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DALAPON TOLERANT VARIETIES - A POSSIBLE BASIS FOR PURE SWARDS OF *LOLIUM PERENNE* L.

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Summary New varieties of Perennial ryegrass (*Lolium perenne* L.) have been bred from plants selected for their high level of dalapon tolerance. Experiments are reported in which it is demonstrated that these new varieties are more tolerant to dalapon than normal varieties under both glasshouse and field conditions. It is concluded that dalapon probably has a more strongly selective effect against unwanted grasses and a less adverse short term effect on productivity in swards containing the new varieties than in swards containing normal varieties. Certain aspects of the use of dalapon, such as dosage and time of application, need to be re-investigated using tolerant varieties.

Résumé Les variétés nouvelles de ray-grass anglais (*L. perenne*) ont été produits des plantes, choisi pour leur niveau supérieur de tolérance à dalapon. On rapports des essais, dans lesquels on démontre que ces variétés nouvelles sont plus tolérant à dalapon que des variétés normales, sous les conditions de serre et aussi de champ. On estime que dalapon a un effet plus fortement sélectif contre des herbes indésirables et un effet moins adverse et courte terme sur la productivité en gazons contenant les variétés nouvelles, que des gazons contenant des variétés normales. Des aspects certains de l'usage de dalapon, tel que le dosage et le temps d'application demandent d'être examiner de nouveau utilisant des variétés nouvelles.

INTRODUCTION

Cultivated varieties of Perennial ryegrass, of native or exotic origin, are widely sown for medium and long term leys in the British Isles. Certain other native grass species, most of them generally regarded as less desirable, gradually invade sown grassland and the proportion of Perennial ryegrass declines. The value of breeding superior varieties of Perennial ryegrass for cultivation is seriously reduced by this tendency to die out in farming conditions, whether because of competition from other grasses or because they are inherently short lived. In testing new varieties, there is therefore much emphasis on their ability to persist (e.g. Camlin, 1978; Anon, 1977). There should be equivalent interest in management techniques which assist sown grasses to survive. One such technique is the treatment of swards containing a proportion of Perennial ryegrass with low doses of dalapon (Haggar and Oswald, 1976). This treatment has less phytotoxic effect on Perennial ryegrass than most other grasses, and hence helps to increase the proportion of Perennial ryegrass in the sward. Haggar and Elliott (1978) were unable to show that the treatment also leads to consistently increased sward output as measured by animal performance. Three interpretations, not mutually exclusive, of their results might be advanced.

Results

Table 1

Relative tolerance of four varieties of Perennial ryegrass to dalapon in 3 glasshouse experiments

Variety	Foliar tolerance (0-6) 1975/76	1976/77	1977/78	Regrowth (0-4) 1975/76	1976/77	1977/78
DRP 4	-	4.2	3.7	-	2.6	2.5
Stormont Rathlin	3.2	3.8	3.2	1.1	1.9	1.0
Melle	2.8	3.0	3.4	0.4	0.6	0.2
Barlenna	2.5	2.6	3.2	0.3	0.4	0.2
S.E.	0.21	0.37	0.30	0.18	0.29	0.18
Probability	NS	<0.05	NS	<0.05	<0.01	<0.001

From the results in Table 1, it can be seen that the difference between the selected and the standard varieties in their resistance to foliar damage is small, but in their regrowth after clipping it is considerable. DRP 4, which was a product of a more rigorous selection programme, is consistently more tolerant than Stormont Rathlin.

FIELD EXPERIMENT 1

Materials and methods

To test a dalapon tolerant variety under field conditions, a replicated trial of 1.5 x 5.0 m plots was sown on 20 September 1972. The tolerant variety in this trial was DRP 1, a synthetic variety very closely related to Stormont Rathlin. There were two standard varieties, Melle and Aberystwyth S.23: the latter is intermediate between Melle and Barlenna in degree of tolerance (Faulkner, 1974). The sowing rate, 1500 viable seeds per m^2, was within the range of normal farm practice. Yields were recorded by mowing 3 or 4 times a year at 6-8 week intervals for 3 full harvest years, and compound fertiliser was applied after each cut. There were separate plots for the three treatments described below.

1. Dalapon at 7.2 kg a.e./ha in 1973, and at 3.6 kg a.e./ha in 1975

2. Dalapon at 3.6 kg a.e./ha in 1974

3. No dalapon

Dalapon was applied as the sodium salt without a wetting agent in 450 ℓ/ha of water in the second half of June in each year, about one week after the first cut, using an Oxford Precision Sprayer.

Results

The dalapon treatments did not cause much death of ryegrass tillers or foliage, but could be seen to cause slight scorch and to reduce growth temporarily. In all three years, yields of the sprayed plots Stormont Rathlin in the cut after spraying were somewhat higher than those of Melle and about double those of Aberystwyth S.23 (Table 2). Since Aberystwyth S.23 generally yielded less than the other varieties in the unsprayed plots at this cut, the yields of the sprayed plots of each variety are also quoted as a percentage of that of the unsprayed ones of the variety. Even after making this allowance, however, the effect of dalapon is clearly most severe on Aberystwyth S.23.

1. Background variation, as frequently happens in animal production experiments, was large in relation to any differences between the treatments.

2. The invading grasses were as valuable to the grazing animals as the Perennial ryegrass.

3. The genotypes of Perennial ryegrass (mostly Aberystwyth S.23) were not ideally suited to the treatment.

Differences between varieties of Perennial ryegrass in their response to dalapon in field conditions have been reported by Wright (1968) and Faulkner (1974). To make full use of variation in the species, individual tolerant plants have been selected and bred at Loughgall and thus new varieties of Perennial ryegrass have been synthesized. The experiments reported below were designed to demonstrate that these new varieties were significantly more tolerant than standard varieties, and thus that the value of dalapon for sward improvement should be re-assessed.

GLASSHOUSE EXPERIMENTS

Materials and methods

A standard technique has been devised for comparing the degrees of tolerance of progeny or varieties produced in the breeding programme. It was designed to be as discriminating and as rapid as possible without being unduly subject to the irregularities of response which might be shown by young seedlings.

