SESSION 7C

CEREALS: RECENT ADVANCES IN WEED CONTROL AND PGR USE

SESSION ORGANISER	MS P. H. MOULT
POSTERS	7C-1 to 7C-10

CH-900, A NEW TRIAZOLE HERBICIDE FOR PADDY RICE

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ABSTRACT

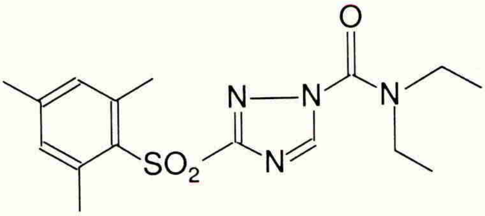
A series of 1-carbamoyl-3-phenylsulfonyl-1,2,4-triazoles were synthesized and examined for herbicidal effects. Among them 1-(diethylcarbamoyl)-3-(2,4,6-trimethylphenylsulfonyl)-1,2,4-triazole (code number CH-900) was the most effective. CH-900 has many advantages in protecting rice from weeds. CH-900: 1) has potent effects on _Echinochloa_ _oryzicola_ and a high selectivity for transplanted rice plant at a dosage of 200-300 g AI/ha, 2) is effective from the pre-emergence stage through to the three-leaf stage of the weed, 3) has a good residual activity of more than forty days after treatment against the weed, 4) controls certain other annual and perennial weeds as well. CH-900 can therefore be used independently or as a component in a herbicide mixture.

INTRODUCTION

CH-900 is a new potent triazole herbicide discovered in 1987, and is being developed by Chugai Pharmaceutical Co., Ltd.(Takeuchi _et_ _al_. 1990, Kanzaki _et_ _al_. 1991). Since 1990, many experiments have been conducted at public institutes in Japan.

Chemical and physical properties

Structural formula :



Empirical formula : $C_{16}H_{22}N_4O_3S$

Molecular weight : 350.45

Appearance : white crystalline solid

Melting point : 113 - 114 ℃

Water solubility : 2.5 mg/l (at 20℃)

Toxicity

Acute oral LD50 (rats) : > 5000 mg/kg

Ames test (mutagenicity): negative

MATERIALS AND METHODS

Formulations

Compounds formulated as 10% emulsifiable concentrates were used for the pot tests. For the field tests, CH-900 was formulated as a 1% granule concentrate.

Relationships between chemical structure and herbicidal activity

Herbicidal activity of the compounds under paddy field conditions was evaluated by pot test in a greenhouse with two species of plant, Echinochloa oryzicola and rice (cv. Nipponbare).

Herbicidal spectrum

Pre-emergence herbicidal activity of CH-900 against lowland weeds was evaluated under paddy field conditions. In addition, herbicidal activity against Echinochloa oryzicola at 1-, 2- and 3-leaf stages was investigated.

Residual activity

The pot tests to evaluate residual activity were conducted outdoors. Echinochloa oryzicola was sown on the 10th, 20th, 30th, 40th and 50th day after treatment. Activity was measured by the weight of the dried shoots 14 days after sowing.

Field test

A field test with plot sizes up to $5m^2$ was completely randomized with three replicates. CH-900 was applied at a dosage of 300 g AI/ha 4 or 14 days after transplanting rice (cv. Koshihikari, 2.5-leaf stage).

RESULTS AND DISCUSSION

Relationships between chemical structure and herbicidal activity

The herbicidal activity against Echinochloa oryzicola varied according to the substituents and/or their positions on the benzene ring. The introduction of lower alkyl, alkoxy or halogen groups at the 2,6 positions or 2,4,6 positions on the benzene ring further enhanced the herbicidal activity. Of the compounds evaluated, CH-900 gave very good control of Echinochloa oryzicola and showed a high selectivity for transplanted rice (Tables 1 and 2).

Herbicidal spectrum

CH-900 showed strong activity at a dosage of 10 g AI/ha, particularly against Echinochloa oryzicola and Cyperus difformis, without causing any injury to the transplanted rice. Also, it controlled Monochoria vaginalis, Scirpus juncoides and annual broadleaved weeds at a dosage of 50-100 g AI/ha (Table 3).

The activity of CH-900 against Echinochloa oryzicola at the 2- and 3-leaf stages was stronger than that of pretilachlor (Figure 1).

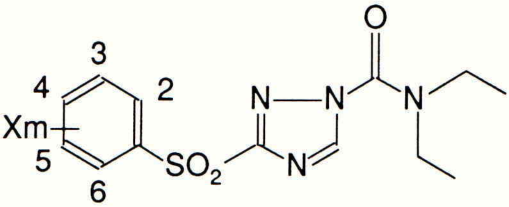
Residual activity

CH-900 had a good residual activity against *Echinochloa oryzicola* for more than 40 days after treatment and was effective for much longer than pretilachlor (Figure 2).

Field test

CH-900 effectively controlled *Echinochloa oryzicola* and *Cyperus difformis* from the pre-emergence to the 2.5-leaf stage at a dosage of 300 g AI/ha without any injury to the transplanted rice (Table 4).

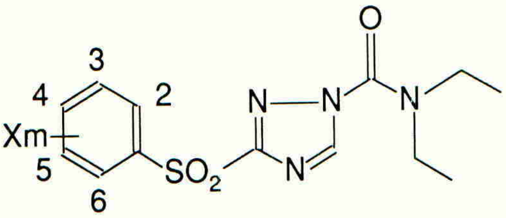
TABLE 1. The pre-emergence herbicidal activity of 1-diethylcarbamoyl-3-phenylsulfonyl-1,2,4-triazoles



Compound Xm	m.p. (℃)	Herbicidal activity *Echinochloa oryzicola* (ED90, g AI/ha)
H	88 - 89	100
2-Me	110 - 111	30
3-Me	135 - 136	40
4-Me	111 - 112	50
2-Me	110 - 111	30
2-Et	oil	20
2-Cl	84 - 85	30
2-OMe	oil	60
2-CF_3	oil	50
2,3-Me_2	92 - 93	30
2,4-Me_2	oil	100
2,5-Me_2	77 - 78	30
2,6-Me_2	111 - 112	5
2,4,6-Me_3 (CH-900)	113 - 114	5

Note: Activity was evaluated under paddy field conditions, 3 days after sowing *Echinochloa oryzicola*.

TABLE 2. The pre- and post-emergence herbicidal activity of 1-diethylcarbamoyl-3-phenylsulfonyl-1,2,4-triazoles



Compound		Herbicidal activity		Crop injury
		Echinochloa oryzicola (ED90, g AI/ha)		Rice (ED10, g AI/ha)
Xm	m.p. (℃)	pre-em.	post-em.	
2-Me, 6-Me	111 - 112	5	50	1000
2-Me, 6-Et	82 - 83	5	60	2000
2-Me, 6-Cl	105 - 106	5	60	1500
2-Me, 6-OMe	125 - 126	30	70	625
2-Et, 6-Et	oil	10	90	2000
2-Cl, 6-Cl	155 - 156	10	100	2000
2, 6-Me_2, 4-Me (CH-900)	113 - 114	5	50	2000
2, 6-Me_2, 4-OMe	oil	10	70	625
2, 6-Me_2, 4-Br	124 - 125	10	100	2000
2, 4-Me_2, 6-OMe	oil	10	50	1000
2, 4, 5-Me_3, 6-OMe	138 - 139	5	50	1000

Rice: Transplanted rice (cv. Nipponbare, 2.5-leaf stage)
Application timing: rice = 3 days after transplantation
pre-em. = 3 days after sowing *Echinochloa oryzicola*
post-em. = 2.2-leaf stage *Echinochloa oryzicola*

TABLE 3. The herbicidal activity and crop injury of CH-900 (greenhouse test)

Compound	Dosage (g AI/ha)	Rice injury	Herbicidal activity					
			Eo	Cd	Mv	Bl	Sj	Sp
CH-900	5	0	9	9	1	1	0	0
	10	0	10	10	5	4	2	0
	50	0	10	10	10	8	9	0
	100	0	10	10	10	10	10	0

Herbicidal activity and crop injury were evaluated visually by a 0 to 10 rating system: 0 = no effect, 10 = complete death.
Rice: Transplanted rice (cv. Nipponbare)
Abbreviation of weed names: Eo: *Echinochloa oryzicola*, Cd: *Cyperus difformis*, Mv: *Monochoria vaginalis*, Bl: Annual broadleaved weeds, Sj: *Scirpus juncoides*, Sp: *Sagittaria pygmaea*.
Application timing: 3 days after transplanting rice and sowing weeds.

Figure 1. The herbicidal activity of CH-900 against *Echinochloa oryzicola* at 3 leaf stages (greenhouse test)

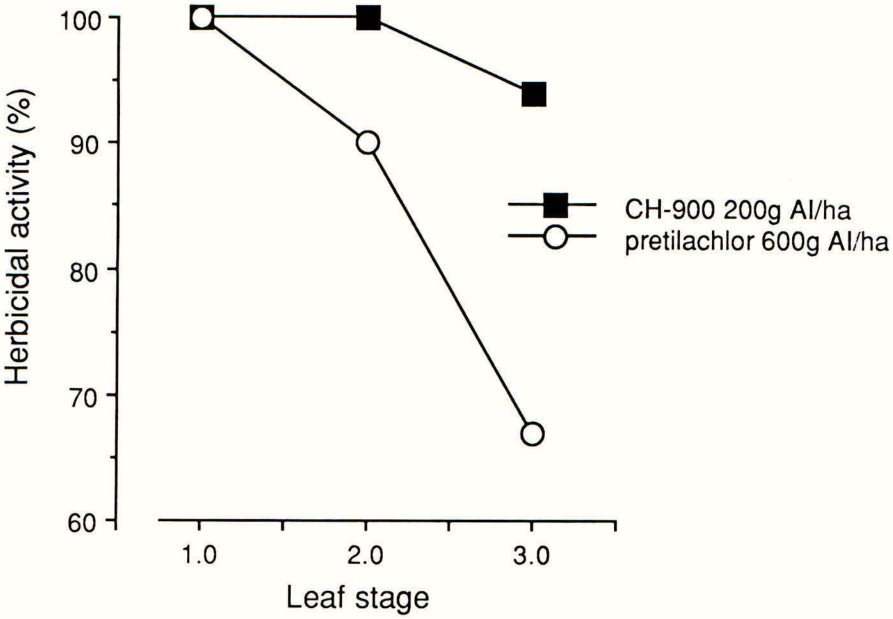


Figure 2. The residual activity of CH-900 against *Echinochloa oryzicola* (outdoor pot test)

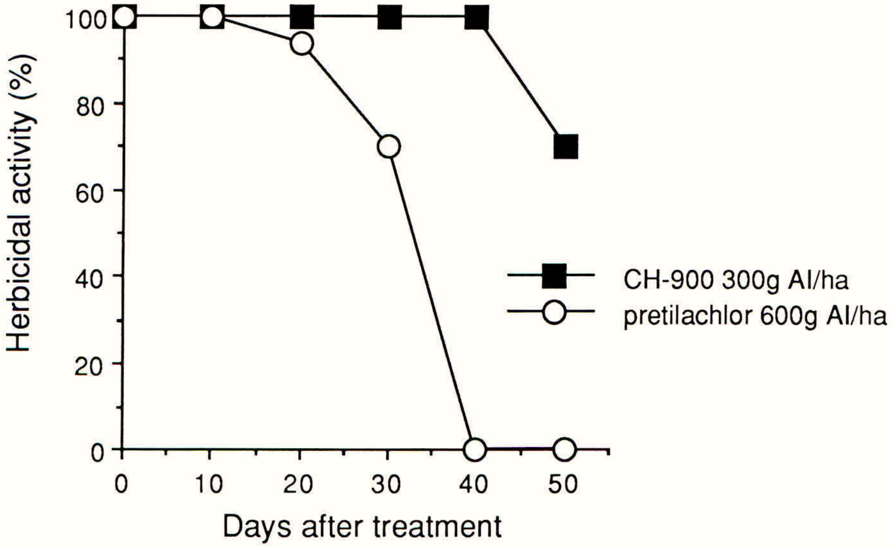


TABLE 4. The herbicidal activity and crop injury of CH-900 (field test)

Compound	Dosage (g AI/ha)	Timing DATR	Rice injury	Herbicidal activity Eo	Cd	Mv	Bl	Sj	Cs	Sp
CH-900	300	4	0	10	10	10	7	7	7	0
		14	0	10	10	7	5	5	3	0
Pretilachlor	600	4	0	10	10	8	8	8	5	0
		14	0	7	9	2	6	6	0	0

DATR: days after transplanting rice
Timing: 4 = 0 - 0.5-leaf stage *Echinochloa oryzicola*
14 = 2 - 2.5-leaf stage *Echinochloa oryzicola*
Abbreviation of weed names: see Table 3, Cs: *Cyperus serotinus*

ACKNOWLEDGEMENTS

We wish to express our thanks to Professor Makoto Kon-nai of Utsunomiya University for his suggestions. We also thank Director Teizo Kondo, Deputy Senior Manager Masahiro Yoshimoto and Mr. Shin-ya Kojima in the Agrochemical Division, Chugai Pharmaceutical Co., Ltd. for their support in this work.

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WILD-OAT SEED PRODUCTION AND SEED FATE AFFECTED BY HERBICIDES

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ABSTRACT

In a three year field experiment in winter wheat, the fate of plants and seeds of Avena ludoviciana was studied after one season with herbicide application and two following seasons with no herbicide treatment. In the season of herbicide application, there were higher numbers of wild-oat panicles and seeds per m^2 compared with the numbers produced in the two following seasons. This was due to the regrowth of wild-oat plants in the first season, and to the smaller numbers of seeds and lower levels of seed viability in the two seasons after some of the herbicide treatments. Persistence in the soil of imazamethabenz also contributed to reduced emergence of wild-oats the year after application. These resulting low weed populations did not affect grain yield, in any of the three seasons. The majority of seeds (more than 50%) were shed prior to harvest. Of those seeds collected at harvest, most were with grain and the least with straw.

INTRODUCTION

In situations where there could be reduced herbicide usage without economic loss, more information is needed on the relationship between herbicide response to wild-oat (Avena ludoviciana) seed production and fate, particularly where the weed population has been allowed to build up over successive years without herbicide use.

Although much has been published on the effects of chemicals on wild-oat plants, very little has been written about their effect on seeds produced by surviving plants, for example viability, dormancy, and emergence pattern.

An experiment was therefore begun in 1988 in which a commercial wheat cultivar was grown for three seasons in the same plots.

In the first season only, six herbicides were applied for wild-oat control, with no herbicide application in the second and third seasons. The effects of the herbicide treatments on wild oat plant, seed production and fate, crop growth and yield were studied in all three years.

MATERIALS AND METHODS

Field experiment

The experiment was conducted at the Agricultural Research Station of Northwestern Greece. The soil was silty-clay with pH 7.4. In the season prior to the experiment the crop grown was wheat. The field was naturally infested with a high population of wild-oat (A. ludoviciana). The wheat cultivar used, Dio (Triticum aestivum) is representative of commercially available cultivars for the area. In each year of the experiment prior to drilling, the experimental area was ploughed to a depth of 10-15 cm and disced. Wild-oat plants began to emerge with the wheat and emergence continued until the early spring, when the herbicides were applied.

The experiment was of the randomized complete block design with four replicates and an individual plot size of 2.25X10 m.

Herbicides were applied only in the first year, using a plot-sprayer with a 2 m boom and spray volume ranged 300-400 l/ha in April 12, 1989. All herbicide rates are expressed as active ingredient and are presented in the results tables.

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

Shortly before harvest, wild-oat plants were collected from two random quadrats, each 0.5 m^2. The plants were hand-pulled, dried, weighed and counted. At the same time, wild-oat seeds from each treatment were collected to study the emergence of seedlings in pot experiments. The seeds were collected only from spikelets in which the seeds were loose and contained both a primary and a secondary seed. The seed was stored dry at 20-25°C until planting in pots on 25 October 1989. Only full seeds were planted. In addition, the numbers of spikelets and seeds per panicle (10 panicles per plot) were counted. The mean number of seeds per panicle was determined, and seed production per square meter was calculated, based on the density of panicles.

Grain and straw yield were taken using a plot combine harvester, and a cleaned grain sample used for thousand grain weight and test-weight determination. From each plot, wild-oat seeds were collected and counted from harvested grain and straw.

Pot experiments

Four hundred primary and secondary wild-oat seeds from each treatment were sown at a depth of 50 mm in soil in four plastic pots, each 150 mm in diameter and 10 mm deep. The pots were placed in the field and were kept moist by watering. The soil samples were taken from:-

a) an untreated area of the experimental field outside the trial plot,

b) from the control, imazamethabenz and imazamethabenz+pendimethalin treated plots, (after harvest in the first season).

Four samples of soil, 10X10 cm to depth of 15 cm (depth of ploughing) were taken. The samples from each plot were bulked, thoroughly mixed and then carefully sieved. Four sub-samples consisting of 1 kg (d.wt) were transferred to the pots.

The emergence of wild-oats in each pot was recorded weekly and the emerged seedlings removed. The soil was disturbed periodically.

Seedling emergence ceased after 18 months. For analysis, seedling emergence was partitioned into three phases, 1 November 1989 to 31 January 1990, February 1990 to July 1990 and October 1990 to May 1991. Analysis of variance was performed and when the F-test treatment effect showed significance at 0.05 level the treatment means were separated using LSD range test.

RESULTS

Wild oat control

All the herbicides applied in the first season (1988-89) except flamprop-M-methyl, flamprop-M-isopropyl and imazamethabenz+pentimethalin significantly reduced the number of wild-oat panicles, despite wild-oat regrowth after two months due to wet weather conditions. However, the increase in grain yield was not affected.

In the two seasons following the first year of herbicide use (1989-90 and 1990-91), wild-oat panicle numbers were significantly lower in the herbicide treated plots than in the untreated plots. The most effective treatment was imazamethabenz (2 and 9 panicles m^2) (Table 1).

TABLE 1. Effect of herbicides on wild-oat panicle number and wild-oat seeds/m^2

Treatment	Rate	Panicles/m^2			Heigh cm	Seeds/m^2		
	g AI/ha	1989	1990	1991	1989	1989	1990	1991
Control		0 ac* (67.7)	0a (97)	0 a (57.5)	65ad	0ad (881)	0a (973)	0a (2364)
Flam M	324	24.2cg	82.5df	67.8cd	57dh	39eg	77fg	69bc
Flam	600	66.8hi	79.4ce	73.4de	48h	75h	78fh	80de
Flam M-I	600	24.4cg	61.9be	54.3bc	55eh	44fg	67bf	58b
Dicl	720	64.9hi	84.5df	80.3e	59cg	66gh	86gi	84ef
Fen	96	70.2i	88.7df	73.4de	59cg	66gh	90gi	80de
Imaz	400	41.7ei	97.9f	84.3ef	52fh	42fg	97i	88f
Imaz+pend	300+990	33.2ch	95.9f	73.9de	50gh	51fh	95hi	75ce
Imaz+pend	300+825	56.9gi	87.6df	74.8de	52gh	63gh	89ei	74cd

Flam M=flamprop-M-methyl, Flam=flamprop-methyl, Flam M-I=flamprop-M-isopropyl, Dicl=diclofop-methyl, Fen=fenoxaprop-P-ethyl, Imaz=imazamethabenz, Imaz+pend=imazamethabenz+pendimethalin.

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

Wild-oat growth and seed production

Wild-oat plants from herbicide treated plots had smaller stem diameters, panicles and height than those from control plots. The differences in size persisted throughout the growing season and were reflected in the numbers of seeds produced.

