Proceedings 1980 Crop Protection Conference - Weeds

TOWARDS AN UNDERSTANDING OF PARAQUAT TOLERANCE IN *LOLIUM PERENNE*

J.S. Faulkner, C.B. Lambe and B.M.R. Harvey

Department of Agricultural Botany, Queen's University, Newforge Lane, Belfast BT9 5PX

Summary Paraquat tolerant varieties of Lolium perenne have been selected for paraquat tolerance and have been shown, under differing circumstances, to be three- to ten-fold more tolerant than normal varieties. Investigation of the relationship between seedling age and tolerance suggests that tolerance is greater in very young seedlings and decreases as their photosynthetic activity increases.

Studies on the mechanism of paraquat tolerance in photosynthetic tissues have not revealed differences in uptake or distribution of the herbicide but have shown that tolerant varieties have a greater capacity to detoxify superoxide radical and hydrogen peroxide which arise on reoxidation of paraquat reduced by the photosynthetic electron transport chain. Recent experiments show that paraquat uptake by roots and distribution of the herbicide in root tissue is also similar for tolerant and normal varieties of L. perenne. This suggests that, as for leaves, the mechanism of tolerance is related to the biochemical action of the herbicide.

Résumé Des variétés de Lolium perenne qui furent choisies pour leur tolérance de paraquat, ont montré, dans des circonstances différentes, qu'elles sont trois fois jusqu'à dix fois plus tolérant que les variétés normales. L'investigation de la connexité entre l'age du jeune brin et tolérance suggère que la tolérance est plus forte chez les sauvageons qui sont très jeune, et qu'elle diminue pendant que leur activité de photosynthèse augmente.

Des études sur le machinisme de la tolérance de paraquat des tissus de photosynthèse n'ont pas révélé des différences de l'absorption ou la mise en distribution de l'herbicide, mais elles ont démontré que les variétés tolérantes ont une capacité plus forte pour désintoxiquer suroxyde radical et l'eau oxygénée qui se présentent a la réoxydation de paraquat réduite par la chaîne de transport de l'électron de photosynthèse. Des expériences de date récente montrent que l'absorption de paraquat par les racines et la distribution de l'herbicide dans le tissu des racines est aussi semblable pour les variétés normales et tolérantes de Lolium perenne. Ce fait suggère que, comme c'est aussi vrai pour les feuilles, le machinisme de la tolérance a un rapport proche avec l'action biochimique de l'herbicide.

INTRODUCTION

Paraquat is a fast acting contact herbicide which kills the leaf tissues of most green plants. Perennial species which have substantial reserves in the form of rhizomes, tap roots, woody stems etc., generally recover from spraying with paraquat. Other plants may be completely killed, but there is variation between species in degree of susceptibility.

In the early stages of herbicide development, single species were often regarded as genetically homogeneous in their response to a particular herbicide. However, differences between strains of Agrostis stolonifera L. in susceptibility to 2, 4-D were reported by Albrecht (1947) and many other comparable examples have been found since then. Blackman (1950) foresaw that intraspecific variation in herbicide response meant that the selective pressure of repeated applications of a herbicide might lead to the evolution of herbicide resistant weeds. This predicted phenomenon has become a reality in several species, particularly in the form of resistance to triazine herbicides, although it has not happened as rapidly nor as often as might have been feared (Grignac, 1978; Gressel and Segel, 1978). On the positive side, Blackman (loc. cit.) also foresaw the possibility of harnessing intraspecific variation to create herbicide tolerant crop varieties.

In Lolium perenne L. small differences between varieties in their susceptibility to paraquat were reported by Wright (1968). The question then arose - could selective breeding produce a paraquat tolerant variety of L. perenne so that swards of this economically important grass could be freed from invasive grasses by application of a herbicide previously regarded as total rather than selective?

Further investigations showed that there was considerable plant to plant variation in paraquat tolerance within populations of L. perenne, and that this variation had a continuous pattern with a moderately high level of heritability (Faulkner, 1974). A programme of deliberate selection for paraquat tolerance was therefore undertaken. For selection purposes, critical doses of the herbicide were applied, mainly to young seedlings of genetically segregating populations.

The genetic material used in the selection programme included existing varieties, breeder's stocks, and wild collections. One collection was particularly important and has contributed genes to most of the tolerant lines which have now been developed. This collection came from a cereal field which had been sprayed with paraquat for stubble cleaning before direct drilling for about ten successive years, and in which L. perenne was present as a weed. The paraquat tolerant variety Causeway, which is now on the National List, was selected out of this collection. Our experimental work outlined in this paper has been carried out on Causeway and a few related lines with a similar level of paraquat tolerance. Significantly more tolerant lines have recently been bred by combining tolerance genes from different sources.

THE EXPRESSION OF TOLERANCE

Degree of tolerance

The relative tolerances of selected paraquat tolerant lines and normal varieties of L. perenne have been compared under a range of contrasting experimental conditions. Invariably the selected lines were significantly more tolerant. For those experiments in which several doses of the herbicide were applied, estimates were made of the factor by which the dose would have to be altered to give equal effects on tolerant and normal varieties (the "tolerance differential"). These experiments are summarised in Table 1. Although the observed tolerance differential varied from under 3 to over 10, there was no immediately obvious explanation of this variation related to growth stage, mode of herbicide application, environment, or choice of varieties.

Table 1

Relative paraquat tolerance of normal (N) and tolerant (T) varieties in various conditions

Criterion of tolerance	Environment	Varieties compared	Tolerance differential	Reference
Germination in paraquat solution	Dark incubator	Causeway (T) Barlenna (N)	>10	Faulkner and Harvey (in press)
Germination & survival in sprayed soil	Glasshouse	Causeway (T) S. 101 (N)	ca 3	Faulkner and Harvey (in press)
Germination & survival under sprayed microsward	Glasshouse	Causeway (T) Barlenna (N)	ca 9	Faulkner (in press)
Survival of sprayed 2 leaf seedlings	Glasshouse	PRP II (T) Barlenna (N)	5.6	Faulkner 1975
Scorch & survival of sprayed mature sward	Field	Causeway (T) Talbot (N)	ca 4	Faulkner (unpub.)
Non-wilting of excised leaves with cut ends in paraquat solution	Growth cabinet	PRP IX (T) Barlenna (N) Kent Ind. (N)	ca 3	Harvey *et al.* 1978

Experiment - Paraquat tolerance and age

To investigate the relationship between paraquat tolerance and seedling age, paraquat was sprayed onto glasshouse-grown seedlings of varieties Causeway and Barlenna at stages ranging from 7 to 24 days from sowing. The sequence of stages was obtained by successional sowing in seed trays of potting compost at 2-3 day intervals. Typical seedlings had 2 leaves on day 12, a first tiller on day 18, and 2-3 tillers on day 24. Seedlings that germinated after spraying were disregarded. Paraquat was sprayed as a commercial formulation at 0.02 or 0.04 (Barlenna) and 0.12 or 0.24 (Causeway) kg ha^{-1} of active ingredient. For each variety and herbicide level, 6 replicate batches of 28 seeds (ages 7-15 days at spraying) or 14 seeds (ages 18-24 days at spraying) were sown.

The ability of the seedlings to survive paraquat treatment increased with age in both varieties, but in Barlenna the increase was more rapid than in Causeway (Fig 1). Thus it seems that the tolerance differential is highest (over 6) in very young seedlings and decreases with age, at least within the relatively narrow range examined. Although this conclusion was not apparent from the results of the experiments given in Table 1, it is compatible with them if the experiment on paraquat treated soil is disregarded. (The estimate of a tolerance differential of less than 3 in this experiment was a very approximate one because the highest level of paraquat applied had only a small effect on the tolerant variety).