The technique involves the use of a heated glasshouse with supplementary lighting in mid-winter. Two seeds per 10 cm pot are sown in a loam based potting compost. The pots are placed in moist sand beds where they are watered by capillary action. The light period is 16 hours at 20^{o}C, the dark period 8 hours at 10^{o}C. After germination the seedlings are thinned to one per pot where necessary. To reduce irregularities due to varying distances from the lamps or heaters, the positions of the pots are systematically changed every 10 days. Experiments are normally conducted on randomized block designs. Because of the variation in response among plants of the same variety, it is considered necessary to base comparisons on at least 32 plants per variety. At 6 weeks from sowing, weak plants (fewer than 3 tillers) are discarded and all remaining plants are sprayed with the sodium salt of dalapon at 21.6 kg a.e./ha in 450 ℓ/ha of water without a wetting agent, using a laboratory scale sprayer specially designed for uniform application (Beatty, Courtney and Faulkner, unpublished). Between two and three weeks after spraying, foliar damage on every plant is recorded by an experienced observer on a 0-6 scale, with the low end of the scale representing complete kill and the high end negligible damage. All plants are then clipped at a height of 2.5 cm. After a further two weeks, degree of recovery is scored on a 0-4 scale. Many plants of normal varieties are killed outright by this treatment (score 0). In the most tolerant plants, there is normal extension regrowth of all tillers (score 4). Other plants show a range of responses involving the death or distorted regrowth of some or all tillers.

Using this technique, two synthetic varieties of Perennial reygrass produced from selected dalapon tolerant parents have been compared with two standard varieties. One of the tolerant varieties, Stormont Rathlin, is undergoing National List trials; the other, DRP 4, was first synthesized in 1976 and was not therefore available for the first of the three experiments reported in Table 1. The two standard varieties, Barlenna and Melle, were among the most susceptible and resistant respectively of the diploid varieties tested in field conditions by Faulkner (1974).

In the second cut after spraying, there were no significant differences among the varieties or between the sprayed and unsprayed plots in any of the three years (Table 2). It seemed therefore that there was neither a residual growth retarding effect of the dalapon, nor any compensatory growth in the sprayed plots.

Table 2

Field experiment 1: dry matter yield of three varieties in two cuts following dalapon treatment. Yields are quoted in kg/ha and, in brackets, as a percentage of the yield of unsprayed plots of the variety

Variety	1973 (7.2 kg/ha) 1st cut	1973 (7.2 kg/ha) 2nd cut	1974 (3.6 kg/ha) 1st cut	1974 (3.6 kg/ha) 2nd cut	1975 (3.6 kg/ha) 1st cut	1975 (3.6 kg/ha) 2nd cut
S. Rathlin	1482 (58)	2531 (100)	641 (67)	1111 (87)	1760 (64)	2002 (106)
Melle	893 (34)	2401 (91)	451 (42)	1154 (107)	1485 (59)	1950 (94)
Aber. S.23	718 (30)	2548 (103)	286 (32)	1175 (97)	897 (44)	1950 (93)
S.E.	51	76	37	104	97	99
Probability	<0.01	NS	<0.01	NS	<0.01	NS

The proportion of Perennial ryegrass remained very high throughout this experiment; even in the unsprayed plots, there was over 90% ryegrass in the herbage cut on 20 June 1975. Unsown grasses, notably *Holcus lanatus* L., comprised only a very small fraction of the herbage, although there was significantly more in the unsprayed than in the sprayed plots. No differences in degree of contamination with unsown grasses were detectable between the varieties of Perennial ryegrass in either sprayed or unsprayed plots.

FIELD EXPERIMENT 2

Materials and methods

Because of the low level of infestation with unsown grasses in the above experiment, it was decided to establish a similar experiment in which "weed grasses" would be deliberately introduced in some plots. Stormont Rathlin was used as a dalapon tolerant variety, Melle and Aberystwyth S.23 as standards. The 1.5 x 5.0 m plots were drilled on 21 March 1975 at two sowing rates: 400 and 1250 viable seeds per m^2. On 4 April 1974, small amounts of seed of *Poa trivialis* L. and *Holcus lanatus* were broadcast over the plots which had been drilled at the lower rate (henceforth called "weedy" plots in contrast to "pure" plots). The experiment was cut three times a year in 1975 and 1976. On 18 September 1975, 6 days after the second cut, some of the plots were sprayed with 3.6 kg a.e./ha of dalapon in the same way as in field experiment 1, the other plots remaining unsprayed.

Results

Establishment and growth of the sown grasses were slow and erratic in 1975, apparently because of unusually dry soil conditions, leading to a higher than expected level of background variation in the experiment. Nevertheless some meaningful results were obtained.

Yields of unseparated herbage on the sprayed plots in the remaining cut after spraying in 1975, and in the first cut in 1976 are given in Table 3. After spraying, growth in the autumn of 1975 had clearly been better in Stormont Rathlin than in the other varieties, and in the "pure" plots than in the "weedy" ones. The greater suppression of growth in the "weedy" plots was presumably due to the presence, at least before spraying, of a substantial proportion of the very susceptible grasses, P. trivialis and H. lanatus. It is not clear whether there was a residual effect of dalapon on growth in spring 1976; on average the sprayed plots, especially those of Melle and Aberystwyth S.23, were less productive than the unsprayed ones, but the high level of background variation precludes any certainty about this effect.

Table 3

Field experiment 2: dry matter yield of "weedy" and "pure" plots of three varieties after spraying with dalapon at 3.6 kg a.e./ha on 18 September 1976. Yields are quoted in kg/ha and, in brackets, as a percentage of the yield of unsprayed plots of the variety

	1st cut (24.10.1975)		2nd cut (10.6.1976)	
	Weedy	Pure	Weedy	Pure
S. Rathlin	651 (52)	1108 (72)	8922 (90)	9924 (114)
Melle	403 (30)	838 (52)	8161 (88)	8853 (99)
Aber. S.23	364 (28)	742 (47)	8555 (88)	9225 (89)
S.E.	65		511	
Probability (varieties)	<0.01		NS	
Probability (weedy vs pure)	<0.001		NS	

Table 4

Field experiment 2: proportion (angular degrees) of Perennial ryegrass in herbage on "weedy" plots, cut on 10 June 1976. Untransformed percentages are given in brackets

	Dalapon	No Dalapon
Stormont Rathlin	76.5 (95)	47.6 (55)
Melle	65.5 (83)	48.8 (57)
Aberystwyth S.23	65.0 (82)	52.7 (63)
S.E.	4.1	
Probability (dalapon + varieties)	<0.001	

Botanical analyses of the herbage harvested on the "weedy" plots on 10 June 1976 showed conclusively that treatment with dalapon had caused an increase in the proportion of Perennial ryegrass (Table 4). Furthermore it appeared that plots of Stormont Rathlin had benefitted more than those of the other two varieties, being 95% ryegrass in the sprayed plots as compared with 55% in the unsprayed plots.