Wild-oat seed production was reduced after treatment with herbicides as a result of a reduction in number of the plants or in number of seeds per panicle compared to untreated plots.

In the season of herbicide application (1988-89), the seed production per m² in treated plots was lower than in the control plots, the most effective treatment was flamprop-methyl. In the following season (1989-90), the reduction in seed production was higher and the results were not comparable to that of the previous year in terms of effectiveness of treatment. Imazamethabenz plots gave the greatest reduction in wild-oat seeds per m². In the third season (1990-91), seed numbers increased relative to the previous year.

TABLE 2. Effect of herbicides on wild-oat seedling % emergence and grain yield kg/ha

Treatment	Rate g AI/ha	Wild oat seedling % emergence Nov 89-Jan 90	Feb 90-June 90	Oct 90-May 91	Total	Grain yield Kg/ha 1989	1990	1991
Control		40ce*	7.9	19.9	79cd	100h (1973)	100h (981)	100d (3346)
Flam M	324	17k	3.8	9.2	31k	159ad	175af	140bc
Flam	600	31gi	10.3	5.2	46hi	143ce	171bg	142ac
Flam M-I	600	54a	4.8	20.9	80ac	143ce	159cg	141ac
Dicl	720	45bc	5.6	14.2	65f	140ce	191ac	134c
Fen	96	37df	6.1	16.6	60fg	151be	186ad	142ac
Imaz	400	14k	6.1	6.0	26k	142ce	209a	148ab
Imaz+pend	300+990	35eg	6.8	14.4	56g	139df	207ab	149a
Imaz+pend	300+825	18jk	7.1	13.4	38j	160ac	180ae	148ab

Flam M=flamprop-M-methyl, Flam=flamprop-methyl, Flam M-I=flamprop-M-isopropyl, Dicl=diclofop-methyl, Fen=fenoxaprop-P-ethyl, Imaz=imazamethabenz, Imaz+pend=imazamethabenz+pendimethalin.
* Figures with a common letter do not differ significantly at $p<0.05$.

The fate of seeds during harvest

More than 50% of the total seeds produced had been shed naturally before harvest. The number of seeds as contaminants of grain was related to the degree of shedding at harvest and the number of seeds produced after of different treatments. Highest numbers were shed to the soil, less were found in the grain and the least in the straw (Table 3).

Seed viability was unaffected by passing through the combine harvester as germination ability of the seeds was the same as that of the seeds collected by hand.

Grain yield

The overall effect of herbicide application was to increase grain yield not only in the year of application, but also in the following two years without any herbicide application. In the year when the herbicides were applied, the yield increases were 39% to 60% higher than that of the untreated control. In the following year (no treatment), the yield increases tended to be greater with the herbicides treatments which gave the higher decrease in wild-oat. In general, in the second year yields were reduced overall, but the percent yield increases for the treated plots compared will untreated were higher than those in the first year (Table 2). The yield increases were due to increases in the thousand grain weights.

TABLE 3. Number of wild-oat seeds collected from the grain and from the straw.

Treatment	Rate	1989				1990			
		Grain*		Straw**		Grain*		Straw**	
	g AI/ha	per Kg	per m²	per Kg	per m²	per kg	per m²	per kg	per m²
Control		155.1a	30.5a	31.0a	2.7a	73.6a	6.6be	65ab	6.5b
Flam M	324	39.1cd	12.5c	15.6bf	1.4cg	29.3fh	4.6eg	30.8eg	3.1dh
Flam	600	19.0hi	5.4ik	2.8k	0.3j	29.1fh	4.8eg	38.3cg	3.9dh
Flam M-I	600	28.9fg	8.1gh	8.9gi	0.8gj	34.1dg	4.7eg	59.3ac	4.8ac
Dicl	700	41.4b	11.4bd	23.4b	1.8cf	50.4bf	9.8a	28.5eg	3.8ch
Fen	96	9.6k	2.61	17.1bd	0.6hj	30.0eh	5.2df	28.0fg	2.6gh
Imaz	400	30.9eg	8.6fh	6.2hk	0.6hj	10.8h	2.1g	21.3g	2.7fh
Imaz+pend	300+990	18.2hj	5.0jk	13.3cg	1.3dh	23.0gh	5.1df	20.3g	1.8h
Imaz+pend	300+825	32.7df	10.2df	26.8a	2.5ab	35.0dh	6.0cf	38.5cg	5.1ad

Flam M=flamprop-M-methyl, Flam=flamprop-methyl, Flam M-I=flamprop-M-isopropyl, Dicl=diclofop-methyl, Fen=fenoxaprop-P-ethyl, Imaz=imazamethabenz, Imaz+pend=imazamethabenz+pendimethalin.
* Collected from grain yield after harvest of 1 m² and of 1 kg of grain.
** Collected from straw yield after harvest of 1 m² and of 1 kg of straw.
Figures with a common letter do not differ significantly at $p<0.05$.

Seedling emergence

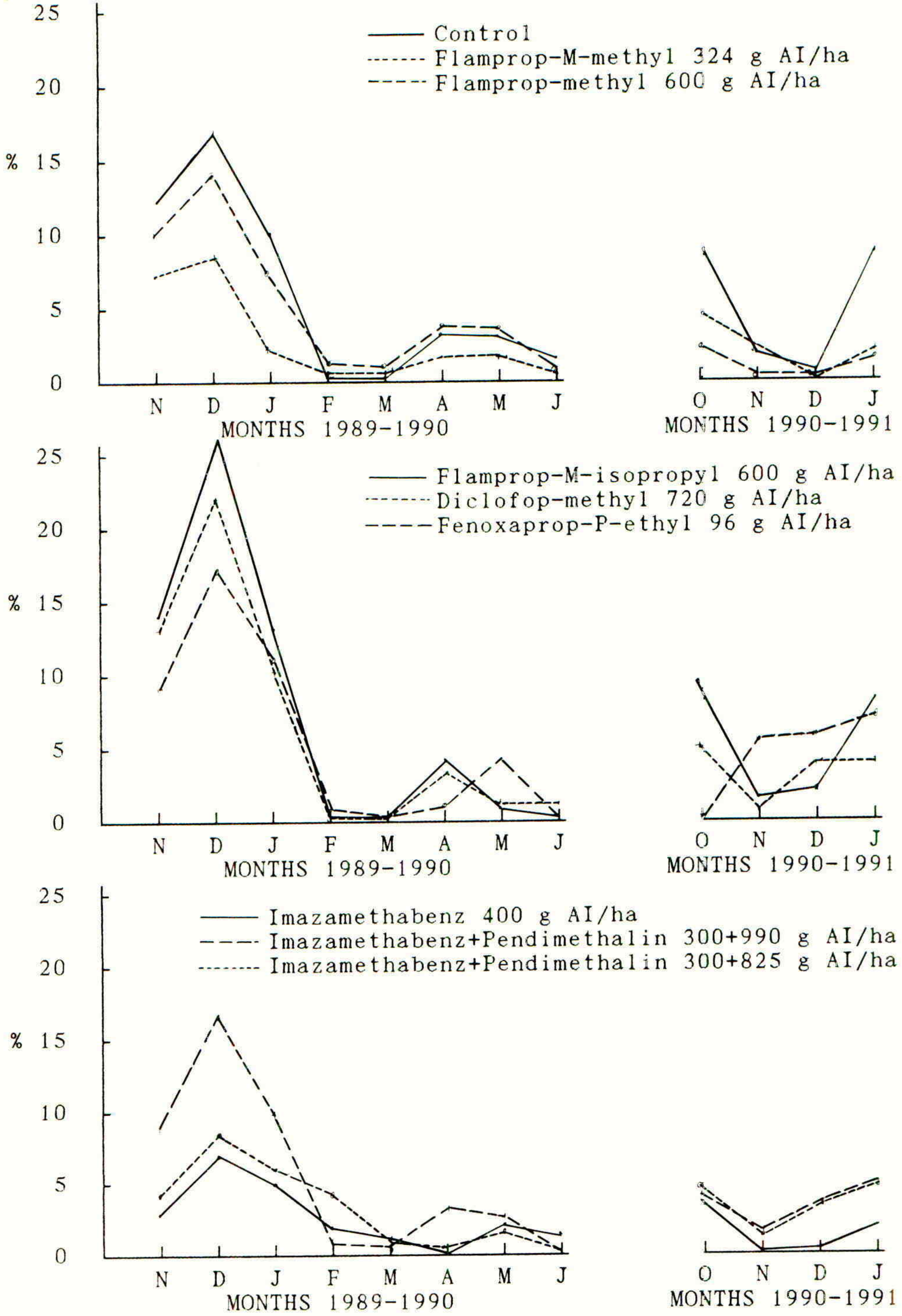
Emergence of wild-oat seedlings began within ten days of sowing in pots. Seeds from all treated and untreated plants had the same trend of emergence, therefore they had the same levels of dormancy at the time of collection (Fig. 1).

Seeds from treated plants had different germination levels. The seeds from imazamethabenz treated plants showed the lowest emergence followed by flamprop-methyl and the seeds from untreated plants and from flamprop-M-isopropyl treated plants showed the highest emergence. Seeds from other treatments exhibited an intermediate level of emergence. There were wide differences between the treatments with regard to the percent emergence, but not in timing of emergence.

The total number of emerged seedlings represented 26% to 80% of the original number of viable seeds sown (Table 2).

A large proportion of the seedlings from seeds of imazabethabenz treated plants died within a few days of emergence. The seed often appeared normal and viable but the seedlings were frequently retarded and deformed and did not develop beyond the coleoptile stage. Some seedlings showed inhibited growth of the seminal roots, but not of the later-developing crown roots, resulting in survival of most of these seedlings, while in others

FIGURE 1. % emergence of wild-oat seedlings from seeds produced after herbicide applications in 1989.



all root growth was inhibited and no seedlings developed beyond the 1-leaf stage.

The seeds which had not germinated by 22 months after sowing were examined at the end of June 1991. Only a few contained a full hard caryopsis and could therefore be classed as viable (Wilson, 1981).

Seeds from untreated plants sown in soil from imazamethabenz treated plots showed 10% less emergence than seeds in soil from untreated plots.

DISCUSSION

The results show the importance of A. ludoviciana seeds returning to the field after herbicide treatments. The dramatic decline in wild-oat numbers which took place over the three years must be attributed to the herbicide treatments applied the first year. This decline was due to a reduction in wild-oat panicles and production of seed with low germination levels in the year of herbicide application. Skorda (1974) has shown that there was considerable reduction in the return of viable seed to the soil by flamprop-M-isopropyl and flamprop-methyl. This is also demonstrated in the second year of this experiment where numbers of seedlings emerging in the autumn were small in relation to the total seed reserves because of low levels of germination and of survival after emergence in competition with wheat crop. The persistence of imazamethabenz in the soil contributed to the reduced emergence of wild-oat seedlings. Persistence of imazamethabenz residues in the same field with the same soil type was found in another experiment using sugarbeet sensitivity (Efthimiadis et al., 1989). The low emergence of seeds from plants treated with this herbicide, coupled with the reduction of emergence due to soil residues resulted in the smallest number of wild-oat panicles (2 and 9/m^2) in the two years (1990 and 1991) without treatment, even though the total number of seeds produced in the year of treatment was very large. This could lead to easy wild-oat eradication, combined with use of a "herbicide glove" or hand roguing. Considerable variation in seed viability occurred between herbicides. Differences in seed viability between herbicides has been reported before (Haddow & Jordan, 1979; Moncorge & Debray, 1979).

Seeds from all treated and untreated plants had the same trend of emergence, and therefore had the same levels of dormancy at time of collection. A similar pattern of behaviour was reported in Australia where rapid dormancy breakdown occured in growth chambers under high temperatures (25-30°C) particularly when the soil was moist (Quail & Carter, 1968).

It would seem that the problem of A. ludoviciana in Greece is more attributable to survivors shedding seeds than to the persistence of existing seed reserves, since the initially dormant seeds do not survive for more than two years at any burial depth (Skorda et al., for publication).

The fate of seeds of A. ludoviciana produced in wheat fields seems to be strongly dependent upon date of maturity, the possibility of shedding early before harvest and the methods used for crop harvesting. Immature wild-oat seeds are retained in the glumes, the efficiency of the combine in separating the seeds from the glumes is therefore important with regard to grain or straw contamination. In the year of herbicide application, the panicles resulting from regrowth were immature or matured very closed to harvest. The amount of weed seeds passing through the combine harvester was therefore high and the proportion of seed removed from the field, as grain contaminants, was lower than that from the untreated control.

This experiment was carried out on a site with a naturally occurring high infestation of A. ludoviciana and has shown that one year of herbicide application can, to a considerable extent, reduce the rate of build-up of the population. These treatments kept the field at a low weed density which did not affect the grain yield during the three years of the experiment. This dramatic reduction in population was achived by the efficient use of herbicides which resulted in not only a decrease in seed production, but also in a reduction of seed viability.

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REPEATED HERBICIDE TREATMENTS FOR THE LONG TERM CONTROL OF ARRHENATHERUM ELATIUS IN WINTER CEREALS

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ABSTRACT

The long term control of Arrhenatherum elatius (onion couch) in winter cereals was investigated from 1987-1991 in replicated plot trials on sites with high, and very high infestations, in South Glamorgan and Avon. Various rates and timings of imazamethabenz-methyl applied singly or in sequence, with or without pre-harvest glyphosate, and single treatments of flamprop-M-isopropyl were compared. Treatments were repeated for up to three seasons to obtain an additive effect. Control of seed head production, bulbil weight, numbers and viability, and weed regrowth was examined. Crop yields were recorded.

Several imazamethabenz-methyl rates/timings gave good control of aerial development, particularly lower rate sequences or higher rates timed in early winter or March, significantly increasing crop yield. Including pre-harvest glyphosate in sequence significantly reduced bulbil weight, numbers and viability longer term. Flamprop-M-isopropyl controlled aerial development with crop yield benefits, but longer term control of bulbils was less effective.

INTRODUCTION

The arable grass weed Arrhenatherum elatius var bulbosum (onion couch) occurs as a serious and expanding local problem, generally in association with loam soils of open texture, commonly on limestone brash and chalk downs. It propagates vegetatively by producing bulbil chains, as well as by seed production, making it difficult to control in winter cereals, particularly long term (Samuel, 1985). Practices of minimal/ reduced cultivations, autumn sowing and continuous cereals have enabled bulbil chains to develop and proliferate, thus aiding weed spread (Pierce, 1984; Khan, 1987).

Control options have included cultural means such as deep autumn cultivation, encouraging crop competition, spring sowing and use of mown and grazed grass leys. Chemical control in the winter cereal crop has proved variable (Ayres, 1985). More recently, imazamethabenz-methyl has been used in the first part of the season (Gussin, 1989); flamprop-M-isopropyl and glyphosate have been used in the latter part (Samuel, 1985).

Between 1987-1991 the long term chemical control of high infestations of onion couch in winter cereals was investigated comparing the then newly introduced imazamethabenz-methyl with flamprop-M-isopropyl and glyphosate.

MATERIALS AND METHODS

Replicated plot trials in crops of winter wheat cv. Slejpner (in 1987/88 and 88/89) and barley cv. Marinka (89/90) in Avon, and cv. Igri (87/88) in South Glamorgan were used to evaluate onion couch control at sites of very high and high natural infestation. Various rates/timings of imazamethabenz-methyl applied singly or in sequence, with or without pre-harvest glyphosate were compared with single treatments of flamprop-M-isopropyl with or without adjuvant oil, and various rates of pre-harvest glyphosate alone. Table 1 contains the details. Treatments were applied using an Oxford Precision Sprayer fitted with 8002 nozzles operating at 200 kPa delivering 220 litres of water/ha. In the one year (87/88) South Glamorgan trial, plot size was 10.0 m x 3.0 m. In Avon there were two trials, with plot size 18.0 m x 2.25 m. Treatments were re-applied for three seasons (1987-90) in trial 1, and two (1988-90) in the adjacent trial 2, to evaluate cumulative effects on weed control. After 1989/90 plots were left uncultivated and uncropped for another season.

Control of seed head production was assessed in July/ August (crops GS80-92) using 5 x 0.1 m^2 quadrats/plot, except in 1989/90 when drought prevented heading. Bulbil control was measured by digging up 3 x 0.1 m^2 x 0.1 m deep quadrats of soil shortly post harvest, counting and weighing bulbils fresh. Viability of material from South Glamorgan was tested by unreplicated potting of bulbil chains and separated single bulbils into compost, placing in a cold glasshouse over winter and recording % shoot emergence, ie shoot numbers/ bulbil numbers x 100, nine months later.

The effects of treatments on regrowth in the subsequent seasons prior to further treatment were assessed visually as % ground cover or regrowth scores (0=nil, 9=100% ground cover). Final total tiller counts were made in June 1991. Cereal grain yield at 85% d.m. was determined in the Avon trials.

RESULTS

Control of seed head production (Table 2)

In South Glamorgan, with the lowest untreated population (148 heads/m^2), good control was obtained in one season. The 0.36 kg/ha, winter/March imazamethabenz-methyl sequence (treatment 7) gave 100% control, and all 0.72 kg/ha single sprays gave 90% control or better, spring timings being the most effective. The 0.36 kg/ha single sprays gave 75-80% control, similar to the flamprop-M-isopropyl treatment. In Avon in 1987/88 (trial 1) the untreated population was well over three times greater and control much lower than in South Glamorgan. Single 0.36 kg/ha imazamethabenz-methyl sprays gave 13-36% control. The 0.72 kg/ha sprays, spring applied (treatments 13 & 15) gave 50-65% control, the flamprop-M-isopropyl treatment 47%. In the first year of the Avon trial 2, the untreated population was only 40% of trial 1 and control levels

TABLE 1
Treatments:-
Products, Rate of application and Timings

PRODUCTS, RATES
d;D: 0.36* or 0.39 kg ai/ha; 0.60 or 0.72* kg ai/ha of imazamethabenz-methyl: 'Dagger', 0.30 kg ai/litre.
R;$\underline{R}$: 1.08; 1.44 kg ai/ha of glyphosate: 'Roundup', 0.36 kg ai/litre.
Ra : 0.72 kg ai/ha of glyphosate plus 0.88 kg ai/ha of tallow amine ethoxylate wetter/spreader: 'Frigate', 0.80 kg ai/litre, 0.5 litre/ 100 litres water.
C : 0.60 kg ai/ha of flamprop-M-isopropyl: 'Commando', 0.20 kg ai/litre.
Ca : 0.60 kg ai/ha of flamprop-M-isopropyl plus 1.48 kg ai/ha of highly refined mineral adjuvant oil: 'Swirl', 0.59 kg ai/litre.

* The 0.36 & 0.72 kg ai/ha rates were used in 1987/88 only.