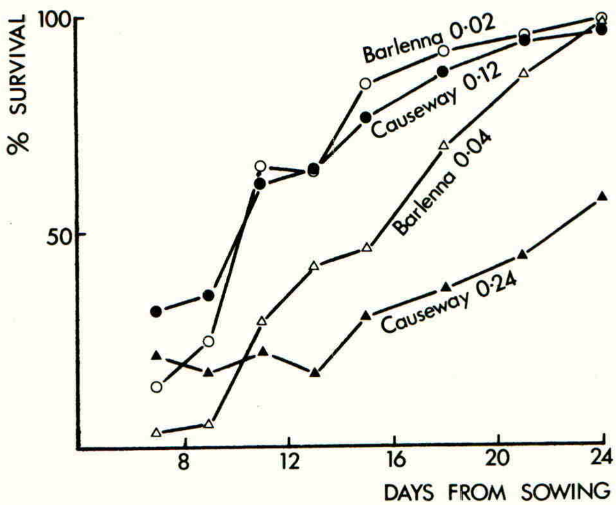
Experiment - Paraquat tolerance in roots

The tolerance of paraquat by Causeway at germination, even in darkness, indicates that the tolerance mechanism is not confined to photosynthetic tissues. Confirmation of this point has been obtained by studying the effects of paraquat on excised root systems.

Excised roots of hydroponically-grown seedlings were incubated in paraquat solution. Each replicate contained four root systems and there were three replicates per variety. After 8 h, the proportion of brown nodal root tips was

Figure 1

Survival of seedlings sprayed with paraquat in relation to age at spraying



Regression coef. and S.E. (probits)	
Barlenna 0.02	0.220 ± 0.014
Barlenna 0.04	0.210 ± 0.012
Causeway 0.12	0.146 ± 0.011
Causeway 0.24	0.065 ± 0.009

scored and the increase in conductivity of the medium due to solute leakage from the roots was measured. On both criteria, roots of the normal variety Kent Indigenous were damaged in either 1.5 or 3×10^{-4} M paraquat, but there was no significant damage to roots of Causeway at either concentration (Table 2).

Taken together, the results of this experiment and the studies of germination not only show that paraquat tolerance operates in non-photosynthetic tissues, but also suggest that the tolerance differential in such tissues may even be higher than in photosynthetic tissues. Were this the case, the decline of the tolerance differential with increasing age in seedlings might be explained by the increasing role of photosynthesis in seedling growth.

THE MECHANISM OF TOLERANCE IN FOLIAGE

Several conceivable explanations of paraquat tolerance can be dismissed, at least as major components of the mechanism.

No differences have been detected in the ability of normal and tolerant L. perenne to take up paraquat. When ^{14}C-paraquat solution was applied to leaf surfaces, or supplied to cut ends of excised leaves by immersion, equal amounts of radioactivity were subsequently found in leaf tissues of the two types of plant (Harvey et al., 1978). Distributions of radioactivity within the leaf tissue were also indistinguishable.

Table 2

The effects of 8 h immersion in paraquat solution on excised roots of normal (Kent Indigenous) and tolerant (Causeway) *L. perenne*

Paraquat concentration (M)	Brown root tips (%)		Solute leakage (ohms^{-1} x 10^{-5})	
	Kent Ind.	Causeway	Kent Ind.	Causeway
0	1.5	0	7.0	6.3
1.5 x 10^{-4}	56.9	1.7	10.5	6.7
3.0 x 10^{-4}	73.1	1.6	16.1	7.1
			S.E. $\pm$0.91	

There is no evidence that paraquat tolerant L. perenne is able to metabolise paraquat. Harvey et al. (loc. cit.) dipped the foliage of intact plants into ^{14}C-paraquat solution. In electrophoretograms of extracts of the foliage taken two days later, radioactivity was confined to the position of authentic paraquat. No signs were found that radioactive degradation products had been released into the atmosphere or into the rooting medium.

Paraquat tolerance does not seem to be associated with any differences in the translocation of paraquat within the plant. Although there is some evidence of differences between varieties in paraquat mobility (Harvey et al., loc. cit.) these differences appear to be unrelated to paraquat tolerance.

Positive clues about the basis of tolerance have been obtained from the enzyme studies of Harper and Harvey (1978). They estimated the relative activities of three enzymes in crude extracts of 4 paraquat tolerant lines and 11 normal varieties. On average the activities of catalase, peroxidase and superoxide dismutase were respectively 32%, 36% and 50% higher in tolerant lines than in normal varieties.

The toxic action of paraquat in the light is believed to arise from the production of superoxide radical and hydrogen peroxide by the reaction of molecular oxygen with reduced paraquat radicals formed during photosynthesis (Farrington et al., 1973). Since catalase and peroxidase are detoxifiers of hydrogen peroxide, and superoxide dismutase of superoxide radical, it was proposed by Harper and Harvey (loc. cit.) that elevated levels of these three enzymes are responsible for paraquat tolerance. In the current state of knowledge about the mode of action of paraquat, it is impossible to decide whether the higher levels of the three enzymes account fully for the degree of paraquat tolerance observed, or whether there is some additional mechanism at work.

THE MECHANISM OF TOLERANCE IN ROOTS

An interesting question arises from the observations that paraquat tolerance operates in non-photosynthetic tissues, ie. germinating seeds and roots: is the mechanism of paraquat tolerance in non-photosynthetic tissues the same as in photosynthetic ones, and if so does this mean the mode of action of paraquat is essentially the same in both circumstances? Two experiments designed to help in answering this question are reported here.

Experiment - Paraquat uptake by roots of 3 varieties

Excised root systems were incubated at 20^{o}C in ^{14}C-methyl labelled paraquat (five replicates per variety, each with three roots in 11.1 ml 3 x 10^{-14} paraquat, 0.045 Ci mol^{-1}) and depletion of radioactivity from the medium was equated with paraquat uptake. It was found that there were no significant differences between varieties in amounts of paraquat taken up at any of the three sampling times (Table 3) although after 46 hours, slightly less paraquat was detected in roots of Causeway than of the other two varieties.

Table 3

Uptake of ^{14}C-paraquat by excised root systems of 3 *L. perenne* varieties (disintegrations per minute)

Variety	Uptake time (h)		
	6	22	46
Kent Ind.	53,791	61,605	72,860
Barlenna	49,062	61,316	72,061
Causeway	52,392	60,828	65,623
S.E.	±3,508	±3,818	±3,907
significance	NS	NS	NS

Experiment - Paraquat distribution in root tissues of 3 varieties

Excised root systems were incubated for three or twenty-four hours in ^{14}C-paraquat (three replicates per variety, each with three roots in 11.1 ml 3 x 10^{-4}M paraquat, 0.90 Ci mol^{-1}). After incubation, the roots were washed eight times in distilled water to remove paraquat in the tissue free space. The roots were then frozen (-20^{o}C) and thawed (+20^{o}C) twice to rupture membranes, washed twice more in distilled water to remove paraquat in cytoplasm and vacuoles, and finally washed three times in 3 x 10^{-4}M ^{12}C-paraquat to remove most of the adsorbed labelled paraquat. Each wash lasted 15 minutes in 10 ml of liquid, and duplicate 0.5 ml samples were taken from the liquid after washing for measurement of radioactivity removed from the roots. Little radioactivity was removed in the last wash of each of the 3 stages. Residual radioactivity in the tissues was determined by counting the roots in scintillation fluid and correcting for quenching by the channel ratio method.

No statistically significant differences were found between the varieties in the proportion of radioactivity located in the free spaces, vacuoles and cytoplasm, or adsorbed to root tissues (Table 4). In Causeway, a slightly lower proportion of the paraquat taken up was adsorbed, but the reverse would have been expected if adsorption were involved in paraquat tolerance.

Table 4

Distribution of ^{14}C-paraquat in excised root systems of 3 *L. perenne* varieties

Variety	Paraquat uptake time (h)	Total uptake (dpm x 10^3)	% paraquat in 3 fractions		
			Free space	Cytoplasm + vacuole	Adsorbed to roots
Kent Ind.	3	1388	36.1	21.9	42.0
Barlenna	3	1281	33.6	22.2	44.2
Causeway	3	1276	34.7	26.4	38.9
S.E.		73	2.02	1.42	2.28
significance		NS	NS	NS	NS
Kent Ind.	24	2025	24.2	23.1	52.8
Barlenna	24	2064	23.1	25.8	51.1
Causeway	24	1683	28.7	25.7	45.7
S.E.		±75	±1.44	±1.16	±1.98
significance		*	NS	NS	NS

In this experiment, significantly less paraquat in total was taken up in 24 hours by Causeway than by the other two varieties. In the previous experiment, there was no difference after 22 hours of paraquat uptake but a small (non-significant) difference after 46 hours. Since paraquat tolerance is expressed by roots within 8 hours of exposure to the herbicide (Table 2), reduced uptake at a later stage cannot be an initial part of the paraquat tolerance mechanism. It is possible, however, that this reduced uptake is a supplementary part of the mechanism or that it is an incidental result of the altered metabolism of the root systems of tolerant plants.