DISCUSSION

The technique for improving Perennial ryegrass swards described by Haggar and Oswald (1976) involves spraying dalapon at 2.8 kg a.e./ha onto actively growing herbage in midsummer. It is based on the principle that most of the common undesirable grasses in lowland grassland are more susceptible than Perennial ryegrass to dalapon, and that therefore the application of a sub-lethal dose of the herbicide will curtail growth of the undesirable grasses more than that of Perennial ryegrass, thereby encouraging the latter to dominate the sward. The technique is, however, subject to several drawbacks. In the short term, it arrests sward growth (Oswald, Haggar and Elliott, 1972); this can be a particularly serious effect in midsummer when grazing may become scarce. The selectivity of dalapon in favour of Perennial ryegrass is not great enough to ensure complete control of other grasses: indeed some common grasses, including Festuca spp. (Fisher and Faulkner, 1975), are at least as tolerant as Perennial ryegrass, and even the more susceptible ones, such as Poa trivialis and Agrostis spp., are not normally eliminated by the technique (Oswald, Haggar and Elliott, 1972). Most dicotyledonous grassland weeds are rather resistant to dalapon and may even spread as a result of its use (Oswald, Haggar and Elliott, 1972). The purpose of seeking varieties of Perennial ryegrass with a higher level of tolerance to dalapon is to find ways of producing leys in which these drawbacks would be alleviated or removed, thus making the technique more effective and perhaps more flexible in timing and herbicide rate.

Differences in degree of dalapon tolerance were found among 35 varieties of Perennial ryegrass by Faulkner (1974). Whereas these differences were considered to have a bearing on the dalapon technique for sward improvement, they were not thought to be large enough to make a substantial difference to the selectivity of the herbicide between Perennial ryegrass and other grasses. It was therefore considered worthwhile to try to breed varieties with a higher level of tolerance. The glasshouse experiments reported in this paper showed that such varieties have been produced. The two field experiments have confirmed that the higher level of tolerance is reflected in sward conditions by a smaller short term depression of productivity after spraying with the herbicide. In one of the experiments there was also evidence that the herbicide had a more beneficial effect on botanical composition in swards based on a tolerant variety. The second experiment also illustrated the important, though rather obvious, point that the degree to which sward productivity is checked depends upon the proportion of susceptible grasses in the sward before spraying.

These experiments were designed primarily to demonstrate that the varieties selected at Loughgall exhibited greater dalapon tolerance than other varieties of Perennial ryegrass; several questions about the use of dalapon on them arise as a consequence.

Midsummer was selected as the optimal time for applying dalapon to Agrostis/Lolium swards because Allen (1965) had found the greatest selectivity against Agrostis stolonifera L. at this time. Whereas A. stolonifera is a major component o[f] many long established grasslands, it is less important than, for example, Poa spp. i[n] younger leys. Since it is envisaged that dalapon would be first applied to swards o[f] a tolerant variety in their early years when Agrostis stolonifera would be relativel[y] unimportant, it may be more effective to spray at a different time of year such as i[n] the spring. It may also be that spring applications would be well suited to a continuous grazing system of management in which herbage tends to be abundant in spring and scarcer in midsummer. Dalapon has sometimes been found to be less phytotoxic in spring than at some other seasons (e.g. by Thompson, 1959), so it is possible that the dosage required in spring would be higher than in summer.

Dalapon is more or less neutral in its effects on the proportion of dicotyledonous weeds in normal mixed swards, though it tends to increase the proportion of Whit[e] clover (Trifolium repens L.) (Oswald, 1972; Haggar and Elliott, 1978). In swards including dalapon tolerant varieties of Perennial ryegrass, the action of dalapon might be expected to be less beneficial to clover and somewhat antagonistic to dicotyledonous weeds. An analogous change in selectivity has been observed with paraquat resistant Perennial ryegrass: applications of paraquat normally favour the clover component of a mixed sward, but in swards based on a paraquat resistant ryegrass, the clover component may decline after an application of paraquat (Faulkner, 1976, 1978).

Other aspects of the use of dalapon for sward improvement which could be re-assessed with dalapon tolerant varieties include the height of foliage at spraying, the effect of ryegrass plant frequency in the sward at spraying, the possibility of oversowing with seed of a tolerant variety after spraying, and integration with the "one-pass" seeding technique (Squires, Haggar and Elliott, 1976).

It is important that any dalapon tolerant varieties should not be inferior in other agronomic properties to other varieties of Perennial ryegrass. In several trials at Loughgall in which no dalapon was applied, Stormont Rathlin has performed at least as well or somewhat better than control varieties (Faulkner, unpublished). Assuming that these results can be confirmed elsewhere, there is good reason for a revival of interest in grassland improvement using dalapon.

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THE USE OF PARAQUAT FOR CONTROLLING WEEDS IN SEEDLING SWARDS OF PARAQUAT RESISTANT LOLIUM PERENNE L.

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Summary In the two experiments with Stormont Causeway, a paraquat resistant variety of Perennial ryegrass (Lolium perenne L.), paraquat was applied at rates from 0.05 to 0.60 kg a.i./ha at various stages in the establishment of young swards. Yields of unseparated herbage at the first cut declined with increasing paraquat levels. Nearly all treatments controlled dicotyledonous weeds satisfactorily. Unsown grasses, where present, were reduced or eliminated by most treatments. None of the treatments appeared to have affected the establishment of the Perennial ryegrass sward adversely, and some actually increased the yield of Perennial ryegrass herbage at the first cut. It was concluded that a treatment of 0.2 kg a.i./ha at the 4-5 tiller stage could be recommended as having a trivial effect on yield, but controlling nearly all weeds; moderate deviations from this recommendation would be unlikely to have a serious effect.

