RETARDANTS WHEN SPRAYED USING THE CONTROLLED DROPLET APPLICATION TECHNIQUE

M R Alder, Lynne Gregory

ICI Agrochemicals, Jealott's Hill Research Station, Bracknell
Berkshire RG12 6EY, UK

ABSTRACT

Small plot trials carried out between 1986 and 1989 have shown that both mefluidide and paclobutrazol applied to grass by controlled droplet application can give effective retardation of the sward.

Results of six replicated trials carried out on amenity turf have shown that it is feasible to apply mefluidide and paclobutrazol both alone and in mixture using controlled droplet application. However it is important to optimise spray quality as efficacy is influenced by number of droplets and droplet size, the optimum size being between 250 and 450 microns.

INTRODUCTION

The main areas to benefit from use of retardants are high profile difficult-to-mow areas where standards must be maintained eg sight lines on roadsides. Often these areas are difficult to spray using tractor mounted equipment because of the presence of road signs and other obstacles so spraying, or mowing, by hand is necessary. This is the type of area where use of a controlled droplet application technique (cda) can be of the greatest advantage. Other areas where this type of spraying may be of benefit are around trees, along fence lines, in cemeteries and in plots of bulbs where mowing is impossible. Paclobutrazol and mefluidide are commercially available grass retardants that have previously been reported for use within these areas (Lever *et al*, 1982; Atkin, 1984).

Controlled droplet application techniques offer many advantages over conventional knapsack spraying. These include minimal operator contamination, lower volumes, light equipment and simpler calibration.

Initial field evaluation using grass retardants with this technique generated encouraging data where variations in spray volumes and droplet size was shown to affect the biological efficacy of each material.

MATERIALS AND METHODS

Formulation

The active ingredients were formulated as oil-in-water emulsions and aqueous-based concentrates.

Table 1. Formulations

Active Ingredient	Formulation Type	Concentration ai % w/v	Application volume l ha^{-1}	Application rate kg ha^{-1}
mefluidide	SL	1.33	30	0.4
		2.66	15	0.4
paclobutrazol	SC & EW	5.0	30	1.5
		10.0	15	1.5
paclobutrazol + mefluidide	SC	1.33 + 10.0	30	1.5 + 0.2
		5.0 + 0.67	15	1.5 + 0.2

Application equipment

The equipment used for these trials was a commercially available variable swath sprayer and for practical reasons volumes of 15 and 30 litres per hectare were adopted.

The concentrated formulation was supplied in a ready to use form and simply attached to the sprayer feed tube. The chemical was then allowed to flow through the tube via an on/off valve then enter a flow control chamber. From this point the chemical flow is restricted and fed onto a rotating atomising disc, where the droplets are formed at the edge of the toothed shaped disc. The droplet size and swath width are controlled by increasing or decreasing the rotating speed of the disc. (Frost, 1978) By altering the concentration of the formulation it is possible to apply a retardant at the same rate of active ingredient per hectare in different volumes.

The soluble liquid and suspension concentrate formulations, together with a blank oil in water emulsion to represent a standard emulsion for comparison were first sprayed in the laboratory to evaluate droplet size and number. All droplet size analysis was carried out using a PMS particle size laser analyser measuring all droplets in the range of 1.0 to 940 microns. Each sample was taken over a period of one hundred seconds.

Trial Design and Sites

The three field experiments reported were sited at Reading, Slough and Severnside. All sites comprised mixed swards, including *Lolium perenne*, cut regularly to a height of 2.5-5 cm. The experimental design was a randomised block with four replicates. Plot size was either 7.5 or 15m^2. Treatments varied from site to site an details are given in tables 4, 5 and 6.

Table 2. Field trials and application dates

Trial	Site	Spray Date	Objective
1.	Reading	29/5/86	Comparison of formulation type
2.	Reading	23/4/87	Effect of volume of application
3.	Severnside	16/5/89	Effect of swath width

ASSESSMENTS

Canopy heights were measured using a polystyrene tile float resting on the sward to give grass height above the soil surface, 5 measurements were taken at random throughout the plot. Visual assessments were made of retardation and phytotoxicity, scored on a 0 to 100% scale where 0 = no effect and 100 = dead.

RESULTS

Characterisation of spray

Table 3. Droplet size analysis

FORMULATION	FLOW RATE mls/min	VOL l/ha	SWATH m	NMD* u	VMD** u	Number of droplet per sample
paclobutrazol SC	90	15	1.00	322	376	1,640
	180	30	1.00	372	452	2,116
	90	30	0.50	591	701	635
	45	30	0.25	>940	-	-
mefluidide SL	90	15	1.00	300	383	2,080
	180	30	1.00	347	390	2,107
	90	30	0.50	463	660	1,430
	45	30	0.25	>940	-	-
Blank EW	90	15	1.00	306	413	2,561
	90	30	0.50	503	560	956
	180	30	1.00	323	400	2,400

* Number median diameter, ** Volume median diameter

Results clearly demonstrate number of droplets is proportional to the swath width which in turn is directly related to disc speed. The Paclobutrazol + mefluidide mixture gave similar results to paclobutrazol alone and are therefore not shown.

Comparison of formulation

Table 4. Sward height and percentage retardation - paclobutrazol using a 1 m swath applied at 1.5 kg ha^{-1} in 15 l ha (Trial site 1)

FORMULATION	% RETARDATION			% PHYTOTOXICITY		
DAT*	14	28	60	14	28	60
oil-in-water emulsion (EW)	25	26	28	<10	<10	0
suspension concentrate (SC)	18	26	26	0	0	0
untreated (cm)	6.0	7.2	9.5	0	0	0

* Days after treatment

No differences in retardation were noted when comparing formulation type but phytotoxic effects were seen at 14 and 28 days after treatment with the oil-in-water emulsion.

Effect of volume

Table 5. - Effect of volume on sward height (Trial site 2)

Treatment	kg ai/ha	15 l/ha height cm			30 l/ha height cm		
	dat*	30	50	72	30	50	72
paclobutrazol	1.5	10.4 (11)	18.3 (11)	29.3 (0)	8.6 (26)	15.4 (25)	21.9 (20)
paclobutrazol + mefluidide	1.5 + 0.2	7.8 (33)	11.6 (43)	19.0 (30)	7.1 (39)	9.7 (52)	16.5 (40)
Untreated		11.7	20.5	27.3	11.7	20.5	27.3

Values in parenthesis ( ) equal percentage reduction in growth

* Days after treatment

Treatments with paclobutrazol were more effective when sprayed at the higher volume, droplet number was almost double that of the lower volume as shown in table 3.

Effect of swath width

Table 6. - effect of swath width on sward height (Trial site 3)

SWATH cm	100		50		25	
DAT*	28	60	28	60	28	60
Treatment	Grass height cm					
paclobutrazol SC	10.6	10.4	10.1	11.7	10.3	13.3
mefluidide SL	7.4	7.0	9.4	10.5	9.8	12.1
paclobutrazol + mefluidide SC	7.8	9.0	8.9	9.0	9.0	10.2
Untreated			9.9	12.8		

* Days after treatment

Applications at the widest swath involving greater droplet numbers and smaller droplet size (table 3) showed the greatest sward height reduction.

DISCUSSION

Paclobutrazol and mefluidide are retardants with very different modes of action. Paclobutrazol is best applied very early season before the onset of growth and being soil active requires high rainfall to achieve full potential (Lever et al, 1982). This series of trials was conducted each year in early summer and this is reflected in the efficacy of the paclobutrazol treatments. Mefluidide must be sprayed when the grass is in active growth, it is foliar absorbed and inhibits growth for six to eight weeks after application (Atkin, 1984). The two products are therefore complementary and the mixture can produce retardation and seedhead suppression of a mixed grass sward over a period of 3 months or more.

Paclobutrazol and mefluidide are used commercially for the control of grass growth and are applied with conventional equipment at between 200 - 500 litres per hectare.

Cda spraying involves low volumes of application, (5 - 30 l/ha) larger droplets and fewer numbers of droplets, therefore coverage is not as complete as when spraying conventionally.

Type of formulation can also be important as the products are supplied ready for use and applied without dilution. Formulation type was considered first and results showed very little difference in levels of retardation when comparing water based formulations with oil-in-water emulsions, but sprays of oil-in-water emulsions resulted in slight phytotoxic effects. For this reason all other trials were conducted with water based formulations.

Spray quality is of great importance when applying grass retardants by cda. Size and number of droplets in the spray may be varied in two ways, either by altering the flow rate across the disc or increasing or decreasing disc speed. Results showed a slight increase in efficacy when application volume was increased from 15-30 l/ha. (Table 5). From table 3 it can be seen that an increase in volume from 15 lha^{-1} to 30 lha^{-1} has very little effect on droplet size but a large effect on droplet number, thus giving better coverage and a more effective result. This is likely to be true especially where the main route of uptake of the chemical is foliar.

Droplet size does influence degree of grass retardation. It can be deduced from table 6 that as droplet size increases the retardation effect in grass growth of the sward decreases. For effective retardation droplet size should be below 450 microns. For maximum effect it is important that the mean droplet size should not drop below 200 microns since very small droplets could lead to spray displacement. Sprays with an average droplet size within the range 250-450 microns appear to be desirable.

By optimising formulation type, volume of application, disc design and speed cda methods of application should offer an effective lower volume method of spraying grass retardants.

ACKNOWLEDGEMENTS

The authors wish to thank Mr Neil Fletcher of ICI Agrochemicals for his assistance in supplying droplet size analysis.

REFERENCES

Atkin, J.C. (1984) The use of mefluidide to control grass growth in amenity areas. Aspects of Applied Biology 5 - 37-44.

Frost, A.R. Rotary atomisation. Proceeding 1978 British Crop Protection Conference Monograph No 22, 7-21.

Lever, B.G.; Shearing, S.J.; Batch, J.J. (1982) PP333 a new broadspectrum growth retardant. Proceedings 1982 British Crop Protection Conference - Weeds 3-10.

SESSION 8A

COSTS AND BENEFITS OF WEED CONTROL – ACHIEVING THE BALANCE

CHAIRMAN	MR G. W. CUSSANS
SESSION ORGANISER	DR P. J. W. LUTMAN
INVITED PAPERS	8A-1 & 8A-2
RESEARCH REPORTS	8A-3 to 8A-7

ECONOMICS OF CROP PROTECTION IN EUROPE WITH REFERENCE TO WEED CONTROL

J.B. DENT, R.H. FAWCETT, P.K. THORNTON

The Edinburgh School of Agriculture, Edinburgh

ABSTRACT

At present, prophylactic weed control in cereals is an economically sound practice for most farmers. European Community cereal prices, however, are continuing to decline in real terms, and the environmental and societal impacts of pesticide use are perceived as being increasingly important. In time, the situation may be reached where other weed control practices are more economic. One option then open to farmers will involve the establishment of decision rules that specify when spraying should take place. The economic threshold model can be used as the basis of such rules and it can be revised to take account of (a) the spatial distribution of weeds in a field and thereby reduce variability of estimates of weed density, and (b) crop loss caused by wheeling and spray damage. As political pressure increases, government could make use of the "polluter pays" principle. An "environmental levy" on spray material costs would have a large effect on the total chemical discharge into the environment, but a much smaller effect on farmers' gross margins.

INTRODUCTION

Many estimates have been made about the amount of crop lost due to weeds and there are of course, large regional and seasonal variations. Physical reduction of crop output would appear to be within the range of 8 per cent estimated in the USA by Pimentel (1978) to 25 per cent which might occur in developing countries (Parker & Fryer, 1975). Such figures are acknowledged to be little better than "best-guesses" and yet the economic consequences of such losses are even more difficult to determine. Economic losses due to weeds do not only, or even primarily, relate to reduced farm income. They involve all aspects of rural and regional development and knock-on impacts of reduced farm production, impact on regional employment and income, income distribution, trade and therefore external balance of payments performance at National level, currency exchange rates and inflation. In less developed countries other measures may involve costs related to high infant mortality rates, direct medical costs, loss of earnings due to a lack of fitness of the population to work and therefore painfully slow general economic progress.

COSTS OF WEED CONTROL

Direct costs of weed control

The cost of chemicals used in control can be relatively easily determined. Table 1 expresses the costs of chemicals used in weed control in winter wheat and spring barley in both England and Wales and in Scotland as a percentage of the total allocatable costs of production on cereal growing farms.

Table 1 Proportion of allocatable costs of cereal production taken-up by weed control chemicals in 1985. (Average for cereal growing farm).

	WINTER WHEAT		SPRING BARLEY	
	England and Wales	Scotland	England and Wales	Scotland
Broadleaved	2.6	2.6	3.0	3.3
Annual grass/ wild oats	3.9	0.05	1.3	0.4
Mixed Broad-leaved + grass	2.2	1.5	0.6	0.1
Couch/perennials	0.4	0.2	0.4	0.4
Total weeds	9.2	4.4	5.3	4.1
Total cost £/ha	33.5	15.3	18.3	13.4

(after Davidson, 1986)

Also, given for reference, is the total average cost for weed control across all farms in England and Wales and in Scotland that produce either winter wheat or spring barley. Apart from winter wheat grown in England and Wales, the average proportion of the allocatable costs attributable to chemicals for weed control, is relatively small and in the region of 5 per cent. While costs obviously vary from one farm to another, the average costs of weed control are not high within the United Kingdom. Obviously, on any one farm the costs may be much higher or less than these figures.

Such detailed information from other countries within the EEC is less easy to obtain but figures are available which indicate the average proportion of variable costs accounted for by crop protection products (ie for pests, diseases and weeds) across all farms within each country. Figures vary a good deal from 8.8 per cent in France to 1.9 per cent in the Netherlands (CEC, 1989). National comparisons of this nature, while generally interesting, have to be interpreted carefully since crop production practices, rotations, soil type and climate all influence the approach to crop protection within a country. While on-farm cost of weed control chemicals is not a negligible budgetary item, it may not be seen as large in the eyes of a risk-averse farmer with a predilection for clean fields. Such a farmer will tend towards a prophylactic application of weed control chemicals as long as the financial margin for cereal enterprises remains relatively buoyant.

European pricing policy for cereals

In recent years, the European Commission has attempted to control what it sees as excess cereal supply by imposing restraint on price increases and by imposing policies that indirectly increase the costs to the cereal producer. Taking all agricultural produce together, the ecu average intervention price set by the Commission has declined in real terms in each of the last three years. However, individual countries have made independent decisions to devalue the average green currency exchange rates in each year. This has meant that, for most of the countries within the Community, the average real production prices have not declined anywhere near as rapidly as the intervention price would suggest. Most governments are sheltering their agricultural industry from the Commission policy of stationary intervention price levels. Effectively, agricultural pricing policy has been "imported" back to the domain of individual national governments. This 'importation' is such that different green exchange rates apply for individual commodities. The substantial devaluation of the cereal green pound is shown in Table 2.

Table 2 Cereal green exchange rate

	1986	1987	Jan 1 1989	1989/90
£ Stirling/ecu	0.626994	0.656148	0.675071	0.701383
% increase in £ price		4.6	2.9	3.9
% inflation		3.5	4.4	4.8

Source: CAP Monitor
AgraEurope

As far as wheat and barley are concerned, in the UK, the average recorded producer prices for years during the 1980s are shown in Table 3.