TIMINGS
w: early winter (December); crop GS12 onwards, onion couch active, GS11/12
e: early spring (March); when onion couch began to grow actively
m: mid spring (April); 3-4 weeks after e: onion couch tillering
l: late spring (May); Crop GS32, crop and onion couch growing vigorously; as product label recommendations
p: pre-harvest (July/August); as product label recommendations
REPLICATION all treatments were replicated three times

Treatment No., Product rates, sequences and timings

	Timings					Trial structure (+/- = treatment included/absent)			
	w	e	m	l	p	S.Glam. 87/88	Avon 1 87/88	Avon 1 88/89 89/90	Avon 2 88/89 89/90
1	d					+	+	-	-
2	d				+ R	+	+	-	-
3		d				+	+	-	-
4		d			+ R	+	+	-	-
5			d			+	+	-	-
6			d		+ R or Ra	+°	+	-	-
7	d +	d				+	+	+	+
8	d +	d			+ R or Ra	+°	+	+	+
9		d +	d			-	-	-	+
10		d +	d		+ R	-	-	-	+
11	D					+	+	+	+
12	D				+ R or Ra	+°	+	+	+
13		D				+	+	+	+
14		D			+ R or Ra	+°	+	+	+
15			D			+	+	+	+
16			D		+ R or Ra	+°	+	+	+
17					Ra	+	+	-	-
18					R	-	-	+	+
19					$\underline{R}$	+	+	-	+
20				C		+	+	-	+
21				Ca		-	-	-	+
22 }	Untreated					+	+	+	+
23 }	controls					+	+	+	+
24 }						+	+	+	+

° = Ra rate

TABLE 2 Control of onion couch seed head production. Cereal grain yields.
Number of panicles/m^2 above the crop canopy, as percentage control relative to untreated.
Grain yield, t/ha at 85% d.m., as percentage of untreated
(- = treatment not in trial, ... = treatment not relevant)

			S.Glam.	Avon Trial 1					Avon Trial 2		
			1987/88	1987/88 (Yr 1)		88/89 (Yr 2)		89/90(Yr 3)	1988/89 (Yr 1)		89/90(Yr 2)
Treatment Code (See table 1)			Panicles % Control	Panicles % Control	Wheat Yield % of Control	Panicles % Control	Wheat Yield % of Control	Barley Yield % of Control	Panicles % Control	Wheat Yield % of Control	Barley Yield % of Control
1	d	w	80	26	138	-	-	-	-	-	-
2	d:R	w:p	..	..	...	-	-	-	-	-	-
3	d	e	75	13	155	-	-	-	-	-	-
4	d:R	e:p	..	..	...	-	-	-	-	-	-
5	d	m	75	36	192	-	-	-	-	-	-
6	d:R	m:p	..	..	...	-	-	-	-	-	-
7	d,d	w,e	100	44	267	89	187	142	88	136	127
8	d,d:R	w,e:p	...	..	...	96	200	144	..	...	122
9	d,d	e,m	-	-	-	-	-	-	72	124	113
10	d,d:R	e,m:p	-	-	-	-	-	-	..	...	136
11	D	w	90	40	226	71	172	123	71	122	115
12	D:R	w:p	..	..	...	74	180	142	..	...	131
13	D	e	98	51	195	58	177	133	76	125	111
14	D:R	e:p	..	..	...	77	199	154	..	...	138
15	D	m	98	65	231	50	153	120	55	111	107
16	D:R	m:p	..	..	...	75	193	144	..	...	129
17	Ra	p	..	..	104	-	-	-	-	-	-
18	R	p	-	-	-	7	111	153	..	106	130
19	R	p	..	..	103	-	-	-	..	94	130
20	C	l	79	47	139	-	-	-	75	120	111
21	Ca	l	-	-	-	-	-	-	77	123	106
22}	Mean of		0	0	100	0	100	100	0	100	100
23}	untreated		(148)	(544)	(1.23)	(222)	(2.75)	(2.70)	(221)	(4.20)	(3.25)
24}	controls										
LSD	5%		±53.2%	±32.2%	±46.4%	±25.4%	±27.4%	±23.9%	±41.0%	±21.3%	±16.8%
CV%			80.9	28.4	16.4	29.8	10.4	10.9	60.4	10.9	8.5

achieved in one season were generally 70% and above. The two spray 0.39 kg/ha imazamethabenz-methyl sequence (7) gave 88% control, and the single 0.60 kg/ha rate in March (13) 76%, similar to the two flamprop-M-isopropyl treatments, where the adjuvant oil had little effect (20, 21).

In the second year of the Avon trial 1, the much drier season reduced the untreated population by 60%. However, there were cumulative effects of treatments. The most effective imazamethabenz-methyl treatment was the 0.39 kg/ha winter/March sequence (7), giving 89% control; including pre-harvest glyphosate enhanced control to 96%, a trend evident in all the 0.60 kg/ha imazamethabenz-methyl/glyphosate sequences, 74-77% control being achieved. Pre-harvest glyphosate alone (18) gave 7% control.

Effects on bulbil viability, weight and numbers (Table 3)

The viability study revealed, in general, greater germination by singles than bulbil chains. All treatments reduced viability compared with untreated material. Glyphosate sequenced with imazamethabenz-methyl, consistently gave greatest control of shoot emergence (85-100%), the 1.44 kg/ha rate of glyphosate alone also resulting in 85% control. Rate and timing effects of imazamethabenz-methyl were not conclusive, the winter/March timings tending to work better.

In South Glamorgan (results not shown) all treatments reduced bulbil numbers/m^2. Earlier applied treatments were more effective than those in mid-late spring. Effects on bulbil weight were variable, but all imazamethabenz-methyl/glyphosate sequences caused significant reduction.

At the Avon trial 1, all treatments gave weight reduction (7-63%) in year one, the greatest from the 0.36 kg/ha, two spray imazamethabenz-methyl sequence followed by glyphosate (8). Reduction in numbers was variable; sequences of the above two materials had greatest effect.

After three years, two with dry seasons, weight of untreated bulbils had reduced by 66%, but numbers had increased by 22%. However, cumulative treatment effects occured. All significantly reduced bulbil weight compared with untreated, imazamethabenz-methyl/glyphosate sequences being the best, particularly winter/March sequences or single sprays (8, 12, 14), being better than glyphosate alone. Imazamethabenz-methyl alone was best as a low rate sequence in winter/March (7). The Avon trial 2 results (bulbil results not shown) were more variable after two seasons, but similar trends to those above were seen. Flamprop-M-isopropyl plus adjuvant oil reduced bulbil weight by 87% relative to untreated, compared to 50% without adjuvant oil, but differences were not significant.

Effect of treatments on subsequent regrowth (Table 4)

Imazamethabenz-methyl/glyphosate sequences significantly reduced subsequent regrowth, usually being better than the individual materials alone. The final total tiller counts in 1991, showed that the higher rate single imazamethabenz-methyl sprays in March or April (14, 16), or the lower rate two spray treatment applied winter and March (8), plus glyphosate gave best long term control. In Avon trial 2, the 0.39 kg/ha sequence in March/April (10) and the 0.60 kg/ha winter spray (12), plus glyphosate also gave good control. Flamprop-M-isopropyl plus adjuvant oil (21) was marginally better than without oil, giving results similar to a number of imazamethabenz-methyl alone treatments.

TABLE 3 Effects on bulbil viability, weight and numbers

Bulbil viability, as % control of % shoot emergence relative to untreated. Mean of chains and singles. Bulbil weight, g/m², and numbers/m², as % control relative to untreated.

Treatment Code (See table 1)			S.Glam. 1987/88	Avon Trial 1 1987/88 (Yr 1)		89/90 (Yr 3)	
			Viability % Control	Weight % Control	Number % Control	Weight % Control	Number % Control
1	d	w	28	19	- 9	-	-
2	d:R	w:p	90	26	17	-	-
3	d	e	48	30	8	-	-
4	d:R	e:p	100	56	35	-	-
5	d	m	45	31	2	-	-
6	d:R	m:p	86	55	35	-	-
7	d,d	w,e	59	43	- 2	82	69
8	d,d:R	w,e:p	91	63	40	98	95
9	d,d	e,m	-	-	-	-	-
10	d,d:R	e,m:p	-	-	-	-	-
11	D	w	9	54	42	46	44
12	D:R	w:p	97	51	43	98	95
13	D	e	53	10	-41	72	61
14	D:R	e:p	94	54	17	98	94
15	D	m	45	16	-10	44	31
16	D:R	m:p	85	46	26	96	91
17	Ra	p	52	7	10	-	-
18	R	p	-	-	-	73	62
19	<u>R</u>	p	85	13	18	-	-
20	C	l	41	18	13	-	-
21	Ca	l	-	-	-	-	-
22}	Mean of		0	0	0	0	0
23}	untreated		(213)	(2314)	(7610)	(782)	(9290)
24}	controls						
LSD 5%			-	±35.6%	±43.6%	±44.0%	±46.2%
CV%			-	30.7	30.1	63.2	58.8

TABLE 4 Effect of treatments on regrowth

Onion couch % ground cover (GC), Regrowth score (RS) and tiller numbers/m². All expressed as % control relative to untreated.

	S.Glam. 1987/88	Avon Trial 1 1987/88 (Yr 1)	1991	Avon Trial 2 1991
	GC % Control May '89	RS % Control Dec '88	Tillers % Control June '91	Tillers % Control June '91
1	- 6	14	-	-
2	79	41	-	-
3	-16	8	-	-
4	72	56	-	-
5	54	8	-	-
6	64	59	-	-
7	31	22	51	27
8	77	67	94	86
9	-	-	-	13
10	-	-	-	89
11	25	22	19	24
12	69	56	84	78
13	40	19	28	23
14	69	67	95	76
15	43	14	27	26
16	61	59	93	73
17	74	33	-	-
18	-	-	56	55
19	89	30	-	63
20	52	3	-	6
21	-	-	-	28
22}	0	0	0	0
23}	(20.4)	(9.0)	(2170)	(1960)
24}				
LSD 5%	±65.3%	±12.6%	±23.1%	±25.8%
CV%	70.5	10.8	25.1	27.7

Cereal grain yield (Table 2)

The Avon site was low yielding but some significant yield improvements due to onion couch control were achieved. Level of yield did not always relate consistently to weed control. However, in 1987/88, the best level of control (treatment 15) gave a yield of 231% relative to untreated with treatment 7 giving a 267% relative yield. In subsequent years imazamethabenz-methyl/glyphosate sequences tended to give higher yields than imazamethabenz-methyl alone, the 0.60 kg/ha rate in March plus glyphosate (14) and the 0.39 kg/ha 2 spray sequence, winter/March plus glyphosate (8) tending to give highest yields, although differences between other timings were not always statistically significant.

The glyphosate alone treatment relative yield increased with each season. Flamprop-M-isopropyl plus adjuvant oil (21) in year one of the Avon trial 2 gave a 123% relative yield compared with untreated wheat; without oil it did not differ significantly from untreated. Neither treatment gave a significant yield improvement in the second year.

DISCUSSION

Crop yield reductions due to onion couch exceeded 60% on the heavily infested site. Repeated usage over three seasons of the herbicide options available in winter cereals significantly controlled a serious weed problem. Aerial growth was controlled, reducing current-crop competition, and bulbil weight, numbers and viability reduced in the longer term, all contributing to crop yield improvement.

Imazamethabenz-methyl gave good seed head control (90-100%) at the South Glamorgan site, and 89% in the high Avon population after two years. The lower rate sequence, treating the still active weed early winter to weaken tillering potential, followed by a March treatment targeted at tillering/early bulbil formation effectively reduced fertile tiller production. Higher rate sprays in March or April did the same, being aimed at the most vulnerable stage of tillering and bulbil initiation, when translocation would be greatest (Khan, 1987). The efficacy of these timings was also seen in bulbil weight and number reduction over three seasons. These timings concur with the results of Gussin (1989), obtained on significantly lower initial populations.

However, using pre-harvest glyphosate in sequence with imazamethabenz-methyl significantly improved and extended the control of onion couch. This technique proved effective in wheat and barley, and yield increases occured. The viability study showed the ability of the above sequences to reduce regenerative potential of bulbils. Bulbil weight and numbers declined significantly after three years of treatment, the glyphosate augmenting the control initiated by imazamethabenz-methyl lower rate sequence and higher rate single sprays, particularly early winter/March timings. Regrowth in the following seasons was consistently curtailed, illustrated in the final tiller counts in 1991. April timings also showed good regrowth control. However, these could diminish green tissue survival and reduce subsequent uptake of glyphosate. Glyphosate alone treatments gave good long term control of bulbil weight, number, and tillers, at a level between those obtained by glyphosate/imazamethabenz-methyl sequences, and those of the latter material alone. The 1.44 kg/ha glyphosate rate was slightly better. This rate has been recommended for bulbil control, with pre-harvest timing to target green weed tissue, preferably in a winter barley crop. Alternatively a pre-or post-harvest sequential split application has been recommended (Anon, 1989).

Flamprop-M-isopropyl also gave good seed head control but longer term bulbil control was variable; including adjuvant oil tended to improve it. Other reports (Luers, 1987; Pierce, 1984) of three-year repeated treatments noted reduction in bulbil size and viability, as well as reducing seed germination in the year of treatment. A flamprop-M-isopropyl/glyphosate sequence was not tested, but Samuel (1985) found similar bulbil control as with glyphosate alone.

The 0.39 kg ai/ha sequence of imazamethabenz-methyl in early winter/early spring worked well. To meet current label recommendations, a sequence of 0.39 kg ai/ha in the autumn followed by 0.51 kg ai/ha in the spring could be used, or alternatively a single 0.51 or 0.60 kg ai/ha application in the spring. These should be followed by pre-harvest glyphosate, the rate depending on weed population. These treatments have significantly reduced high populations and protected crop yield. At least three seasons of treatment may be required on high population sites. Once populations have declined, pre-harvest glyphosate alone may be enough to control the weed long term. A combination of cultural and chemical methods could enhance rate of control (Khan, 1987).

ACKNOWLEDGEMENT

Financial support for this work from the Ministry of Agriculture, Fisheries and Food is gratefully acknowledged.

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FENOXAPROP-ETHYL - A SUMMARY OF UK TRIALS ON GRASS-WEED CONTROL IN WHEAT

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ABSTRACT

Trials carried out in wheat throughout the United Kingdom with fenoxaprop-ethyl, a post-emergence selective graminicide, show very high and consistent levels of control of Alopecurus myosuroides (black-grass), Avena spp. (wild-oats) and other annual grasses. Applied at 120-180 g AI/ha from the autumn through to late spring, fenoxaprop-ethyl gave a mean of 97% control of A. myosuroides and 98% control of Avena spp.

The high levels of weed control achieved with fenoxaprop-ethyl were reflected in high yield responses. In addition, tolerance trials show this compound to be selective in all varieties of winter and spring wheat tested.

INTRODUCTION

Alopecurus myosuroides (black-grass) and Avena fatua and Avena ludoviciana (wild-oats) continue to be the most serious and widespread annual-grass weeds affecting wheat crops in the United Kingdom. Existing, mainly residual-acting herbicides, have not always given sufficient control, particularly of A. myosuroides, due to various soil (Cussans et al., 1982) and/or weather conditions (Hewson & Read, 1985; Read & Hewson, 1988a). Populations of these weeds have continued to increase in intensity and geographic spread and this has led to weed control strategies to enhance the foliar activity of the treatments used (Read & Hewson, 1988b). There is clearly a need for a more effective foliar-acting graminicide, such as fenoxaprop-ethyl.

The active ingredient of fenoxaprop-ethyl was first introduced as a selective herbicide for the control of grass weeds in broad-leaved crops (Bieringer et al., 1982). The opportunity to control these annual grass weeds in wheat with such a highly effective herbicide came about following the discovery of fenchlorazole-ethyl (Hoe 070542) by Hoechst AG (Bieringer et al., 1989), which when formulated with fenoxaprop-ethyl, enabled the mixture to be safely used in wheat.

Fenoxaprop-ethyl is translocated following absorption through the leaves and stems of grass weeds. The site of action is the growing point at the base of the stem. Grass weeds are killed due to inhibition of the enzyme acetyl-CoA-carboxilase (Köcher et al., 1982 and 1989). In addition, fenoxaprop-ethyl is of very low toxicity and under normal conditions of field use, presents no risk to the spray operator, consumer or environment.

This paper presents results of field trials carried out by Hoechst UK Limited with fenoxaprop-ethyl for the control of grass weeds in wheat.

MATERIALS AND METHODS

All trials were carried out on commercially-grown crops of winter or spring wheat in England and Scotland, covering a range of locations and cultivars.

A total of 293 efficacy trials was carried out over seven years from 1985 to 1991 on A. myosuroides and 176 on A. fatua and/or A. ludoviciana. In addition, 29 trials were carried out on other grasses, including Poa trivialis, Apera spica-venti, Phalaris paradoxa and Phleum pratense. All these trials were sprayed at one of three timings which were basically 'autumn', when the weeds were from the two leaf stage up to GS 23 (from early November to early January); 'early spring', when the weeds were up to GS 29 (from January up to April); and 'late spring', when the weeds were up to GS 39 (from mid-February to early June). Trials were designed as randomised blocks with three replicates and a plot size of 12-20m^2.

A further 126 trials were carried out on weed-free sites between Autumn 1985 and Spring 1990, on a range of winter and spring wheat varieties to investigate their tolerance to single and double doses of fenoxaprop-ethyl applied at a range of crop-growth stages. These trials were also designed as randomised blocks but with four replicates of each treatment and a plot size of 12-20m^2.

Applications to all the trials were made using a hand-held van der Weij Azo small-plot precision sprayer at an operating pressure of 250 kPa, delivering 200 l/ha, using eight flat fan nozzles spaced 25cm apart on a 2m boom.

Chemical treatments used in the trials and their active ingredient content were as follows:-

fenoxaprop-ethyl, 'Cheetah', 60 g/l oil in water emulsion
diclofop-methyl, 'Hoegrass', 380 g/l EC
difenzoquat, 'Avenge 2', 15% w/v soluble concentrate
flamprop-m-isopropyl, 'Commando', 200 g/l EC
isoproturon, 'Arelon Liquid', 553 g/l SC or 'Arelon WDG', 82.5% w/w water dispersible granule

Counts of grass-weed seed heads were carried out as soon as all the heads had emerged, using random quadrats, which varied in size from 0.1 to 0.5m^2 according to the density of the weed.

In the tolerance trials, crop vigour was assessed at one week, three weeks and monthly intervals following application, using a percentage scale. Yields from all the tolerance trials and some efficacy trials were taken, using a Hege small-plot combine harvester.

RESULTS

Efficacy trials

Data is presented separately for trials carried out in the autumn and the spring according to the growth stage of A. myosuroides (Tables 1-3) and Avena spp. (Tables 4-6). A mean of 97% control of A. myosuroides and 98%

TABLE 1. Percentage control of <u>Alopecurus myosuroides</u> 'autumn' application, up to weed GS 23 (November to early January).

Treatment	Rate (g AI/ha)	YEAR 1987	1988	1989	1990	Mean
fenoxaprop-ethyl	120	96	98	97	97	97
isoproturon	2475	73	90	77	75	78
Heads/m² on control		660	316	445	541	477
No. trials		9	9	25	9	52

TABLE 2. Percentage control of <u>Alopecurus myosuroides</u> 'spring' application, up to weed GS 29 (January to April).

Treatment	Rate (g AI/ha)	YEAR 1986	1987	1988	1989	1990	1991	Mean
fenoxaprop-ethyl	150	98	97	96	99	97	99	98
isoproturon	2063	94	67	74	82	64	77	73
Heads/m² on control		635	655	480	289	511	498	476
No. trials		3	17	22	27	34	12	115

TABLE 3. Percentage control of <u>Alopecurus myosuroides</u> 'late spring' application, up to weed GS 39 (mid-February to early June).

Treatment	Rate (g AI/ha)	YEAR 1985	1986	1987	1988	1989	1990	1991	Mean
fenoxaprop-ethyl	180	97	98	96	97	95	93	93	96
flamprop-M-isopropyl	600	-	-	-	62	-	72	85	(70)
Heads/m² on control		1100	696	625	382	358	356	337	503
No. trials		7	14	30	23	30	15	7	126

TABLE 4. Percentage control of <u>Avena fatua</u> 'autumn' application, up to weed GS 23 (November to early January).

Treatment	Rate (g AI/ha)	YEAR 1987	1988	1989	1990	Mean
fenoxaprop-ethyl	120	100	99	97	98	98
diclofop-methyl	570	100	99	89	95	95
Panicles/m² on control		134	55	84	157	116
No. trials		3	5	6	11	25

TABLE 5. Percentage control of <u>Avena fatua</u> 'early spring' application, up to weed GS 29 (January to April).