Résumé Dans deux essais avec Stormont Causeway, une variété de ray-grass anglais (L. perenne) résistant à paraquat, paraquat était appliqué au taux de 0.05-0.60 kg m.a./ha à des stades varieuses de l'établissement des jeunes gazons. Les rendements de l'herbage non séparé au premier coupage ont diminué avec des niveaux de paraquat croissants. Presque tous les traitements ont réglementé les mauvaises herbes dicotylédones. Les herbes non-semées, où présent, étaient reduites ou éliminées par la plupart des traitements. Aucune des traitements ne semblent d'avoir affecté l'établissement du gazon de ray-grass anglais contrairement, et quelques-uns ont actuellement augmenté l'herbage de ray-grass anglais au premier coupage. On a estimé qu'une traitement de 0.2 kg m.a./ha à l'etade de 4-5 de tallage peut être recommandé d'avoir un effet trivial sur le rendement, mais controllant presque toutes les mauvaises herbes; des déviations modérées de cette recommandation serait improbable d'avoir un effet sérieux.

INTRODUCTION

A new concept of grassland weed control was introduced with the breeding of paraquat resistant Perennial ryegrass (Lolium perenne L.) at Loughgall (Faulkner, 1975). The purpose of this breeding was to create superior grass varieties in which a wide range of weeds, including invasive grasses, could be controlled by a single herbicide at any stage in the development of the grass sward. The successful control of Poa trivialis L. by spraying with paraquat at 0.3 kg a.i./ha in the first spring of an autumn sown sward was described in a preliminary report by Faulkner (1976). In the two experiments reported below, a close examination was made of the short term effects of paraquat applied to April and August sown swards in the year of sowing. The likely degrees of weed infestation were unknown in either experiment at the time of sowing.

MATERIALS AND METHODS

Experiment 1

The first experiment took place in a field at Loughgall which had been under grass for many years until it was ploughed in 1976. An attempted direct reseed in autumn 1976 failed. On 27 April 1977, the whole field was drilled with the paraquat resistant variety of Perennial ryegrass, Stormont Causeway. Soon after germination, a light application of compound fertiliser was made, supplying 50 kg/ha of N, 5 kg/ha of P, and 10 kg/ha of K. An area of uniform appearance amounting to 15m x 30m was fenced off for the experiment.

The experimental area was divided into 36 plots of 2.5m x 5.0m, arranged as 3 replicates of 12 plots. Within a replicate the plots were arranged as 3 groups of 4, each group being reserved for spraying on a separate date. Three levels of paraquat were applied on each date, leaving the fourth plot in each group as an unsprayed control. The dates of spraying, growth stages of the ryegrass at spraying, and levels of paraquat applied are described in Table 1. The herbicide was applied as the commercial formulation with wetting system in 333 litres of water per hectare using an Oxford Precision Sprayer fitted with Allman 00 nozzles at a pressure of 2.2 bars.

A strip along the centre of each plot was cut with a motorscythe at a height of 4 cm on 8 August 1977. The cut herbage was weighed and sampled for determination of dry matter content and for botanical analysis. Individual weed species were recorded separately, but amalgamated for statistical analysis. The results of the botanical analysis were transformed from percentage composition figures to angular degrees, and analyses of variance were carried out according to a split-plot design.

Table 1

Treatments applied in experiment 1 (sown 27 April 1977)

Date of application	25 May 1977	15 June 1977	4 July 1977
Growth stage at application	2 leaves	4-5 tillers	10-20 tillers (15-20cm high)
Paraquat levels, kg a.i./ha	0.0	0.0	0.0
	0.05	0.10	0.15
	0.10	0.20	0.30
	0.20	0.40	0.60

Experiment 2

This experiment was carried out on a site which had grown a cereal crop in 1976 and been fallowed for most of 1977. It was sown on 18 August 1977 by broadcasting Perennial ryegrass cv. Stormont Causeway at about 30 kg/ha with a Sisis Lospred fertiliser distributor. At sowing, fertiliser was applied to give 60 kg/ha of N, 15 kg/ha of P, and 45 kg/ha of K.

The design of the experiment was identical to that of experiment 1, with a total of 36 plots assigned to the same number of herbicide treatments and control plots. Details of the rates and dates of application are given in Table 2. The growth stages at spraying were somewhat earlier than those in experiment 1.

Table 2

Treatments applied in experiment 2 (sown 18 August 1977)

Date of application	5 Sept 1977	13 Sept 1977	13 Oct 1977
Growth stage at application	1-2 leaves	3 leaves/ 1st tiller	6-8 tillers
Paraquat levels, kg a.i./ha	0.0	0.0	0.0
	0.05	0.10	0.15
	0.10	0.20	0.30
	0.20	0.40	0.60

A cut was taken on 7 November 1977 for estimation of herbage yields. Botanical analysis of samples of the cut herbage was not attempted since the proportions of weeds present were obviously too low to be reliably estimated by this method. Instead, the number of dicotyledonous weeds in each plot was estimated by eye and scored on a 0-5 scale before the herbage was cut. The most numerous weed species in each plot were noted.

In March 1978, fertiliser was applied at the same rates as at sowing, and a further cut was made on 16 May 1978.

RESULTS

Experiment 1

Symptoms of paraquat damage were evident on dicotyledonous weeds within a few days of spraying. Some of the paraquat treatments also produced visible effects on the Stormont Causeway plants. Applied at the 2-leaf stage, 0.2 kg/ha of paraquat killed a very small proportion of the seedlings, but the lower doses had little visible effect. The plots sprayed with 0.4 kg/ha at the 4-5 tiller stage, and all plots sprayed at 10-20 tillers suffered a little scorching of the Stormont Causeway, although in no case was a substantial proportion of the foliage actually killed.

Yields of unseparated herbage were affected by the herbicidal treatments (Table 3; Figure 1). Spraying with up to 0.2 kg/ha of paraquat at the 2-leaf and 4-5 tiller stages resulted only in trivial yield depressions. The other treatments, which coincide with those in which scorching was noted, had greater effects on yield.