Table 3 Average Producer price £/100kg in nominal terms

	1980	1985	1986
Wheat	10.03	11.18	11.07
Barley	9.38	10.66	10.83

Source: Commission of the European Communities (1989)

There has, of course, been a levelling out of average price received for both commodities and in real terms, farmers are on average receiving less for their cereal output. There has however been no dramatic fall toward what might be considered a world market price for cereals, and farmers are therefore still encouraged to maintain the input of chemicals for crop protection. Should the price of cereals fall further in real terms, farmers are likely to view all input costs more carefully and the prospect of a different rational decision about chemical inputs may occur. A similar reaction might be anticipated if the cost of chemicals increased more rapidly than the general inflation rate. Extreme price or cost pressure would either encourage farmers to move out of cereal production or to move to more extensive methods. The European Commission prefers a policy of extensification and such direction would suggest reduced chemical inputs.

Secondary impacts of chemical application

There are a range of costs and benefits which relate to decisions about the use of chemicals for weed control which do not impact on farm budgets and which are not taken into account by farmers when making economic decisions. The costs of reduced yield, which may result from lack of appropriate weed control, and which will be felt at regional and national level, have been mentioned previously.

There are a further set of externalities which need to be taken into account and these relate to the environmental and social consequences of chemical application in agriculture. From an ecological position, such costs include : the build-up of chemical residues in the soil; the contamination of water supplies affecting both wildlife and humans (Croll, 1985); the direct reduction of wildlife diversity. From a societal point of view, other costs are for example, adverse effects on operators, bystanders and consumers. The costs of such items are, of course, extremely difficult to determine in an objective way. It is not the purpose of this paper to attempt such an appraisal, but rather to emphasise that publicly perceived costs are as real as actual costs. Such concerns are being expressed by the public through the electoral system as exemplified in the substantial increase in the 'green' vote in the June 1989 European Parliamentary elections, and through the press. Currently the only way in which individual farmers feel any environmental "cost" from their actions, is through the limitation of chemicals which are available for use through the "Approved Chemicals List". The implication here is that a chemical appearing on the Approved List is assumed to have no environmental or social impact and is in some sense safe to use (Tooby, 1988). From the public standpoint a much more satisfactory situation would apply if it were possible to establish a polluter-pays system. It is difficult, however, to establish a clear cause and effect linkage between application of a chemical by an individual farmer and any subsequent environmental impact.

Economic decisions by individual farmers concerning the application of chemicals for weed control are then made in circumstances which bear an incomplete reflection of the true situation. Firstly, the prices of cereal products are set at an artificial level above what may be perceived as a world prices, and secondly, not all costs and benefits flowing from individual farmers actions can be taken into account. As the price of cereals in Europe decreases, and as the environmental cost of chemical application as perceived by the public becomes greater, farmers will be under pressure to modify their traditional policies. How the environmental costs will be brought to bear on farmers' decisions cannot be predicted but one option recently proposed in the Pearce report to the Minister responsible for the Environment would be to impose a general "environmental levy" on all chemicals used in agriculture & horticulture.

Possible on-farm strategies for reducing chemical inputs

Should a farmer be induced by legislation or economic pressure to move from prophylactic weed control there are several courses of action open to him:

1. reduce the dose level while still maintaining a prophylactic approach (Davies 1987).
2. establish a more complex set of rules about when and what to spray.
3. change the rotation of the farm to permit more mechanical and cultural control over weeds.
4. use one or more of a range of new practices such as biological control.

All the above options will potentially involve less chemical input and will bear lower environmental costs. Reducing the dose is clearly the simplest effective method, but still may involve superfluous treatment and possible increased variability of efficacy, (Davies 1987). Changing the crop rotation is a major whole-farm decision and would not find favour with many farmers in the short-term. Similarly biological control methods are likely only in the longer term. The possibility of farmers taking a more objective approach to chemical control holds out promise of reducing the more global societal and environmental costs, both real and perceived. Such an approach demands a reappraisal of threshold concepts and the practicalities of applying them and the remainder of this paper is concerned with these problems.

THRESHOLD MODELS IN WEED CONTROL

The concept of a threshold in weed control practice can be summarised as follows: as the weed population per unit area increases, the gain in crop yield from chemical control becomes greater than the cost of the chemicals and their application. The threshold density is where the cost of control is equal to the net benefit from control. Provided appropriate aids to calculation are available, practical application of the threshold concept requires the farmer to ascertain whether the weed density is greater than the threshold density. Currently, any error of estimation of weed density will have little economic consequence to the farmer because cereal prices are still relatively high and only internal costs of spraying are recognized in management decisions. Lower prices and/or higher input costs will force thresholds up and because of the nature of the relationship (see Figure 3 for example) somewhat more precision in threshold recognition will be desirable.

Conceptual problems with existing threshold models

1. Threshold concepts are dependent on experimental evidence in which crop loss is related to weed densities. For example, for wild oats in wheat the experimentation of Carlson,Hill and Baghott (1981) formed the basis of the Cousens (1985) model and took place over contrived weed densities from 2 to 30 plants per square foot. Even the lower end of this range represents quite severe weed density and current thresholds have been shown to be at weed densities of less than one plant per square foot and therefore outside the experimental range from which the relationship was developed. The method of extrapolation from a density of zero to two plants per square foot can make a substantial difference in the threshold determination.

2. Weeds are generally not uniformly random in distribution through a field. Many weed species show a marked tendency to cluster, leaving large areas of a field relatively free of weeds altogether. Determination of

average weed density in this circumstance is relatively meaningless. For any given weed density in a field, yield loss will be greatest when there is a uniform random distribution of the weed species. If the same total weed population for a field were concentrated into 10 per cent of the area of the field, at consequent high density within this 10 per cent of the area, there is a much lower overall crop loss irrespective of the variability within the patch simply because 90 per cent of the field is weed free and the impact of each weed plant is much reduced (Cousens, 1985). Figure 1 demonstrates this effect for 90 per cent, 60 per cent, 30 per cent and 0 per cent weed free areas against a range of average weed densities. Threshold models of the type posed by Cousens et al (1986) have assumed that there is no area of a field free altogether from weeds and therefore assumes a yield loss function similar to the 0 per cent weed free curve in Figure 1. This of course results in a low threshold and therefore encourages the use of herbicide. If, however, a weed population is distributed in patches in the field, rather than uniformly spread, the crop loss functions shown in Figure 1 indicate that a farmer could tolerate a much heavier average weed population without applying chemicals. In other words the threshold point is higher as any particular population of weeds is concentrated into a smaller area of the field. As increased concentration of the weed population occurs, chemical application is less likely to be the dominant economic strategy. Furthermore, thresholds for large patches can be independently determined and chemical spraying can be limited to those particular large patches. The threshold for each patch could be determined as if there were a uniform random distribution within the patch. Either not spraying because field thresholds are high due to concentration of the weed population or simply treating large patches independently and spraying these areas only, provides a strategy for farmers that will substantially reduce the amount of chemical applied.

3. In any weedy crop the application of chemicals will have some impact on healthy crop plants (Farahbaksh et al, 1988; Tottman, 1988). This damage, together with wheeling effects, should be taken into account when determining thresholds. Of course, wheeling losses may not be attributable totally to application of herbicides since they may also be incurred in other pest control applications. The greater the damage to healthy crop plants due to chemical application, the higher the threshold must be for a positive decision to apply chemical control measures to the field. Figure 2 illustrates the way that the threshold increases, first with a 2.5 per cent crop loss due to wheeling damage and then assuming a further 2.5 per cent of crop loss due to the chemical application per se.

Practical problems in the application of threshold models

Current threshold models may readily be adapted to take account of the three areas of refinement suggested in the previous section. However, in order to develop such refined threshold models, the patchiness of weed populations would need to be determined and monitored. This can be achieved by some form of aerial surveillance which could replace current crop walking for weeds. Such aerial surveillance would provide the basis for mapping the location of the weed population. The authors have developed a rudimentary procedure using low altitude helium balloons and remote control photography coupled with digital mapping methods which will permit determination of the weed-free area within any field. The prospect of locating weed patches within fields would (a) constitute the first step in determining the threshold for a field as a whole and (b) would permit patch spraying of annual weeds on the current crop and location of persistent weeds which maybe sprayed in the following season. Aerial surveillance techniques have potential for enhancing the threshold concept through making it more practical, easier and more accurate to apply.

It would appear that there is a case for re-evaluating the application of threshold models and, in the light of newer evidence concerning the patchy distribution of weeds within fields, this re-evaluation could take the form of case study aerial surveillance combined with computer simulation. There are prospects for the reduction of both farm and environmental costs of weed control if farmers make more objective decisions based on re-developed threshold models.

Political action and environmental cost

Governments within Europe are finding themselves under increased pressure from the electorate to respond to environmental problems. One way in which governments may respond to pressures for less chemical inputs into cereal farming could be to impose a levy on weed control chemicals. Figure 3, constructed from simulations based on Cousens (1985) and Cousens et al (1986), shows the impact on the calculated economic threshold of wild oats in a winter wheat as the weeds are condensed into a smaller area of the field for various scenarios. The threshold increases steadily as the weeds are concentrated into a smaller area of the field and quite dramatically as the weed free area approaches 60 per cent. However, it is also clear from Figure 3 that, if the cost of chemicals were doubled by the imposition of a levy, the threshold of application would also increase. Economically rational farmers therefore could be encouraged to make savings in chemical application by the imposition of a levy of this size, while at the same time not being too severely handicapped in circumstances where it was essential for them to apply chemicals for control. More damaging inducements would be provided for farmers by permitting the real price for grain to fall to a world market level. The impact of a reduction in price of milling wheat from £125 to £89 per tonne on the threshold, assuming no additional levy for chemical application, is also shown in Figure 3.

In the above example the reduction of chemical discharge by imposing of 100 per cent levy on chemicals exceeds that achieved by a 30 per cent decrease in the real price of wheat but with less damaging effects on farm finances. Furthermore, such a levy would apply only to those who use chemicals and not to the whole population of cereal farmers, as would a cut in produce price. It is closer therefore to a polluter-pays concept. This is independent of the degree of patchiness but as the weed free area increases the absolute reduction in chemicals could be much greater. Such general statements would need to be improved to provide sound information for policy-makers. But further experimentation into crop loss functions, research into weed patchiness in crops and persuasion of farmers to adopt a threshold approach to decision making would be needed.

CONCLUSIONS

The societal and environmental benefits from any level of reduction in chemical use remains unmeasured. Public perception now seems likely to become the driving force for Governments in Europe to act. Costs associated with meeting enhanced quality standards for water and pesticide residues in food may be interpreted as the amount society is prepared to pay for such improvements. It could well be that external benefits from reduced chemicals are judged in this kind of broad context and not determined in a formal scientific sense. In such a circumstance, action for reduced chemical inputs could be required at any time and agronomists, weed scientists and the chemical industry need to be working to provide new approaches for farmers.

REFERENCES

Carlson,H.; Hill,J.; Baghott, K. (1981) Wild Oat Competition in Spring Wheat. Proceedings Thirty third Annual California Weed Conference, 13-24.

CEC (1989) The Agricultural Situation in the Community, 1988 Report. Commission of the European Communities, Brussels.

Cousens, R. (1985) A simple model relating yield loss to weed density. Annals Applied Biology. **107**, 239-252.

Cousens, R.; Doyle, C.J.; Wilson, B.J.; Cussans, G.W. (1986) Modelling the Economics of Controlling Avena Fatua in Winter Wheat. Pesticide Science, **17**, 1-12.

Croll, B.T. (1985) The effects of the agricultural use of herbicides on fresh water. Proceedings of WRC Conference on "Effects of land use on fresh water", Stirling, June 1983.

Davies, D.H.K. (1987) An approach towards reducing herbicide costs in winter barley. Proceedings of Crop Protection in Northern Britain, 7-12.

Davidson, J.G. (1986) UK cereals, 1985/86: Part 1 - Production economics; Agricultural Enterprise Studies in England and Wales, Economic Report No.101. Agricultural Economics Unit, University of Cambridge.

Farahbakhsh, A.; Murphy, K.J.; Dominy, P.J. (1988) Effects of tralkoxydim on cereals and grass weeds with reference to nitrogen and light interactions. Aspects of Applied Biology, **18**, Weed Control in Cereals and the Impact of Legislation on Pesticide Application, 81-90

Parker, C.; Fryer, J.D. (1975) Weed control problems causing major problems in world food supplies. FAO Plant Protection Bulletin, **23**, 83-95.

Pimentel, D. (1978) Socioeconomic and legal aspects of pest control. In: E.H.Smith and D.Pimental (eds). Pest Control Strategies,. 55-71. Academic Press, New York.

Tooby, T.E. (1988) Aims and objectives of pesticide regulations; a challenge to industry. Aspects of Applied Biology, **18**, Weed Control in Cereals and the Impact of Legislation on Pesticide Application, 285-291

Tottman, D.R.; Steer, P.M.; Martin, T.D. (1988) The tolerance of cereals to several foliage-applied broad-leaved weed herbicides at different growth stages. Aspects of Applied Biology, **18**, Weed Control in Cereals and the Impact of Legislation on Pesticide Application, 145-156

FIGURE 1 YIELD LOSS FUNCTIONS FOR DIFFERENT SPATIAL DISTRIBUTIONS: WILD OATS ON WINTER WHEAT

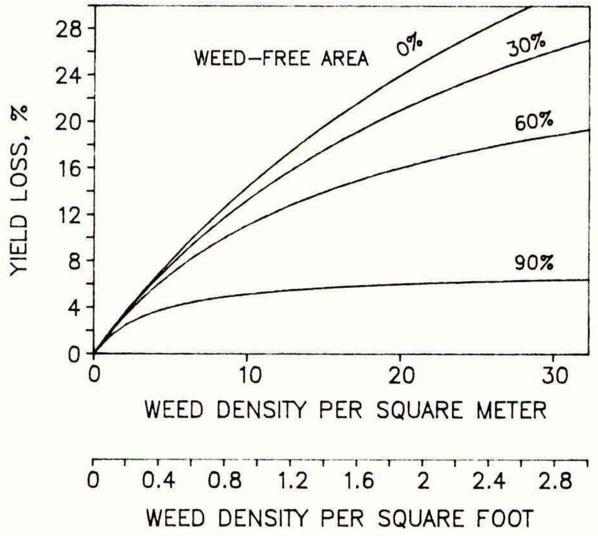


FIGURE 3 ECONOMIC THRESHOLD AS A FUNCTION OF WEED-FREE AREA FOR VARIOUS SCENARIOS: WILD OATS ON WINTER WHEAT

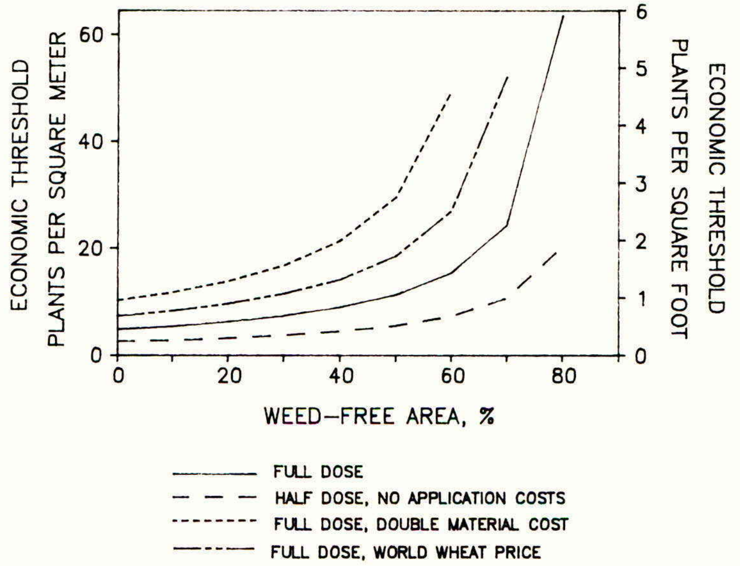
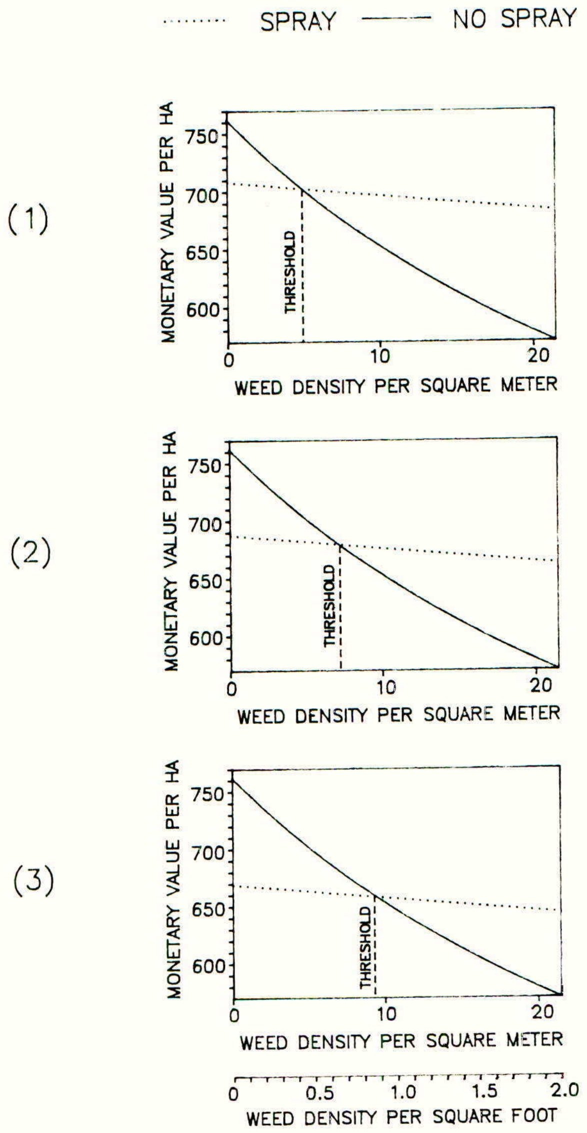