CONCLUSION

These results show that paraquat tolerance in roots is unlikely to be due either to reduced uptake or binding of the herbicide. A mechanism similar to that proposed for leaves would appear more probable but the involvement of superoxide radical in paraquat toxicity to non-photosynthetic plant tissues has not yet been demonstrated. Currently, we are investigating the mode of paraquat toxicity in roots and also assaying the activities of superoxide dismutase, catalase and peroxidase in roots of paraquat tolerance and normal varieties of *L. perenne*.

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Proceedings 1980 British Crop Protection Conference - Weeds

METHODS OF TESTING THE REACTION TO HERBICIDES OF VARIETIES OF PEAS (PISUM SATIVUM L. (partum)), BROAD BEANS (VICIA FABA L. (partum) AND DWARF BEANS (PHASEOLUS VULGARIS) AND THE PRACTICAL VALUE OF THE RESULTS

J.M. King

Processors & Growers Research Organisation, Thornhaugh, Peterborough PE8 6HJ

Summary The methods for testing the reaction of varieties of peas, broad and dwarf beans to herbicides are described and data from replicated experiments is presented. This yield data has confirmed that assessments for visual damage can be used with reasonable confidence to predict the sensitivity of legumes to herbicide applications. A wide range in the degree of sensitivity to herbicides was established in all three legumes.

Résumé Les méthodes pour mettre à l'epreuve la réaction des variétés des pois, des grosses fèves et des haricots vert aux herbicides sont rapportées, et les données des expériences répétées sont présentées. Ces données du rendement out ratifié que la vérification pour le dégât visible puisse être utilisé avec assez de la confiance pour prédire la sensitivite de ces récoltes aux applications d'herbicide. L'étendue considerable du degré de la sensitivité des pois et des grosses et haricots vert aux herbicides a été établi.

INTRODUCTION

With the development in the late 1940's and early 1950's of herbicides suitable for use in peas it soon became obvious that some varieties were more tolerant than others, and Roberts & Woodford (1951) presented data classifying 'picking' varieties as most sensitive to dinoseb, 'vining' and 'threshing' (dried) varieties as intermediate and 'field' peas as least susceptible. Results of tests with commonly used pre-sowing wild oat herbicides and pre & post-emergence general purpose herbicides, on a range of 'vining' and 'threshing' pea varieties were reported by Reynolds (1960), and differences in sensitivity were found. In Phaseolus beans wide varietal differences in the sensitivity to monolinuron have been established and Verlaat & Scheeringa (1971) published the results of a three year study using a laboratory test where the plants were grown in water culture containing a range of concentrations of the herbicide. Throughout the past 20 years PGRO have been involved in testing the reaction of varieties of peas, dwarf beans and broad beans to a wide range of herbicides used in these crops. The annual testing of new varieties before they are widely grown has become a necessary and useful study to provide information for advisory purposes. This paper describes the methods which have been developed over the past twenty years and the practical use made of the results.

METHOD AND MATERIALS

The testing for varietal reaction to herbicides comprised two types of field tests. The first was carried out on a large number of varieties and herbicides, involving observation studies on plants treated with higher than normal rates of chemical. The second was the more detailed study of the reaction of a small number of varieties to specific materials in replicated experiments which were taken to yield. Data from such work was used to confirm results from the routine observation studies. In the observation studies single or double rows of each variety were sown in the field using a 2 m Nordsten 'Ceres' corn drill for peas and dwarf beans, while broad beans were sown by hand. Varieties were replicated three or four times. Herbicides were sprayed across the variety rows in 2 m bands with untreated areas being left between pairs of treated plots. Materials were applied using a van der Weij 'Azo' plot sprayer fitted with Birchmeir cone nozzles at a volume of 560 l/ha, with the exception of post-emergence wild oat herbicides which were applied at 220 l/ha. In early work 2 x normal rates were used, but in several tests no herbicide effects were recorded on any variety and the rates have now been standardised to 4 x normal for pre-emergence soil-acting herbicides and 3 x normal for post-emergence materials. Even at 4 x normal rate surface applications of pre-emergence herbicides in some years failed to give sufficient effect on the crop and since 1970 these materials have been shallowly incorporated by means of a rotovator before the crop is sown. In this way root uptake is ensured without the need for irrigation to leach the materials into the root zone. The plants were assessed on a simple 1 to 5 scale for visible effects, reference being made to standard varieties of known susceptibility.

The varieties were classified as follows:-

1 - Highly tolerant
2 - Tolerant
3 - Slightly sensitive
4 - Moderately sensitive
5   Highly sensitive

Tests are carried out for two or three years before final classification is decided.

Leaf wax is thought to be important in relation to damage to peas from contact herbicides such as dinoseb-amine, and varieties were tested before the application of post-emergence herbicides using a 1% crystal violet dye solution as described by Amsden & Lewins (1966). This test is in general use by advisors and fieldsmen and has proved useful in determining the condition of leaf wax in commercial crops (King 1978). Plants are carefully dipped into the solution and the amount of dye retained on the leaves subjectively assessed. The leaf wax was classified as follows:-

1 - Very good, less than 5%	leaf	area	showing	retention
2 - Good,	5 - 10%	"	"	"	"
3 - Moderate,	10 - 20%	"	"	"	"
4 - Poor	20 - 30%	"	"	"	"
5 - Very poor, more than 30%		"	"	"	"

In the replicated yield experiments plot size was 10 m^2 and treatments were replicated three or four times. The experiments were carried out on the Thornhaugh trial grounds, in 1975 the soil was a sandy loam, in 1976 it was a fine sandy loam and in 1978 a very fine sandy loam. The materials were applied with a van der Weij sprayer at 560 l/ha, pre-sowing treatments being incorporated with a rotovator.

The broad bean experiments were sown by hand at a spacing of 10 cm in 45 cm rows. The peas were sown with a 2 m cereal drill at a target population of 95 plants/m^2 in 20 cm rows. Effects of the treatments on crop vigour were assessed during the season.

The effects from the pre-emergence materials took the form of chlorosis, necrosis and where severe, loss of plant, while the post-emergence bentazone plus MCPB application caused chlorosis, distortion and some stunting. Yield of shelled beans and peas were recorded and maturity was measured by means of a tenderometer (TR). The herbicides gave a high degree of weed control and little weed competition occurred.

RESULTS

Peas

The results of assessments carried out on widely grown varieties of peas over a three year period for their reaction to herbicide applications appear in Table 1

Table 1

The reaction of varieties of vining & dried peas to some commonly used herbicides, observation tests 1976 - 78

Variety	Herbicide						
	A	B	C	D	E	F	G
Vining peas							
Avola	-	2	2	3	3	2	-
Dark Skinned Perfection	2	2	2	2	3	2	2
Num	1	3	3	3	3	2	-
Puget	1	1.5	1.5	2	2	2	2.5
Scout	2	2.5	2	2.5	3	2	2
Sprite	2	2	2	2.5	3	3	2
Surprise	1.5	3	3	4	5	4	3
Dried peas							
Dik Trom	-	2	2	1	2	1	-
Maro	1.5	1	1	1	1.5	1	2
Vedette	2.5	3.5	3.5	3.5	4.5	3	2.5

Key: Herbicide
A Chlorthal dimethyl + methazole, pre-emergence
B Terbutryne + terbuthylazine "
C Trietazine + simazine "
D Dinoseb-amine, post-emergence
E Bentazone + MCPB "
F MCPB "
G Diclofop-methyl "

Reaction 5 Highly sensitive

Surprise was included as a known sensitive variety, although it is no longer grown commercially. The tests indicated that Vedette and Surprise were the most sensitive varieties and the small-seeded type Num was also slightly sensitive to four of the herbicides. The dried peas Maro and Dik Trom were the most tolerant varieties. Chlorthal-dimethyl plus methazole, the pre-emergence herbicide developed for safe use on sandy soils, was well tolerated by all the varieties, even those showing sensitivity to other materials, while bentazone plus MCPB was the least well tolerated post-emergence herbicide.

The assessments for leaf wax using crystal violet dye and the subsequent damage from dinoseb-amine appear in Table 2. It can be seen that there was not very good correlation between leaf wax assessments and the degree of damage from the contact herbicide with the exception of Vedette which consistently showed poor leaf wax.