Treatment	Rate (g AI/ha)	YEAR 1988	1989	1990	1991	Mean
fenoxaprop-ethyl	150	99	98	99	99	99
diclofop-methyl	1140	91	94	86	-	(92)
difenzoquat	990		-	-	90	(90)
Panicles/m² on control		210	152	118	179	145
No. trials		7	5	16	13	41

TABLE 6. Percentage control of <u>Avena fatua</u> 'late spring' application, up to weed GS 39 (mid-February to early June).

Treatment	Rate (g AI/ha)	YEAR 1985	1986	1987	1988	1989	1990	1991	Mean
fenoxaprop-ethyl	180	98	99	99	98	98	94	96	98
flamprop-M-isopropyl	600	75	82	85	90	85	81	78	84
Panicles/m² on control		96	74	53	281	208	134	169	123
No. trials		4	5	49	16	5	17	14	110

TABLE 7. Percentage control of other grass weeds with fenoxaprop-ethyl (no. of trials).

Grass Weed	Autumn (up to GS 23)	Early Spring (up to GS 29)	Late Spring (up to GS 39)
Poa trivialis	100 (2)	97 (4)	94 (4)
Phleum pratense	100 (1)	90 (2)	89 (2)
Phalaris paradoxa	93 (3)	91 (4)	88 (2)
Apera spica-venti	-	97 (3)	94 (2)

TABLE 8. Crop yields expressed as percentage of untreated (= 100) from applications of fenoxaprop-ethyl to control _Alopecurus myosuroides_.

Timing	Autumn	Early Spring	Late Spring
Rate (g AI/ha)	120	150	180
fenoxaprop-ethyl	207	177	188
Untreated yield (t/ha)	4.87	4.47	4.21
No. of trials (seasons)	12 (3)	39 (5)	42 (6)

TABLE 9. Crop yields expressed as percentage of untreated (= 100) from applications of fenoxaprop-ethyl to control _Avena fatua_.

Timing	Autumn	Early Spring	Late Spring
Rate (g AI/ha)	120	150	180
fenoxaprop-ethyl	156	206	154
Untreated yield (t/ha)	4.83	4.48	4.08
No. of trials (seasons)	5 (3)	5 (3)	31 (6)

TABLE 10. Relative crop yields expressed as percentage of untreated (= 100) from tolerance trials applied in the 'autumn'.

Treatment	Rate (g AI/ha)	YEAR 1985	1986	1987	1988	1989	Overall Mean
fenoxaprop-ethyl	120	98	101	101	101	99	100
" "	240	98	103	99	97	99	100
diclofop-methyl	1140	102	101	100	98	97	99
" "	2280	101	101	101	96	99	99
Untreated (Yield t/ha)		9.45	6.57	8.57	7.92	8.20	7.68
No. of trials		1	9	4	6	6	26

TABLE 11. Relative crop yields expressed as percentage of untreated (= 100) from tolerance trials applied in the 'early spring'.

Treatment	Rate (g AI/ha)	YEAR 1986	1987	1988	1989	1990	Overall Mean
fenoxaprop-ethyl	150	103	100	101	100	99	100
" "	300	98	101	97	100	98	100
diclofop-methyl	1140	98	99	104	101	100	100
" "	2280	102	101	102	101	100	101
Untreated (Yield t/ha)		9.10	7.10	7.57	7.49	7.80	7.46
No. of trials		1	11	4	7	5	28

TABLE 12. Relative crop yields expressed as percentage of untreated (= 100) from tolerance trials applied in the 'late spring'.

Treatment	Rate (g AI/ha)	YEAR 1985	1986	1987	1988	1989	1990	Overall Mean
fenoxaprop-ethyl	180	98	101	96	97	99	99	98
" "	360	96	101	99	97	98	100	99
diclofop-methyl	1140	100	97	103	97	98	97	100
" "	2280	95	96	102	96	99	98	99
Untreated (Yield t/ha)		7.59	7.88	7.38	8.35	7.90	7.75	7.68
No. of trials		6	4	30	9	8	15	72

control of Avena spp. was achieved overall. Results on other grasses can be found in Table 7. No adverse effects on crop vigour were observed in any of the trials.

Yields from the efficacy trials are presented separately for A. myosuroides (Table 8) and Avena spp. (Table 9).

Tolerance trials

Data is again presented separately for trials carried out in the autumn (Table 10) and in spring (Tables 11 and 12) according to the crop growth stage at application. No significant crop vigour effects were observed in any of the trials nor were there any significant effects on yield.

DISCUSSION

The level of control of A. myosuroides and Avena spp. achieved with fenoxaprop-ethyl was extremely high, irrespective of the time of application. Control was also very consistent from site to site, season to season and under various soil, seedbed and weather conditions, unlike the standard treatments which tended to give more variable control. These results reflect previous experiences with the product in the UK (Read & Hewson, 1990), in North America (Anderson et al., 1989) and in many other parts of the world (Huff et al., 1989). Fenoxaprop-ethyl also gave good control of some other grass weed species (P. trivialis, A. spica-venti, P. paradoxa and P. pratense).

Crop safety was extremely good and at no time were significant adverse effects noted in the trials. Yield data confirmed that fenoxaprop-ethyl is very safe to the crop, whether treated in the autumn or spring up to GS 39.

The high and consistent levels of grass weed control, coupled with good crop safety and wide window of application offered by fenoxaprop-ethyl allow farmers to benefit now from improved levels of weed control and the opportunity to achieve management of black-grass for the first time.

ACKNOWLEDGEMENTS

The authors would like to thank the farmers who kindly provided trials sites and also colleagues in the Technical Department of Hoechst UK Limited for their invaluable assistance.

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IMPROVED SELECTIVE GRASS WEED CONTROL IN SEMI-DWARF WHEAT BY EXOGENOUS GIBBERELLIC ACID

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ABSTRACT

Pot experiments have shown that gibberellic acid (GA) applied prior to or simultaneously (as a tank-mixture) with post-emergence herbicides to two grass weeds *Phalaris paradoxa* and *P. brachystachys* resulted in a significant increase in their sensitivity to foliar application of methabenzthiazuron and diclofop. A GA-sensitive tall wheat cultivar FA8193 responded to application of GA in a similar manner as the grass weeds and became more sensitive to post-emergence application of methabenzthiazuron. The GA-insensitive semi-dwarf wheat cultivar Lakhish, however, did not respond to GA and remained tolerant to methabenzthiazuron. GA added to the spray solution of several herbicides applied post-emergence to semi-dwarf Bet-Hashita wheat, grown in the field, did not alter the response of the crop to the herbicides, indicating the potential of GA in improving herbicide performance and lower herbicide input in semi-dwarf wheat crops.

INTRODUCTION

Selective control of grass weeds in cereal crops such as wheat and barley has always been a difficult task due to the taxonomic affinity between the crop and weeds. The selectivity of the currently used graminicides is not high enough to allow an increase of the herbicide rate in order to achieve adequate control of grass weeds without causing severe damage to the crop. Field performance of graminicides is often inconsistent and influenced by environmental condition such as temperature, humidity and soil moisture (Caseley, 1987; 1990).

Various attempts have been made to improve the efficacy of different herbicides, in order to lower chemical input to the environment and reduce the cost of weed control in arable crops (Varsano & Rubin, 1988; 1991). Dickson *et al.*, (1988; 1990) have shown that pre-treatment with GA increased the growth inhibition caused by glyphosate, diclofop and fluazifop to oats (*Avena sativa*). GA also improved the control of johnsongrass (*Sorghum halepense*) with fluazifop (Lee *et al.*, 1989a; 1989b; Yassin *et al.*, 1989). Moreover, Pinthus (1972), reported that pre-treatment with chlormequat (CCC), a known inhibitor of GA synthesis (Wheeler, 1980), significantly increased wheat tolerance to both terbutryn and simazine.

Currently, the majority of wheat cultivars grown throughout the world are dwarf or semi-dwarf. Unlike the tall wheat cultivars which dominated the fields until the mid seventies, the dwarf and semi-dwarf cultivars are not responsive to exogenous GA (Gale & Hanson, 1982). GA insensitivity is defined as a lack of elongation of the coleoptile and/or the sheaths of the first leaves following GA application (Gale & Gregory, 1977). The inheritance of the GA sensitivity and of that of dwarfisms is controlled by the same genes or by genes which are closely linked (Gale & Marshall, 1975). Our working hypothesis was based on the possible existence of differential sensitivity to GA between grass weeds and semi-dwarf wheat cultivars. The aim of this study was to examine the possibility of improving the selective performance of post-emergence herbicides in wheat and grass weeds by GA application, thus, allowing farmers to reduce the herbicide input.

MATERIALS AND METHODS

Spring wheat (cvs. FA8193 and Lakhish), *Phalaris paradoxa* and *P. brachystachys* were grown from seeds in 16x13x9 cm plastic pots. Ten wheat and 25 *Phalaris* plants were grown in perforated pots containing either vermiculite enriched with N, P, and K, 200 ppm of each or in a 1:1:1 (*V/V*) mixture of vermiculite, peat and sandy-loam soil enriched with 2.5 g 'Osmocote' and 175 mg 'Micromix' fertilizers per pot. The pots were held in a cooled glasshouse with temperature range from 4°C (min) to 30° C (max) with ambient photoperiod and light intensity.

Commercially formulated methabenzthiazuron ('Tribunil', Bayer, Germany), diclofop ('Iloxan', Hoechst, Germany) and gibberellic acid (GA) ('Berelex', ICI, UK) were used in the pot experiments. Chemicals were applied post-emergence (unless otherwise stated), on plants having three expanded leaves using a chain driven sprayer equipped with a 8001E - Tee-Jet nozzle delivering 340 l/ha at 25 psi. The spray solution was maintained at pH 4.0 by adding 1.5 ml/l urea phosphate just before application. Plant shoots were harvested approximately two weeks after treatment and their height, fresh and dry weight determined. In certain cases percent damage caused by the treatment was visually estimated and recorded. All glasshouse experiments consisted of four or six replicates in a randomized design and were repeated at least twice.

A field trial was carried out in a commercial semi-dwarf wheat (cv. Bet-Hashita) field which received all the regular treatments except herbicides. The soil was silty-clay and total seasonal rainfall and irrigation amounted to 530 mm. Commercialy formulated herbicides (see Table 5) were applied post-emergence at their recommended rates with and without GA at 50 ppm (wt/*V*), when the wheat plants were at the three to four leaf stage (GS 13-14). The spray solution was maintained at pH 4.0 and applied with a motorized knapsack sprayer delivering 250 l/ha. The trial consists of four replicates in a randomized block design with 16m^2 drilled plots of which 10 m^2 were combine-harvested.

RESULTS

Pre-emergence application of GA to both grass weeds grown in vermiculite as a soil drench (250 ml/pot of 25 ppm solution) resulted in a visible increase in plant height as expected (data not shown), and caused slight and negligible reduction of shoot dry weight (Table 1). Under these conditions, methabenzthiazuron applied post-emergence at the recommended rate (1.4 kg AI/ha) caused severe damage to both weed species whereas diclofop did not affect their growth. Application of either herbicide to plants pre-treated with GA resulted in a significant increase in shoot damage of both weeds as compared to that caused by the herbicides applied alone (Table 1).

TABLE 1. Effect of pre-emergence application of GA on the phytotoxicity of methabenzthiazuron and diclofop applied post-emergence to two *Phalaris* spp.

Herbicide (kg AI/ha)	GA (25 ppm)	*P. paradoxa*	*P. brachystachys*
		Shoot dry wt. (mg/plant)	
None	-	9.6	8.1
	+	8.8	8.0
Methabenzthiazuron	-	3.9	3.1
(1.4)	+	2.1*	2.6
Diclofop	-	10.7	8.1
(0.54)	+	2.5**	4.2*

*, ** Significant GA effect at $p<0.05$ and $p<0.01$, respectively

This increase in herbicidal activity induced by pre-emergence applied GA was more pronounced in diclofop than in methabenzthiazuron and in *P. paradoxa* more than in *P. brachystachys*. The efficacy of pre-emergence application of GA was compared to that of a tank mixture of GA with methabenzthiazuron (Table 2). GA itself had no obvious effect on the growth of *P. brachystachys*. GA applied as either a pre-emergence treatment or as a tank mixture with methabenzthiazuron significantly increased the injury caused by the herbicide alone, even when applied at a low rate (Table 2). These data suggest that simultaneous application of GA and the herbicide as a post-emergence tank mixture is feasible.

TABLE 2. Response of *P. brachystachys* to methabenzthiazuron applied post-emergence following pre-emergence or post-emergence (tank-mix) with GA (25 ppm)

Methanenz-thiazuron	GA application		
	None	Pre-emergence	Post-emergence
(kg AI/ha)	Shoot dry wt. (mg/plant)		
0.0	6.7	7.9	6.2
0.35	5.0	3.6	3.8
1.40	5.6	4.4	4.3
LSD (0.05)	---------- 0.92-----------		

GA applied post-emergence as a tank mixture with either methabenzthiazuron or diclofop enhanced the appearance of injury symptoms (Table 3). In *P. brachystachys*, four days after treatment, the GA effect was more pronounced at high rates of both herbicides. In *P. paradoxa* however, the effect was visible only at the highst rate of diclofop. Later on (12 days after treatment), the advantage of the added GA remained visible mainly when combined with low rates of both herbicides, while plants treated with the highest rate were already dead.

The tall wheat cultivar FA8193 responded to GA with a significant increase in plant height and shoot weight, whereas GA had no such effect on the semi-dwarf cultivar Lakhish (Table 4). Both cultivars exhibited a high degree of tolerance to methabenzthiazuron applied at double the recommended rate (2.8 kg AI/ha), and only when treated with fpur times the recommended rate, some damage was observed. Combination of GA with different rates of methabenzthiazuron resulted in a reduction of both plant height and shoot biomass in FA8193 but not in Lakhish. This, indeed, should be attributed to the higher sensitivity of FA8193 to exogenous GA than that of Lakhish, established in previous observations (Pinthus, 1987). Furthermore, the relatively high tolerance of the semi-dwarf cultivar to the GA-herbicide combination supports our hypothesis regarding the feasibility of exploiting the differential GA responses between weeds and semi-dwarf wheat for improved grass weed control.

In the field trial the addition of GA (50 ppm) to the herbicide did not alter the response of semi-dwarf Bet-Hashita wheat to herbicides applied at the recommended rate. Unfortunately, grass weed infestation was rather low and did not permit any conclusive evaluation of the expected contribution of the GA addition to their control. No injury symptoms or growth inhibition were observed in wheat plants throughout the season in any of the treatments examined. In spite of some differences between herbicide treatments, no significant yield decline due to GA addition was observed (Table 5).

TABLE 3. Response of *Phalaris paradoxa* and *P. brachystachys* to various rates of methabenzthiazuron and diclofop applied post emergence with and without GA.

	P. paradoxa				*P. brachystachys*			
	4 DAT*		12 DAT		4 DAT		12 DAT	
Herbicide (kg AI/ha)	GA -	GA +	GA -	GA +	GA -	GA +	GA -	GA +
	Injury (%)							
<u>Methabenzthiazuron</u>								
0.35	0	0	20	40	10	10	75	95
0.70	0	0	40	40	40	60	80	100
1.40	0	0	40	60	60	85	100	100
<u>Diclofop</u>								
0.09	0	0	20	20	10	10	75	95
0.18	0	0	60	75	10	40	80	100
0.54	20	60	80	100	20	60	100	100

* DAT = Days after treatment.

TABLE 4. Effect of methabenzthiazuron applied post-emergence with and without GA on the growth of tall FA8193 and semi-dwarf Lakhish wheat cultivars.

		FA8193		Lakhish	
Methabenz-thiazuron (kg AI/ha)	GA (25 ppm)	Plant height (cm)	Dry weight (g/plant)	Plant height (cm)	Dry weight (g/plant)
0	-	49.9	0.25	48.2	0.17
	+	56.9**	0.29*	45.8	0.17
1.4	-	56.1	0.26	43.0	0.17
	+	52.6*	0.25	45.5	0.16
2.8	-	52.6	0.26	44.4	0.14
	+	52.0	0.20*	44.3	0.14
5.6	-	45.8	0.11	41.1	0.09
	+	30.0**	0.08*	41.2	0.10

*, ** Significant GA effect at $p<0.05$ and $p<0.01$, respectively.

DISCUSSION

In the present study, a clear effect was observed of GA on plant height and little effect on plant dry weight in GA-sensitive wheat and weeds, but not in the GA-insensitive wheat Lakhish. Similar results were reported for oat plants treated with 200 ppm GA (Dickson *et al.*, 1988; 1990). It seems that pre-emergence administration of GA, when the compound penetrates through the germinating seeds and roots, is slightly more effective than foliar application, but the latter is far more practical for field application.

TABLE 5. Effect of herbicides applied post-emergence with and without GA on plant height and grain yield of cv. Bet Hashita semi-dwarf wheat.

Herbicide	Rate (kg AI/ha)	GA (50 ppm)	Shoot length (cm)	Grain yield (kg/ha)
Control	-	-	70	4231
	-	+	69	4060
Methabenzthiazuron	1.40	-	70	4220
		+	71	3900
Diclofop	0.54	-	71	4113
		+	72	4278
Tralkoxydim	0.25	-	73	4514
		+	68	4220
Fenoxaprop*	0.15	-	73	4510
		+	75	4407
LSD (0.05)			7.6	804

* + safener

Previous studies have shown that application of gibberellic acid may modify the activity of several herbicides in plants (see Rademacher, 1989 for recent review). Our results clearly indicate that GA selectively enhanced the performance of methabenzthiazuron and diclofop on *Phalaris* spp. and tall wheat, but not on the semi-dwarf wheat. The data from the field trial showing that GA combined with several herbicides caused almost no damage to the semi-dwarf wheat support the results obtained in the glasshouse experiments.

Diclofop and fluazifop were reported to cause severe membrane disruption in sensitive grasses due to inhibition of the key enzyme acetyl-coenzyme A carboxylase, which is involved in fatty acids biosynthesis (see Duke & Kenyon, 1988 for recent review). It was reported that GA enhances diclofop activity in oats due to an increased rate of stem and leaf expansion (Andrews, *et al.,* 1989). Dickson *et al.,* (1990) suggested that the GA-induced increase in herbicidal activity of diclofop, fluazifop and glyphosate is due to an extension of membranes and cell walls and an increase in herbicide translocation. Lee & Bendixen (1989b) have shown that GA increases the absorbtion of fluazifop in johnsongrass and alters its partitioning in the plant. We suggest that alteration of sink-source relations induced by GA may result in a modified assimilates movement in the phloem, thus affecting the translocation of phloem-mobile herbicides such as diclofop and fluazifop.

The urea herbicide methabenzthiazuron is known as inhibitor of PSII electron transport in the chloroplast. No alteration in photosynthesis was observed in either tall or semi-dwarf methabenzthiazuron-treated wheat due to GA treatment (Sibony, unpublished data). The effect of GA on membrane integration and cell size may result also in an increased methabenzthiazuron uptake and translocation.

The observed enhancement of herbicidal activity by adding GA to the spray solution and the established differential GA sensitivity between semi-dwarf wheat and grass weeds, should be exploited for lowering herbicide input and reduce the pesticide load on the environment. This should be further examined under field conditions with a wide spectrum of weeds and wheat cultivars.

ACKNOWLEDGMENT

This research was supported in part by a grant awarded by The Wolfson Fund.