FIGURE 2 THE ECONOMIC THRESHOLD, WILD OATS ON WINTER WHEAT: (1) STANDARD MODEL PARAMETERS, (2) INCLUDING 2.5% WHEELING DAMAGE, (3) INCLUDING 2.5% WHEELING DAMAGE AND 2.5% YIELD LOSS DUE TO SPRAYING



THE HERBICIDE DOSE-RESPONSE CURVE AND THE ECONOMICS OF WEED CONTROL

J.C. Streibig

Department of Crop Science, Royal Veterinary and Agricultural University, Thorvaldsensvej 40, 1871 Frederiksberg C., Denmark

ABSTRACT

The dose-response relationships, the costs of herbicides and the economic thresholds are important concepts for the efficient and environmentally safe use of herbicides. The link between dose-response curves and economic thresholds is discussed and some examples of how to arrive at an economic optimum for weed control are given.

INTRODUCTION

The European community's concern for the use of pesticide *sensu lato* has stimulated the interest in reducing herbicide use by so-called objective methods. Over the years numerous approaches have been published and the first attempt to review 10 years of work on thresholds was given by Behrendt (1986) who showed that the models used in threshold estimation were only able to explain between 5 to 10 % of the total variation encountered in the field. More recently Cousens (1985), Cousens *et al.* (1987), Martin *et al* (1987) and Poole & Gill (1987) have attempted a more effective approach but still the threshold models were not always able to explain the variation satisfactorily when applied in practical situations (Streibig *et al.*, 1989). The same problem applies to the use of dose-response curves in the field (Pritchard & Streibig, 1990). Under planned experiments dose-response curves and yield-weed density curves can, however, describe a large proportion of the variation encountered under controlled conditions.

Recently the interest in combining the knowledge of the dose-response curve and the yield-weed density curve has even been more encouraged in Denmark than elsewhere. In Denmark, the public debate on pesticides and the environment initiated a political action plan from 1986 which states that the total pesticide consumption has to be reduced by 25% before the end of 1989 and a further reduction of 25% before 1997. The reduction goal is based on the average Danish pesticide use for 1981-85. The reduction is not only based on quantity but also on intensity of use, in order to take into account the use of the novel sulfonylureas with a recommended dose of only a few grammes per ha. (Haas, 1989).

The purpose of this paper is to outline some links between the herbicide dose-response curve and the use of threshold models and also to briefly discuss the relevance of the precision of threshold estimates.

THE DOSE-RESPONSE CURVE

When response, for example dry weight or number of surviving plants, of a weed species is plotted against the logarithm of herbicide doses, one often finds a sigmoid curve which is symmetrical around its point of inflexion (Fig. 1). The upper limit of the curve is an estimate of the weed production without herbicides and the lower limit at high doses is approximately zero (Streibig, 1980; 1988). The curve may sometimes deviate a little from the basic form. For example, as weeds treated with a post-emergence herbicide will have produced some dry matter before treatment, high doses will not result in a zero weight, and some herbicides can stimulate plant growth at low, non-toxic, doses (Brian & Cousens, 1988).

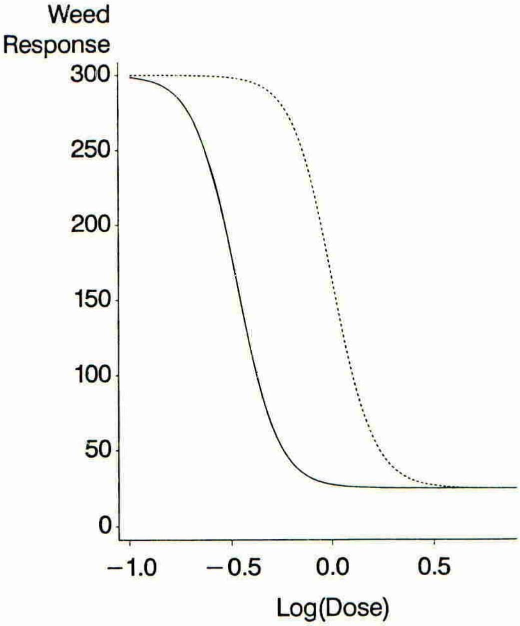


Fig. 1. Dose-response curves for two herbicides.

Provided the sigmoid relationship holds in Fig. 1, the weed response such as dry matter per unit area ($\underline{U}_s$) on the dose $\underline{z}_s$ can be described by a logistic model:

$$\underline{U}_s=(\underline{D}-\underline{C})/(1+\exp(-2(\underline{a}+\underline{b}\cdot\log(\underline{z}_s))))+\underline{C}\ ;\quad \underline{b}<0.$$

where $\underline{D}$ denotes the upper and $\underline{C}$ the lower limit. In the linear term $(\underline{a}+\underline{b}\cdot\log(\underline{z}_s))$, the parameter $\underline{a}$ determines the horizontal location of the steepest part of the curve and $\underline{b}$ is proportional to the slope of the curve in the vicinity of the point of inflexion. The ED_{50} value is defined as the dose resulting in a plant response half way between the upper and lower limit of the curve $((\underline{D}+\underline{C})/2)$ and the dose is similar to the point of inflexion $(10^{(-a/b)})$.

If we wish to compare the effectiveness of two herbicides having the same mode of action and we have herbicide doses covering the entire range from virtually no effect at low doses to complete kill at high doses, it is reasonable to assume that the two dose-response curves are identical in all their parameters except for that determining their relative horizontal displacement. In this case we could define one of the herbicides as a standard (s) and the other as a test (t). Then the model for the test will be

$$\underline{U}_t=(\underline{D}-\underline{C})/(1+\exp(-2(\underline{a}+\underline{b}\cdot\log(\underline{R}\cdot\underline{z}_t))))+\underline{C}\ ;\quad \underline{b}<0.$$

$\underline{R}$ denotes the relative displacement between the two curves (Fig. 1) and is defined by the ratio

$$\underline{R}=\underline{z}_s/\underline{z}_t$$

This relative displacement is often called the relative potency. If $\underline{R}$ is smaller than unity, the potency of the test herbicide is less than that of the standard, and if $\underline{R}$ is greater than unity the test is more potent than the standard. If the response curves are mutually parallel then $\underline{R}$ is constant over the whole dose range. In the present case in Fig. 1, the relative potency is 3.00 at any one response level considered. The relative potency of 3.00, however is a measure of the biologically difference in potency and not the economic difference. If the standard herbicide costs 20 ECU ha^{-1} and the test costs 30 ECU ha^{-1}, then the relative economic 'potency' is 2.00. This means that whatever the response level the use of the test herbicide is twice as profitable as the standard herbicide

The measurement of the relative biological or economic potency answers the question many farmers ask about the use of herbicides "When I use a certain rate of herbicide 's' which rate of herbicide 't' must I use to obtain the same effect?"; or if the standard and the test herbicide are a herbicide administered alone and with an adjuvant, then the relative potency answers the question "If I add an adjuvant to my spray how much less herbicide can I use without loosing any effect?".

THE DOSE-RESPONSE CURVE AND ECONOMICS

Often we are not able to fully describe the responses over the whole feasible dose-range from virtually no control at low doses to complete control at large doses; but the general shape in Fig. 1 can in many situations be reduced to a straight-line fit by either transforming the response or the dose or both. This is the case in Fig. 2 where clopyralid was applied alone ($\underline{y}=4.40-5.44\underline{z}$) and in a tank mix at 0.75 kg ha^{-1} with 2,4-D ($\underline{y}=4.00-5.44\underline{z}$) to control a noxious perennial weed, Chondrilla juncea L. (Skeleton weed) in a barley crop in Victoria, Australia (Pritchard & Streibig, 1990). The assessment was done 13 month following spraying and the response curves were assumed to be parallel. In this case the doses were not logarithmically transformed, i.e. the difference between doses was constant. Therefore the difference in cost between the two treatments, clopyralid with or without 2,4-D, in obtaining the same density will remain constant for all density levels. This difference in costs will be

$$C_c((4.40-4.00)/5.44)-0.75C_d$$

where C_c denotes cost of clopyralid (A\$116.70 kg^{-1}) and C_d cost of 2,4-D (A\$8.00 kg^{-1}). Therefore spraying a tank mix with clopyralid and 0.75 kg of 2,4-D will always cost A\$2.58 ha^{-1} less than using clopyralid alone to achieve the same final density.

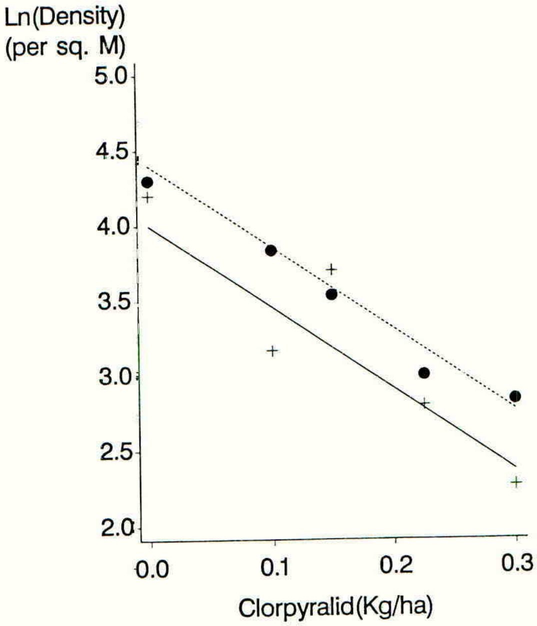


Fig. 2. Parallel dose-response curves for <u>Chondrilla juncea</u> 13 months after application of clopyralid (---●---) and clopyralid plus 2,4-D (0.75 kg ha^{-1}) (—+—) (From Pritchard & Streibig, 1990).

In another experiment the dose-response curves were not parallel, so the relative cost of using clopyralid alone or with 2,4-D at 1.5 kg ha^{-1} will change with the final density required. This can be shown graphically in Fig. 3 demonstrating that if a final density of less than 10 shoots m^{-2} is the aim, then it will be more economical to add 1.5 kg ha^{-1} of 2,4-D to the rate of clopyralid.

THE YIELD-WEED DENSITY RESPONSE CURVE

Two response curves are currently being used to find economic thresholds for weeds. The first one is widely used in some European countries and forms a basis for recommendations on herbicide labels. It is based on a yield increase, derived from the yield in the untreated control, in response to a weed density after spraying with a herbicide. In this approach the 'base line' or frame of reference is the yield in untreated control (Beer, 1979; Jensen, 1986; Springer & Heitefuss, 1988). One of the main objections to this approach, not always pointed out in the literature, is that the regressions often account for less than 10% of the total variation in yield (Behrendt, 1986). The second response curve is based on crop yield in response to density of the weeds and does not anticipate any weed control. Hence, its 'base line' or frame of reference is yield in a weed free environment (Cousens, 1985; 1987; Pannell, 1988). By using these curves one can arrive at economic thresholds based on the expected weed kill after a herbicide treatment. The functional relationship can be described by

$$\underline{y}=\underline{Y}_{wp}(1-\underline{Id}/(100(1+\underline{Id}/\underline{A})))$$

where $\underline{y}$ is the observed yield and $\underline{d}$ the weed density. The parameters $\underline{Y}_{wf}$ denotes the weed free yield, $\underline{I}$ the initial percentage yield loss when weed densities approach zero and $\underline{A}$ the maximum percentage yield loss at high weed densities.

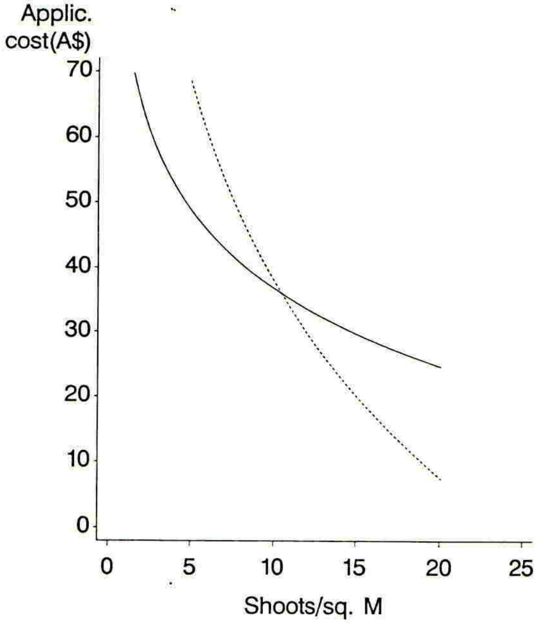


Fig. 3. Economics of controlling *Chondrilla juncea* with clopyralid (----) and clopyralid plus 2,4-D (1.5 kg ha^{-1}) (—) when the dose-response curves have different slopes (From Pritchard & Streibig, 1990).

Conceptually, this relationship appears more attractive than the one based on yield in untreated control and has recently been used for assessing the economic thresholds for several weed species (Poole & Gill, 1987; Streibig *et al.*, 1989) and also in a more strict economic sense by Auld, Menz & Tisdell (1987).