The results of the botanical analyses are presented in their transformed state in Table 3, and as yields of ryegrass herbage in Figure 1. All four components were significantly affected by the herbicide treatments. The proportion of ryegrass was increased significantly by all treatments except 0.2 kg/ha at the 2-leaf stage. Other grasses, which were comprised mainly of *Poa annua* L., were generally reduced by paraquat, but the amounts present were small even in the unsprayed plots. There was a tendency for White clover (*Trifolium repens* L.) to decline with increasing dosage. Dicotyledonous weeds were strongly affected by the treatments, but for this component the minima occurred at the middle dose for each growth stage. The rather large component of weeds in the plots sprayed with 0.2 kg/ha at the 2-leaf stage consisted mostly of *Urtica dioica* L.; this species was distributed unevenly through the experiment, probably because of the regeneration of rhizome fragments with a clustered distribution. The other major weed species, Ranunculus repens L. and Stellaria media (L) Vill., were found as seedlings and the incidence of both was reduced by all treatments.

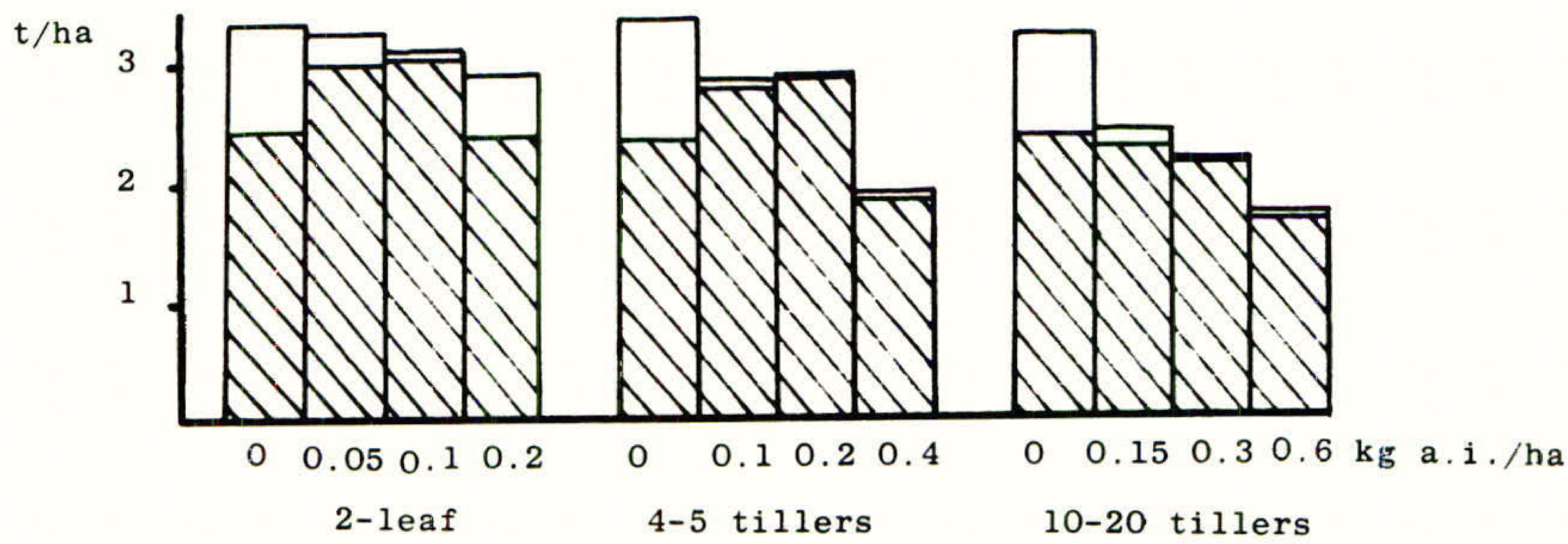
Table 3

Experiment 1: dry matter yield (kg/ha) and composition (angular degrees) of herbage cut on 8 August 1977

Growth Stage	Paraquat kg/ha	Yield kg/ha	Perennial ryegrass	Other grasses	White clover	Dicot weeds
2 leaves	0.0	3370	59.4	3.3	6.6	29.1
	0.05	3290	73.9	2.3	5.5	14.1
	0.10	3160	81.8	3.8	5.2	1.6
	0.20	2950	66.4	0.0	2.1	23.0
4-5 tillers	0.0	3420	56.8	3.8	8.4	31.7
	0.10	2900	80.0	0.0	5.4	7.3
	0.20	2960	85.4	0.0	4.6	0.0
	0.40	1970	79.2	0.0	4.4	8.7
10-20 tillers	0.0	3280	60.2	6.6	8.9	27.0
	0.15	2460	78.7	0.0	6.2	8.0
	0.30	2250	81.8	3.6	6.4	2.1
	0.60	1790	79.5	0.0	5.8	8.7
LSD 5% (same growth stage)		520	9.4	3.8	3.8	10.3
LSD 5% (different growth stage)		740	14.4	5.8	5.8	16.3

Figure 1

Experiment 1: yield of Perennial ryegrass (shaded) and other herbage (unshaded) after paraquat treatments applied at 3 growth stages



Experiment 2

The overall visual effect of the paraquat in this experiment was less than in experiment 1 because of the lighter weed infestation. The highest rate, 0.4 kg/ha, applied at the middle stage killed a few of the Stormont Causeway seedlings and retarded growth in the remainder with the result that some bare soil was still visible at the time of the first cut. The other herbicide treatments had less visual effect although there was a little scorching of the plots sprayed at 6-8 tillers.

In the November cut, herbage yields for each date of spraying declined with increasing dosages of paraquat (Table 4; Figure 2). In general the reductions in yield were similar in magnitude to those found in experiment 1, but as proportionate reductions they were higher because the overall yield level was lower.