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SEQUENTIAL HERBICIDE APPLICATIONS FOR BLACK-GRASS (ALOPECURUS MYOSUROIDES) CONTROL ON MINERAL SOILS WITH A STRONG TENDENCY TO ADSORB SOIL APPLIED HERBICIDES (HIGH Kd)

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ABSTRACT

During harvest years 1987-89, 15 experiments were carried out on commercial winter wheat crops using mixtures and sequences of tri-allate, chlorsulfuron/metsulfuron methyl, diclofop-methyl, isoproturon and chlorotoluron for the control of black-grass (Alopecurus myosuroides). Many of the sites selected showed a strong tendency to adsorb soil applied herbicides. Most of the treatments tested gave high levels (over 98%) of control at one or more sites. On average a high level of control (88%) was achieved from a tank-mix of chlorsulfuron/metsulfuron methyl + isoproturon applied early post-emergence. This was almost matched by an early post-emergence applied tank mix of diclofop-methyl + isoproturon (82.7%). A sequence of autumn applied isoproturon followed by a spring application of isoproturon gave the best control (95.7%) but this treatment was not tested in all years. Isoproturon as a single autumn application gave 74.6% control. When applied in the spring this treatment gave 48.6% control. The effect of the Kd of the site is discussed and it is concluded that in only some cases does the adsorption of the site explain the variability in results. Eleven of the sites were harvested and responses of up to 300% of the yield of the untreated plots were recorded. Yield response was loosely correlated with level of black-grass control with around 35 kg/ha of grain resulting from each 1% improvement in black-grass control.

INTRODUCTION

Heavy soils (clay/silts) in the central and eastern arable areas of England have traditionally grown winter wheat. Cultural practices in the middle to late 1970s encouraged early establishment of winter wheat by minimal (shallow) cultivations and straw disposal by burning. These practices on heavy soils not only encouraged a rapid build up of black-grass (Alopecurus myosuroides), but also resulted in an increase in the level of organic matter and burnt straw residues in the topsoil which could adsorb residual (soil-applied) herbicides and render them less effective (Moss, 1984). The area of heavy soils affected by this situation has never been accurately quantified but is clearly very substantial. For good reasons, farmers on these soils are reluctant to change their cropping or cultivation regime as these soils are best suited to autumn established crops. Sowing spring crops can be very delayed in a wet spring. While there has been a general increase in the amount of rotational ploughing (ie. fields ploughed approximately once every 3 to 5 years) there is considerable reluctance by farmers on heavy soils to plough, since minimal cultivations by tined equipment working approximately 7.5 cm deep tend to produce a very good soil structure in the topsoil with an increase in organic matter (including burnt straw residues).

The topsoil environment of these soils is a very difficult one for most residual herbicides to work effectively in. Most residual herbicides rely on root uptake by weeds and high levels of burnt straw residues tend to adsorb the herbicide. This can be partially measured by Kd, as demonstrated by Cussans et al., (1982). Herbicides in the substituted-urea group are most commonly used for black-grass control and practical experience has suggested that chlorotoluron performed less well than isoproturon on high adsorptive soils.

ADAS in 1985/86 started a series of experiments to investigate the use of five herbicides with slightly different characteristics and identify sequences which offered the most effective control of black-grass. The five herbicides chosen were tri-allate, chlorsulfuron/metsulfuron-methyl, diclofop-methyl, chlorotoluron and isoproturon. Tri-allate was chosen because it has vapour activity and does not need soil water to take it to the weed. Uptake is normally by the emerging shoot as it passes through the treated layer. Chlorsulfuron is known to be less strongly adsorbed by soil organic matter (and probably burnt straw residues) making it more available in the topsoil. Diclofop-methyl is mainly a foliage-acting herbicide (ie taken up mainly through the foliage) but also having a period of residual activity. Chlorotoluron and isoproturon were included as reference treatments. The 1985/86 results showed particular promise for chlorsulfuron based treatments (Flint, 1987). However during 1988 this chemical was withdrawn from the UK market by the manufacturer after problems with residues in some following broad-leaved crops. In harvest years 1988 and 1989 the treatments were amended to include only one based on chlorsulfuron and in 1989 to examine the effect of trifluralin.

MATERIALS AND METHODS

Fifteen experiments were carried out on a range of soil types in England in harvest years 1987 (5 sites), 1988 (4 sites) and 1989 (6 sites). All experiments were on commercially grown crops of winter wheat with naturally occurring populations of black-grass. Details of the sites are given in Table 1.

A range of pre-emergence, early post-emergence and spring treatments were applied with a plot sprayer at 200 - 225 l/ha of water with either 11002 or 8002 Tee-jets at 200, 210 or 250 kPa. Minimum plot size was 12m x 2m with 3 replicates. A complete randomised block design was used. The Kd of each site was measured by sampling the top 2.5 cm of soil in the autumn, after drilling but before herbicides were applied.

Herbicides tested included tri-allate, chlorsulfuron/metsulfuron methyl, diclofop-methyl, isoproturon, chlorotoluron and trifluralin alone, in tank-mix or as sequences. Full details of the chemicals used including the rates of AI used and application timings are given in Table 2.

The efficacy of herbicides was assessed by counting black-grass heads per m^2 in late June or July. Quadrat size varied according to black-grass density. In 11 of the experiments grain yield from a plot of at least 20 m^2 was measured by plot combine.

TABLE 1. Details of sites, location, soil type and husbandry.

Site Number	Location	Harvest year	Soil Type	Kd (chlorotoluron)	Variety	Drilling Date
1	Somerset	1987	Silty Clay	7.3	Avalon	20.10.86
2	Lincs	1987	Silty Clay Loam	5.5	Avalon	4.10.86
3	Norfolk	1987	Silty Clay Loam	13.4	Moulin	8.10.86
4	Bucks	1987	Silty Clay Loam	11.8	Mission	7.10.86
5	Lincs	1987	Sandy Loam	7.9	Brimstone	15.10.86
6	Norfolk	1988	Organic Silty Loam	11.1	Galahad	29.10.87
7	Oxon	1988	Silty Clay Loam	8.2	Mercia	23.10.87
8	Bucks	1988	Silty Clay Loam	8.6	Avalon	2.10.87
9	Dorset	1988	Silty Clay	5.6	Avalon	1.10.87
10	Norfolk	1989	Silty Loam	7.7	Mercia	2.11.88
11	Northants	1989	Clay	4.8	Slejpner	11.10.88
12	Dorset	1989	Clay	6.9	Galahad	7.10.88
13	Warwicks	1989	Clay	6.6	Hornet	29. 9.88
14	Oxon	1989	Organic Silty Loam	2.9	Mercia	4.10.88
15	Bucks	1989	Silty Clay	7.2	Galahad	5.10.88

RESULTS AND DISCUSSION

Weed Control

The level of black-grass control was very variable between sites and seasons. Levels of control were generally highest in 1987 harvest year. Table 2 contains an adjusted mean % control figure. This is intended to even out the differences between sites and season and to aid more meaningful comparisons to be made. The adjusted mean has been calculated by comparing each treatment with the average of 4 standard treatments (numbers 10, 11, 15 and 16) at each site. The performance of that treatment, as a percentage of the 4 standards, was then meaned across the sites at which it was present. This was converted back into a percentage control figure by expressing it as a percentage of the average of the standards across all sites. The unadjusted performance of all the treatments, at each site, can be found in Table 3.

Black-grass populations in July ranged from 113 to 1890 heads/m^2 and averaged 731. Overall, almost all treatments achieved over 98% control at one or more sites, even at high Kd. Of the treatments that were present at all sites the highest level of control was 88% from chlorsulfuron/ metsulfuron methyl + isoproturon (treatment 10) applied early post-emergence. This was almost matched (82.7% control) by diclofop-methyl + isoproturon applied at the same timing (treatment 15). At this timing isoproturon alone gave 74.6% control (treatment 11) and chlorotoluron 61.2% control (treatment 16). The two spring treatments, isoproturon alone

TABLE 2. Treatment details, adjusted mean % black-grass control and number of sites.

	Chemical treatment	kg AI /ha	Timing	Adjusted mean % control	Number of sites
1	tri-allate	2.25	a	47.4	5
2	tri-allate +	2.25	a	80.7	5
	chlorsulfuron/metsulfuron methyl	0.02			
3	tri-allate followed by	2.25	a	79.6	5
	chlorsulfuron/metsulfuron methyl	0.02	b		
4	chlorsulfuron/metsulfuron methyl	0.02	a	71.1	5
5	tri-allate +	2.25	a	84.7	4
	chlorsulfuron/metsulfuron methyl	0.02			
	followed by diclofop-methyl	0.567	b		
6	chlorsulfuron/metsulfuron methyl	0.02	a	77.6	5
	followed by tri-allate	2.25	b		
7	chlorsulfuron/metsulfuron methyl	0.02	a	84.3	5
	followed by diclofop-methyl	1.134	b		
8	chlorsulfuron/metsulfuron methyl	0.02	a	83.7	5
	followed by diclofop-methyl	0.567	b		
9	chlorsulfuron/metsulfuron methyl	0.02	a	75.5	5
	followed by isoproturon	2.1	c		
10	chlorsulfuron/metsulfuron methyl	0.02	b	88.0	15
	+ isoproturon	2.5			
11	isoproturon	2.5	b	74.6	15
12	diclofop-methyl	1.134	b	77.5	5
13	diclofop-methyl +	1.134	b	83.4	5
	chlorsulfuron/metsulfuron methyl	0.02			
14	diclofop-methyl +	0.567	b	82.0	4
	chlorsulfuron/metsulfuron methyl	0.02			
15	diclofop-methyl + isoproturon	0.567 + 2.5	b	82.7	15
16	chlorotoluron	3.5	b	61.2	15
17	diclofop-methyl	0.567	b	51.0	3
18	isoproturon	2.1	c	48.6	15
19	diclofop-methyl + isoproturon	0.567 + 2.1	c	56.5	15
20	isoproturon	2.5	b	95.7	10
	followed by isoproturon	2.1	c		
21	isoproturon + trifluralin	2.5 + 0.96	b	75.0	6
22	diclofop-methyl + isoproturon	1.134 + 2.1	c	73.8	6
23	trifluralin	0.96	b	59.3	6
	followed by isoproturon	2.1	c		
24	isoproturon	3.75	b	74.0	6
25	isoproturon	1.875	b	83.9	6
	followed by isoproturon	1.875	c		
	Untreated heads per m^2 (July)			731	

Treatment timings a (pre-emergence)
b (black-grass 2-3 leaves)
c (Spring, black-grass up to GS 22-23)

(treatment 18) and diclofop-methyl + isoproturon (treatment 19), gave poorer results at 48.6 and 56.5% control respectively. These results confirm the benefit of chlorsulfuron based treatments, in combination with isoproturon, for black-grass control on a range of mainly high Kd soils. It is encouraging that this performance is almost matched by an autumn applied tank-mix of diclofop-methyl + isoproturon. The advantage of the addition of diclofop-methyl to isoproturon, about 8% in both the autumn and spring, may have been influenced in this series of sites by the known presence of black-grass partially resistant to diclofop-methyl on the farm where sites 3, 6 and 10 were located. However this improvement in performance is in line with other ADAS trials (unpublished), but lower than the 19% improvement reported in some cases (Read & Hewson, 1988b).

Overall the best results were achieved from a sequence of autumn isoproturon (2.5 kg AI/ha) followed by spring isoproturon (2.1 kg AI/ha) (treatment 20) which gave almost 96% control on average. This was the only treatment for which the adjusted mean performance was better than the chlorsulfuron/ metsulfuron methyl + isoproturon treatment. Although only tested at six sites in 1989 the sequence of isoproturon (1.875 kg AI/ha) autumn and spring (treatment 25) appeared to be similar in its effectiveness to the diclofop-methyl + isoproturon (treatment 15) tank-mix.

Spring treatments gave poorer results. This has been shown in previous experiments (Baldwin, 1979) and confirmed more recently (Read & Hewson, 1988a). Smaller black-grass is easier to kill in autumn/winter. Drier conditions with larger weeds in the spring make control more difficult. Isoproturon gave 26% less control in spring compared with an autumn application (treatment 18 and 11). The addition of diclofop-methyl to isoproturon (treatment 19) gave an improvement of about 8% over the spring applied isoproturon alone but this was still at an inferior level to the autumn treatments.

Only some of the performance is explained by Kd of the site. Generally the chlorsulfuron/metsulfuron methyl + isoproturon (treatment 10) was least affected by Kd. Next least affected was autumn applied diclofop-methyl + isoproturon (treatment 15), then autumn applied isoproturon (treatment 11), autumn applied chlorotoluron (treatment 16), spring applied diclofop-methyl + isoproturon (treatment 19) with spring applied isoproturon (treatment 18) being most affected. However at sites 1 (Kd 7.3), 5 (Kd 7.9) and 10 (Kd 7.7) the performance of all the treatments listed above was good. At a Kd of 7.2 (site 15) and Kd of 8.2 (site 7) the results were much poorer. It is clear from these results that Kd is only part of any explanation in variability in black-grass control. It is likely that at high Kd (over about 6) environmental conditions become more important and increase the likelihood of variable results.

Grain Yield

Of the 15 sites 11 were harvested and grain yield measured. The full results of these sites are given in Table 4. The highest responses, up to 300% of the untreated yield, were recorded on the sites with over 1000 black-grass heads m^2 on the untreated plots. The lowest yield responses however, were not at site 14 which had the lowest level (113 heads/m^2) of black-grass, but at site 2 which had 495 heads/m^2. In only one case was yield reduced over the untreated plots. This was at site 3 where spring applied diclofop-methyl + isoproturon (treatment 19) gave 77% of the

TABLE 3. Black-grass control as % of untreated by individual site.

Treatment No.	Site Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	52	99	8	53	72										
2	96	100	99	87	90										
3	98	98	92	93	86										
4	94	97	99	36	89										
5	100	100	99		96										
6	97	99	99	63	95										
7	99	100	100	99	95										
8	100	100	99	95	96										
9	99	98	98	84	65										
10	100	98	99	93	95	98	80	92	76	100	93	85	67	99	20
11	98	98	94	89	90	89	33	62	67	92	74	62	26	88	64
12	98	99	72	89	98										
13	100	98	98	95	97										
14	99	99	96		89										
15	99	98	97	94	96	91	37	77	81	97	92	71	57	99	50
16	99	97	34	89	48	85	23	57	68	92	45	17	46	94	47
17		95	21		63										
18	83	96	70	42	37	78	20	33	70	97	58	32	6	57	6
19	94	94	47	52	60	76	13	50	71	81	62	50	35	79	18
20						96	70	92	95	98	92	71	64	99	65
21										95	80	62	37	99	44
22										80	83	54	61	86	35
23										79	91	37	20	91	28
24										98	92	67	40	99	25
25										97	96	54	56	98	54
Untreated (heads/m^2)	580	495	1069	672	1233	314	245	344	304	1211	1114	823	1890	113	562
Kd (chlorotoluron)	7.3	5.5	13.4	11.8	7.9	11.1	8.2	8.6	5.6	7.7	4.8	6.9	6.6	2.9	7.2
Treatment dates															
a (pre-emergence)	24/10	9/10	10/10	7/10	6/11	-	-	-	-	-	-	-	-	-	-
b (black-grass GS12/13)	29/11	10/12	12/12	28/11	4/2	21/12	4/12	13/11	26/11	20/12	13/12	5/12	7/11	4/11	1/11
c (black-grass GS22/23)	9/4	31/3	30/3	12/3	13/3	2/3	31/3	17/2	15/2	7/3	21/2	7/3	31/1	14/2	31/1

TABLE 4. Grain yield as % of untreated by individual site.

Treatment No.	Site Number 2	3	5	6	8	9	10	11	12	13	14	Adjusted Mean	Adjusted % control*
1	106	117	162									165	52.4
2	102	288	204									228	88.1
3	102	225	198									209	84.0
4	103	260	193									217	87.0
5	100	257	203									219	90.0
6	102	308	193									229	89.5
7	109	277	196									227	90.0
8	103	240	202									216	90.0
9	102	234	181									204	79.2
10	101	282	204	117	139	135	282	265	208	327	118	202	92.9
11	102	269	167	121	146	126	268	203	182	177	115	171	75.3
12	109	138	176									182	81.6
13	101	254	202									218	89.5
14	108	236	181									209	86.5
15	109	258	151	115	146	136	272	244	180	213	113	184	87.7
16	111	206	166	106	139	133	250	109	117	193	118	160	60.7
17	103	147	190									181	52.7
18	102	171	114	105	141	127	200	197	146	168	105	154	54.8
19	107	77	138	106	151	135	235	178	132	177	109	154	63.6
20				109	153	137	285	275	189	254	120	198	93.3
21							268	254	178	175	102	183	77.6
22							112	231	154	191	107	157	79.2
23							207	244	151	128	103	159	63.7
24							285	247	181	224	115	196	82.9
25							294	275	177	238	107	202	85.1
LSD (p<=0.05)	15.1	70.1	32.9	11.8	19.1	19.6	30.6	50.7	38.9	41.4	14.6		
Untreated (tonnes/ha)	4.55	1.73	3.13	5.46	3.00	4.33	2.62	2.32	3.56	1.73	6.68	3.56	
(black-grass heads/m²)	495	1069	1233	314	344	304	1211	1114	823	1890	113	810	

* Adjusted mean % black-grass control of the 11 sites which were harvested

untreated yield. The cause of this is unclear since no visible crop damage was recorded.

Generally the yield response was in line with the figures for percentage control of black-grass and was of the order of 1% extra grain yield for each 1% improvement in black-grass control. This is equivalent to about 35 kg/ha grain for each 1% improvement in black-grass control and is identical to earlier results (Clarke, 1987).

ACKNOWLEDGEMENTS

Financial support for this work from the Ministry of Agriculture, Fisheries and Food (MAFF) is gratefully acknowledged. The author would also like to thank his colleagues for carrying out the experiments, analysing and supplying the data. The willing co-operation of the farmers on whose farms these experiments were sited is also gratefully acknowledged.

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PROHEXADIONE-CALCIUM, A NEW PLANT GROWTH REGULATOR FOR CEREALS AND ORNAMENTAL PLANTS.

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ABSTRACT

Prohexadione-calcium, calcium salt of 3,5-dioxo-4-propionylcyclohexanecarboxylic acid, is a promising new plant growth regulator with foliar activity on a wide range of plants, inhibiting gibberellin biosynthesis at the 3β-hydroxylation step of GAs. Prohexadione-calcium can be used as an antilodging agent for small grain cereals such as rice, wheat and barley. It can also be used as a growth retardant for turf grasses to reduce mowing times or as a dwarfing agent for flower and ornamental plants.

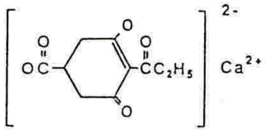
This paper provides chemical and physical properties, toxicological profile, and biological effects of prohexadione-calcium.

INTRODUCTION

The use of plant growth regulators as antilodging agents in cereals and as growth retardants in turf, flower and ornamental plants has become common practice recently. Prohexadione-calcium is a new plant growth regulator discovered and developed by Kumiai Chemical Industry Co., Ltd. and Ihara Chemical Industry Co., Ltd.(Toyokawa et al,1987; Takahashi et al,1987). This paper describes its chemical, physical and biological properties, its use as an antilodging agent in cereals and as a growth retardant in turf, flower and ornamental plants.