Fitting the above model to *Chondrilla juncea* data from an experiment by Wells (1971) gave the following parameters: A=93.08% and I= 3.33% m^2plant^{-1}. By converting the yield difference to A$ by assuming a weed free yield of 1.5 t ha^{-1} (A$130 t^{-1}), herbicide application cost of A$55 ha^{-1} and a 90% weed kill, one arrives at a economic threshold of 15 shoots m^{-2}. The relationship between profit and shoot density m^{-2} clearly shows that there is a maximum in Fig. 4 (Streibig *et al.*, 1989). This optimum profit is brought about by the shape of the yield-weed density response curve. A combination of the dose-response curves for clopyralid with or without 2,4-D and the yield-weed density curve is presented by Pritchard & Streibig (1990) and formed the basis for the relationship between profit and the rate of clopyralid in Fig. 5.

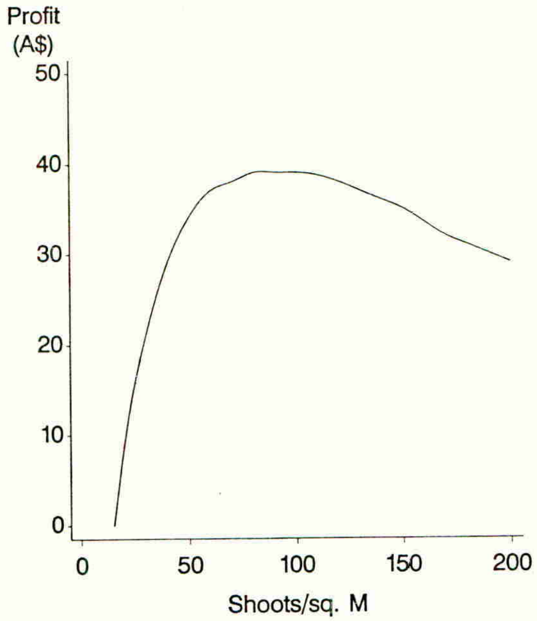


Fig. 4. Profit for control of *Chondrilla juncea* at various densities in wheat (From Streibig *et al*, 1989).

DISCUSSION

When spraying at recommended rates with a selective herbicide we strive to find the balance between maximum weed kill without loosing selectivity and without using too much chemical. A particular dose, however, has different effect on weeds and crop depending on a range of factors when replicated in time. These variations can be ascribed to what could be called the effective dose. The effective dose is a function of many factors associated with the herbicide, the target weeds and the climatic and edaphic conditions as well as interactions between these factors. The effective dose can rarely be measured quantitatively but conceptually it can be defined as the amount of active ingredients reaching their site of action in the plant. An indirect way of assessing the effective dose is to use the parallel line assay technique (Streibig, 1984). The difference in effective dose and apparent dose can be illustrated in Fig. 1. The relative potency of the two response curves can be a measure of how different spraying conditions or different development of the weeds etc can change the position of one and the same response curve horizontally along the dose axis. This approach has been used in the so-called factor adjusted dose technique presented at this conference by Kudsk (1989).

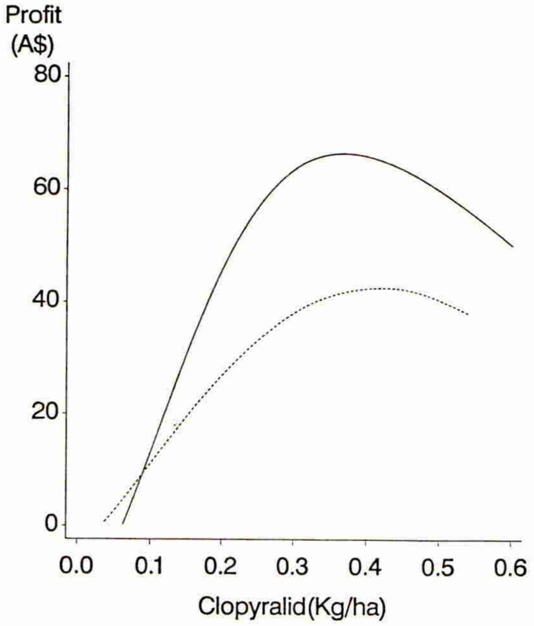


Fig. 5. Relationship between profit and rate of clopyralid (-----) and clopyralid plus 2,4-D (1.5 kg ha^{-1}) (—) to control Chondrilla juncea, based on Figs. 3 and 4. (From Pritchard & Streibig, 1990).

As was the case with the herbicide dose-response curve similar modifications can be applied to the yield-weed density curve. The effective density of a weed population is a function of, for example, the weed species, their time of emergence relative to the crop, and their distribution pattern in the field as well as interaction between these factors.

In principle, description of any dose-response curve and yield-weed density curve does not necessarily have any validity under conditions other than those of their estimations. Therefore, any general use of such relationships, however their precision, still leaves the end user at risk. As pointed out by Auld & Tisdell (1987) where risk aversion occurs, specific economic thresholds, or reduction in herbicide dose under favourable conditions become less relevant to decision making for the farmer.

The practical implication of poor precision of estimates of dose-response curves and yield-weed density curves depends on the expected yield level in weed free environment. In high input agriculture, for example that of Northern Europe, with an average yield of 6 to 8 t. ha^{-1}, low precision estimates result in an economic confidence interval exceeding the cost of herbicide application. In low input agriculture, for example in Australia, with an expected weed free yield between 1 and 2.5 t. ha^{-1}, poor precision does not necessarily have the same effect upon threshold levels. It is obvious that a 10% yield loss in Northern Europe is about 0.6 to 0.8 $t.ha^{-1}$, whereas in Australia is only is 0.1 to 0.25 $t.ha^{-1}$.

Perhaps one of the beneficial side effects of the use of economic thresholds and lowering of dose rates in certain instances is to lower selection pressure from herbicides on the weed flora with a consequent delay in the development of resistent weeds.

REFERENCES

Auld, B.A.; Menz, K.M.; Tisdell, C.A. (1987) Weed Control Economics. Academic Press Inc. (london) Ltd.

Auld, B.A.; Tisdell, C.A. (1987) Economic thresholds and response to uncertainty in weed control. Agricultural systems, 25, 219-227.

Beer. E. (1979) Ermittlung der Bekämpfungsschwellen und wirtschaftlichen Schadensschwellen von monokotylen und dikotylen Unkräutern im Winterweizen und Wintergerste anhand von Daten aus der amtlichen Mittelprüfung. Dissertation Göttingen.

Behrendt, S. (1986) Einige Gedanken zur Unkrautbekämpfung in der Zukunft. Proceedings EWRS symposium 1986, Economics Weed Control, 407-417.

Brian, P.; Cousens, R. (1989) An equation to describe dose responses where there is stimulation of growth at low doses. Weed Research, 29, 93-96.

Cousens, R. (1985) A simple model relation yield loss to weed density. Annals of Applied Biology, 107, 239-252.

Cousens, R. (1987) Theory and reality of weed control thresholds. Plant Protection Quarterly, 2, 13-20.

Cousens, R; Brian, P; O'Donovan, J:T.; O'Sullivan, P.A. (1987) The use of biologically realistic equations to describe the effects of weed density and relative time of emergence on crop yield. Weed Science,35, 720-725.

Haas, H. (1989) Danish experience in initiating and implementing a policy to reduce herbicide use. Plant Protection quarterly, 4, 38-44.

Jensen, P.K. (1986) Skadetaerskler for tokimbladet ukrudt i Vaarbyg. Tidskrift for Planteavl, 90, 369-376.

Kudsk, P. (1989) Experiments with reduced herbicide doses in Denmark and the development of the concept of factor-adjusted doses. Brighton Crop Protection Conference-Weeds 1989. (in print).

Martin, R.J.; Cullis, B.R.; McNamara, D.W. (1987) Prediction of wheat yield loss due to competition by Wild Oats (Avena spp.). Australian Journal of Agricultural Research, 39, 487-499.

Pannell, D. (1988) Theory and reality of weed control thresholds: a comment. Plant Protection Quarterly, 3, 43-44.

Poole, M.L.; Gill, G.S. (1987) The use of weed density - crop yield relationship for prediction yield losses in the field. Brighton Crop Protection Conference- Weeds 1987, 945-954.

Pritchard, G.H.; Streibig,J.C. (1990) Skeleton weed (Chondrilla juncea L.) control with clopyralid and clopyralid plus 2,4-D. Weed Research, 30, (Accepted for publication)

Springer, B.; Heitefuss, R. (1988) Einfluss des Einsatzes von Herbiziden unterhalb und oberhalb der wirtschaftlichen Schadensschwellen auf den Ertrag von Winterweizen in Abhängigkeit von Stickstoffdüngung und Fungiziden. III. Wirtschaftlichkeit. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, 95, 772-590.

Streibig, J.C. (1980) Models for curve-fitting herbicide dose-response curves. Acta Agriculturae Scandinavica, 30, 59-64.

Streibig, J.C. (1984) Measurement of phytotoxicity of commercial and unformulated soil-applied herbicides. Weed Research, 24, 327-331.

Streibig, J.C. (1988) Herbicide bioassay. Weed Research, 28, 479-484.

Streibig, J.C. Combellack, J.H.; Pritchard, G.H.; Richardson, R.G. (1989) Estimation of thresholds for weed control in Australian cereals. Weed Research, 29, 117-126.

Wells, G.J. (1971) Skeleton weed (Chondrilla juncea) in the Victorian Mallee 4. Effect of fallowing on wheat yield and weed populations. Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 313-318.

MODELLING AS AN AID TO WEED CONTROL MANAGEMENT

C.J. DOYLE

The West of Scotland College, Auchincruive, Ayr, KA6 5HW

ABSTRACT

An examination is made of the role that computer models can have in identifying appropriate strategies for controlling weed populations in both arable and forage crops. Attention is focussed on the use of models for determining economic losses from weeds, setting thresholds for spraying and predicting the optimum timing and intensity of herbicide use.

INTRODUCTION

Employing weed control measures every year, regardless of infestation levels or cost, will seldom be economic. Instead cost-effective use of herbicides will depend on knowing when to spray. In turn this necessitates clear guidance on three issues: (i) the 'threshold' level of weed infestation below which it is uneconomic to spray for a particular weed and crop; (ii) the optimum time within the year to apply the herbicide; and (iii) the optimum herbicide dose.

With few exceptions, field trials cannot directly provide answers to all these questions. As a rule, because of constraints of cost and time, experiments are conducted for only one or two years and at a limited range of sites and herbicide doses. Furthermore, for pasture weeds, few trials are carried out with grazing livestock. The consequences of this are considerable. First, by confining measurements to a single year, only the immediate benefits of weed control can be assessed. However, for many weeds, there is a real possibility of re-invasion, as a result of germination of seeds stored in the soil (Auld _et al_. 1987). This can greatly affect the threshold level for spraying, as demonstrated by Doyle _et al_. (1984) and Cousens _et al_. (1986). Second, as weed responses to herbicides can vary markedly between sites, it is difficult to extrapolate results from a few sites to the UK as a whole. Third, the tendency in field experiments to study only one or two levels of herbicide dose often makes it difficult to derive the optimum level of application. Not infrequently, the higher dose is uneconomic, while the lower application rate is sub-optimal. Fourth, the widespread practice of evaluating weed control in pastures under cutting rather than grazing regimes can lead to erroneous conclusions (Doyle, 1982; Doyle _et al_. 1984).

A ROLE FOR COMPUTER MODELS?

While an extension of the scale and time period of many field trials would help to remedy these deficiencies, the issue of cost is likely to preclude this. A possible cost-effective alternative to more and increasingly expensive experimentation is to link herbicide trials with the development of computer models capable of simulating weed reproduction, growth and competition. By using the data collected from trials to develop mathematical relationships suitable for a computer model, broadly optimal weed control strategies can be identified.

In particular, judicious use of mathematical models can provide guidance on three practical issues: (i) the conditions under which the use of herbicide is economically justified; (ii) the minimum level of weed infestation below which control is uneconomic; and (iii) the optimum frequency and timing of control measures. The first of these issues needs information on the costs and benefits of weed control. The second requires the 'economic threshold level' of weed infestation to be determined, while the third needs the optimum pattern of herbicide application to be identified.

Costs and benefits of weed control

For most arable crops, though not easy, it is relatively straightforward conceptually to determine the costs and benefits of weed control and for the majority the question is not whether to use herbicides, but when and how much. In contrast, for forage crops the same process is rather involved. First, while wild oats invading a field of spring barley are of no value to the cereal grower, the same is not true of a 'weed' grass like rough meadow-grass (Poa trivialis) from the viewpoint of the livestock producer, in that it has a feed value (Doyle, 1982). Second, many forage crops are not traded, so that their value has to be imputed from their contribution to livestock production. Third, as forages only have a value if they can be efficiently converted into marketable animal products, the value depends on the management skills of the farmer. Thus, in contrast to arable crops, evaluation of the probable benefits of weed control in a forage crop has to take into account not only of the effect on yields, but also on the degree of crop utilisation by the livestock.

Notwithstanding the difficulties of determining the benefits of herbicide use for forage crops, it is more critical to correctly estimate them. Being mainly low value crops, the issue is frequently whether weed control in any form is economically justified. The answer is often complex, as illustrated by the results from a study of the economics of controlling broad-leaved dock (Rumex obtusifolius) in grassland (Doyle et al., 1984). Within the range of observed responses and practices, whether it is profitable to regulate R. obtusifolius with asulam has been shown to depend on the efficacy of the herbicide, the efficiency of grass utilisation by the stock and the initial degree of dock infestation, as illustrated in Table 1. Only by using a mathematical model has it been possible to explore the results obtained from experiments and translate them into management prescriptions regarding herbicide use.

Of course, the initial costs of developing a mathematical model of weed reproduction and management is not low. However, for the majority of weeds, the cycle of growth and reproduction is broadly similar. Therefore, having constructed one weed management model, it is a relatively low-cost exercise to extend to it other weeds. Typical is a model of the seed cycle for musk thistle (Carduus nutans), developed by Moore et al. (1989) and shown schematically in Figure 1.

TABLE 1. Conditions under which controlling <u>Rumex obtusifolius</u> with a herbicide is likely to be economic (+) or uneconomic (-).

Efficacy of herbicide	High		Low	
Efficiency of grass use	High	Low	High	Low
High dock infestation	+	+	-	-
Low dock infestation	-	-	-	-

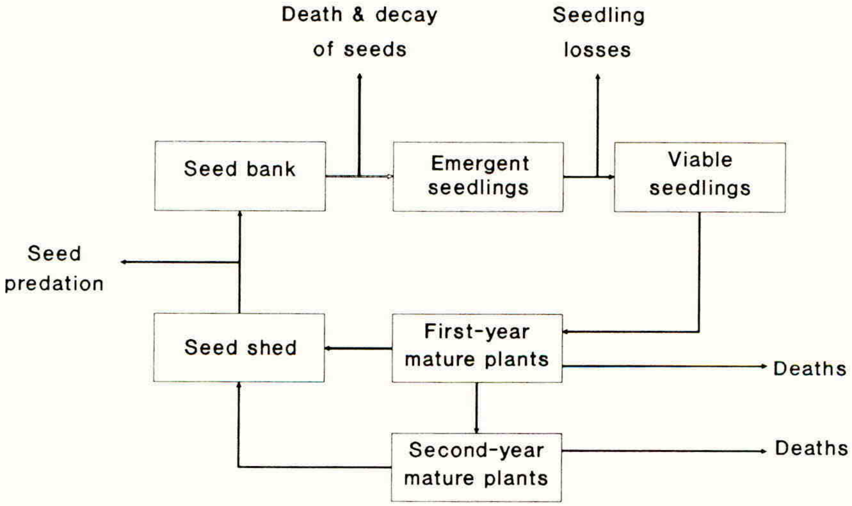


FIGURE 1. Schematic representation of the musk thistle seed cycle.