Table 4

Experiment 2: dry matter yield (kg/ha) of herbage in two cuts, and weediness scores before first cut

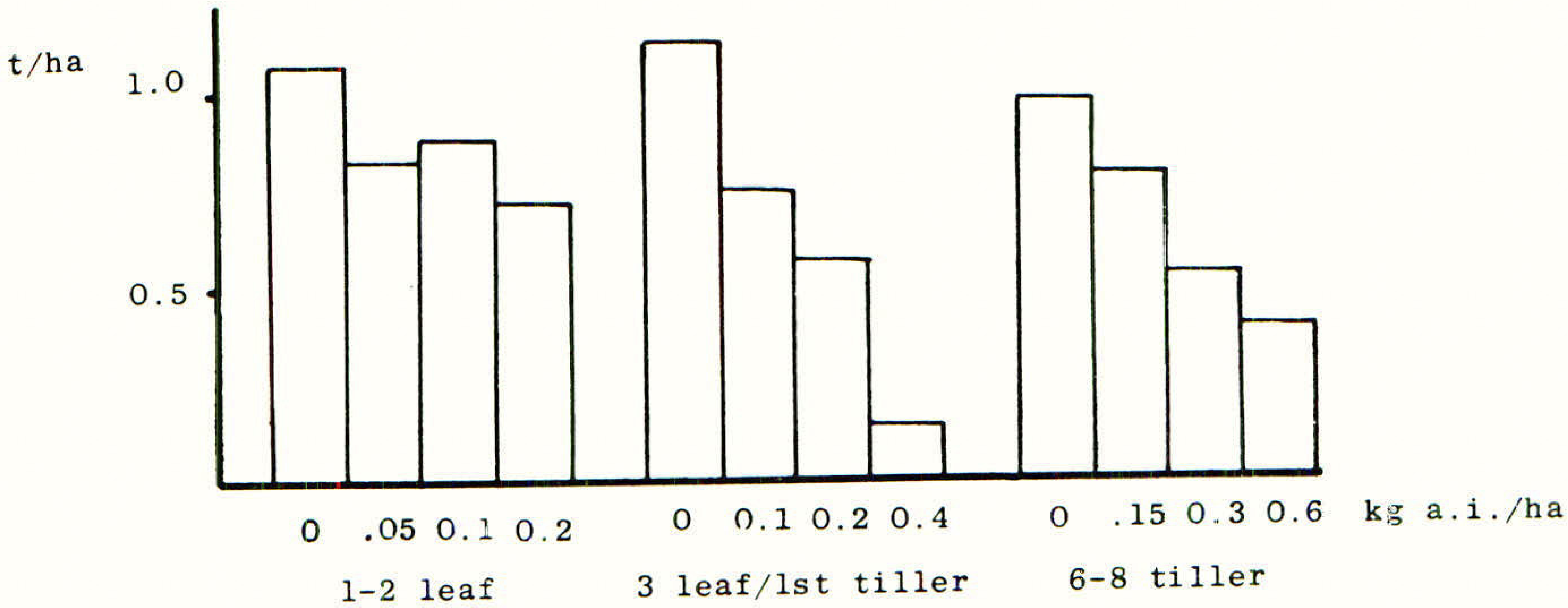
Growth Stage	Paraquat kg/ha	Yield 7.11.1977	Yield 16.5.1978	Weediness 7.11.1977
1-2 leaves	0.0	1080	4890	4.3
	0.05	830	4430	1.7
	0.10	890	4140	0.0
	0.20	720	4200	0.7
3 leaves/ 1st tiller	0.0	1140	3630	4.0
	0.10	750	4270	0.0
	0.20	570	4340	0.0
	0.40	140	4830	0.0
6-8 tillers	0.0	980	3940	4.0
	0.15	790	3940	0.3
	0.30	520	3980	0.0
	0.60	390	3840	0.0
LSD 5% (same growth stage)		230	N.S.	-
LSD 5% (different growth stage)		370		-

Weeds were distributed in small numbers throughout the unsprayed plots, the main species being Fumaria officinalis L., Lamium hybridum Vill., Senecio vulgaris L. Sinapis arvensis L., Sonchus asper (L.) Hill, and Stellaria media. As a whole, these weeds were markedly reduced as a result of the paraquat treatments (Table 4). Some seedlings of F. officinalis, L. hybridum, and S. asper either survived or avoided the earliest set of treatments, and a few plants of S. arvensis were not killed by 0.15 kg/ha applied at the latest stage.

After the November cut, it appeared that none of the treatments had given rise to thin or patchy swards. In accordance with this judgement, no significant differences in yield could be detected in the cut taken on 16 May 1978 (Table 4). At this date the whole experiment consisted of a virtually pure stand of Perennial ryegrass. The treatment which had caused the most severe initial effects, 0.4 kg/ha of paraquat at the middle growth stage, gave rise to one of the highest mean yields observed at this cut, indicating at least that no lasting damage had been done to the ryegrass.

Figure 2

Experiment 2: yield of unseparated herbage in first cut after paraquat treatments applied at 3 growth stages



DISCUSSION

The application of paraquat to seedling swards of a resistant variety of Perennial ryegrass in the early stages of growth has two aims: firstly to ensure that weeds do not prevent the satisfactory establishment of a uniform and dense grass sward; and secondly to remove from the young sward any seedlings of species which may progressively invade the sward at a later stage.

These two experiments were concerned primarily with finding the best way of achieving the first aim. Altogether 18 combinations of treatment involving paraquat were applied and every one of them reduced the weed content of the herbage at the first cut, most of them severely so. The less effective treatments were among those applied at or before the 2-leaf stage of the grass, and it is likely that in these instances many of the weeds present at the time of cutting had not emerged above the soil surface at the time of spraying.

Unsown grasses, although only present in one trial in small quantities, were also reduced or eliminated by most treatments. Of the three less effective treatments, two were among those applied at the 2-leaf stage. Successful control of heavy infestations of invading grasses by spraying young stands of resistant Perennial ryegrass with paraquat has been obtained in other experiments (Faulkner, 1976 and unpublished).

The effect of paraquat on White clover in experiment 1 was less severe than on dicotyledonous weeds, but was the reverse of that encountered in swards of susceptible grasses, for example by Williams and Palmer (1969). A reduction in the clover content following the use of paraquat on young swards of resistant Perennial ryegrass has been observed previously, and was suggested to be due to the susceptibility of juvenile clover plants (Faulkner, 1976). The evidence from experiment 1 could be interpreted to mean that the applications at the latest growth stages had less effect on the clover content than at the earlier ones, but the figures are ambiguous on this point. Effects on clover should preferably be judged over a longer term.