CHEMICAL AND PHYSICAL PROPERTIES

Chemical formula :



Chemical name (IUPAC) : calcium salt of 3,5-dioxo-4-propionylcyclohexanecarboxylic acid
Common name (BSI) : prohexadione-calcium
Code number : BX-112, KIM-112, KUH-833
Empirical formula : C10 H10 Ca O5
Molecular weight : 250.27
Appearance : White fine powder
Melting point : > 360° C
Vapour pressure : 1.335×10^{-5} Pa at 20° C
Solubility : 174.2 mg/l in Water at 20 °C, 1.11 mg/l in methanol

TOXICOLOGY OF TECHNICAL MATERIAL

Acute toxicity	: Oral LD50 rats, mice	> 5000 mg/kg
	Dermal LD50 rats	> 2000 mg/kg
	Inhalation LC50 rats	> 4.2 mg/l
Acute fish toxicity	: Carp LC50	> 150 mg/l
	Bluegill sunfish LC50	> 100 mg/l
	Rainbow trout LC50	> 100 mg/l
Irritation	: Skin, rabbit	non-irritant
	Eye, rabbit	minimum
Mutagenicity	: Non-mutagenic by the Ames Test, DNA damage and micro nucleus test.	
Teratogenicity	: Non-teratogenic, Rat and rabbit.	
Subchronic toxicity (3-week feeding study)	: No effect level,Rats : 1000 ppm, Dogs : 80 mg/kg/day	

FORMULATIONS

Flowable concentrates or dry flowable formulations at different contents of active ingredient are available.

MODE OF ACTION

Prohexadione-calcium reduces stem and internode elongation of a number ofplants. It has relatively low activity following application to soil and is taken up principally by plant foliage. The growth retardation of rice plants caused by the compound is fully alleviated by exogenously applied gibberellins(GA), GA1 or GA3, but not by GA19 or GA20. It acts by inhibiting gibberellin biosynthesis in the plant at the 3β-hydroxylation of GAs, the last step of gibberellin activation (Nakayama *et al*, 1990).

ENVIRONMENTAL STUDIES

The degradation of this compoundin soil is very rapid, and microbial degradation plays a major role. This rapid soil metabolism allows for rotational crop flexibility.

MATERIALS AND METHOD

In greenhouse tests conducted in Japan, prohexadione-calcium was applied as a 25% flowable formulation. Post-emergence application was made with a water volume of 1000 l/ha 15-25 days after seeding or transplanting, when seeded plants reached 1-4 leaf growth stage. A non-ionic surfactant was added to the spray solution. Plant height and root weight measurement were made 20 or 30 days after treatment. Also pre-emergence soil application and pre-plant soil incorporation applications were made. Ornamental chrysanthemum(*Chrysanthemum morifolium*)was treated 3 times at intervals of 10 days by over-the-top foliage or partial (growing point) spray treatment at 500ppm concentration. Plant height and flower bud diameter were measured at various intervals. The effect of prohexadione-calcium on the plant height and mowed turf weight of Japanese carpetgrass(*Zoysia matrella*) was examined at rates of 125-500 g AI/ha. There were two mowings during this trial at 30 and 50 days after treatment.

Field experiments were performed between 1988 and 1991 in Western Europe and Japan. The field trials for winter wheat and barley were conducted with 4 replicates in accordance with the regulations of the German and French authorities. The plot size was at minimum 12 m² and received optimal fertilizer and plant protection treatments. Prohexadione-calcium was applied as 10% dry flowable formulation, and in spray volumes of 250 to 400 l/ha. No surfactant was added. Standard compounds were commercially available formulations. Crop height and lodging were assessed at various intervals after treatment. Growth stages were defined according to the decimal code for cereals. In field trials for transplanted rice conducted in Japan, prohexadione-calcium was applied as 1% flowable formulation with adjuvants. The size of replicated randomised field plots was 25 m². The compound was applied in a spray volume of 1000 l/ha. The application was carried out with small plot spraying equipment.

RESULTS AND DISCUSSION

Greenhouse tests demonstrated plant growth inhibitory activity of prohexadione-calcium at low rate on a wide range of monocotyledonous and dicotyledonous plants, including woody plants. The activity applied post-emergence was superior to pre-emergence or soil-incorporation activity. In comparison with a clear inhibitory activity on plant height, no effect was observed on root fresh weight of rice seedlings (Tables 1, 2 and 3).

TABLE 1. Growth inhibitory activity of prohexadione-calcium applied post-emergence and evaluated 30 days after treatment (greenhouse tests)

Plant species	Rate g AI/ha		Plant species	Rate g AI/ha	
	1000	300		1000	300
Barley	3	3	Soybean	2	1
Wheat	3	3	Cotton	3	2
Rice	3	3	Sugar beet	3	2
Maize	1	1	Cucumber	3	2
Japanese lawngrass	3	3	Morningglory, ornamental	3	3
Japanese carpetgrass	3	3	Chrysanthemum, ornamental	3	2
Bermudagrass	3	2	Flower cabbage, ornamental	3	2
Creeping bentgrass	3	2	Carnation, ornamental	3	2
Kentucky bluegrass	2	2	Cockscomb, ornamental	3	2
Perennial ryegrass	3	2	Mandarin orange (planted)	2	1
Italian ryegrass	3	2	Apple (planted)	2	1

Score: 0 = no inhibition, 1 = 1-20% inhibition, 2 = 21-50% inhibition, 3 = > 50% inhibition

TABLE 2. Percentage reduction of plant height with prohexadion-calcium pre-emergencesoil surface and pre-plant soil-incorporation treatments

Plant species	Soil surface treatment			Soil incorporation treatment		
	Rate g AI/ha			Rate g AI/ha		
	3000	1000	300	3000	1000	300
Barley	0	0	0	10	0	0
Wheat	0	0	0	6	0	0
Rice	0	0	0	20	6	0
Soybean	0	0	0	0	0	0
Cotton	0	0	0	0	0	0
Sugar beet	0	0	0	0	0	0

TABLE 3. Effects of prohexadione-calcium on plant height and root fresh weight of rice seedlings when applied post-emergence(greenhouse trials)

Treatment	Plant height				Root fresh weight			
	Rate g AI/ha				Rate g AI/ha			
	400	200	100	50	400	200	100	50
Prohexadione-calcium	62	71	84	90	103	100	101	100
Untreated	17.4 cm = 100				105 mg = 100			

The influence of prohexadione-calcium on the morphology of ornamental chrysanthemum by over-the-top foliage spray treatment and partial, growing point, spray treatment was assessed. Both whole plant and growing point treatments induced a dwarfing effect on plant height of chrysanthemum, the leaf and flower bud size remaining unchanged(Table 4).

Prohexadione-calcium inhibited turf plant growth of Japanese carpetgrass(<u>Zoysia matrella</u>) at 125-500 g AI/ha. It also reduced strongly mowed grass weight at 30 DAT. The turf growth recovered remarkably in the next 20 days. These results demonstrate that prohexadione-calcium can be used without damage as a growth retardant for turf grasses to reduce mowing times (Table 5).

TABLE 4. Effects of prohexadione-calcium on plant height, flower bud size of ornamental chrysanthemum by over-the-top foliage spray treatment and partial(growing point) spray treatment at a concentration of 500ppm solution

Treatment	Application method	Plant height(cm)			Flower bud size (cm)
		27DAT	46DAT	69DAT	83DAT
Untreated		64.8	91.2	106.3	21.0
Prohexadione-calcium	Over-the-top	46.5	56.2	64.0	20.7
	Partial	46.3	60.5	72.5	19.3

TABLE 5. Percentage reduction of plant height and mowed fresh weight with prohexadione-calcium against Japanese carpetgrass when applied post-emergence

Treatment	Rate g AI/ha	Plant height				mowed fresh weight	
		10	20	30	50 DAT	1-30	31-50 DAT
Prohexadione calcium	500	47	52	67	28	72	3
	250	28	46	55	18	69	0
	125	19	35	43	13	52	0
Untreated		(16	26	42	46 cm)	(3.1	1.9 g/pot)

Prohexadione-calcium reduced crop height of winter wheat at application timings between GS 29 and GS 45 under field conditions. The early applications mainly reduced the length of lower internodes while the upper internodes were not affected as much. The later timings of application led to a reduction in length of the upper internodes. Rates of 75 and 125 g AI/ha applied GS 30 to 39 resulted in crop shortening of about 7-13% and a lodging index reduction which was superior to the standard compounds used. The yield of prohexadione-calcium treated plots was superior to that of untreated severely lodged plots. These results demonstrate that prohexadione-calcium prevents yield loss due to lodging and it has great potential for use as an anti-lodging agent in wheat and barley (Tables 6 and 7).

In the case of rice, prohexadione-calcium reduced lodging effectively at a lower rate, 10 g AI/ha, than in the case of wheat and barley. The application timing to rice was from 2 weeks before heading to just before heading. Crop yields with prohexadione-calcium were greater than untreated (Table 8).

TABLE 6. Effects of application timing of prohexadione-calcium on crop height and lodging in winter wheat (mean of 2 trials in Germany)

Treatment	Rate g AI/ha	Crop height at GS 69/75	Lodging index* at GS 89
Crop GS 29 at application			
Untreated		116cm=100	54
Prohexadione-calcium	125	94	14
Chlormequat	1440	91	25
Crop GS 35/39 at application			
Untreated		115cm=100	49
Prohexadione-calcium	125	87	1
Mepiquat + ethephon	690	93	40
Crop GS 45 at application			
Untreated		115cm=100	71
Prohexadione-calcium	125	79	1
Mepiquat + ethephon	690	95	55

* lodging index = lodged area(%) x lodging inclination(0 to 100) x 1/100

TABLE 7. Effects of prohexadione-calcium on crop height of winter wheat and winter barley (mean of 3 trials in Germany, France)

Treatment	Rate g AI/ha	Crop GS at application	Crop height at GS 69/71	
			winter wheat	winter barley
Untreated			94cm=100	116cm=100
Prohexadione-calcium	75	30-39	87	93
Chlormequat	1440	25-30	96	
Mepiquat + ethephon	690	37-39	91	95
Ethephon	480	32-39		98

TABLE 8. Effects of prohexadione-calcium on culm length, ear length, lodging and yield of rice at three application timings (12, 5 and 1 DBH, days before heading)

Treatment	Application timing	Rate g AI/ha	% culm length	% ear length	Lodging % area lodged	Yield % of Untreated
Untreated			(87.9cm)	(17.0cm)	32	(4880kg/ha)
Prohexadione-calcium	12DBH	10	93	101	15	106.4
		20	86	99	7	104.3
Prohexadione-calcium	5DBH	10	90	102	9	101.7
		20	85	105	5	102.5
Prohexadione-calcium	1DBH	10	86	106	5	106.6
		20	84	103	3	104.7

CONCLUSIONS

1. Greenhouse tests demonstrated the plant growth inhibitory activity of prohexadione-calcium at low rates on a wide range of monocotyledonous and dicotyledonous plants.

2. The activity when applied post-emergence is superior to pre-emergence or soil incorporation activity, and no effect can be observed on root fresh weight in contrast to a clear inhibitory activity on stem elongation.

3. Prohexadione-calcium induces stem shortening, has flexibility of application timing and prevents yield loss by lodging. It therefore has great potential for use as an anti-lodging agent for small grain cereals such as rice, wheat and barley.

4. It also can be used as a growth retardant for turf grasses to reduce mowing intervals or as a dwarfing agent for flower and ornamental plants.

ACKNOWLEDGEMENTS

The authers would like to acknowledge the co-operation of our colleagues in Kumiai Chemical Company, Ihara Chemical Company, K·I Chemical Reserch Company and BASF Aktiengesellschaft.

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ROLE OF IMAZAQUIN IN AC 4447 : EFFECTS ON ROOTS AND FLAG LEAVES OF WINTER WHEAT

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ABSTRACT

AC 4447, a plant growth regulator containing chlormequat chloride + choline chloride + imazaquin, was initially introduced for the control of lodging in winter wheat. This paper presents the results of studies conducted to determine the role of imazaquin in the combination and the effects of AC 4447 on the winter wheat plant.Studies using 14^{C}-labelled compounds revealed that imazaquin increased the mobility and the pattern of distribution of chlormequat in the plant.Growth chamber experiments in aeroponic conditions showed out that foliar treatment at growth stage 22 (Tottman & Makepeace, 1979) increased the dry matter and the surface area of the root system. Glasshouse studies indicated that application of AC 4447 at growth stage 30 increased the area and the chlorophyll content of the flag leaf blades.Imazaquin reinforced the effects observed on the flag leaves by chlormequat.

INTRODUCTION

AC 4447 was introduced in France in 1985 as a plant growth regulator for the control of lodging in winter wheat.

AC 4447 contains 3 active ingredients:

- chlormequat chloride (CCC) 368 gai/litre, an inhibitor of gibberellic acid synthesis.
- choline chloride 28 gai/litre which increases chlormequat chloride penetration and translocation.
- imazaquin 0.8 gae/litre, an inhibitor of acetohydroxyacid synthase, the first enzyme in the biosynthetic pathway to valine, leucine and isoleucine (Shaner *et al*., 1984).

In field experiments, AC 4447 was showed to shorten the stem and increase the grain yield with or without lodging (Couvreur, 1987; Kleinhans and Lipatoff, 1991). In order to determine the role of imazaquin in AC 4447, 14^{C}-labelled compounds were used to follow uptake, translocation and metabolism of active molecules alone or in combination (AC 4447). Studies of the effects of AC 4447 on roots and flag leaves were conducted in the growth chamber and glasshouse and the influence of these effects on the yield determined

MATERIALS AND METHODS

Effects of imazaquin on uptake, translocation and metabolism of CCC in winter wheat (cv.Fidel)

The experimental procedures used are detailed in Table 1.

TABLE 1. Experimental procedures

	UPTAKE	TRANSLOCATION	METABOLISM
Growth condition	growth chamber	glasshouse	glasshouse
Stage of treatment	22	30	30
Treated leaf no. on the main stem	4	5	7+8
Treatments (*)	1+2+3+4	1+3+4	1+2+3+4
Sampling time (h)	1,6,12,24	1,6,24,48,120,240	3,6,24,72
Replication	3	2	4

(*) 1= ^{14}C-CCC, 2= ^{14}C-imazaquin, 3= AC 4447 (^{14}C-CCC),
4 = AC 4447 (^{14}C-imazaquin)
Dose of compounds was 45µg of CCC and 0.1 µg of imazaquin for each treated leaf.

Uptake and translocation were assessed by measuring radioactivity of the treated leaf, main stem, tillers, roots and of the water used for rinsing the treated leaves. Metabolism of the labelled compounds was determined by counting the radioactivity of the fractions of free imazaquin, CCC and metabolites after separation by chromatography.

Effects of AC 4447 on root growth

The effect of AC 4447 on winter wheat root development was studied using an aeroponic system in a growth chamber. 20 plants received a foliar treatment at growth stage 22 and were compared with 20 non-treated plants. Root length was measured three times a week. Plants were collected 10 days and 20 days after treatment. Root dry matter weight was determined and root surface area was assessed with a titrimetric method (Wilde & Woight, 1949).

Effects of AC 4447 on flag leaves

Field trials showed that application of AC 4447 could increase grain yield even in absence of lodging. This observation lead to the study of the effects of AC 4447 on the flag leaf which makes the greatest contribution to yield. Wheat plants were grown in a greenhouse in PVC tubes (8cm x 40 cm) containing a sandy soil (one plant/tube). Plants were watered daily and fertilized by nutrient solution (Hoagland & Arnon, 1950). Total nitrogen supply was equivalent to 0.125 g per pot. At growth stage 30, plants were divided into 3 batches:

1- Control
2- Plants treated with chlormequat chloride (920 gai/ha) + choline chloride (70 gai/ha) (300 seedlings/m^2)
3- Plants treated with AC 4447: chlormequat chloride (920 gai/ha) + choline chloride (70 gai/ha) + imazaquin (2 gae/ha) (300 seedlings/m^2)

At growth stage 61, plants were collected. Flag leaf area and dry matter weight were measured. The chlorophyll content was determined spectrophotometrically (Inskeep, 1985).

RESULTS AND DISCUSSION

Effects of imazaquin on uptake, translocation and metabolism of CCC in winter wheat (cv. Fidel)

CCC was rapidly absorbed. One hour after treatment more than 80% of the applied 14^{C} was detected in the whole plant (Figure 1). Only 18% of imazaquin was absorbed after one hour. The absorption kinetic of CCC applied alone or in combination with imazaquin was unaltered. However the absorbtion of imazaquin was increased by the addition of CCC. These compounds remained mostly located in the treated organ (85% in the leaf).

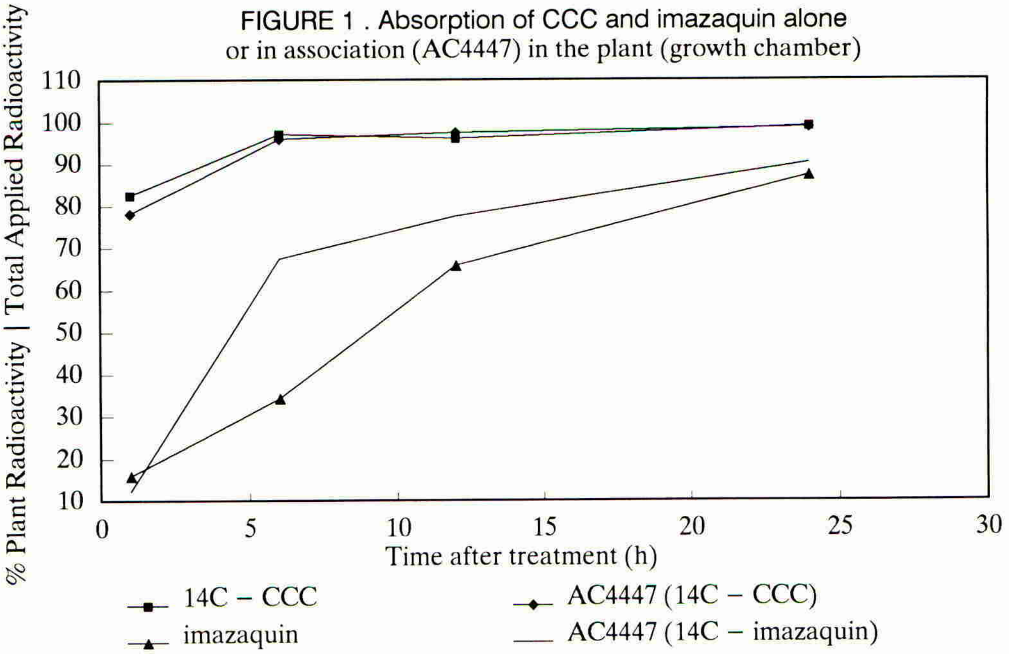


FIGURE 1 . Absorption of CCC and imazaquin alone or in association (AC4447) in the plant (growth chamber)

This confirms the low mobility of CCC (Lord & Wheeler, 1981). After 10 days, imazaquin greatly increased the translocation of CCC into the main stem and tillers, 8.3% and 2.1% respectively of the total applied radioactivity versus 3% and 1.2% for CCC alone (Figure 2). Studies of the metabolism of imazaquin in the plant showed its half life to be 3.3 days when applied alone and 6 days when in combination with CCC (Figure 3). It would appear therefore that the combination CCC and imazaquin reduces the degradation of each of the two compounds.