<u>Economic thresholds</u>

Although the concept of a threshold level of pest incidence, below which it is uneconomic to spray, has been widely employed, the same concept has not yet been extended to weed control strategies (Cousens <u>et al</u>., 1985). Therefore, farmers tend to use herbicides when weeds become visually unacceptable. In many cases, Cousens <u>et al</u>. (1985) believe that this leads to more frequent spraying than is economically optimal. With the cost of chemical sprays now accounting for up to 40% of directly attributable production costs for crops like cereals (Nix, 1988), there is a real need to ensure cost-effective use of herbicides.

One way of doing this for post-emergence herbicides is to determine the threshold level of weed infestation for a particular crop, below which the gains from spraying are exceeded by the costs. Recommendations whether to spray or not can then be linked to the observed intensity of infestation. However, in estimating the threshold level, consideration must not only be given to the benefits in the immediate year from spraying, but also the gains in subsequent years. This is because applications of herbicide will affect not only the present weed population, but also indirectly future populations by preventing a build up of seed in the soil. That this consideration may be critical is shown by a study of the economics of controlling black-grass (*Alopecurus myosuroides*) in winter wheat (Doyle *et al*., 1986). This has shown that the projected threshold weed density for spraying with chlorotoluron declined from 30 to 7.5 plants m^{-2}, if the affect of current weed population on levels in subsequent years is considered. However, to assess the effect of changes in current on future populations of black-grass, it has been necessary to resort to computer simulations. Similarly, Cousens *et al*. (1986) have devised recommended threshold weed densities for spraying for wild-oats (*Avena fatua*) using a computer model.

For pre-emergence herbicides, the problem is more difficult, in that their use demands a spray decision before the new seedling population can be assessed. Therefore, to determine whether a herbicide application will be economic requires some kind of prediction of future weed populations, based on observed infestations in preceding years. Such relationships are best established using computer models. The findings may then be refined in field trials (Cousens *et al*., 1985).

Optimum pattern of herbicide use

Computer models can also be of assistance in answering questions concerning the timing, frequency and level of herbicide use. The simulated effects of altering both the threshold weed density and annual herbicide dose on both the benefits and frequency of spraying for a cereal weed are shown in Figure 2. Specifically, this shows the results of computer simulations performed by Doyle *et al*., (1986) for *Alopecurus myosuroides* invading a field of winter wheat. Chlorotoluron was assumed to be applied at the rate of either 1.75 or 3.5 kg a.i. ha^{-1} in any year that the weed density exceeded a certain threshold level. Threshold densities for spraying from 0 to 50 plants m^{-2} were investigated. From this, two things were evident. First, the most profitable course of action was not to spray every year, but only in those years when the weed density exceeded 5-7 plants m^{-2} as there was an increase in the frequency of spraying, using half doses of chlorotoluron appeared marginally more profitable.

Moore *et al*., (1989) have similarly used a computer model to explore the optimum pattern of herbicide use on grazed pastures in New Zealand to control musk thistle (*Carduus nutans*). However, besides establishing the relationships between the economic threshold, the frequency and the application rate for herbicide, they also investigated the effect of seasonal timing on the economics of spraying. The projected cumulative benefits over a ten-year period for annual applications of 2 kg a.i. ha^{-1} of MCPB made regularly in October, December, May or June are shown in Table 2. Specifically, the results are presented for three different initial levels of thistle infestation. This Table shows that spring and autumn are the best seasons for applying herbicide.

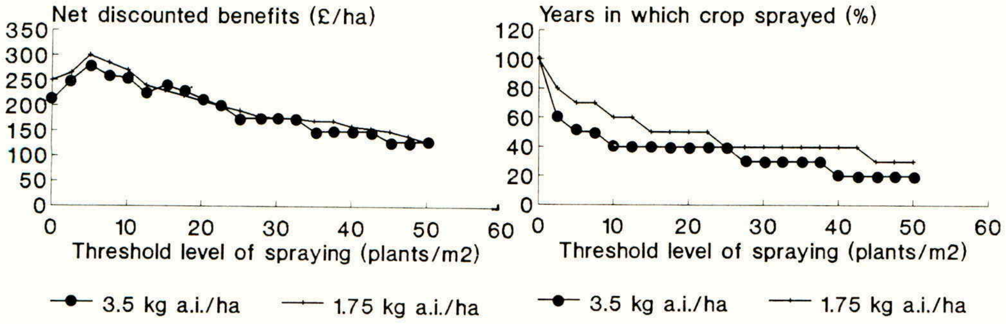


FIGURE 2. Effect of changes in the dose and threshold level of spraying with chlorotoluron to control black-grass in winter wheat on the cumulative benefits and frequency of spraying over a ten-year period.

TABLE 2. Effect of applying MCPB in different months on the net discounted benefits in NZ$ ha^{-1} at three initial thistle densities over a ten-year period.

Initial thistle ground cover, %	Month of herbicide application October (Spring)	December (Summer)	May (Autumn)	June (Winter)
1	-53	-73	-53	-63
5	34	4	15	-2
10	103	34	62	39

CONCLUSIONS

So long as certain basic rules are followed, then computer models can be an effective aid to designing weed control strategies. First, mathematical models are only as good as the data from which they are constructed. Thus, they are no substitute for experimental trials. On the other hand, by integrating mathematical modelling with experimentation, it is frequently possible to evaluate a wide range of farm situations and management strategies quickly and at a comparatively low cost. Second, it is wrong to see computer models as purely farm management tools. In practice, the main contribution of mathematical models may be as research tool, highlighting key parameters requiring further field work before confident management advice can be given. As such, the development of a computer model may be an intermediate stage in designing a weed control strategy, rather than the final goal. Third, it is optimistic to believe that sophisticated management models can generally be used without help from a trained adviser. In the majority of cases, computer models are best conceived as an aid to a farm adviser and not as a substitute. If this last stricture is observed then disappointments arising from inflated views of what models can do will be avoided and their true value recognised.

REFERENCES

Auld, B.A.; Menz, K.M.; Tisdell, C.A. (1987) Weed Control Economics, London: Academic press, pp. 177.

Cousens, R.; Wilson, B.J.; Cussans, G.W. (1985) To spray or not to spray: the theory behind the practice. British Crop Protection Conference - Weeds 1985, 2, 671-678.

Cousens, R.; Doyle, C.J.; Wilson, B.J.; Cussans, G.W. (1986) Modelling the economics of controlling *Avena fatua* in winter wheat. Pesticide Science, 17, 1-12.

Doyle, C.J. (1982) Economic evaluation of weed control in grassland. British Crop Protection Conference - Weeds 1982, 1, 419-427.

Doyle, C.J.; Oswald, A.K.; Haggar, R.G.; Kirkham, F.W. (1984) A mathematical modelling approach to the study of the economics of controlling *Rumex obtusifolius* in grassland. Weed Research, 24, 183-193.

Doyle, C.J.; Cousens, R.; Moss, S.R. (1986) A model of the economics of controlling *Alopecurus myosuroides* Huds. in winter wheat. Crop Protection, 5, 143-150.

Moore, W.B.; Doyle, C.J.; Rahman A. (1989) Economics of controlling *Carduus nutans* on grazed pasture in New Zealand. Crop Protection, 8, 16-24.

Nix, J.S. (1988) Farm Management Pocketbook (1988), 18th edition, Wye: Wye College University of London, pp.203.

ECONOMICS OF CONTROLLING *RANUNCULUS ACRIS* IN NEW ZEALAND DAIRY PASTURES

A.I. POPAY, N.D. BARLOW

MAFTech, P.O. Box 1654, Palmerston North, New Zealand.

G.W. BOURDÔT

MAFTech, P.O.Box 24, Lincoln, New Zealand.

ABSTRACT

Ranunculus acris is an unpalatable weed of dairy pastures in New Zealand. Ungrazed by cattle, it occupies pasture space and reduces pasture productivity. Long term measurements of the effects of herbicides on *R. acris* populations, and of their recovery after herbicide application were modelled to provide information on the economics of different treatments. Damaging effects of MCPA on white clover in pastures were also taken into account.

Annual applications of MCPA at 1 kg ha^{-1} were more profitable than less frequent applications because of the large benefits and relatively small control costs, even when clover damage was taken into account. Although MCPB did not damage clover, it was less profitable than MCPA because it was less effective in controlling *R. acris*. Theoretically, it would still be economic to treat MCPA tolerant biotypes of *R. acris* at 5 kg MCPA ha^{-1}.

INTRODUCTION

Economic studies of the costs of pasture weeds and their control are rare. Auld *et al.* (1987) stressed the difficulties of assessing the economic value of a unit of pasture of a particular quality, and thus of measuring the economic status of weeds which reduce herbage production or intake. However Barlow (1985; 1988) has developed simulation models which can translate pasture to animal production for a wide range of conditions. Popay and Barlow (1988; 1989) have used such models to estimate the economic effects of pasture weeds and their control.

Ranunculus acris (meadow buttercup) is an important weed of dairy pastures in parts of New Zealand (Popay *et al.* 1989). Its leaves have toxic properties, but are not usually eaten, and *R. acris* is regarded as a weed because it takes up pasture space and pasture species growing amongst *R. acris* plants are poorly utilised. Popay *et al.* (1989) published data on the results of long term herbicide trials on *R. acris* and also provided estimates of *R. acris* ground cover and of clover damage resulting from herbicide use. These data are used in the present paper to calculate the economic effects of *R. acris* infestations and their control.

WEED, PASTURE AND PRODUCTION PARAMETERS

Popay *et al.* (1989) showed that control with MCPA at 2kg ha^{-1} was little better than at 1kg ha^{-1}, and that twice-yearly applications generally gave similar results to a single August treatment. Twice-yearly applications, in August and December, only gave better results than the single August treatment if initial control was poor.

Plotting log number of *R. acris* clumps in December or January after an August treatment on log number in untreated plots at the same time showed that August control with MCPA at 1 kg ha^{-1} was density-dependent and averaged 73% (Popay *et al.*, 1989). The results also suggested that 1.5 kg ha^{-1} of MCPB gave only 41% control.

Popay & Barlow (1988) estimated that applying 2,4-D (or MCPA) at 1.0 kg ha^{-1} caused a 40% loss of clover during the summer following treatment, equivalent to a 2% loss in gross margin, or, in a dairy production system, about $36.

Bourdôt & Hurrell (1988) showed that some biotypes of *R. acris* have developed resistance to MCPA and require up to 5 times the normal rate to achieve the same control. This would increase herbicide costs 5-fold and markedly increase clover damage.

Given the above, three scenarios are considered: the optimum frequency of MCPA treatment, assuming 1 kg ha^{-1} applied in August only; the optimum frequency of August MCPB applications at 1.5 kg ha^{-1}; and the optimum frequency of MCPA treatment where resistance requires a 5 kg ha^{-1} rate. In the first two cases, damage to clover is respectively small and non-existent. In the third case, clover loss would probably be close to 100%, and is assumed to cost $36 x 100/40 = $90 ha^{-1}. No allowance has been made for losses in nitrogen fixation resulting from loss of clover. Especially in the case where 5 kg/ha^{-1} of MCPA were applied, these losses could be serious.

Popay *et al.* (1989) also showed that the recovery pattern of *R. acris* after spraying was given by

$$N_{t+1} = 5.36(1 - \exp(-0.746N_t)) \quad - \ - \ - \ - \quad \text{(Equation 1)}$$

where N_t and N_{t+1} = number of clumps m^{-2} in years t and t+1 (December or January counts). This pattern was independent of the control previously applied. The equilibrium population of 5.36 clumps m^{-2} corresponded to a 38% cover loss. For any given frequency of control, the population reaches a long-term equilibrium such that the number of clumps m^{-2} before control is always the same. Given the percentage kill and frequency of control, this equilibrium can be calculated from Equation 1, as can the populations and percentage covers in intermediate years. This also allows the average annual cover to be derived for the given control regime, and compared with the 38% cover in the absence of control. The value of the difference can then be weighed against the average yearly cost of that control regime.

For most pastoral systems the full benefits of any improvement are only realised by raising stocking rate. Holding stocking rate constant gives a smaller benefit or none at all (Barlow, 1985). Here we assume that stocking rate will be increased if *R. acris* is controlled. In this event the % increase in stocking rate and gross margin per hectare will equal the change in maximum % weed cover in any one year. Control every 2 to 3 years allows cover to increase over this time (Fig 1), and long-term stocking rate is more likely to be dictated by the maximum weed cover in any year than by the average yearly cover. If stocking rate is not increased we assume that the benefit will be only 0.75 times that if it is (Popay & Barlow, 1987). The results shown in Fig. 1 are for established control policies after they have reached a steady state.

The losses due to weeds in the year with maximum weed cover are given by Gp/100, where G is the gross margin ha^{-1} for a weed-free dairy production system and p is the average percentage weed cover through the year. If herbicide is applied every second year, the losses due to weeds in the year of application are greater than the weed cover effect itself, because stocking rate is unlikely to have been raised to use the extra pasture production available in that year. Here the losses will be $[(Gp/100) + 0.75G(p_{max} - p/100)]$, where p is the average weed cover through the year and p_{max} is the weed cover in the following year. The average annual weed cost is the average of losses due to weeds in the two years. The same principle applies to 3-yearly application. The yearly cost of the policy will be (c+d)f, where c is the cost per herbicide application, d the losses due to clover damage and f the average number of applications per year (i.e. 0.5 if control is applied every 2 years).

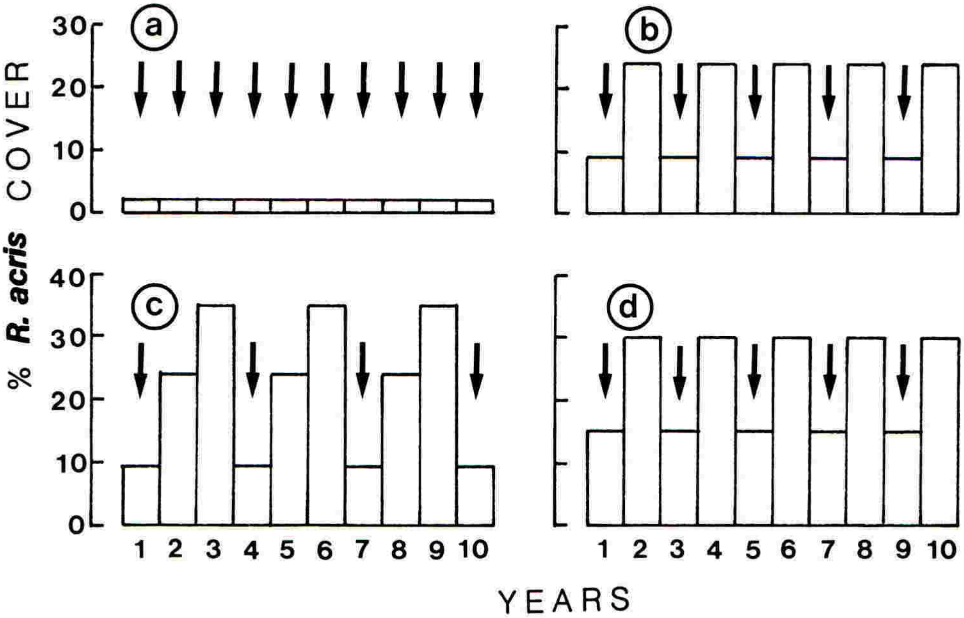


FIGURE 1. The effects of different control policies on December cover of *R. acris*: a) MCPA at 1 kg ha^{-1} yearly; b) MCPA at 1 kg ha^{-1} 2-yearly; c) MCPA at 1 kg ha^{-1} 3-yearly; d) MCPB at 1.5 kg ha^{-1} yearly. All applications in August, in years denoted by arrows.