Table 2

Assessments for leaf wax on the upper part of pea plants & the subsequent damage from dinoseb-amine, 1978 - 80

	Leaf wax			Sensitivity to dinoseb-amine		
Variety	1978	1979	1980	1978	1979	1980
Avola	4	3	5	2	3	3
Dark Skinned Perfection	2	2	4	2	2	2
Num	2	3	3	3	2.5	3
Puget	3	2	3	2	2	2
Scout	2	3	3	2	2	2
Sprite	3	4	2	2	2.5	2.5
Maro	3	2	2	1.5	2	1
Vedette	4	4	5	3	3.5	3.5

Key: Leaf wax 5 - Very poor
Sensitivity 5 - Highly sensitive

As a result of the observation tests undertaken in 1976 and 1977 a replicated yield experiment was carried out on the variety Vedette in 1978, data from which appears in Table 3. The visual assessments and yield results confirmed that Vedette is sensitive to the pre-emergence herbicide mixture terbutryne plus terbuthylazine and the post-emergence mixture bentazone plus MCPB applied at normal and 2 x normal rates, while no adverse effects were seen from chlorthal-dimethyl plus methazole even at the twice normal rate of use.

Table 3

Results of herbicide treatments on sensitive pea variety Vedette - 1978

Treatment	Application	Rate kg a.i./ha	Crop score ≁	Yield t/ha	Maturity (TR)
Chlorthal-dimethyl + methazole	Pre-em.	4.5	10	6.87	141
" "	" "	9.0	10	6.47	138
Terbutryne + terbuthylazine	" "	1.1	8	5.55	121
"	" "	2.2	5	4.75	118
Bentazone + MCPB	Post-em	3.0	6	4.47	106
" "	" "	6.0	3	3.56	108
LSD (P = 0.05)		-	-	0.68	-
S.E. as % gen. mean				10.1	9.8

Key: ≁ Crop score; 10 = No apparent damage; 0 = plants killed.

Broad Beans

The results of observation tests on broad bean varieties are shown in Table 4. The varieties Beryl, Feligreen and Pax were moderately sensitive to the pre-emergence herbicide simazine, while Threefold White was tolerant. Data is presented in Table 5 from a replicated experiment carried out on the varieties Beryl and Threefold White treated with simazine and a mixture of trietazine plus simazine. Twice normal rates were used and each was applied either as an incorporated pre-sowing or post-drilling pre-emergence treatment. It can be seen that the incorporated simazine treatment damaged both varieties, but Beryl was most affected. At harvest the yield of Beryl from this treatment was only 34% of that of the other three less damaging treatments, whereas that of Threefold White was 60% of the mean of the other treatments. There was also a suggestion that the incorporated application of trietazine plus simazine was reducing the yield of Beryl but not Threefold White. The mixture of trietazine plus simazine containing only 0.3 kg ai/ha of simazine appeared safer on the herbicide sensitive variety Beryl than simazine at 1.7 kg a.i./ha. None of the maturity differences were statistically significant.

Table 4

The reaction of varieties of broad beans to some commonly used herbicides, observation tests 1976-78

Variety	Herbicide		
	Pre-emergence		Post-emergence
	Simazine	Trietazine + simazine	Dinoseb-acetate
Beryl	4	2	3
Bianca	3	-	2
Feligreen	4	-	2
Pax	4	2	2
Minica	3	2	2
Primo	3	1	2
Threefold White	2	1	2

Key: Reaction 5 - Highly sensitive

Dwarf Beans

The results of observation tests on dwarf bean varieties are shown in Table 6.

None of the commonly grown varieties were highly sensitive to trifluralin, but Chicobel was moderately sensitive to monolinuron, Provider and Lit were slightly sensitive, while Chicobel, Lit, Provider and Tendercrop were slightly sensitive to bentazone.

Table 5

Results of herbicide treatments on sensitive broad bean variety Beryl & tolerant variety Threefold White - 1975

Treatment	Application	Rate kg a.i./ha	Crop score ≠		Yield t/ha		Maturity (TR)	
		Variety ø	A	B	A	B	A	B
Simazine	Pre-sow	1.7	3.0	4.5	1.39	4.61	142	118
"	Pre-em.	1.7	9.3	9.3	4.12	7.61	162	118
Trietazine + simazine	Pre-sow	1.9+0.3	8.0	8.0	3.74	7.91	157	118
"	Pre-em.	1.9+0.3	9.3	9.8	4.10	7.26	166	119
LSD (P = 0.05)			-	-	0.54	1.01	-	-
S.E. as % gen. mean			-	-	15.3	14.8	6.8	3.3

Key: ≠ Crop score 10 = No apparent damage 0 = plants killed
ø Variety A Beryl; B Threefold White

Table 6

The reaction of varieties of dwarf beans to some commonly used herbicides, observation tests 1976-78

Variety	Herbicide Pre-sowing Trifluralin	Pre-emergence Monolinuron	Post-emergence Bentazone
Bush Blue Lake 274	2	2	2
Cascade	2	2	2.5
Chicobel	1.5	4	3
Lit	2	3	3.5
Provider (white-seeded)	1.5	3	3
Tendercrop (white-seeded)	1.5	2	3

Key: Reaction 5 - Highly sensitive

DISCUSSION

Information on the reaction of varieties of peas and beans to commonly used herbicides is required as soon as those varieties are grown commercially. It is therefore necessary to carry out tests during the final years of their non-statutory performance testing programme. The number of varieties and herbicides prevents each combination being tested in yield experiments, and the field tests which have been developed at PGRO allow for information to be obtained at the earliest possible stage. When the results of these observation experiments have been checked in replicated yield experiments the data has confirmed the sensitivity classifications. It seems therefore that assessments for visual damage can be used with a reasonable degree of confidence to predict the sensitivity of varieties of legumes to herbicide applications, and that such effect will probably be reflected in crop yield. Further confirmation is also generally obtained from commercial crops.

Vedette is widely grown as a dried pea and reports of herbicide damage to this variety have been investigated on many occasions by the Advisory Department of PGRO. Even at recommended doses the variety may be affected under adverse conditions and it is often possible to compare the effects on Vedette and the tolerant variety Maro grown side-by-side and treated in the same way. Similarly with Beryl broad beans and Chicobel dwarf beans instances of damage to commercial crops have been investigated. Although the work enables the sensitivity of varieties to be classified, it does not help to explain why some are more tolerant than others. Some such as the dried pea Maro are tolerant to a wide range of pre- and post-emergence herbicides of several different chemical groups, while the sensitive variety Vedette tends to be sensitive to most materials. The broad bean varieties Feligreen and Pax are moderately sensitive to pre-emergence simazine and yet tolerant to post-emergence dinoseb-acetate. In general, however, this is more exceptional and sensitivity to soil-acting materials has usually indicated that the variety will be more sensitive to post-emergence herbicides. Soil-acting herbicides are incorporated into the root zone and thus it may be assumed that even the tolerant varieties absorb the material, but are more able to break them down within the plant without being affected to the same degree. Verlaat & Scheeringa tests in water culture suggested that this was possible in *Phaseolus* beans.

For several years leaf wax has been assessed on the peas grown in the observation tests before post-emergence herbicides are applied. Comparing crystal violet dye retention and subsequent damage from contact herbicides such as dinoseb-amine have not however, produced consistent results, some varieties exhibiting damage where the leaf wax was apparently good and others little damage where the wax appeared to be poor. A good correlation was obtained with the variety Vedette. Seed and seedling size have also been suggested as a possible cause of herbicide sensitivity, but in this work consistent trends could not be shown. Differences in root habit do not seem to be an explanation for different reactions to soil-applied herbicides since the chemicals can be incorporated into the soil or nutrient solution.

The data provided from herbicide sensitivity tests has proved most valuable enabling chemical manufacturers to list in their labels varieties which can be safely treated and those which cannot be treated. The information is also freely available to growers, processors' fieldsmen, spray contractors and general advisors thus helping to avoid unnecessary crop damage to sensitive varieties.

Acknowledgements

The author wishes to thank the statistical departments at Rothamsted and The National Vegetable Research Station for analysis of data and to gratefully acknowledge the help of his colleagues at PGRO in particular Mrs. C.M. Knott.