FIGURE 2 . Influence of imazaquin on the translocation of CCC to the main stem (glasshouse)

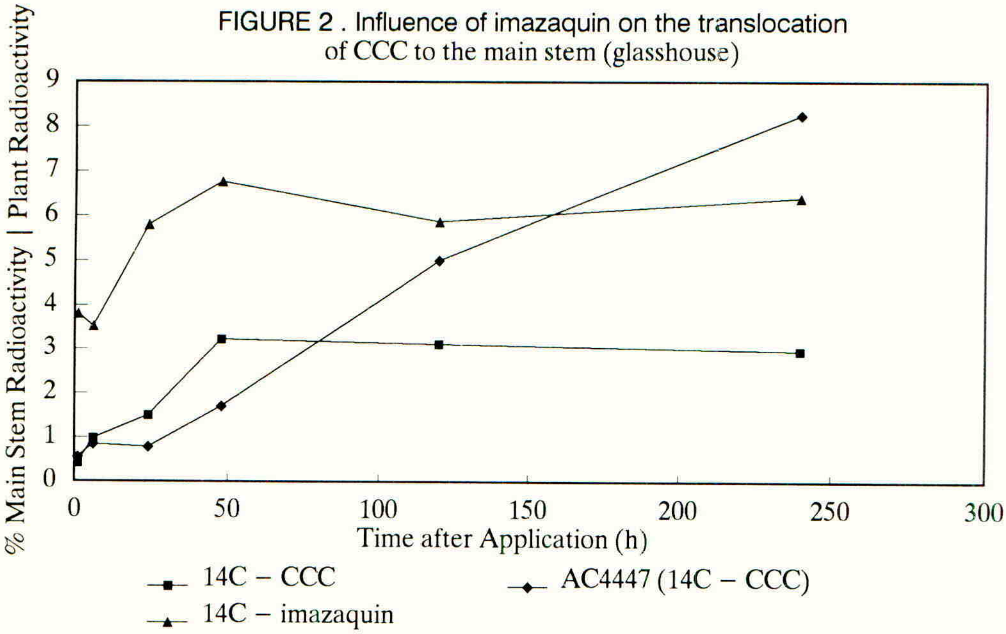
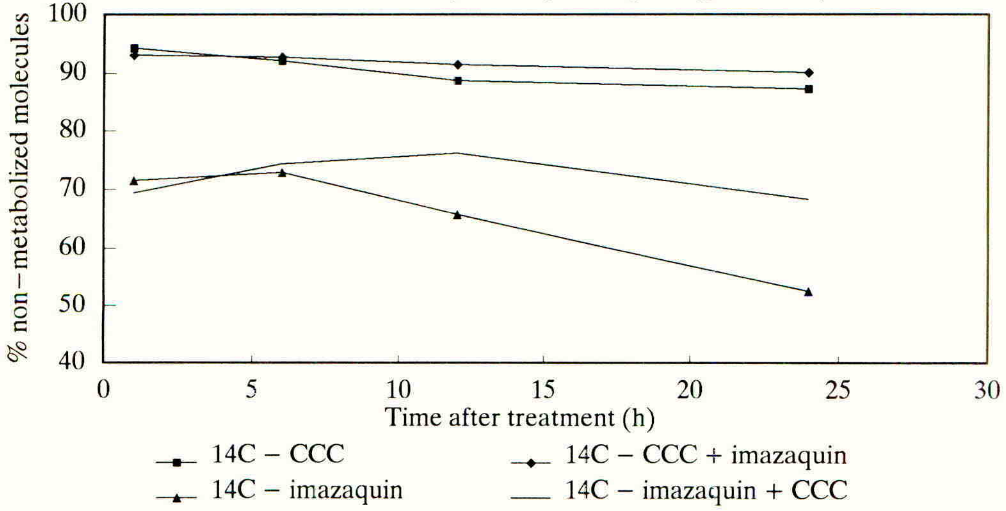


FIGURE 3 . Degradation of CCC imazaquin alone or in association (AC4447) in the plant (glasshouse)

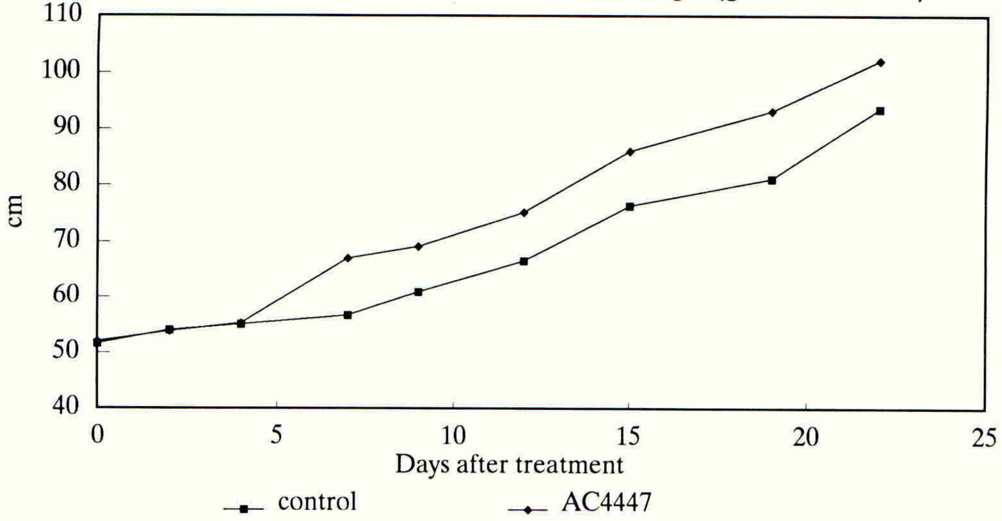


Imazaquin increased the mobility of CCC and modified its translocation pattern into the plant. The metabolism of both imazaquin and CCC were reduced when applied in combination as AC 4447. Increase in mobility and reduction degradation is thought to account for the increased efficiency of AC 4447 as a plant growth regulator.

Effect of AC 4447 on root growth

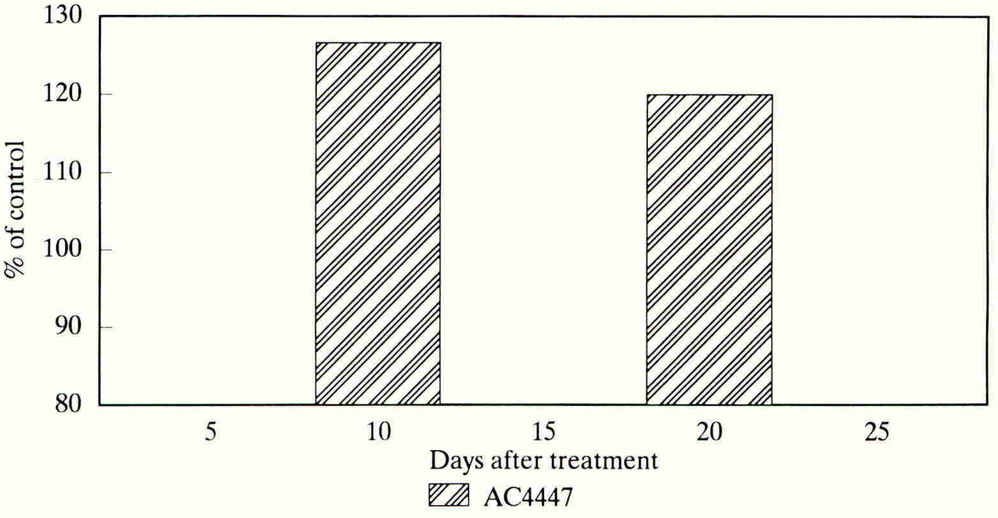
Nine days after treatment, total root length was significantly greater than in the untreated plot (Figure 4).

FIGURE 4 . Effect of AC4447 on the root length (growth chamber)



A significant increase in the root surface area was measured in the treated plants (Figure 5)

FIGURE 5 . Effect of AC4447 on the root surface area



Root dry matter production was also increased following treatment with AC 4447 (15% at 10 days after treatment and 30% after 20 days) (Table 2).

TABLE 2. Effect of AC 4447 on root d.m.wt (g/plant)

	10 DAT	20 DAT
control	0.27	1.87
treated	0.31	2.43
LSD(P=0.05)	0.04	0.07

Humphries (1968) and Hanus (1970) observed similar results on CCC treated plants. De _et_ _al_. (1982) attributed such increases to greater water extraction from deeper soil layers. With the same active ingredient, Pawar & Kadam (1983) noticed an increase of the root/shoot ratio. The modification of the ratio we observed at growth stage 30 indicates a greater dry matter allocation to the roots (Table 3).

TABLE 3 . Effect of AC 4447 on root/shoot ratio

	10 DAT	20 DAT
control	0.37	0.51
treated	0.35	0.57
LSD(P=0.05)	0.01	0.01

Increase of root dry matter production, root length and surface area could enhance resistance to drought and increase mineral uptake.

Effect of AC 4447 on flag leaves

The application of AC 4447 increased the area of the flag leaves on both the main stem and tillers. (Figure 6), the dry matter weight (Table 4) and the chlorophyll content of the flag leaves (Figure 7)

TABLE 4 . Effect of AC 4447 and CCC on the dry matter weight of main stem flag leaf

	Control	AC 4447	CCC
d.m.wt (g)	0.265	0.284	0.267

Similar results were observed with CCC by Feucht (1982).Such results suggest that the combination of CCC + imazaquin can modify flag leaf morphology and chlorophyll synthesis. A comparison between CCC and CCC + imazaquin treatment revealed that imazaquin increased the effects of CCC on the flag leaves. This result could help us to explain the yield increase observed in field experiments due to better grain filling.

FIGURE 6 . Effect of AC4447 and CCC on the flag leaf area

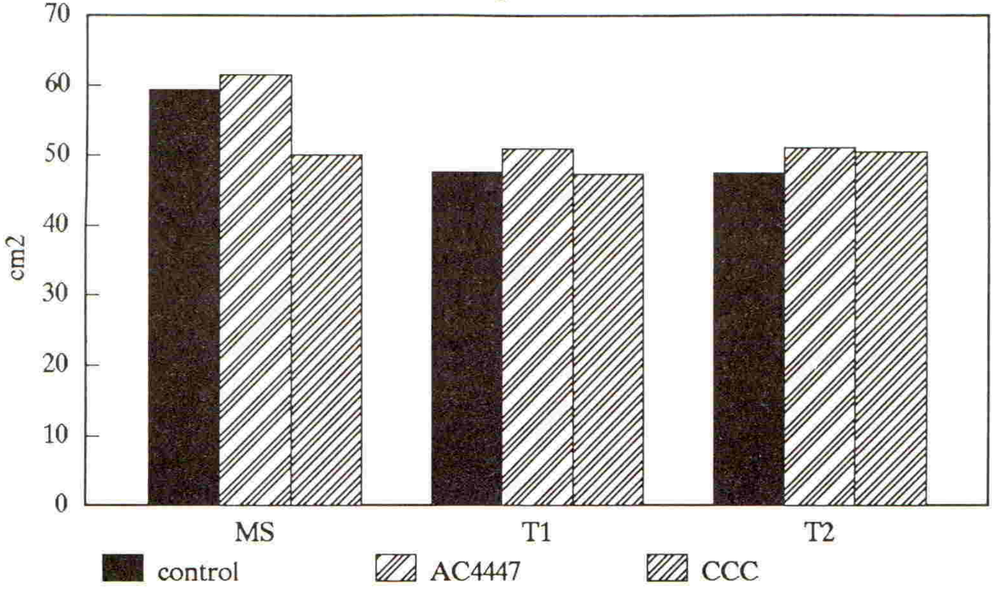
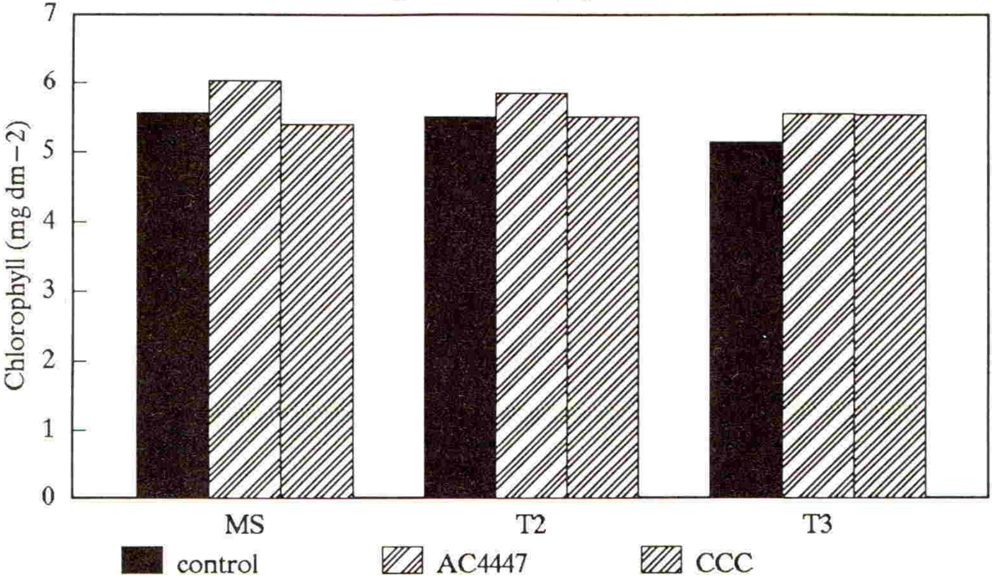


FIGURE 7 . Effect of AC4447 and CCC on the flag leaves chlorophyll content



CONCLUSION

The present work on uptake and translocation of compounds indicated that imazaquin was more mobile than CCC and increased its transfer into different parts of the plant.

Investigation into the effect of AC 4447 on the morphology of the wheat plant showed it to cause modifications such as an increase in flag leaf area and chlorophyll content as well as increasing the root area surface and dry matter weight. These observed changes in morphology, associated with physiological effects, can be related to the yield increases which have been observed in the field and it can be concluded that AC 4447 is more than just an antilodging agent.

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RECENT EXPERIENCE OF TIMING OF GROWTH REGULATORS ON WINTER WHEAT

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ABSTRACT

Timing of application of chlormequat to winter wheat by apical development stage was compared with conventional growth stage timings. The effects of acidified soy lecithin adjuvant and sequences of chlormequat followed by ethephon alone or with mepiquat were also assessed.

Straw shortening effect of chlormequat increased as timing progressed from double ridge stage through to terminal spikelet stage.

Full rate chlormequat and sequences including ethephon based products were most effective in preventing lodging.

Yield responses were obtained in the absence of lodging. Applications of chlormequat at floret primordium stage tended to provide the most consistent positive yield benefit. Yield response was not related to increases in thousand grain weight or specific weight.

INTRODUCTION

Chlormequat has been shown to improve straw stiffness and resistance to lodging in winter wheat. It also has an effect on leaf and root development, and may increase tiller survival and grain number per ear (Humphries & Bond, 1969). On lodged sites chlormequat has raised mean yields by around 0.7 t/ha but has shown little effect on yield in the absence of lodging (Woolley, 1981).

One reason for the lack of yield response on non-lodging sites is the compensatory effect between grain number and grain size. The retention of extra grain sites can result in smaller grain and reduced yields (Roebuck, 1980).

Greater precision in the timing of chlormequat has been suggested as one way to improve growth regulator reliability in cereals

(Cartwright, 1985). Reduced activity through low temperatures at time of application (Hunt & Baker, 1985) may be partially overcome by the use of adjuvants to increase penetration of growth regulators through the leaf surface.

The object of these experiments was to determine whether application of chlormequat by apical development stage could improve the reliability of growth regulator use above that achieved by conventional application timings.

MATERIALS AND METHODS

Nine trials were carried out between 1987 and 1989 on sites in Northumberland/Durham, Kent and Hampshire on the varieties Galahad, Mercia, Longbow, Rendezvous and Avalon. Apical timing of chlormequat 1.13 kg ai/ha ('New 5C Cycocel' 645 g ai/litre) was compared with split treatment, 1.13 + 0.48 kg ai/ha at GS 30 + 31 or a single application of 1.6 kg ai/ha at GS 31. Sequential treatments of split chlormequat followed by mepiquat + ethephon 0.69 kg ai/ha ('Terpal' 305 + 155 g ai/litre) or ethephon 0.24 kg ai/ha ('Cerone' 480 g ai/litre) were also included. Acidified soy lecithin at 0.5% spray volume 'LI 700' was included in extra treatments with chlormequat at terminal spikelet and with split chlormequat.

Treatments were applied using either Oxford Precision or Knapsack sprayers in 200 to 225 l/ha at 2 bars pressure using Allman 00, Tee Jet F 8002 or F 1103 nozzles. Most treatments were applied at temperatures between 6°C and 19°C.

Apical development stage was ascertained by dissection of the growing point (Kirby & Appleyard, 1981), to identify double ridge; glume, lemma and floret primordia and terminal spikelet stage. Decimal growth stages were determined by stem dissection (Tottman & Makepeace, 1979).

RESULTS

Glume primordium coincided with growth stage 30 (pseudostem erect) on most sites while growth stage 31 (first node detectable) was equated with terminal spikelet on 6 sites and floret primordium on 3 sites.

Crop height (Table 1) was reduced by chormequat, with applications at floret primordium or terminal spikelet being more effective than earlier timings, and reducing mean height by 5.1 cm (5.8%). The split treatment at GS 30 + 31 was no more effective than reduced rate treatment at floret primordium or terminal spikelet stage. Addition of soy lecithin adjuvant to chlormequat in 1988 and 1989 reduced mean crop height by a further 1 cm. Sequences including mepiquat + ethephon resulted in mean height reductions of 11.8 cm (13.4%) and with ethephon mean reductions of 9.1 cm (10.4%).

Lodging was recorded on two sites in 1987 only. Lodging reached 24% and leaning 17% on untreated controls on the Northumberland site. Later apical treatments reduced lodging to 5-8%, split chlormequat to 2%, and sequences of chlormequat followed by ethephon based products to

0%. Following severe wind and heavy rain all treatments lodged completely in late August.

On the Kent site lodging reached 52% on untreated controls. Chlormequat at 1.6 kg ai/ha at GS 31 reduced lodging to 12% and the sequence with ethephon to 6%.

Significant yield increases were obtained only in 1988 from chlormequat treatments applied from lemma primordium to terminal spikelet stage on one site and at floret primordium stage on two sites (Table 2). Sequences of chlormequat followed by mepiquat + ethephon increased yield on two sites, and followed by ethephon alone on one site. Both sites were unlodged.

Over all sites there was a trend for floret primordium timing of chlormequat to be the most consistent in producing yield benefits with no reductions. Addition of soy lecithin adjuvant did not improve the reliability of yield response to chlormequat.

Thousand grain weight was not affected by treatment. Specific weight was increased on one site, from lemma primordium and split chlormequat treatment alone and when the latter was followed by ethephon materials, and reduced on one site from split and full rate chlormequat.

Significant yield increases were not accompanied by increases in thousand grain weight or specific weight.

DISCUSSION

Prevention of lodging does not automatically increase crop yield but it helps to preserve the yield potential of the crop. The effect of lodging on yield will depend on the time of lodging in relation to crop maturity and subsequent effects on yield of reduced photosynthesis, increased respiration, increased level of foliar and ear disease and degree of sprouting. Some lodging may help preserve yield potential by reducing the effects of wind induced grain shedding. Lodged experiments are inherently variable and this degree of variability often precludes the attainment of significance in yield comparisons. For maximum protection from lodging sequences of chlormequat followed by ethephon based products proved the most effective on these sites.

Applications of chlormequat at floret primordium stage appeared to be the most consistent timing for this product. This apical stage occurred between 9 and 0 days (average 5) before first node stage.

In this series of experiments the biggest yield response to growth regulator treatment was obtained on a high yield potential site in the absence of lodging. Yield increase was not accompanied by an increase in mean grain size or specific weight and must be attributed therefore to increased grain number.

If grain number is the factor limiting yield then chlormequat should be beneficial providing there are no other factors limiting grain filling. If this is the case a larger grain size would be expected in the absence of chlormequat. This was not the case in these trials.