RESULTS

Considering first the 1 kg ha^{-1} MCPA treatment, if control is applied each year and control gives a 73% kill, equation 1 predicts an equilibrium population, after control, of N_{t+1}, where

$$N_{t+1} = (1 - 0.73) \times 5.36(1 - \exp(-0.746N_t))$$

which is satisfied by $N_t = 0.28$ clumps m^{-2} = 2% cover. If control is applied every 2 years, then

$$N_{t+1} = 5.36(1 - \exp(-0.746N_t))$$

$$N_{t+2} = 5.36(1 - \exp(-0.746N_{t+1}))$$

$$N_t = 0.27N_{t+2}$$

Therefore, $N_t = 0.27 \times 5.36(1 - \exp(-0.746N_{t+1}))$, and

$$N_t = 0.27 \times 5.36[1 - \exp\{-0.746 \times 5.36(1 - \exp(0.746N_t))\}]$$

which is satisfied by $N_t = 1.33$ clumps m^{-2} = 9.4% cover in the year of control, and $N_{t+1} = 3.37$ clumps m^{-2} = 24% cover in the second year. The results for a 3-yearly spray are calculated in a similar way and the patterns of weed cover over time for all policies are shown in Fig 1. Maximum yearly weed cover, average yearly cost and annual gross margin for each policy are given in Table 1.

Frequent applications were more profitable than less frequent ones because of the large benefit and relatively small control costs. Particularly for MCPA, the high benefit was a product both of high equilibrium weed cover and the extent to which it can be reduced by spraying. MCPB is less profitable than MCPA applied at any frequency, and theoretically it would still be worth treating a resistant weed population at 5 kg ha^{-1} of MCPA annually, or at lower frequencies. All the strategies tested were profitable, giving a positive net return on a per hectare basis, but in practice the area of buttercup infestation would need to be large for the absolute dollar benefits to be significant. If stocking rate were not increased and benefits were only 75% of those in Table 1 (see above), it would still be profitable to control and best to do so yearly. However, in this case it is particularly important that the infestation covers a significant proportion of the farm. This is because if stocking rate is fixed, production loss is non-linearly related to cover loss (Barlow, 1988) and small cover losses, averaged over the whole farm, have very little effect.

TABLE 1. Effects of different control policies on maximum yearly cover of *R. acris* and gross margins resulting from the policies. Gross margin ha^{-1} in the absence of weeds = NZ$1780 (milkfat NZ$5.50 kg^{-1}). Cost of 1 kg ha^{-1} MCPA, including application, = NZ$32 ha^{-1} and clover damage costs NZ$36 ha-1. MCPA at 5 kg ha^{-1} costs NZ$100 ha^{-1} plus NZ$90 for clover damage. MCPB at 1.5 kg ha^{-1} costs NZ$48 ha^{-1} with no clover damage.

Control policy	Maximum yearly cover (%)	Annual cost of weed (NZ$ ha^{-1})	Annual cost of treatment (NZ$ ha^{-1})	Annual gross margin (NZ$ ha^{-1})
No control	38	676	nil	1104
MCPA 1 kg ha^{-1}				
yearly	2	36	68	1676
2-yearly	24	330	34	1416
3-yearly	35	461	23	1296
MCPA 5 kg ha^{-1}				
yearly	2	36	190	1554
2-yearly	24	330	95	1355
MCPB 1.5 kg ha^{-1}				
yearly	10	178	48	1554
2-yearly	30	434	24	1322

DISCUSSION

Based on the criteria applied here, chemical control of *R. acris* is economic in a New Zealand factory supply dairy system. Some of the assumptions made in this model could however be questioned. Firstly, the relationship between weed cover and lost animal production is suspect because hard-pressed cattle will push *R. acris* leaves aside to reach vegetation growing among *R. acris* clumps and will occasionally even eat *R. acris* leaves themselves. For this reason, our model may over-estimate the production losses caused by *R. acris*, and therefore the benefits of control.

The effects of clover damage caused by MCPA are hard to quantify. Our model only accounts for losses of metabolisable energy, and does not take into account reduced nitrogen fixation by herbicide-damaged clovers. Nitrogen losses could be substantial, even after the application of MCPA at 1 kg ha^{-1}. Again, this means an over-estimation of the benefits of control.

Although our analysis shows that annual treatment with MCPA is the most profitable strategy, it will almost certainly result in *R. acris* populations with increased resistance to MCPA (Bourdôt and Hurrell, 1988). It may therefore be more profitable in the long term to treat less frequently, thus reducing the selection pressure.

REFERENCES

Auld, B.A.; Menz, K.M.; Tisdell, C.A. (1987) *Weed Control Economics*, London; Academic Press, pp. 78-83.

Barlow, N.D. (1985) Value of sheep pasture, and the relationship between pasture production and stocking rate. *New Zealand Journal of Experimental Agriculture*, **13**, 5-12.

Barlow, N.D. (1988) Pasture, pests and productivity: simple grazing models with two herbivores. *New Zealand Journal of Ecology,* **10**: 43-56.

Bourdôt, G.W.; Hurrell, G.A. (1988) Differential tolerance of MCPA among giant buttercup (*Ranunculus acris*) biotypes in Takaka, Golden Bay. *Proceedings New Zealand Weed and Pest Control Conference*, **41**, 231-234.

Popay, A.I.; Barlow, N.D. (1988) Costs of some weeds of dairy pasture and their control. *Proceedings New Zealand Grassland Association*, **49**, 177-180.

Popay, A.I.; Barlow, N.D. (1989) Economics of controlling weeds of permanent pasture. *Proceedings 16th International Grassland Congress* (In press).

Popay, A.I.; Edmonds, D.K.; Lyttle, L.A.; Phung, H.T. (1989) Chemical control of giant buttercup (*Ranunculus acris*). *New Zealand Journal of Agricultural Research*, **32**, 299-303.

THE COST-EFFECTIVENESS OF DIFFERENT APPROACHES TO HERBICIDE USE IN CONTINUOUS WINTER WHEAT

M. J. PROVEN

MAFF, ADAS, Drayton Experimental Husbandry Farm, Alcester Road, Stratford upon Avon, Warwickshire, CV37 9RQ

J. B. S. FREER

MAFF, ADAS, Bridget's Experimental Husbandry Farm, Martyr Worthy, Winchester, Hampshire, SO21 1AP

ABSTRACT

Two herbicide programmes of varying cost and designed to give full weed control were compared with a third which used a responsive, opportunist approach. The programmes were compared under two cultivation systems in continuous winter wheat, for five years on a shallow silty clay loam and for three years on heavy calcareous clay. Average herbicide costs for the three programmes were £71/ha, £44/ha and £33/ha at Bridget's and £107/ha, £53/ha and £55/ha at Drayton. At both sites, and irrespective of cultivation system, the reduced cost insurance programme gave a higher yield and a superior margin of output over chemical costs than either the full insurance or the opportunist programme. The opportunist programme gave similar yields, and consequently higher margins over chemical costs, to the full insurance programme. Poor yields after the opportunist programme were often due to poor weed control. The low yields after the full insurance programme are less easily explained and the possibility of herbicide damage cannot be ruled out.

INTRODUCTION

Expenditure on weed control can form a significant proportion of the variable costs of winter wheat production in the important wheat growing areas in the southern half of England (Nix and Hill, 1989). A conventional herbicide programme with, for example, an isoproturon-containing herbicide used in the autumn and mecoprop or a sulphonyl urea in the spring will account for about 20% of variable costs. An extra graminicide applied in the autumn or spring together with a second or more expensive broadleaved weed herbicide can raise the proportion to 35%.

Simplistically, this may be viewed as a requirement for a 'breakeven' yield increase of 0.3 - 1.0 t/ha. In reality the financial benefit of different intensities of herbicide usage should not be treated in this way as the influence of treatments in year 1 on the problem and the treatment required in subsequent years is greater than with other agrochemicals. Single year experiments designed to investigate herbicide efficacy cannot reliably identify the best long term strategies. A method which more accurately models the 'real world', either mathematically or biologically, is needed. The work described in this paper adopted the latter approach, and a long term trial comparing three different herbicide programmes in continuous winter wheat was begun in 1981, with a second site being added in 1983.

MATERIALS AND METHODS

Sites

The study was conducted at two of the Ministry's experimental husbandry farms between 1982 and 1986. At Bridget's EHF, near Winchester and on shallow silty clay loam over chalk, a site was used continuously for five years. At Drayton EHF, near Stratford upon Avon on heavy calcareous Lias clays, the treatments were only applied in the 1984, 1985 and 1986 harvest years. Both sites were cropped with continuous winter wheat for the duration of the experiment.

Cultivations

At both sites, the herbicide programmes were implemented at two locations under different cultivation regimes. In one, straw was baled, stubble was burnt and the following wheat crop established by direct drilling (Bridget's EHF) or following tined cultivations (Bridget's EHF and Drayton EHF). With the other, straw was chopped and returned and primary cultivation was done with a mouldboard plough.

Herbicide programmes

Three different approaches to herbicide use were tested at each site. The Full Insurance Programme (FIP) was intended to give 'complete' weed control with high cost prophylactic treatments. The Reduced Cost Insurance Programme (RCIP) was also intended to embrace a measure of prophylaxis but care was taken in the selection of herbicides and frequency of their use in an effort to reduce costs. The Opportunist Programme (OP) was a responsive one in which herbicides were not generally used until a specific weed problem had been identified.

Although the herbicide programmes were prescribed, the chemicals actually used varied both between sites and between years. At Bridget's EHF, the same chemicals were used in any one year for both cultivation treatments. At Drayton EHF, the cultivation treatments were dealt with independently and thus the programmes, but not necessarily the chemicals used, were common.

The herbicide programmes are summarised in Table 1.

TABLE 1. Herbicide programmes - number of active ingredients (a.i.) used, number of applications and approximate herbicide costs (£/ha).

Prog	Active ingredients used/year		Number of spray operations/year		Average herbicide cost (£/ha)	
	Bridget's	Drayton	Bridget's	Drayton	Bridget's	Drayton
FIP	5.2	7.5	2.6	3.7	71.20	107.30
RCIP	4.0	3.3	2.0	2.3	43.60	52.50
OP	2.6	3.5	1.2	2.2	33.40	54.80

Assessments

At Bridget's, weed populations were assessed by estimating the percentage of ground covered by weeds at 10 points/plot. The assessments were done late in the season, just before or just after the crop was harvested except in 1983 when they were done in late April (post treatment). At Drayton, weeds were counted in 10 x 0.1/m² quadrats/plot. These counts were not done at the same time each year although they were always post treatment, with the crop at GS37-75.

At both sites, grain yield was measured by taking one or more combine cuts through the plots.

Design

At both sites, the different cultivation areas were adjacent but separate and an independent randomised complete block design, with three replicates, was used on each area to test the three herbicide programmes. The same treatments were applied to large plots (12 m or 24 m x $\geq$ 100 m) for the duration of the experiment.

RESULTS AND DISCUSSION

Weed assessments

Assessments of weed populations at Bridget's and Drayton are shown in Tables 2 and 3 respectively.

TABLE 2. Assessment of weed cover, Bridget's EHF (0 = nil, 10 = complete cover)

Harvest year	Date of assessment	FIP		RCIP		OP	
		blw	grasses	blw	grasses	blw	grasses
1982	23/07/82	0.49	0.18	1.15	0.22	1.13	0.82
1983	26/04/83	0.10	0.05	0.25	0.15	1.00	0.25
1984	07/08/84	0.00	0.10	0.68	0.09	2.14	0.82
1985*	post harvest	118	23.5	118	30.0	204	72.0
1986	post harvest	-	0.13	-	0.27	-	0.85

*Plants/m²

At Bridget's EHF the predominant broadleaved weed was field pansy (Viola arvensis). The main grass weeds were rough-stalked meadowgrass (Poa trivialis), blackgrass (Alopecurus myosuroides) and sterile brome (Bromus sterilis).

TABLE 3. Mean weed populations, Drayton EHF (plants/m², 1 = wild oats (Avena fatua and A. ludoviciana); 2 = cleavers (Galium aparine); 3 = other broadleaved weeds)

Harvest year	FIP 1	FIP 2	FIP 3	RCIP 1	RCIP 2	RCIP 3	OP 1	OP 2	OP 3
1984	0.0	0.5	0.0	0.1	4.7	0.1	0.1	3.7	0.1
1985	0.0	0.6	0.4	1.7	4.1	0.4	6.4	0.1	0.5
1986	0.0	0.9	29.5	0.3	4.8	41.5	0.2	3.8	88.6

At Bridget's, herbicide programme usually had an important effect on weed populations, with V.arvensis and A.myosuroides frequently reaching levels which would trigger treatment using current threshold systems, when using the OP. Grass weeds were consistently a greater problem after direct drilling or minimal cultivations whereas the highest populations of V. arvensis were usually found following ploughing. At Drayton, a high initial population of cleavers in the RCIP plots was only contained rather than controlled over the course of the trial. With the OP in 1985, failure to apply a specific wild oat herbicide in the spring left a population which undoubtedly affected yield. Grass weeds were generally worse when minimal cultivations were used although B. sterilis was a persistent problem on the ploughed site.

Grain yields

TABLE 4. Bridget's EHF - yield of grain (t/ha at 85% DM)

Harvest year	Cultivation	FIP	RCIP	OP
			(SED ± 0.283)	
1982	Direct drill	7.92	7.89	7.50
	Plough	7.30	7.56	6.90
			(SED ± 0.430)	
1983	Direct drill	7.99	8.38	8.32
	Plough	8.42	8.41	8.13
			(SED ± 0.298)	
1984	Direct drill	8.57	9.43	9.05
	Plough	7.93	8.42	7.88
			(SED ± 0.284)	
1985	Direct drill	7.56	7.91	7.61
	Plough	6.56	7.03	7.09
			(SED ± 0.296)	
1986	Min. cults.	5.66	6.77	6.17
	Plough	7.23	7.47	7.12
Mean	Min. cults.	7.54	8.08	7.73
	Plough	7.49	7.78	7.42

TABLE 5. Drayton EHF - yield of grain (t/ha at 85% DM)

Harvest year	Cultivation	FIP	RCIP	OP
			(SED ± 0.299)	
1984	Min. cults.	8.43	8.73	7.85
			(SED ± 0.236)	
	Plough	10.21	10.08	10.04
			(SED ± 0.314)	
1985	Min. cults.	7.28	7.23	5.86
			(SED ± 208)	
	Plough	7.81	8.45	7.64
			(SED ± 0.155)	
1986	Min. cults.	6.57	6.40	6.80
			(SED ± 0.160)	
	Plough	8.59	8.83	8.56
Mean	Min. cults.	7.43	7.45	6.84
	Plough	8.87	9.12	8.75

At Bridget's EHF the RCIP consistently outyielded the other regimes. Given the low weed populations, it is not unreasonable to suggest that the lower yield given by the FIP (which was significant ($P<0.05$) in 1984 and 1986) may have been the result of measurable phytotoxicity from the more intensive herbicide programme. Although the herbicides used varied from year to year, the FIP was generally distinguished by using BLW as well as grass herbicides in the autumn and a specific wild oat herbicide in the spring. The RCIP also significantly ($P<0.05$) outyielded the OP in 1982, 1984 and 1986. This may be attributed to the higher weed populations generally borne by the latter treatment (Table 2).