It is important in agricultural practice that any measure taken for the purpose of weed control does not have a severely adverse effect on the crop. If Perennial ryegrass itself, rather than herbage in general, is regarded as the crop, then some of the treatments in experiment 1 actually gave rise to increased crop yields at the first cut (Figure 1). However, it is realistic neither to discount entirely herbage other than the sown grass, nor to regard it as of equal value to the sown grass. Weeds present at establishment may have some nutritional value to ruminant animals on the one hand, but an insidious effect on the long-term productivity of the sward on the other. Therefore, only a treatment which controls the unsown species and no more than slightly reduces the overall productivity in the short-term can be regarded as unequivocally beneficial. These two conditions are met by nearly all the treatments used in these experiments, for even the most severely affected swards lost only a small fraction of the annual yields which would have been expected. However, the greater yield depressions incurred after some of the higher dosages were unnecessary in that similar degrees of weed control could have been achieved with a lower dosage. There was also some evidence that applications at or before the 2-leaf stage of the grass allowed some late germinating weeds to escape the effects of the herbicide. It may thus be concluded that the optimal rates, at least for the weed flora encountered in these experiments, lie in the range 0.1 to 0.3 kg/ha applied from the appearance of the first tiller onwards; a good target would be 0.2 kg/ha at the 4-5 tiller stage. Somewhat higher rates might be appropriate for seed crops in which herbage production is unimportant. However the use of paraquat on young swards of resistant Perennial ryegrass is a robust technique, for it is unlikely that moderate misjudgements of timing or application rate, or the accidental overlapping of sprayer courses, would have drastic effects.

Acknowledgements

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DIFENZOQUAT FOR THE CONTROL OF WILD OATS (AVENA SPP.) IN RYEGRASS SEED CROPS

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Summary Six replicated trials were conducted in ryegrass seed crops. Three trials are described in which difenzoquat was applied at 1.0 kg a.i./ha at four times of application from autumn to spring. Three further trials investigated single treatments in autumn at dosages of 0.5 to 1.0 kg a.i./ha; sequential treatments in autumn and spring at dosages up to 1.0 + 2.0 kg a.i./ha; and single spring treatments at 1.0 or 2.0 kg a.i./ha.

Of the single applications those applied in the autumn or winter were generally more effective than spring treatments. Sequential applications were consistently more effective for the control of *Avena* spp. than single treatments applied either in autumn or spring. In two trials, increases in seed yield were obtained following herbicide treatments and there were no indications of crop reductions following the highest dosages applied.

INTRODUCTION

Difenzoquat is highly effective for the control of *Avena* spp. in wheat and barley (Winfield 1974) and is widely used on these crops in many countries. The chemical is applied in the U.K. at 1.0 kg a.i./ha with 0.5% v/v non-ionic wetting agent in the spray mixture, and is effective over a wide range of *Avena* spp. growth stages from 2 leaves to jointing.

It was demonstrated that eight varieties of perennial ryegrass and one variety of Italian ryegrass showed good to excellent tolerance of difenzoquat dosages up to 2.0 or 3.0 kg a.i./ha (Oswald and Haggar, 1974; Mead and Finch, 1976). The efficacy of difenzoquat for the control of *Avena* spp. in ryegrass seed crops has previously been reported by Mead and Ross (1976).

The present series of trials during 1975/76 and 1976/77 were designed to determine the optimum times and growth stages for application of difenzoquat for *Avena* spp. control, and to compare single with sequential treatments. The effects of dosages of difenzoquat greater than 1.0 kg a.i./ha on the seed yield of crops were investigated.

METHOD AND MATERIALS

Trials were conducted in Eastern and Southern England on commercial crops of ryegrass grown for seed. Details of locations and crops for the six trials are given in Table 1. All trial sites contained natural infestations of *Avena* spp.

Table 1

Details of sites and crops

Year	Trial No.	Location	Species	Variety	Seeding date
1975/76	1	Broxted, Essex	perennial	Reveille	April 1975*
	2	Hemel Hempstead, Herts	perennial	Meltra	29th Sept 1975
	3	Burnt Fen, Suffolk	Italian	RvP	3rd Oct 1975
1976/77	4	Gt.Dunmow, Essex	perennial	S101	March 1976*
	5	Birdbrook, Essex	perennial	Barlenna	Sept 1976
	6	Tisted, Hampshire	perennial	Cropper	8th Sept 1976

*ryegrass undersown into spring barley

Trials 1 to 3 during 1975/76 were designed to compare the effects on *Avena* spp. infestations of single applications of difenzoquat methyl sulphate at 1.0 kg a.i./ha at each of four different times of application at each site. Trials 4 to 6 were designed to compare the efficacy of single and sequential treatments at different dosages and to measure the tolerance of crops to dosages higher than would be used for control of *Avena* spp. Ethofumesate was applied as a standard product at the first time of application in trials 4 to 6.

A non-ionic wetting agent was added to all difenzoquat spray mixtures. The concentration of wetting agent was 0.5% v/v for all treatments in trials 1 to 3. In trials 4 to 6 wetting agent was added at 0.5% to difenzoquat applied at 1.0 and 2.0 kg a.i./ha, and at 0.25 and 0.375% v/v respectively, where difenzoquat was applied at 0.5 or 0.75 kg a.i./ha.

Randomised block designs were used with three replicates in 1975/76 and with four replicates in 1976/77. The stage of growth of the crop and of *Avena* spp. was recorded at each time of application. Treatments were applied at 200 l/ha and 2.8 bar spray pressure using an Oxford Precision Sprayer fitted with flat fan nozzles. Plot size was 2.5 x 20m or 3 x 15 m.

Trials were inspected at 4-6 week intervals after treatment for any visual effect of treatments on crops. Records of *Avena* spp. control in late June or early July were by estimate of reduction in spikelet numbers in trials 1 to 3, using the method described by Holroyd (1972), and by panicle counts in trials 4 to 6.

Estimates of seed yield were obtained in trials 5 and 6 from an area of $32m^2$ in the centre of each plot by combine harvester adapted for use on experimental plots.

RESULTS

Control of *Avena* spp.

Mean reductions of *Avena* spp. infestations following experimental treatments are presented in Tables 2 and 3.