TABLE 1 CROP HEIGHT (cm)

			1987			1988			1989		
	GS	North	Hants	Kent	Durham	Hants	Kent	North	Hants	Kent	Mean
	SED ±	1.21	1.27	1.5	2.77 NS	1.29	2.09	2.1	2.1	3.8	
CCC	d.r	96.5	83.5	96.0	104.3	76.5	95.2	63	86	72	85.9
"	gl.pr	96.1	81.9	98.2	101.7	76.0	93.3	64	83	72	85.1
"	l.pr	93.6	81.9	93.1	101.0	76.1	91.2	65	79	70	83.4
"	fl.pr	91.9	76.3	95.5	106.0	73.1	88.9	63	79	n.a.	
"	t.sp	91.7	77.3	95.7	103.7	74.7	91.2	63	81	67	82.8 (80.1)
CCC Split	30+31	93.3	80.0	97.3	102.7	74.4	91.3	62	80	73	83.8 (80.6)
CCC Split + A	30+31 32-37	92.2	73.2	92.0	102.7	68.0	78.8	59	69	50	76.1
CCC Split + B	30+31 37-45	92.3	79.7	90.4	101.0	73.5	82.5	60	75	55	78.8
CCC	31	-	-	92.8	103.7	72.1	88.0	60	81	71	(79.3)
CCC + Adj	t.sp				103.3	73.6	90.1	63	76	68	(79.0)
CCC Split + Adj	30+31				103.7	73.3	89.8	60	78	73	(79.6)
Untreated control		99.2	82.5	100.1	104.9	76.4	97.9	65	88	77	87.9 (84.9)
Degrees freedom		28	27	26	28	27	26	28	27	26	
CV %		1.56	2.0	2.2	3.3	2.1	2.8	4.0	3.3	6.70	

CCC = Chlormequat A = mepiquat + ethephon B = ethephon Adj = soy lecithin adjuvant.
( ) = mean for 1988 + 1989 only

TABLE 2 YIELD RESPONSE T/HA (85% DM)

				1987			1988			1989	
	Rate kg ai/h	Timing/ GS	North	Hants	Kent	Durham	Hants	Kent	North-	Hants	Kent
			Gal	Gal	Av	Long	Gal	Merc	Gal	Rend	Merc
		SED ±	0.367NS	0.202NS	0.19NS	0.232	0.184NS	0.144	0.266NS	0.21NS	NS
CCC	1.13	d.r	0.21	0.02	-0.01	0.43	-0.26	0.08	0.48	0.10	0.41
"	1.13	gl.pr	0.45	0.02	0.02	0.48	-0.10	0.04	0.21	0.02	0.57
"	1.13	l.pr	0.21	-0.18	-0.08	0.66	-0.20	0.18	0.18	0.21	-0.30
"	1.13	fl.pr	0.46	0.02	0.10	0.69	0.20	0.39	0.27	0.03	n.a.
"	1.13	t.sp	0.68	-0.23	-0.06	0.54	-0.16	0.11	0.61	0.09	0.34
CCC Split	1.13+0.48	30+31	0.49	0.08	0.17	0.56	-0.16	-0.05	0.38	-0.16	0.05
CCC Split + A	1.13 + 0.48 0.69	32-37	0.65	-0.04	-0.15	1.06	-0.21	0.34	0.16	-0.32	-0.29
CCC Split + B	1.13+0.48 0.24	30-31 37-45	0.39	0.28	0.30	0.86	-0.34	0.20	0.08	-0.10	0
CCC	1.6	31	-	-	0.18	0.69	-0.21	0.10	0.10	-0.01	0.57
CCC+Adj	1.13+0.48	t.sp	-	-	-	0.40	-0.13	0.22	0.22	-0.28	0.12
CCC Split+Adj	1.13+0.48	30+31	-	-	-	0.63	-0.51	0.07	0.14	-0.02	0.40
Untreated			6.6	8.75	7.71	9.45	7.26	7.81	6.13	8.48	6.62
Degrees freedom			28	27	26	28	27	26	28	27	26
CV			6.45	2.8	3.5	2.8	3.2	1.8	5.15	3.0	9.1

CCC = Chlormequat. A = mepiquat + ethephon. B = ethephon. Adj = soy lecithin at 0.5% spray volume.
Gal = Galahad, Av = Avalon, Long = Longbow, Merc = Mercia, Rend = Rendezvous

ACKNOWLEDGEMENTS

The authors are indebted to the co-operating farmers for providing sites, to the commercial companies who provided the materials and to ADAS colleagues in Newcastle upon Tyne, Reading and Wye for experimentation and data preparation. Financial support for this work from the Ministry of Agriculture, Fisheries and Food is gratefully acknowledged.

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EFFECT OF PGRS AND NITROGEN RATE ON GRAIN YIELD AND QUALITY OF MARINKA WINTER BARLEY

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ABSTRACT

A total of 12 trials were undertaken over 3 seasons (1987-89) on a range of soil types to investigate the effect of different plant growth regulator (PGR) regimes and a range of nitrogen rates on the yield and quality of the stiff strawed winter barley varieties, Marinka and Concert. Nitrogen increased grain yields with the 160 kg/ha rate giving the optimum economic yield at most sites. The effects of PGR treatment on yield were less consistent and more variable between trials with significant yield increases and decreases recorded. Where lodging occurred, it increased with increasing nitrogen rates. Mepiquat chloride plus 2 chloroethylphosphonic acid at full rate alone or at reduced rate in sequence after chlormequat chloride plus choline chloride were the most effective in reducing straw height and lodging. Chlormequat consistently reduced thousand grain weight, and although grain nitrogen levels increased with increasing nitrogen rates they were unaffected by PGR treatment. There were no significant interactions in the responses to PGR and nitrogen treatments.

INTRODUCTION

Earlier work with older varieties of winter barley such as Igri has shown small yield responses to plant growth regulators (PGRs) based on chlormequat even in the absence of lodging (ADAS, 1982), and until recently the price of commercial formulations was such that routine use could be widely considered. The slight extra yield could be viewed as a bonus should it arise in the normal course of a lodging control programme.

However varieties change and many newer varieties are stiffer strawed than their predecessors. Similarly growth regulators change and the use of 2-chloroethylphosphonic acid (ethephon) based products, although more expensive, gives more consistent lodging control. Any yield increase from the use of these products must come from more efficient crop structure and lodging avoidance as they are used later in the development of the crop, whereas the early anti-gibberelin action of the chlormequat products can increase the number of grain per ear, (Williams et al., 1982), or the number of tillers surviving (Matthews et al., 1982).

A programme of chlormequat + choline chloride followed by ethephon + mepiquat chloride produced reliable lodging control in weak strawed varieties of malting winter barley (Garstang, 1987). This trial series was designed to test the responsiveness of a more recent stiff strawed winter barley variety, Marinka, to different rates of nitrogen, and to show how yield and lodging were affected by the use of different programmes of plant growth regulators.

MATERIALS AND METHODS

A total of 12 trials were undertaken over 3 seasons (1987-89) at 10 sites on a range of soil types in England and Wales: silty loam (Suffolk, Gwent 1988, Dyfed 1988), sandy silty loam (Clwyd, Gwent 1987, Herts, Dyfed 1989) and sandy loam (Gwent 1989, Northants). Marinka was grown at all sites except at the Gwent site in 1987 where Concert was grown. Nitrogen and PGR treatments were factorially combined in a fully randomised block trial with 3 replicates. Plot size was in the range 2-3m wide by 18-24m long. Ammonium nitrate at various rates (see results) was applied by hand in combination with a range of PGR treatments (Table 1) which were applied with hand-held knapsack sprayers in 200 l water/ha at 200-250 kPa pressure.

TABLE 1. PGR Treatments

Treatment		kg ai/ha	Timing
1	Untreated	-	-
2	*chlormequat chloride/ choline chloride	1.613	GS 30
3	chlormequat chloride/ choline chloride	1.613	GS 30
	**2 chloroethylphosphonic acid/ mepiquat chloride	0.305 0.155	GS 37
4	2 chloroethylphosphonic acid/ mepiquat chloride	0.305 0.155	GS 37
5	2 chloroethylphosphonic acid/ mepiquat chloride	0.61 0.31	GS 37

* applied as 2.5 l/ha' New 5C Cycocel'
** applied as 1 l/ha 'Terpal'

RESULTS

There were no significant interactions between PGRs and nitrogen at any of the sites in any of the years. The responses to these two factors are therefore discussed separately.

1987 harvest

Nitrogen significantly increased yield at all sites up to a maximum of 160 kg/ha (Table 2). Significant lodging only occurred at the Clwyd site and levels increased with increasing nitrogen (15% at 160 kg/ha and 41% at 240 kg/ha) but were unaffected by PGR treatment (Table 3). Both chlormequat treatments (Treatments 2 and 3) reduced yield at this site and chlormequat alone (Treatment 2) reduced yield of Concert at the Gwent site (Table 3). There was a marked trend for an associated reduction in thousand grain at both these sites (Table 4). By contrast at the Suffolk site, all PGR treatments except treatment 4 increased yield and no detrimental effects on grain quality were evident.

TABLE 2. Effect of nitrogen on yield (t/ha) - 1987

Site	Nitrogen rate (kg/ha) 80	120	160	200	240	280	Mean	SED (48 df)
Suffolk	-	7.46	7.71	7.73	7.46	7.54	7.58	0.11
Clwyd	5.73	6.08	6.10	6.21	6.30	-	6.06	0.16
*Gwent	-	5.78	6.49	6.62	6.66	6.57	6.42	0.19

* Variety Concert

TABLE 3. Effect of PGR on yield (t/ha) - 1987

Site	Treatment 1	2	3	4	5	Mean	SED (48 df)
Suffolk	7.32	7.65	7.76	7.52	7.63	7.58	0.11
Clwyd	6.27	5.04	5.89	5.98	6.14	6.06	0.16
*Gwent	6.66	6.21	6.40	6.40	6.45	6.42	0.18

* Variety Concert

TABLE 4. Effect of PGRs on thousand grain weight 1987

Site	Treatment 1	2	3	4	5	Mean	SED (48 df)
Suffolk	48.6	48.9	47.8	48.7	47.2	48.2	0.6
Clwyd	45.4	42.5	43.7	43.9	44.6	44.0	NS
*Gwent	47.9	45.9	45.6	47.1	47.0	46.7	NS

* Variety Concert

1988 harvest

Nitrogen significantly increased yields at all sites except Suffolk (Table 5). At the Gwent site, there was a reduction in yield at the two highest nitrogen rates which was linked with an increase in lodging (from 23% at 160 kg/ha to 33% and 28% at 240 and 280 kg/ha nitrogen respectively). At the other three sites, nitrogen increased yield, the optimum for Herts and Gwynedd being 160 kg/ha and Dyfed 200 kg/ha nitrogen. Significant yield increases were obtained from PGR treatment at two of the five sites but these were not linked with any control of lodging (Table 6). Treatment 3 increased yield at Dyfed and treatments 3 and 5 increased yield at Gwynedd.

Lodging occurred at the Suffolk, Herts and Gwent sites and increased with increasing nitrogen rates (Table 7) with the largest increases occurring above 160 kg/ha nitrogen. Lodging control with PGR was only evident at the Herts site (Table 8). Treatments 3 and 5 reduced lodging but there were no associated yield benefits. These two treatments were also the most effective at reducing stem height at all sites and treatment 2 was the least effective.

Reductions in specific weight with increasing nitrogen were greatest at the Herts and Gwent sites where lodging was most severe. Treatment 5 reduced specific weight at the Dyfed site, whilst treatments 2 and 3 had the lowest specific weights the Gwynedd site. Grain nitrogen levels were unaffected by PGR treatment but increased significantly with increasing nitrogen rates.

TABLE 5. Effect of nitrogen on yield (t/ha) - 1988

	Nitrogen rate (kg/ha)							
Site	80	120	160	200	240	280	Mean	SED (48 df)
Suffolk	-	9.05	9.15	9.16	9.13	8.78	9.05	NS
Herts	-	6.21	6.55	6.63	6.55	6.42	6.47	0.09
Gwent	-	9.06	9.09	9.12	8.76	8.70	8.45	0.17
Dyfed	4.92	5.65	6.01	6.32	6.40	-	5.86	0.13
Gwynedd	5.83	6.37	6.72	6.67	6.78	-	6.46	0.18
Mean	-	7.27	7.50	7.58	7.97	-		

TABLE 6. Effect of PGR treatment on yield (t/ha) 1988

Site	1	2	3	4	5	Mean	SED (48 df)
Suffolk	8.99	9.17	8.94	9.18	9.00	9.06	NS
Herts	6.38	6.55	6.52	6.42	6.48	6.47	NS
Gwent	8.66	8.98	9.08	8.87	9.13	8.94	0.17
Dyfed	5.87	6.02	6.08	5.71	5.62	5.86	0.13
Gwynedd	6.37	6.53	6.36	6.47	6.64	6.47	NS
Mean	7.25	7.45	7.40	7.33	7.37		

TABLE 7. Effect of nitrogen on % lodging - 1988

Site	120	160	200	240	280	Mean	SED (48 df)
Suffolk	4	5	11	24	34	16	10
Herts	0	10	48	61	61	36	6
Gwent	14	21	23	33	28	24	5
Mean	6	12	27	39	41		

No lodging was recorded at the Dyfed or Gwynedd sites.

TABLE 8. Effect of PGR treatment on % lodging 1988

Site	PGR Treatment 1	2	3	4	5	SED (48 df)
Suffolk	18	17	15	14	13	NS
Herts	40	44	29	38	29	5.8
Gwent	23	22	28	20	26	NS
Mean	27	28	24	24	22	

1989 harvest

At the two sites where there was a yield response to nitrogen, there was no yield increase above the 160 kg/ha nitrogen rate (Table 9). Little (<3%) or no lodging occurred at all four sites and significant yield reductions due to PGR treatment were evident at three of the four sites (Table 10). At the Herts and Northants sites, the chlormequat chloride treatment (treatment 2) was lower yielding than the untreated and at Dyfed site the untreated outyielded the PGR sequence (treatment 3). Specific weight and thousand grain weight were both reduced by treatment 2 at the Northants site (Table 11).

Although there were no treatment effects on lodging, straw height reduced with increasing nitrogen rate (Table 12) and PGR treatment at 3 of the 4 sites. Treatments 2, 3 and 5 had the shortest straw whilst treatment 4 showed the least reduction in crop height. This contrasts with previous seasons where treatment 4 has been more effective than treatment 2. Increasing nitrogen reduced specific weight at the Herts and Dyfed sites. Grain nitrogen analysis was undertaken at these two sites and although unaffected by PGR treatment it increased with increasing nitrogen at the Dyfed site.

TABLE 9. Effect of nitrogen on yield (t/ha) - 1989

Site	Nitrogen rate (kg/ha) 80	120	160	200	240	Mean	SED (48 df)
Herts	-	6.53	6.67	6.78	6.61	6.65	0.07
Northants	-	8.35	8.17	8.33	8.31	8.29	NS
Gwent	-	5.66	5.85	6.00	5.78	5.82	0.10
Dyfed	6.66	6.60	6.44	6.51	-	6.55	NS
Mean	6.66	6.78	6.78	6.91	-	6.83	

TABLE 10. Effect of PGR treatment on yield (t/ha) 1989

Site	Treatment 1	2	3	4	5	Mean	SED (48 df)
Herts	6.72	6.53	6.62	6.72	6.78	6.65	0.09
Northants	8.44	8.05	8.33	8.41	8.50	8.29	0.16
Gwent	5.84	5.79	5.69	5.87	5.98	5.82	NS
Dyfed	6.63	6.55	6.36	6.66	6.68	6.55	0.11
Mean	6.90	6.73	6.75	6.92	6.98	6.83	

TABLE 11. Effect of PGR on specific and thousand grain weight - Northants site 1989

Treatment	Specific weight (kg/hl)	Thousand grain weight (g)
1	71.0	47.2
2	69.6	45.0
3	70.5	46.2
4	71.2	48.0
5	70.9	46.6
SED(48 df)	0.5	0.9

TABLE 12. Effect of nitrogen straw height (cm) 1989

Site	Nitrogen rate (kg/ha) 80	120	160	200	240	Mean	SED (48 df)
Herts	-	96	94	90	91	93	2
Northants	-	96	93	93	90	93	2
Gwent	-	92	90	92	88	90	2
Dyfed	97	96	96	94	90	96	NS
Mean	-	95	93	92	90	93	

DISCUSSION

The results of these trials over 3 years at a total of 12 sites show there is no significant interactive effect on yield or lodging between nitrogen and PGRs. Increasing the rate of nitrogen applied significantly increased yield at 10 of the 12 sites.

PGRs were more variable in their effect producing significant increases in yield at 3 sites, significant reductions at five sites, and no significant effects at 4 sites. Table 13 shows the mean effect of PGRs on the increase, decrease and no effect groups.

TABLE 13. The effect of PGR programmes on grain yield (t/ha) grouped by Increase, Decrease and No change

	Treatment				
	1	2	3	4	5
Increase	7.28	7.55	7.64	7.37	7.46
Decrease	6.94	6.48	6.72	6.83	6.91
No change	6.80	6.90	6.88	6.98	7.02

Where increases occurred programmes including chlormequat + choline chloride gave the greatest increases. In common with other work (Garstang; 1987), this yield increase was enhanced still further, but to a lesser degree, by a later treatment with ethephon + mepiquat chloride.

The ethephon + mepiquat chloride treatments alone, whilst showing an increase over the untreated control, produced smaller increases in yield than the chlormequat alone. Increases in structural efficiency of the crop canopy resulting from ethephon + mepiquat chloride use seem less beneficial to yield than the probable changes to grain sites resulting from chlormequat use. At all three sites growing conditions were such that yield increase was not accompanied by a decrease in thousand grain weight. If the number of grain sites were increased, growing conditions were such that it was not to the detriment of grain weight, and consequently yields were increased.

Of the three sites showing an increase in yield only one showed a reduction in lodging from the PGR programmes.

The mean yield of the five sites where yield reductions were obtained showed the greatest reduction from programmes where chlormequat + choline chloride had been used. The crop was not upright at three of the five sites (lodged at two) in the absence of PGRs, all three being in Wales.

Where yield was reduced following chlormequat + choline chloride the thousand grain weight was lower at all five sites irrespective of lodging. The lowest thousand grain weights were recorded in 1989 at a site with grass, swedes and spring barley in the rotation, ie., a rotation with a potentially high soil mineral nitrogen (SMN). It was also the tallest crop with the greatest area (only 18%) leaning at harvest, in what was a very low lodging season. Of the other four sites where yields were reduced, the two with grass in the rotation produced the greatest reduction in thousand grain weight from treatments involving chlormequat + choline chloride.

In trials with malting barley it has been shown (Garstang and Giltrap, 1990) that high SMN is associated with increases in the amount of small grains produced. The presence of relatively high nitrogen levels at establishment allow a vigorous development of the plant, tillers and potential seed sites. The use of chlormequat, which further enhance this effect, taxes the plants capacity to fill the sites. In favourable seasons this is not a problem and yield increases are obtained. In dry seasons reduction in yield can result (3 out of the 5 "reduction" sites were in 1989), and where lodging occurs on "fertile" sites with high SMN, filling an additional quota of extra grain sites is a problem.

Typically many barley crops in the west of the country are grown on sites, with grass in the rotation and consequently high SMN. Chlormequat based products are less effective at controlling lodging than ethephon based products, and also increase the number of grain sites. Wet weather and lodging makes it harder for crops to fill all the grain sites.

On mixed farms in the wetter west, or in dry arable areas on high SMN sites ethephon products would appear to offer less risk of yield reduction. It is noteworthy that the mean yields increased on the yield decrease sites as ethephon was added to the PGR programmes.

These results highlight the possible importance of SMN in deciding whether chlormequat based products are "at risk" of producing yield reductions should unfavourable grain filling conditions arise.

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