The RCIP also gave the highest yield on average at Drayton EHF, although at this site its superiority over the FIP was not as consistent. Again, a range of herbicides was used, but the FIP typically differed from the RCIP by the addition of BLW and wild oat herbicides in the autumn and wild oat herbicides in the spring. The lower yield from the OP in 1985 was associated with relatively high populations of wild oats (see Table 3).

Other workers have also reported negative yield responses to herbicide use in cereals (Davies, 1988), whereas some have shown the highest yields when generous prophylactic programmes were used (Jarvis, 1988). However, in the work described by Jarvis the low and high levels of input embraced all agrochemicals.

Financial appraisal

The relative financial benefit of the different programmes is illustrated in Table 6. Given that the RCIP gave the highest yield and was substantially cheaper than the FIP whilst costing little more than the OP (Table 1), it is not surprising to find that it returned the best financial performance. If the application costs are also considered, at a notional cost of £6 - £10/ha, they serve to further disadvantage the FIP whilst not involving sufficient savings for the OP to become superior (see Table 1, 'number of sprays'). Although finding that the highest yield came from his FIP, Jarvis (1988) also showed a better financial return from a lower input, 'managed', approach. In the trials described here, the FIP could be criticised for excessively high use of chemicals and the RCIP and OP for lack of objectivity in decisions to treat. Work on cost effective weed control, funded by the Home-Grown Cereals Authority, which aims to resolve these objections, is currently being done by several research and development organisations.

TABLE 6. Margin of grain output over herbicide costs - increase or decrease compared with margin obtained using FIP (£/ha)

Harvest year	Drayton EHF		Bridget's EHF	
	RCIP	OP	RCIP	OP
1982	-	-	+42	+9
1983	-	-	+34	+24
1984	+73	+24	+99	+70
1985	+94	-4	+75	+44
1986	+44	+35	+82	+48
Mean	+70	+18	+66	+39

ACKNOWLEDGEMENTS

The authors would like to thank members of staff, present and past, at both EHF's for their involvement in the design and conduct of this series of experiments.

REFERENCES

Davies, D.H.K. (1988). Yield responses to the use of herbicides in cereal crops; East of Scotland trials 1979-88. Aspects of Applied Biology, 18, 47-56.

Jarvis, R.H. (1988). The Boxworth Project: Crop protection practices and profitability. Aspects of Applied Biology, 17, 37-45.

Nix, J. and Hill, P. (1989). Farm Management Pocketbook, (19th ed). Ashford, Department of Agricultural Economics, Wye College, University of London.

YIELD RESPONSES TO HERBICIDE USE AND WEED LEVELS IN WINTER WHEAT AND SPRING BARLEY IN SCOTTISH TRIALS AND CONSEQUENCES FOR ECONOMIC MODELS

D.H.K. DAVIES, A.J. WHITING

East of Scotland College of Agriculture, West Mains Road, Edinburgh EH9 3JG

G.M. WHYTOCK

North of Scotland College of Agriculture, King's Road, Aberdeen AB9 1UD

ABSTRACT

Trials in winter wheat and spring barley in Scotland consistantly show little or no yield response at a wide range of weed levels to use of commercial herbicide doses. Halving doses occasionally improved yield, but was generally profitable because of reduced cost whilst maintaining adequate levels of weed control. Preliminary results from a 1988/89 trial series indicate that there is no consistant effect on crop yield from herbicide use down to 12.5% commercial doses, despite reducing weed control over a wide range of weed levels. The use of herbicides simply to suppress weeds, however, would have effects on factors such as harvesting and weed seed returns. More information is required before practical economic models which examine crop/weed relationships at very low herbicide rates can be developed.

INTRODUCTION

There is considerable interest in the more efficient use of herbicides in cereals to reduce costs and environmental impact. However, modellers describing crop/weed relationships tend to ignore the influence of the means of weed removal on the crop. Furthermore, such model and much trials work, have tended to concentrate on single species relationships with major weeds, and have ignored the very common situation, typically found in the field, where there is a complex of individually less aggressive weeds. Davies (1988), reviewing trials in the east of Scotland between 1979-88, reported that there was a chance of a reduction in winter wheat yield where herbicides were used in crops with mixed weed populations below about 75 plants/m^2. Similarly, in spring barley negative yield responses occurred when maximum weed ground cover was below 30%. Courtney and Johnson (1986) have reported yield reductions in spring barley at lower weed populations and Askew and Scourey (1982) showed that several herbicides reduced wheat yield in the absence of weeds. Further data from Scottish trials is presented in this paper on the response of winter wheat and spring barley to herbicides. Data from trials where reduced doses of herbicide have been used is presented to determine whether crop safety may be improved without serious reductions in weed control. The consequences of the results for economic modelling of crop/weed relationships are discussed.

METHODS

The trials were all undertaken on commercial or Scottish Agricultural Colleges (SAC) farms in the south-east or west of Scotland. Full details of trial methods and materials are given in Davies (1988), but all trials were of incomplete block design with three replicate blocks. Plots were a minimum of 2 m x 20 m. Assessment of control was based on percent ground cover remaining and plots were yielded using a Claas Compact combined. Results are presented at 15% grain moisture content. Information is not given on herbicides used to reduce the amount of data presented as a wide range of treatments have been examined. The data reported in the tables represent meaned results to show overall trends in response to herbicide use. Full details of herbicides and results are available in SAC trial reports. The main weeds in the wheat crops were Stellaria media and Poa annua; there was a wider range of weeds in spring barley with polygonaceous weeds, S. media, Fumaria officinalis and Galeopsis tetrahit amongst the most frequent.

Data are presented in Table 1 from a long-term series in spring barley from the west of Scotland in which use of herbicides was compared with untreated controls.

Results of an east of Scotland series in winter wheat are given in Table 2, where half-dose pre-emergence followed by half-dose spring post-emergence treatments were compared with full-dose pre-emergence treatment. The total cost of the sequential programmes were less than 75% of the full-rate treatment.

The potential for improved crop safety is also examined in a spring barley series (Table 3), where half-dose broad-spectrum post-emergence herbicide rates are compared with full-rates.

Table 4 gives preliminary data from a series established in 1988/9 season in winter wheat and spring barley where the effect of reduced rate herbicide treatments on weed level and yield interaction are compared. Results from early post-emergence application of a diflufenican + isoproturon formulation (55% wt/V flowable formulation, 'Panther') in wheat, and a spring post-emergence application of metsulfuron-methyl (20% wt/wt w.d.g., 'Ally') + mecoprop (57% w/b a.c., 'Iso-Cornox' 57) in wheat and spring barley, at rates down to 12.5% of full recommended rate, are given in the table.

RESULTS

Data from the results of west of Scotland trials (Table 1) on spring barley confirm the erratic yield response of this crop to weed control noted from other sites (Davies, 1988). A good yield response from control of a low weed level was noted in WSB81, but a poor response from control of a relatively high weed level in WSB85/1. In four of the seven trials reported, yields were reduced by the use of herbicides although not significantly, and overall there was no significant increase in yield from use of a herbicide.

Table 1. Yield and weed control responses to herbicide treatments in spring barley, West of Scotland 1981-88.

Year	Trial	Treatment Date	No Treatments	Maximum % ground cover (weeds) Trtd	Maximum % ground cover (weeds) Untr	Mean yields t/ha Trtd	Mean yields t/ha Untr	SED
1987	WSB81	20 May	7	1	6	5.89	5.58	0.280
1985	WSB85/1	8 May	10	2	35	3.92	4.17	0.170
1985	WSB85/2	7 May	6	1	11	5.02	5.20	0.191
1986	WSB86	30 May	7	1	12	7.69	7.62	0.240
1987	WSB87	16 May	6	1	13	5.38	5.39	0.250
1988	WSB88/1	13 May	3	3	13	5.15	5.26	0.248
1988	WSB88/2	18 May	4	3	7	4.71	4.77	0.212

Table 2. Yield and weed control responses to half-rate herbicide sequences in winter wheat, East of Scotland, 1984-88.

Year	Trial	No of treatments Half seq	No of treatments Full	Maximum % ground cover (weeds) Untr	Maximum % ground cover (weeds) Half seq	Maximum % ground cover (weeds) Full	Mean yields t/ha Untr	Mean yields t/ha Half seq	Mean yields t/ha full	SED
1984	WWA184	5	17	24	6	2	8.6	(8.6)	8.3	0.22 (0.15)
1985	WWA185	3	3	42	11	10	7.63	7.81	7.73	0.161
1988	WWA188	5	1	9	0	0.1	7.54	7.22	7.12	0.230
1988	WWA288	3	1	1	0.1	0.1	5.90	6.05	6.01	0.378
1988	WWA388	3	1	26	1	0	9.70	9.51	9.36	0.218

Trtd = treated; Untr = untreated; Half seq = half-dose sequence; Full = commercial dose.

Table 3. Yield and weed control responses to half-rate herbicide treatments in spring barley in Scotland, 1987-8.

Year	Trial	No of treatments		Maximum % ground cover (weeds)			Mean yields t/ha			SED
		Half seq	Full	Untr	Half seq	Full	Untr	Half seq	Full	
1988	WSB88	1	1	13	2	5	4.77	4.92	4.58	0.212
1987	ESB187	1	4	33	3	8	5.50	5.20	5.35	0.300
1987	ESB287	1	4	3	2	2	6.30	6.70	6.63	0.251
1987	ESB387	1	4	33	10	10	6.45	6.50	6.43	0.300
1988	ESB188	2	4	35	3	3	6.41	6.89	6.88	0.218
1988	ESB288	2	4	61	5	5	6.90	7.01	7.20	0.250
1988	ESB488	2	2	20	0	0	7.39	7.55	7.55	0.140

Table 4. Effect of reducing herbicide dose on yield of (a) winter wheat and (b) spring barley in south-east Scotland trials; 1988/89.

Site	Treatment Timing	Maximum % Ground cover (weeds)	Yield (t/ha) Herbicide Dose					SED
			Full	50%	25%	12.5%	0	
Winter Wheat								
1.	Early post-em	48	5.51	5.92	5.46	5.85	5.56	0.375
2.	Early post-em	18	7.67	7.51	7.69	7.70	7.63	0.124
3.	Early post-em	71	6.35	6.63	6.55	6.22	5.77	0.300
4.	Spring post-em	48	5.24	5.27	5.76	6.05	5.56	0.375
5.	Spring post-em	18	7.19	7.52	7.38	7.40	7.63	0.124
6.	Spring post-em	71	5.79	5.56	5.96	5.98	5.77	0.300
Spring Barley								
4.	Post-em	84	5.01	4.71	4.71	5.13	4.72	0.261
5.	Post-em	29	5.90	5.97	6.04	5.84	5.65	0.270
6.	Post-em	10	3.93	3.80	3.55	3.96	3.94	0.336

Full rates: 1, 2, 3 = 2 l/ha; 4, 5, 6 = 30 g + 3.6 l/ha

Untr = untreated; Full = commercial doses; Half seq = half-dose sequence.

Where half-dose sequential herbicide treatments were used in the 1984-88 winter wheat trials (Table 2), there was only one site where there was a significant difference in yield response. There was a slight overall tendency to higher yield from use of half-rate herbicides. Yield response was not related to weed density controlled. Similarly, there was no clear yield response in spring barley trials (Table 3) to weed density controlled, confirming earlier trials work (Davies, 1988). Yield was statistically improved by use of the reduced dose herbicide in only one site (WSB88).

In the 1989 reduced rate trial series (Table 4), there was again no consistant yield response to herbicide rate in wheat or spring barley, even when doses of herbicide were reduced well below 50% of commercial rates, despite greatly reduced weed control at low rates (Whiting; personal communication).

DISCUSSION

Using data available from earlier trial results (Davies, 1988) and the information available from trials described in this paper, there may be a risk of yield loss from use of herbicides which is greater than the yield benefit from weed control when weed populations are less than about 35% maximum seasonal ground cover in winter wheat, but this effect is not quite statistically significant. At higher levels of weed density there is an erratic yield response, which may indicate that herbicide effects on the crop have masked the effects of weed control. In spring barley, although yield responses to herbicide use at sites where maximum ground cover of weeds drop below 30% are sometimes negative, there is no statistical evidence for a herbicide response. Yield responses are often surprisingly low at higher weed levels. Once a mixed weed population, lacking major individual competitors such as G. aparine, A. myosuroides, drops below a threshold, there may be an increased risk of herbicide keep masking the effect of weeds on crop yield. Jensen (1985), reviewing Danish trials on spring barley also showed poor yield responses, with a negative response to use of herbicide in 27% of trials.

These Scottish results are based on full recommended commercial rate herbicide treatments. There may be a case where weed levels are relatively low, or drop below certain threshold levels, that reduced herbicide rates should be considered, or possibly the herbicides omitted altogether, to improve cost-effectiveness and possibly reduce the potential for crop damage. There are a number of reasons for weed control, well-documented elsewhere (Elliot, 1980) so many farmers may not be willing to allow weeds to remain unchecked. However, the reduction of herbicide dose may allow sufficient control of lower levels of weeds to be a practical proposition. A limited range of half rate sequential treatments have been evaluated in Scottish trials in winter wheat and spring barley (Tables 2 and 3) up to 1988. Yield response to halving dose of herbicide were not usually significant, but in some trials in winter wheat the half rate sequential treatments improved yield over full-rate herbicide treatments. However, the yield improvement was so small that the main benefit to the farmer and the environment would simply be in the reduced cost and quantity of herbicide used. The spring barley results are less consistent, and again, differences due to herbicide rate are not in general significant, but reduced doses are unlikely to be disadvantageous in the long-term, and are probably advantageous in economic terms at quite high mixed weed densities.

Initial analysis of the 1988/89 trial series (Table 4) tends to confirm lack of a consistant relationship in winter wheat and spring barley between herbicide rate, weed level, and crop yield, down to very low rates of herbicide. Other reasons for weed control in cereals then become more important if large numbers of certain weeds can be left partially suppressed rather than fully controlled without affecting yield. Inevitably, more weeds would remain alive at very low herbicide rates to effect harvesting, and to seed, which would have long-term consequences.

An important consequence of the results described in this paper and elsewhere is the impact of such information on practical weed management models. Most models describing crop/weed relationships, and the effects of population and development of weeds have ignored the impact of the method of weed removal. It is evident that in the first stages of such modelling the basic crop/weed relationship is the most important factor. However, the model is not complete without considering that the method of control timing and dose of herbicide may have an effect on the relationship, and the parallel economic model. If reduced herbicide rates come to be considered a long-term strategy then the use of herbicides simply to reduce the competitive effects of weeds to a level where crop yield is not affected is a possibility. However, such a strategy has the effect of complicating the development of practical economic models to determine crop/weed relationships.

To develop such models which include all aspects and consequences of reducing herbicide rates requires much more experimental evidence. Current studies in part funded by the H-GCA are designed to give the modeller more of such data for decision-making models, and the farmers a practical approach to efficient and environmentally sensitive use of herbicides.

ACKNOWLEDGEMENTS

The authors wish to thank G.W. Wilson, Dr V. Heppel, Dr N Fisher and numerous field teams for their help over the years. A.J. Whiting, and part of the 1989 trial series, is funded by the Home-Grown Cereals Authority.

REFERENCES

Askew, M.F. and Scourey, L.R.K. (1982). The effect of some herbicides and herbicide sequences on the yield of two winter wheat cultivars in the absence of weeds. Broad-leaved weeds and their control in cereals, Aspects of Applied Biology, 1, 211-217.