Table 2 The effect on wild oats of difenzoquat applied at four times of application - 1975/76

Trial no.	Dosage (kg a.i./ha)	Application date	Crop growth stage	Wild oat growth stage	Wild oat control (spikelets/m^2)	Wild oat control % reduction*	Sig by 'F' test
1	0	-	-	-	(2,391)		
	1.0	21.10.75	3-4 leaves + some tillers	3-4 leaves + tillers		98.3^{a}	
	1.0	28.11.75	4-5 leaves + tillers	4-5 leaves + tillers		94.3^{a}	***
	1.0	3.3.76	4-5 leaves + tillers	4-5 leaves + tillers		85.0^{b}	
	1.0	20.4.76	6 leaves + tillers	5-6 leaves + tillers		80.0^{b}	
2	0	-	-	-	(1,716)		
	1.0	12.11.75	2-3 leaves + some tillers	2-3 leaves + tillers		98.5	
	1.0	20.2.76	3 leaves + tillers	3-4 leaves + tillers		76.7	N.S.
	1.0	20.4.76	4 leaves + tillers	4-5 leaves + tillers		94.2	
	1.0	18.5.76	6 leaves + tillers	5-6 leaves + tillers		72.1	
3	0	-	-	-	(7,316)		
	1.0	13.11.75	2 leaves	3-4 leaves + tillers		88.2^{b}	
	1.0	1.3.76	3 leaves + tillers	4-5 leaves + tillers		98.8^{a}	***
	1.0	12.4.76	5 leaves + tillers	5-6 leaves + tillers		90.1^{b}	
	1.0	6.5.76	6 leaves + tillers	6 leaves + tillers		75.5^{c}	

*Statistical analyses of weed control data were conducted on log (x+1) transformed surviving spikelets/m^2. Means are compared by Duncan's New Multiple Range Test. Means with common superscripts (a, b and c) are not significantly different at p = 0.05.

Table 3 The effect on *Avena* spp. and yield of ryegrass of difenzoquat and ethofumesate 1976/77

			Wild oat control (% reduction)*			Relative seed yield (%)	
Trial no:			4	5	6	5	6
Application dates:			9/11/76 & 2/5/77	19/11/76 & 2/5/77	15/12/76 & 10/5/77		
Growth stages	crop†:		3-4L +T & 5-6L +T	2-3L & 4-5L +T	3L +T & 6L +T		
	Avena:		4-5L +T & 6L +T	3-4L &T & 4-5L +T	2-5L +T & 4-6L +T		
	difenzoquat dosage (kg a.i./ha)						
code	Autumn	Spring					
A	0	0	(12 panicles/m^2)	(296 panicles/m^2)	(18 panicles/m^2)	100^{a} (1.62t/ha)	100 (3.20t/ha)
B	0.5	0	90.7^{bc}	99.6^{b}	91.2^{d}	177^{bc}	119
C	0.75	0	70.6^{c}	100^{a}	95.4^{bcd}	176^{bc}	115
D	1.0	0	85.1^{bc}	100^{a}	95.9^{cd}	173^{bc}	107
E	0.5	1.0	98.4^{b}	100^{a}	99.8^{bc}	178^{bc}	114
F	0.75	1.0	98.8^{bc}	100^{a}	98.5^{bcd}	165^{bc}	107
G	1.0	1.0	100^{a}	100^{a}	100^{a}	178^{bc}	117
H	1.0	2.0	100^{a}	100^{a}	99.9^{b}	180^{bc}	130
I	0	1.0	89.1^{bc}	89.8^{c}	83.1^{d}	151^{b}	105
J	0	2.0	98.8^{bc}	96.5^{c}	99.6^{bc}	151^{b}	120
	Ethofumesate						
K	2.0	0	91.9^{bc}	100^{a}	83.9^{d}	175^{bc}	132
	Sig. by 'F' test		**	***	**	***	NS

†Crop and *Avena* Growth Stages by No. leaves on main stem (L) and presence of tillers (T)
*Statistical analyses of weed control data were conducted on log (x+1) transformed surviving panicles/m^2.
Means are compared by Duncan's New Multiple Range Test. Means with common superscripts (a,b,c and d) are not significantly different at $p = 0.05$.

In trials 1 to 3 the earlier treatments applied during the autumn and winter tended to be most effective (Table 2), and there was less control following the latest time of application in each trial. At site 2 the infestation of *Avena* spp. was irregular and there were no significant differences between treatments. At sites 1 and 3 applications at approximately 3-4 leaves of the crop were most effective.

The results of trials 4, 5 and 6 (Table 3) show some important consistencies between trials. The three sequential applications (E, F and G) were more effective than single autumn or spring treatments (B, C, D, I & K) in trials 4 and 6 where spring germination of *Avena* spp. occurred.

The sequential treatments of difenzoquat at 1.0 + 1.0 kg a.i./ha (G) gave 100% control of *Avena* spp. at each site.

Effects on Crops

Regular inspection of crops following application of treatments at each site revealed very slight discolouration one to three weeks after most treatments, but no subsequent damage or check to the crop at any time. The results of seed harvest measurements in trials 5 and 6 are given in Table 3. The yield in untreated plots was seriously reduced in trial 5 by the very heavy infestation of *Avena* spp. All treatments resulted in substantial increases in yield. Plots treated in spring only (I and J) yielded less seed than autumn only treated plots although these differences were not statistically significant (p = 0.05). At site 6 there was a clear trend for yield increases following all treatments.

There was no suggestion of yield reduction following application of the higher dosages of difenzoquat (H & J).

DISCUSSION

In ryegrass seed crops grown on land where *Avena* spp. are present the weed will often germinate over an extended period, usually from August or September until March or April. Heavy infestations may compete with and reduce the crop stand and vigour during late autumn and winter, and the greatest yield benefit will be obtained from early control. This early treatment, however, may lead to unacceptable contamination from subsequent emergence of *Avena* spp.

Where lighter but not easily rogueable infestations of *Avena* spp. are present the grower may wish to use chemical control with the intention of harvesting an uncontaminated crop. Therefore, at either level of infestation the application of sequential treatments of a herbicide for control of *Avena* spp. would be appropriate to obtain the greatest yield increase and the most reliable control of the weed.

The trials described here demonstrate that difenzoquat was highly selective against wild oats in ryegrass seed crops and is capable of 100% control of heavy or light infestations of *Avena* spp. when applied as sequential treatments in autumn/early winter and spring at 1.0 + 1.0 kg a.i./ha.

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