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SOME CAUSES OF POOR CONTROL OF SENECIO JACOBAEA L. BY HERBICIDES

J.C. Forbes, D.W. Kilgour and H.M. Carnegie

The North of Scotland College of Agriculture, 581 King Street, Aberdeen AB9 1UD

Summary A series of case studies revealed that spraying outside the recommended period and bad spraying technique were the principal causes of poor control of Senecio jacobaea in commercial practice. However, a field trial confirmed that poor control can sometimes occur even with the recommended treatments in good weather conditions. Both trial and case studies emphasised the importance of spraying at the rosette stage, before the start of flowering stem elongation in early June. In a pot experiment, S. jacobaea plants grown at low humidity deposited ten times as much leaf surface wax as plants grown at high humidity, but the two sets of plants did not differ in their susceptibility to 2,4-D at three dose rates, suggesting that reduced herbicide intake following dry weather was not a cause of the instances of poor control.

INTRODUCTION

Trials in Scotland and Ireland have shown that the poisonous grassland weed ragwort (Senecio jacobaea L.) can be controlled by MCPA or 2,4-D applied in late April or May, when the weed is in the rosette stage (Forbes, 1974; North of Scotland College of Agriculture, 1976; Courtney and Johnston, 1976). Good control, as measured by the reduction in number of flowering stems, is normally achieved for two years with a single application of herbicide. This is because both rosettes, due to flower in the current year, and seedlings, due to flower in the following year, are killed. The Scottish Agricultural Colleges (1979) recommend spring spraying, before the beginning of June, for S. jacobaea control in pasture, but because the weed is slow to die after spraying, autumn treatment is recommended for conservation fields to ensure ragwort-free silage or hay, but giving control for only one year. The recommended rates of application are 2.3 kg a.e./ha for MCPA or 2,4-D amine and 1.7 kg a.e./ha for 2,4-D ester. Other, more expensive herbicides which control S. jacobaea but which are more damaging to clover include mecoprop, dichlorprop, asulam + mecoprop + MCPA and various dicamba mixtures (Forbes, 1978).

Recommendations for England and Wales are still to spray S. jacobaea at the flower-bud stage in late June or early July (Ministry of Agriculture, Fisheries and Food, 1978), in spite of evidence from Scotland and elsewhere that the weed is by this stage far less susceptible to the herbicides used. A number of chemical manufacturers have now adopted the Scottish recommendations for their products for the whole of Britain.

Autumn spraying is now established commercial practice for silage and hay fields and very few farmers have expressed dissatisfaction with the results. Spring spraying, however, though always successful in trials, has proved somewhat less reliable in practice, most farmers claiming excellent control but a few, particularly in Moray and Nairn, reporting failure of MCPA or 2,4-D to achieve satisfactory control of S. jacobaea in the year of spraying.

The object of the work described here was to attempt to relate variation in S. jacobaea control to environmental, herbicide, user and plant factors, in the hope that some of the causes of poor control might be identified. The work involved a series of case studies on commercial farms, a field trial in which variation in herbicide performance due to formulation, dose rate and spraying technique was eliminated, and a pot experiment to test the theory that poor control of S. jacobaea in Moray and Nairn might result from restricted herbicide retention or penetration due to increased leaf surface wax in the relatively dry climate and on the drought-susceptible soils of that area.

METHOD AND MATERIALS

Case studies

Thirty-five fields on 21 farms in Moray and Nairn and upper Speyside were identified in which farmers had expressed the intention of spraying for Senecio jacobaea control in spring 1979. A pre-treatment assessment of S. jacobaea plant density in each field was made in May 1979, and flowering stem density was assessed in July 1979 and again in July 1980. All assessments were made by counting in 1 m^2 quadrats arranged at regular intervals on several transects across each field. The same transects and intervals were used for each assessment but the quadrats did not necessarily fall in exactly the same places every time. The number of quadrats per field ranged from 28 to 142, depending on the size of the field and the density of S. jacobaea infestation.

Information collected from the farmer for each field included: area; number of years since grass established; whether or not sheep grazed in the field during the winter; annual nitrogen fertiliser usage; method of utilisation (pasture, silage or hay) in 1978, 1979 and 1980; spraying details, including herbicide, rate, volume, date of application, type of sprayer and nozzles, pressure, and weather conditions before, during and immediately after spraying. Two of the case studies were abandoned because insufficient information was collected.

Field trial

MCPA (2.3 kg a.e./ha) and 2,4-D ester (1.7 kg a.e./ha) were applied on several dates to a moderately light S. jacobaea infestation near sea level at Lossiemouth and a much denser infestation at an altitude of 210 m at Boat of Garten. All spraying was done with a Land-Rover-mounted boom sprayer fitted with fan nozzles, working at a pressure of 2.8 bar and delivering 225 litre/ha of water. Herbicides were applied at Lossiemouth on seven dates from 20 April to 12 June 1979 but spraying at Boat of Garten was not started until 11 May because of persistent lying snow. Plots measured 9.5 m by 40 m. The space available did not unfortunately permit replication, and it was not possible to spray at both sites on the same day. Two plots at Lossiemouth and six at Boat of Garten were left as unsprayed controls.

S. jacobaea density was assessed in a 6 m wide strip down the middle of each plot by counting (a) rosettes in April 1979 (pre-treatment assessment), (b) flowering stems in July 1979, and (c) flowering stems in July 1980. Per cent control was calculated by the method of Forbes (1974) which takes account of initial differences between plots in weed density and background changes in untreated plots.

Pot experiment

Individually potted one-year-old S. jacobaea plants grown from seed and now in the overwintered rosette stage were exposed for three weeks to two simulated weather regimes in a glasshouse. One regime had constant 100% relative humidity and frequent overhead watering, and the other had constant low humidity (50-60%) and just sufficient watering to prevent wilting. Air temperatures of 20-25°C were maintained in both regimes.

Five plants from each regime were then withdrawn for leaf surface wax determination. The total area of 10-20 representative leaves from each plant was measured and these leaves were then immersed for 20 seconds in chloroform in a previously weighed aluminium foil dish. The increase in weight of the dish after evaporation of the chloroform to dryness was taken as a measure of leaf wax.

Forty plants from each regime were sorted into matched sets of 10. One set was unsprayed and the other sets were sprayed with 2,4-D amine at rates equivalent to 0.5, 1 and 2 kg a.e./ha. All plants were then placed outside in identical conditions. After 19 days each plant was scored on a 0-5 scale for epinasty and chlorosis, the main symptoms of herbicide damage at that time.

RESULTS

Case studies

In the event, only 9 of the 33 fields included in the case studies, representing 25% of the area intended to be sprayed, were sprayed during the recommended period, on or before 1 June (Table 1). A further 9 fields (21% of the area) were sprayed in the period 7-17 June, and 6 more (30% of the area) were sprayed between 27 June and 1 August, too late for any effect to show in the July 1979 assessment. The remaining 9 fields (24% of the area) were not sprayed in 1979, but 3 of them were sprayed in the spring of 1980. The unsprayed fields were used to determine the natural changes in *Senecio jacobaea* density over the course of the investigation.

S. jacobaea density in May 1979 ranged from 26 to 2131 plants/100 m^2, with a mean of 450 plants/100 m^2 (mean 344 plants/100 m^2 when weighted for field area). In the unsprayed fields, the number of flowering stems in July 1979 per 100 plants in May 1979 ranged from 30 to 452. This variation was not related to sward age or to any of the management factors considered. It makes assessment of the degree of control achieved in sprayed fields very difficult. A similar variation, from 30 to 240 flowering stems per 100 May 1979 plants, was observed in the unsprayed fields in July 1980. In two of the sprayed fields substantial areas were left unsprayed and a measure of per cent *S. jacobaea* control was obtained (Table 2).

Two factors had an important influence on the level of control achieved in the year of spraying: the presence of missed or underdosed strips which were very obvious in 9 fields at the July 1979 assessment, and the spraying date. Discounting fields with missed strips, all 6 fields sprayed during the recommended period showed good control but only 2 out of 5 (case nos. 24 and 15) sprayed in the 7-17 June period showed a similar level of control.

All sprayed fields with no missed strips showed good *S. jacobaea* control in the year after spraying (1980), regardless of spraying date. One field (case no. 4) had *S. jacobaea* in obvious strips in July 1979 but these were not evident in July 1980. This may reflect underdosing due to inadequate spray overlap rather than complete missing of strips, the highly susceptible seedlings but not the older rosettes being killed by the low rate of herbicide.