Courtenay, A.D. and Johnston, R.T. (1986). An assessment of weed populations and yield response in spring barley subjected to a programme of reduced herbicide usage. Proc. EWRS Symposium 1986, Economic Weed Control, 301-308.

Davies, D.H.K. (1988). Yield responses to the use of herbicides in cereal crops; East of Scotland trials 1979-88. Aspects of Applied Biology, 18, Weed Control in Cereals and the Impact of Legislation on Pesticide Application, 47-56.

Elliott, J.G. (1980). The economic significance of weeds in the harvesting of grain. Proc. 1980 British Crop Protection Conference - Weeds, 3, 787-797.

Jensen, P.K. (1985). A review of yield response to weed control in one thousand spring barley experiments. 1985 British Crop Protection Conference - Weeds, 2, 687-692.

Wilson, B.J. (1986). Yield responses of winter cereals to the control of broad-leaved weeds. Proc. EWRS Symposium 1986, Economic Weed Control, 75-82.

EFFECTS OF WEEDS ON CEREAL HARVESTING EFFICIENCY AND GRAIN QUALITY, AND THE ECONOMIC CONSEQUENCES OF REDUCED WEED CONTROL

B.W. SHEPPARD
Scottish Centre of Agricultural Engineering, Bush Estate, Penicuik, Midlothian, EH26 0PH.

D.H.K. DAVIES, M.C. RICHARDS & A.J. WHITING
Crop Production Department, East of Scotland College of Agriculture, Bush Estate, Penicuik Midlothian, EH26 0PH

ABSTRACT

Reduced levels of weed control, by farmers using lower rates of herbicide or using weed threshhold levels as opposed to insurance spraying, as a guide to whether it is necessary to apply herbicides, may result in weedier crops at harvest. This is likely to impair combine harvester performance in dense weed or lodged crop situations. The use of pre-harvest application of glyphosate as a harvest management tool is shown to significantly improve the performance in these situations but cannot be directly economically justified for this alone where only annual weeds are present as opposed to the perennial weed situation. In cooler wetter climates though, it can be shown to increase the harvesting window, which is likely to be of benefit in wetter autumns.

INTRODUCTION

There is considerable interest from both the environmental and cost benefit points of view in reducing the level of herbicide use in cereal crops. This is likely to result in higher weed populations which as well as affecting yields may also impair combine harvester performance and grain quality. Options considered include the routine spraying low-dose insurance approach and spraying when crops contain a threshhold level of weeds. This second option is obviously preferable from the environmental point of view but opinions on what is the correct threshhold level of weeds requiring herbicide treatment vary widely between farmers and are further confused by varying competitive indices of different weed species (Cousens *et al.*, 1985; Wilson 1986). This can result in crops becoming weedier than would be liked at harvest. A recent development has been for farmers faced with this problem to use glyphosate pre-harvest both to effect a kill of weeds (particularly perennial weeds) and to desiccate both crop and weeds, making harvesting easier. Another benefit of this technique is that in some instances grain moisture can be reduced (Sheppard *et al.*, 1984). This earlier work was in relatively high populations of *Elymus repens*, more recent work, using reduced levels of glyphosate, has looked at the effects on the crop and on harvesting where much lower populations of mainly annual weeds were involved and, where there was uneven ripening of crops. This paper reviews a series of trials carried out in 1985 which has been reported elsewhere (Richards & Sheppard, 1985) and a further series of trials carried out in 1988.

MATERIALS AND METHODS

All trials took place in SE Scotland and used the the same techniques of weed population assessment, and combine performance measurement detailed in earlier trails (Sheppard et al., 1982). Pesticide application however was by a Van der Wiej knapsack sprayer at 200 l/ha spray volume at 2 bar pressure. Trials were of randomised block design using 3 or 4 replicates. Plot size varied from between 3 x 20 m to 6 m x 30 m.

1985 Trials

In these 4 trials, three on winter barley and one on spring barley, with a variety of annual grass and broadleaved weeds, crops were continually monitored, grain samples being taken and oven dried to establish moisture content. Glyphosate, at five different rates, was applied on the first suitable spraying day after the grain had reached 30% moisture content wet basis (MCWB). After spraying, moisture contents from ripe ears and green ears were monitored where weather permitted, until harvest. Two to three hours before harvest, whole crop moisture samples were taken to establish whether treated plots could have been harvested earlier in the day. Desiccation of the green crop and weeds were also assessed by visual observation. Combine harvester performance was compared at three of the four sites. Glyphosate treatments ranged from 360g a.e./ha to 720g a.e./ha, with and without surfactant. However, for this short paper only the highest rate of glyphosate (720g a.e./ha plus 1 l/ha Team Four80 surfactant) is compared in detail with untreated.

1988 Trials

Four further trials were carried out in 1988 in barley crops in SE Scotland as part of the Home Grown Cereals Authority's funding of research into weed threshhold levels in cereals. The same parameters were measured although changes in grain moisture content were not recorded between spraying and harvest, and pre-harvest crop moisture samples were not taken. Moisture contents of crops at the time of glyphosate application varied between 19% and 26%. Only one rate of application - 540 g a.e./ha glyphosate + 1 l/ha Team Four80 surfactant was used. Harvest took place between 7 and 18 days after treatment. Weed levels at all sites were low, the main problem weeds being *Polygonum aviculare*, *Stellaria media* and *Sinapsis arvensis* and volunteer oilseed rape (*Brassica napus*).

RESULTS

1985 Trials

Grain Moisture

At sites 1 and 3 where there were appreciable amounts of secondary regrowth and hence many green tillers, reductions in the moisture content of grain from these green tillers of up to 48% occurred by 9 days at site 1 and up to 51% by 17 days at site 3. However, only at the other two sites where there were dense weed populations did a significant reduction in overall moisture content of grain at harvest of up to 15.4% occur. For the treatment shown in table 1, this reduction was only significant at site 2 where the reduction was 14.7%.

However, there were no consistent differences between glyphosate treatments. These results suggest that pre-harvest glyphosate does not in general, directly affect the moisture content of the ripe grain but through its desiccating effect on weeds and probably to an extent on green crop avoids moisture transfer to the grain, both in the field and as the whole crop is threshed in the harvester.

TABLE 1. Effect of pre-harvest glyphosate on crop moisture and harvesting

Site		Harvest interval (days)	Grain moisture %	Early crop moisture %	MOG throughput t/h	Separation losses % of yield	Header Losses heads	grain
1	+	13	24.4	34.9	2.9	3.4	13	55
	-		25.6(1.1)	38.2(1.7)	4.2(0.4)	4.4(1.2)	3(4)	14(18)
2	+	32	25.5	43.1*	N.R.	N.R.	N.R.	N.R.
	-		29.9(1.0)	50.8*(3.4)	N.R.	N.R.	N.R.	N.R.
3	+	19	25.2	23.3	3.9	3.7	4	12
	-		24.9(1.4)	33.5(1.8)	4.7(0.2)	5.5(0.7)	6(3)	14(4)
4	+	23	21.5	18.1	3.4	1.1	25	18
	-		24.6(1.0)	19.3(1.5)	5.0(0.5)	1.3(0.3)	17(5)	10(5)

Note: 1. + is where plots were treated with the highest rate of glyphosate; - is where plots received no pre-harvest application.
2. Figures in brackets are Standard Errors of Difference.
3. * Post combining straw moistures.

Crop and Weed Desiccation

Desiccation of the crop and weeds was achieved at all sites. Volunteer wheat was desiccated by up to 91% and *Poa annua* by up to 67% at site one 13 days after treatment. *Galeopsis tetrahit* and *Polgonum persicaria* were well desiccated at site two (92% and 69% respectively) by 26 days after spraying, but at an adjacent site (site 4) sprayed eight days later, desiccation of *Polygonum persicaria* was much poorer (8%) when it was assessed, some 18 days after treatment. Whole crop moistures 1-3 hours prior to harvest were significantly reduced by glyphosate treatment at sites 1 and 3 by up to 18% and 35% respectively, suggesting that earlier harvesting was possible in the treated crop. In the treatments shown in table 1 this reduction ranged from 9% to 30%. Moisture content of the harvested straw was significantly reduced by all treatments at all sites by between 9% and 49%. At site 2, for the treatment shown above, it was reduced by 15%. In all of these desiccation and moisture measurements there was no significant difference between any glyphosate treatment.

Combine Harvester Performance

At two of the three sites where combine performance was monitored, throughput of materials other than grain (MOG) was reduced. This has been shown in earlier trials to lead to a corresponding reduction in grain losses from the combine harvester (Sheppard et al., 1982). However, separation losses on the combine harvester were only reduced at site 3 by from 5.5% to 3.6% of yield. There was again no significant difference between glyphosate treatments. Shedding/combine header losses were also measured, as it had been suggested that glyphosate may cause this, but there was no consistent effect from any treatment. There

1988 Trials

As can be seen in table 2, glyphosate significantly reduced the moisture content of MOG at two of the four sites, by 12 and 18 days after spraying, when harvest took place. This was mainly attributed to desiccation of the crop, which was harvested at 21% and 22% grain moisture content, the largest reduction being where the crop had lodged. At the other 2 sites the lack of effect on MOG levels was attributed to the low moisture content of the crop at

TABLE 2. Effect of pre-harvest glyphosate on crop moistures and yield of MOG

	Harvest interval (days)	Grain moisture %			MOG yield			Straw d.m.		
		+	-	SED	+	-	SED	+	-	SED
Site										
1	12	20.7	20.6	0.15	5.4	6.1	0.26*	73.7	67.7	1.59**
2	7	21.7	22.1	0.39	9.9	11.5	0.40**	67.3	61.7	2.03*
3	18	16.2	16.1	0.17	7.8	8.2	0.28	78.7	79.7	1.90
4	18	16.9	17.0	0.19	7.6	7.7	0.31	44.8	43.2	1.32

\+ denotes treated; - denotes untreated
* Significant p<0.05
** Significant p<0.01
_ 15 degrees of freedom, all others 18.

Weed levels for the four sites were assessed in the spring. Based on this information, table 3 is an estimate of the weed levels at the time of pre-harvest spraying. Weeds at sites 1, 2 and 4 were well senesced at the time of spraying and there was no visible desiccating effect by harvest from the glyphosate treatment. Indeed at site 4 the Stellaria media had died back to such a stage that it was estimated to have an insignificant weed level by this time. It was also noted that desiccation of *Polygonum aviculare* was not achieved at site 3, where there was only 7 days between spraying and harvest. Despite the overall reductions in MOG moisture levels this was not carried through to the grain and no significant reductions in grain moisture content were found at any site.

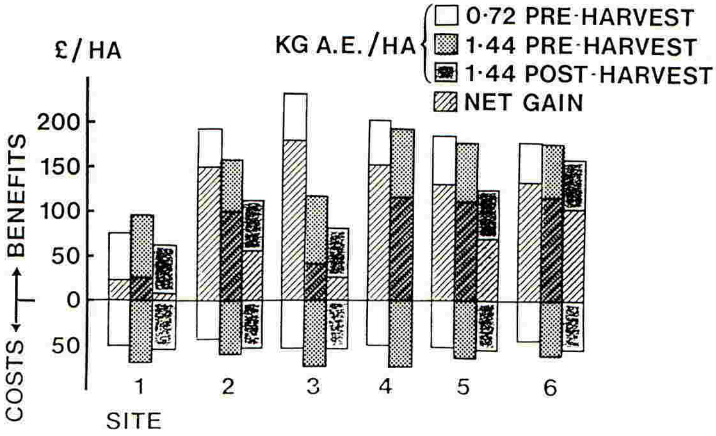
Table 3. Initial weed levels

Treatment	Dominant weeds	Weeds/m²
Site		
1	*Sinapsis arvensis*	2.4
2	*Brassica napus*	2.9
3	*Polygonum aviculare*	4.6
4	*Stellaria media*	0

ECONOMICS

An economic analysis of pre-harvest glyphosate use in six trials controlling couch grass in barley, was partially reported earlier (Sheppard *et. al.* 1984). Fig. 1 shows the analysis for all six trials corrected to 1981/2 prices.

FIGURE 1. Economic assessment of glyphosate used to control *Elymus repens*.



The histograms are assembled from the following:

Benefits: reduced separation losses; reduced drying costs; increased yield of susequent harvest.

Costs: purchase price of chemical; contract cost of application; wheeling losses from pre-harvest spraying.

This work showed that the net benefit, mainly as a result of increased yields in the subsequent year's crop, of this technique in controlling *E. repens* can be as high as £180/ha, where the lower application rate of glyphosate was used. Since then, crop prices have fallen in real terms although glyphosate too has been reduced in price recently by around 20%, so these major overall benefits are still likely to accrue.

However although measurements of subsequent crop yields have not as yet been made on these later trials, using pre-harvest glyphosate merely as a crop management tool to eliminate the amount of greens in the eventual grain sample and to reduce the moisture content of the MOG, thus making harvesting easier, is far harder to quantify. In the earlier *E. repens* control trials (Sheppard *et al.*, 1982), pre-harvest glyphosate lead to reduced separation losses of up to 50% or increased harvesting speeds of up to 31%, In the 1985 trials separation losses were reduced by up to 35%. However, at lower levels of annual weeds, losses are only likely to be at the 1% to 2% level and are unlikely to be reduced by these large amounts.

Indeed yield losses due to crop wheeling damage from pre-harvest spraying, particularly where conventional tractor wheels are used, without wheel deflectors, are likely to exceed this saving (Sheppard 1985). Current costs for this harvest management technique, taking into account the cost of chemical plus surfactant and the application cost, are likely to be in the region of £33/ha. It is unlikely that this can be shown to be directly cost effective as distinct from earlier trials and one can argue that more efficient herbicide control together with growth regulators to avoid lodging would be cheaper. However in difficult autumns in the cooler wetter parts of Britain, where past weed control has been ineffective or misjudged, or where there is uneven ripening of the crop, it could by enlarging the possible harvesting window and in some cases speeding up the harvest operation, mean the difference between harvesting in reasonable time and seeing the crop regrowing on the ground.

ACKNOWLEDGEMENTS

The Authors wish to thank the many farmers who provided land and assistance for these experiments, Monsanto plc. for funding the 1985 trials, the Home Grown Cereals Authority for funding the 1988 trials and all other staff of the East of Scotland College of Agriculture who were involved in them.

REFERENCES

Cousens, R. ; Wilson, B.J. ; Cussans, G.W. (1985) To spray or not to spray: the theory behind the practice. *British Crop Protection Conference - Weeds 1985*, 2, 671-678.

Richards, M.C. ; Sheppard, B.W. (1985) The agronomic effects of glyphosate as a harvest-aid in winter and spring barley. *Trial Report 5/85, East of Scotland College of Agriculture, Crop Production Advisory and Development Department.*

Sheppard, B.W. ; Pascal, J.A. ; Richards, M.C. ; Grant, H. (1982) The control of Agropyron repens by the pre-harvest application of glyphosate and its effect on grain yield, moisture, germination and on harvesting. *British Crop Protection Conference - Weeds 1982*, 3, 953-960.

Sheppard, B.W. ; Richards, M.C. ; Pascal, J.A. (1984) Agronomic effects from the control of Agropyron repens in barley by pre-harvest application of glyphosate. *Weed Research*, 24, 9-16.

Sheppard, B.W. (1985) Minimising cereal crop losses from sprayer wheelings. *British Crop Protection Conference - Weeds 1985*, 1, 349-355.

Wilson, B.J. *(1986) Yield responses of winter cereals to the control of broadleaved weeds. EWRS Symposium - Economic Weed Control, 75-82.*