Table 1

Senecio jacobaea spraying case studies

Case No.	Area (ha)	Spraying details (1979)			S. jacobaea			Strips missed or underdosed	Comments
		Date	Herbicide	Rate (kg a.e./ha)	Plants/100 m^2	Flowering stems/100 May 1979 plants			
					May 1979	July 1979	July 1980		
32	4.6	22 May	2,4-D amine	2.6	54	*	0	no	
12	8.3	23 May	2,4-D ester	1.7	88	11	24	yes	Rain after spraying
9	1.7	25 May	MCPA	2.5	28	21	32	yes	
33	0.6	25 May	MCPA	1.8	282	4	0	no	
7	5.2	29 May	MCPA	1.4	135	9	0	no	
18	1.3	30 May	dichlorprop	2.8	136	4	0	no	
1	2.1	1 Jun	'Graslam'	2.9	135	*	6	no	
2	1.7	1 Jun	'Graslam'	2.9	929	0	2	no	
4	2.1	1 Jun	'Graslam'	2.9	212	46	0	yes	
17	1.0	7 Jun	MCPA	2.3	281	145	4	yes	Rain after spraying
24	1.7	7 Jun	MCPA	2.2	1130				See Table 2
23	4.2	8 Jun	MCPA	1.8	753	96	3	yes	
11	6.0	9 Jun	MCPA	2.3	50	126		no	Ploughed 1980
15	2.5	9 Jun	MCPA	1.8	992	8	0	no	
25	1.7	11 Jun	MCPA	2.2	1320	13	8	yes	
29	2.9	11 Jun	MCPA	1.8	336	18	0	no	
30	1.3	11 Jun	MCPA	1.8	331	34	1	no	
22	1.8	17 Jun	2,4-D amine	2.0	80	91		yes	Ploughed 1980

* Cut before July 1979 assessment but control good.

Table 1 (continued)

Case No.	Area (ha)	Spraying details (1979)			*S. jacobaea*			Strips missed or underdosed	Comments
		Date	Herbicide	Rate (kg a.e./ha)	Plants /100 m^2	Flowering stems/100 May 1979 plants			
					May 1979	July 1979	July 1980		
10	6.9	27 Jun	MCPA	2.3	128	428	29	yes	
20	1.7	10 Jul	MCPA	2.3	126	109		yes	Ploughed 1980
8	1.5	24 Jul	MCPA	2.8	147	156			See Table 2
14	11.7	26 Jul	2,4-D amine	2.0	78	186	0	no	
26	7.5	31 Jul	MCPA	2.1	388	74			Ploughed 1980
5	3.8	1 Aug	MCPA	2.1	342	159	0	no	
3	0.8		not sprayed		2131	66	30		
6	1.2		not sprayed		29	452			Ploughed 1980
13	7.9		not sprayed		56	321	32		Sprayed spring 1980
16	2.9		not sprayed		26	73	58		
19	1.7		not sprayed		692	114	57		
21	2.7		not sprayed		80	68	240		
27	7.5		not sprayed		1088	44			Ploughed 1980
34	1.8		not sprayed		1708	57	22		Sprayed spring 1980
35	1.4		not sprayed		567	30	34		Sprayed spring 1980

Table 2

Control of Senecio jacobaea in partly sprayed fields

	S. jacobaea		
	Plants /100 m^2	Flowering stems/100 m^2	
	May 1979	July 1979	July 1980
Case no. 24 (MCPA, 7 June 1979)			
Unsprayed	1237	620	359
Sprayed	1056	93	33
Control (%)		82	89
Case no. 8 (MCPA, 24 July 1979)			
Unsprayed	150		156
Sprayed	147		4
Control (%)			97

Field Trial

Results of the field trial are given in Table 3. S. jacobaea control in the year of spraying (1979) was strongly influenced by spraying date and by the occurrence of rain or snow before or after spraying. Heavy rain at Lossiemouth immediately after spraying on 20 April resulted in poor control with both MCPA and 2,4-D ester, while lighter rain before spraying on 27 April and after spraying on 4 June reduced the efficacy only of MCPA. Spraying between snow showers at Boat of Garten on 18 May gave, surprisingly, 100% control with 2,4-D ester but only 54% control with MCPA. Spraying later than the end of May, even in dry weather, gave reduced control with both herbicides at both sites. No satisfactory explanation can be advanced for the poor control with both MCPA and 2,4-D at Lossiemouth on 12 May.

Control of S. jacobaea in the year after spraying (1980) was excellent at both sites with both herbicides on all spraying dates, including 12 May at Lossiemouth, except when snow or heavy rain followed shortly after spraying, in which case MCPA was again more seriously affected than 2,4-D ester.

Pot experiment

The results of the pot experiment are given in Table 4. Plants grown at low humidity had ten times as much wax per unit leaf area as plants grown at 100% relative humidity and were markedly more glaucous in appearance. There was, however, no difference between the two sets of plants in their response to 2,4-D at any of the three application rates.

Table 3

Senecio jacobaea control by herbicides sprayed on different dates at two sites

Spraying date (1979)	Weather			Per cent S. jacobaea control			
	In 12h before spraying	During spraying	In 5h after spraying	July 1979 2,4-D ester	July 1979 MCPA	July 1980 2,4-D ester	July 1980 MCPA
Lossiemouth							
20 April	dry	cold	heavy rain	63	26	56	38
27 April	rain	cool	dry	93	59	98	89
4 May	dry	cool	dry	96	92	100	98
12 May	dry	cool	dry	71	72	100	97
19 May	dry	cool	dry	90	85	100	100
4 June	dry	mild	rain	89	31	100	92
12 June	dry	mild	dry	70	73	100	90
Boat of Garten							
11 May	dry	mild	dry	100	100	100	99
18 May	snow	cold	snow	100	54	100	48
1 June	rain	mild	dry	92	88	100	98
9 June	dry	mild	dry	66	69	100	100
15 June	rain	cool	rain	61	46	100	100

Table 4

Leaf surface wax and susceptibility to 2,4-D of Senecio jacobaea grown under high and low humidity

Humidity regime	High	Low
Leaf surface wax (mg/m^2)	52	529
SE	16	97
Response to 2,4-D (average score per plant)		
Dose rate (kg a.e./ha)		
0	0.2	0.1
0.5	1.2	1.4
1	1.4	1.8
2	2.6	2.4
SED	0.3	

DISCUSSION

The case studies (Table 1) show that user error is a major factor giving rise to poor herbicidal control of Senecio jacobaea in commercial practice. Of the 24 fields actually sprayed in 1979, only 9 were sprayed during the recommended spring period and 11, including those detailed in Table 2, had substantial missed or underdosed strips or areas. In two of these 11 fields the imperfect spray coverage was excusable because of the roughness of the pasture, but there remains abundant evidence of bad spraying technique.

This cannot, however, be the only explanation for poor control. There is evidence from the field trial (Table 3) that even when spraying is performed accurately in reasonable weather *S. jacobaea* control can be erratic. It is difficult to explain why both MCPA and 2,4-D ester should have given reduced control when applied on 12 May at Lossiemouth. Weather conditions in the preceding week were cool and humid, not conducive to increased leaf wax development. This result suggests that the cause of variability in *S. jacobaea* control lies in short-term changes taking place in the plants within a population rather than in differences between populations on different sites.

The results of the pot experiment (Table 4) lend no support to the hypothesis that herbicide susceptibility in *S. jacobaea* is related to leaf surface waxiness, but do not completely rule it out. The composition and ultrastructure of the wax formed under the artificial conditions of the experiment may be quite different from that formed on plants in the field; composition is at least as important as amount of wax in influencing 2,4-D penetration into leaves (Norris, 1974). Some work by R J Alston (unpublished BSc thesis, University of Aberdeen, 1980) suggests that spray retention is greater on *S. jacobaea* leaves grown at low humidity than on less waxy leaves grown at high humidity.

The good control of *S. jacobaea* that is almost universally observed following autumn spraying and in the year after spring spraying is evidence that seedlings are much more susceptible to MCPA and 2,4-D than year-old plants. The variability in *S. jacobaea* control in the year of spring spraying probably reflects the fact that rosettes, though less resistant than plants at the stem elongation or flower-bud stage, are of only marginal susceptibility to herbicides, and any factor (user, plant or environmental) which is not optimum may result in poor control.

Acknowledgements

We are grateful to the farmers who participated in the case studies and to Pitgaveny Estate and Mr R B Miller who provided sites for the field trial.

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A COMPARATIVE STUDY OF MANAGEMENT FACTORS LIKELY TO INFLUENCE RHIZOME PRODUCTION BY AGROPYRON REPENS AND AGROSTIS GIGANTEA IN PERENNIAL RYEGRASS SWARDS

A. D. Courtney

Department of Agriculture for Northern Ireland
Field Botany Research Division, Newforge Lane, Belfast BT9 5PX

Summary Data are presented comparing the growth of *Agropyron repens** and *Agrostis gigantea**in association with perennial ryegrass. In an indigenous field infestation where defoliation intervals of between 2 and 8 weeks were compared rhizome levels were contained by defoliation at less than 4 week intervals. A two or four week interval was recorded as being preferable to 8 weeks in a subsequent experiment. The ability of *Agrostis* to prosper at lower N levels than *Agropyron* suggested in field data was confirmed in an experiment where, with a nil nitrogen regime, *Agrostis* with perennial ryegrass produced almost 3 times the rhizome d.m. of *Agropyron* while, when 385 kg N/ha were applied, *Agropyron* produced 4 times more rhizome d.m. than *Agrostis*.

Résumé Des données expérimentales sont présentées qui comparent la croissance d'*Agropyron repens* à celle d'*Agrostis gigantea* en relation du ray-grass Anglais. Dans une infestation indigène d'un champ où des intervalles de défoliation d'entre deux et huit semaines étaient comparées les niveaux de rhizome étaient contenus par des défoliations aux intervalles de moins que quatre semaines. Un intervalle de quatre semaines a été aussi remarqué comme préférable à ceux de deux ou huit semaines dans une expérience juivante. La puissance d'*Agrostis* pour réussir à des niveaux N plus bas qu'*Agropyron* suggérée par des données expérimentales du champ était assurée par une expérience où avec un régime de néant de nitrogène, *Agrostis* avec du ray-grass Anglais (*Lolium perenne*) a produit presque trois fois le rhizome d.m. d'*Agropyron* pendant que, lorsque 385 kg N/ha furent appliqués, *Agropyron* a produit quatre fois plus de rhizome d.m. que *Agrostis*.

INTRODUCTION

There is a large volume of data published (Hoogerkamp 1975 a, Hoogerkamp 1975 b, Schäfer 1971, Cussans 1973) which indicates that there are a wide variety of reasons why *Agropyron* may prosper in grassland. Of particular importance appear to be high N levels and either lax defoliation or an extreme system of defoliation where the vigour and/or the persistence of the sown species is being diminished. These in addition to severe poaching or adverse environmental factors such as summer drought or winter flooding may be expected to favour the ingress and persistence of *Agropyron* in a sward.

*referred to in the text as *Agropyron* and *Agrostis* respectively

The studies reported here represent part of a project to compare growth and development of the two rhizomat ous weed species Agropyron and Agrostis in monoculture and in grassland and involve a series of experiments conducted over a number of years between 1968 and 1976. In the first experiment rhizome records were made from a weed infestation which occurred naturally on an experimental area at the Agricultural Research Institute, Hillsborough, Co. Down where an extensive sequence of defoliation treatments was being applied in a study of sward d.m. production (Chestnutt, et al., 1977). Subsequent to this artificially established microswards were used to determine whether defoliation interval and N level could be demonstrated to have differential effects on the development of Agropyron and Agrostis in association with perennial ryegrass.

METHOD AND MATERIALS

Experiment 1

The effect of defoliation interval and N regime on a natural infestation of Agropyron and Agrostis in association with perennial ryegrass.

The trial area was sown with perennial ryegrass (cv. S24) in the autumn of 1968, and the treatments - 6 cutting frequencies and 3 nitrogen regimes - were commenced in 1969. The cutting intervals 2, 3, 4, 5, 6 and 8 weeks representing 15, 10, 8, 6, 5, and 4 defoliations per annum respectively were continued for 3 years and the trial was concluded in the autumn of 1971. Nitrogen was applied at 336 or 673 kg/ha in aliquots in the spring 2 weeks before the first cut, and one after each cut except the last of the season. In addition the higher rate was also applied as a single dressing in the spring. Potash and phosphate were applied at an annual rate of 180 kg/ha P_2O_5 and 180 kg/ha K_2O in two equal dressings one in the spring and one in July. The treatments were fully randomised in blocks with 4 replicates. The individual plots measured 1.53 x 6.10 m and the plots were cut with a 0.91 m wide reciprocating cutter bar at a height of 4 cm.

Assessment of Agropyron and Agrostis levels

Initially to investigate the feasibility of recording rhizome levels, test core samples were taken from selected plots in the autumn of 1971. These indicated that treatment effects were detectable and the plots were fully sampled in May 1972. Ten 7.5 cm diameter circular cores (456 cm^2) were removed to a depth of 15 cm from each plot. The rhizome samples were washed and separated into the two species. The washed rhizome was laid out on moistened paper towelling in a glasshouse and the viable rhizome, where bud development had commenced, was recorded after 10 days.

Experiment 2

An investigation of N level and defoliation interval on Agropyron and Agrostis in monoculture and in mixture with perennial ryegrass

This experiment was conducted in 60 x 60 cm frame microswards. In May 1970 each microsward was planted with 8 x 15 cm lengths of Agropyron or Agrostis equivalent to 333 cm per m^2 and representing 118 buds of Agropyron and 227 nodes of Agrostis. Shortly after establishment the shoots/m^2 of the two species were approximately equal with Agropyron at 20.2/m^2 and Agrostis at 18.9/m^2. The main treatments were:- nitrogen 75 or 300 kg/ha, cutting intervals 2, 4, or 8 weeks, weed associations - Agropyron or Agrostis in monoculture or in mixture with S24 perennial ryegrass sown at a rate equivalent to 34 kg/ha. Defoliation was applied with hand shears at a height of 2.5 cm and d.m. yield of the species determined. There were four replicate blocks with the main plots split for the N treatment and the species association and defoliation treatments fully randomised within each split plot.

At the end of each year, for three years, of five 7.5 cm diameter circular cores were taken to a depth of 15 cms and rhizome d.m. determined.

Experiment 3

The effect of N fertilizer on the development of Agropyron and Agrostis during the establishment of a perennial ryegrass sward

Four densities of *Agropyron* and *Agrostis* as single noded rhizome fragments with individual shoots were planted on 18-4-1975 at 0, 7, 14, and 28 nodes in S24 perennial ryegrass microswards formed in heavy duty plastic pipes (21.5 cm internal diameter). These microswards were set into an S24 sward established in advance. The microswards were seeded to give an establishment by 2-5-1975 of 75.7 ryegrass plants per microsward equivalent to 2,085 plants m^2. A basal dressing of 200 kg/ha muriate of potash was applied. Nitrochalk equivalent to an annual rate of nil, 187.5 and 385 kg N/ha was applied on 4 occasions (18-4, 27-5, 30-6, 24-7) throughout the year. Using a defoliation interval of 4 weeks, the plots were clipped on six occasions with handshears at a height of 2.5 cm and d.m. yields recorded. At the end of the year the microplots were lifted and records were made of plant and tiller numbers and of rhizome parameters.

RESULTS

In Experiment 1 there were significant effects for defoliation interval and N level on rhizome d.m. yield (Table 1a, b). For both *Agropyron* and *Agrostis* cutting frequency means indicated progressively increasing rhizome d.m. levels as the defoliation interval was increased to more than 4 weeks. Where N was applied in aliquots throughout the season the two species appeared to respond in a differing manner *Agrostis* having higher d.m. yields at the lower N level and *Agropyron* at the higher N level.

Table 1

Rhizome d.m. production (g) in a 4-year old sward (L. perenne cv. S24)

a. Influence of defoliation interval

	Defoliation interval (wk) [D] 2	3	4	5	6	8	DxSp. Sig.	S.E.
Agropyron	0.14	0.40	0.13	0.65	0.61	2.15	***	± 0.143
Agrostis	0.21	0.22	0.33	0.49	0.87	1.43	***	± 0.145 51 d.f.

b. Influence of N level

N level (kg/ha)	336^x	673^x	673^y	Sig.	NxSp. S.E.
Agropyron	0.48	0.85	0.70	*	± 0.103
Agrostis	0.82	0.31	0.63	**	± 0.102 51 d.f.

^{x}applied aliquots after each defoliation
^{y}applied as single dressing in spring

Table 2 (a)

The influence of defoliation on rhizome d.m. in monoculture and mixture

Species	Agropyron			Agropyron/S24			Agrostis			Agrostis/S24			DxSp.	
Defoliation interval [D] (wks)	2	4	8	2	4	8	2	4	8	2	4	8	Sig.	S.E.
Year 1	0.53	0.62	0.75	0.15 (0.28)	0.21 (0.33)	0.56 (0.75)	0.38	1.04	2.17	0.08 (0.20)	0.19 (0.18)	0.49 (0.22)	***	± 0.176
" 2	1.76	3.53	5.51	0.13 (0.08)	0.22 (0.06)	1.16 (0.21)	1.71	4.17	5.44	0.08 (0.05)	0.15 (0.04)	0.69 (0.12)	***	± 0.470
" 3	2.83	5.49	7.76	0.12 (0.05)	0.19 (0.04)	1.06 (0.14)	2.51	3.61	7.97	0.12 (0.05)	0.09 (0.03)	0.66 (0.08)	***	± 0.918

Table 2 (b)

The influence of N level on rhizome d.m. in monoculture and mixture

Species	Agropyron		Agropyron/S24		Agrostis		Agrostis/S24		NxSp.	
N level	N_1	N_2	N_1	N_2	N_1	N_2	N_1	N_2	Sig.	S.E.
Year 1	0.64	0.62	0.27 (0.43)	0.34 (0.54)	1.08	1.32	0.21 (0.20)	0.29 (0.22)	NS	± 0.144
" 2	2.92	4.27	0.46 (0.16)	0.55 (0.13)	4.38	3.16	0.25 (0.06)	0.36 (0.11)	*	± 0.384
" 3	5.50	5.21	0.42 (0.08)	0.33 (0.06)	4.40	4.99	0.33 (0.08)	0.26 (0.05)	NS	± 0.530

(   ) Relative Yields = yield in mixture ÷ yield in monoculture

N_1 = 75 kg N/ha N_2 = 300 kg N/ha

In summary it appears that a defoliation period of no more than 4 weeks is required to give control of both species, and that Agrostis might be more competitive than Agropyron at lower N levels.

In Experiment 2 the two species had similar reaction to defoliation interval (Table 2a), both showing increasing rhizome production with increase in the defoliation intervals investigated. The influence of competition from perennial ryegrass can be seen in the data showing yields in mixture relative to those in monoculture and it is clear that the presence of perennial ryegrass reduced rhizome d.m. production considerably in both experiments. The constraining influence of the perennial ryegrass continued to increase throughout the three year period of the experiment with the 4 weekly defoliation interval being more effective than either the 2 or 8 weekly period for both weed species. Agrostis was limited to a somewhat greater extent than Agropyron by competition from the sown species. Nitrogen regime (Table 2 b), even as a main factor, did not have a significant influence on rhizome production and its interaction with species achieved significance only in the second year. In that year Agrostis in monoculture exhibited significantly higher rhizome production than Agropyron at the lower N level but this was not repeated in the subsequent year nor in association with perennial ryegrass. With perennial ryegrass both species produced higher but not significant, rhizome levels in years 1 and 2 with the high N level but lower in year 3. When the relative yields of mixture versus monoculture are compared the control exerted by S24 increased each year and was slightly greater for both species at the higher N level. Agrostis was more dominated by the ryegrass sward than Agropyron, in all the comparisons.

In summary this experiment suggests that a two or four week defoliation interval might be optimal for the progressive eradication of both species and preferable in the sward to 8 weeks. A differential effect of nitrogen could not be demonstrated; the indication was that for both species in the sward the high nitrogen level had given superior control at the end of the 3 year period.

Experiment 3 was designed specifically to test the influence of N level on the development of the two weed species in competition with ryegrass. It is not intended to present data in detail. Briefly the yields of cut herbage of S24 were significantly depressed by both weed species but with the highest total d.m. yields coming from the Agropyron/S24 association. One aspect of the herbage yield data of interest was the significant species x nitrogen interaction for the proportions of Agropyron and Agrostis in the herbage (Table 4).

Table 4

Weed as % total d.m.

	Nitrogen Level			NxSp.		
	No	N1	N2	Sig.	S.E.	D.F.
Agropyron	38	30	37	***	± 1.3	86
Agrostis	45	30	29			

The contribution of Agropyron in the sward was less than that of Agrostis without applied nitrogen, the species made an equal contribution (30%) at the N1 level and Agropyron was the more dominant at the highest N level. In the destructive harvest data (Table 5) the species x nitrogen interaction was also highly significant, Agrostis compared to Agropyron having 5 times the number of nodes at the No level but only half as many at the highest N level.

In summary this experiment illustrated the differing ability of the two species to respond to Nitrogen, Agrostis being more succesful at low N levels and Agropyron at high N levels.

Table 5

Rhizome development in association with S24 at a range of N levels

(a) Rhizome d.m. (g)	Nitrogen Level No	N1	N2	NxSp. Sig.	S.E.	D.F.
Agropyron	1110	745	996	***	± 142	81
Agrostis	2950	306	212			
(b) No of rhizome nodes						
Agropyron	69	51	61	***	± 15.4	81
Agrostis	376	38	28			

DISCUSSION

The *Agropyron* a data serve to confirm those of Cussans (1973) and the records of Hoogerkamp (1975) that laxity of defoliation is likely to increase the level of an infestation. The large number of defoliation periods available from the first experiment allows the course of change in rhizome levels with defoliation frequency to be more precisely identified and it is possible to suggest that a defoliation interval of 3-4 weeks may be optimal for control of *Agropyron* in the sward. This is also suggested by data from the second experiment where both the more frequent 2 week defoliation and the less frequent 8 week defoliation both give inferior levels of control in association with perennial ryegrass. *Agrostis* in these experiments has been similarly favoured by lax defoliation. The two species do however appear to differ in their response to nitrogen fertilizer, although since this did not occur in experiment 2 it may only be important under extreme conditions as in the final experiment where a nil nitrogen level was included. Williams (1977) has reported this ability of *Agrostis* to produce higher rhizome yields than *Agropyron* at lower N levels in the cereal crop and it may be that the reported preference of *Agrostis* for light land (Ingram 1975) is also reflecting this same ability to prosper under more impoverished conditions. The preference of *Agropyron* for high N levels has in addition been clearly demonstrated by the sward replacement studies of Van Den Berg (1968). *Agropyron* appears more competitive in association with perennial ryegrass than *Agrostis* and may be more inherently tolerant of high N levels.

Acknowledgements

I should like to acknowledge the assistance accorded in the course of these studies by staff at the Agricultural Research Institute, Hillsborough, Co Down, the Biometrics Division of the Department of Agriculture and from within my own Division.

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NOTES

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WEED CONTROL BY PARAQUAT DURING THE ESTABLISHMENT OF PARAQUAT-RESISTANT RYEGRASS

F.W. Kirkham

ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford OX5 1PF

Summary This work confirms the paraquat tolerance of the perennial ryegrass variety Stormont Causeway reported by Faulkner (1975, 1976, 1978). In a field experiment paraquat at 0.15 kg a.i./ha showed promising selectivity between Stormont Causeway and *Poa annua*, *Stellaria media* and *Agrostis stolonifera* when applied to pure stands of the species. White clover (cv. Blanca) tolerated this dose, but was more susceptible than Stormont Causeway to higher doses. In a pot experiment comparing the susceptibility of four white clover varieties, Blanca appeared to be the most tolerant, whilst Kent Indigenous was significantly more susceptible than the others.

INTRODUCTION

The establishment and maintenance of weed-free ryegrass pastures is particularly advantageous where herbage of predictable quality for conservation or early seasonal growth of good quality for grazing is required (Haggar, 1976). *Poa* spp. and *Stellaria media* are frequent invaders of ryegrass swards during establishment (Haggar, 1976; Oswald and Haggar, 1976), and large increases in ryegrass yields can be achieved by controlling these and other indigenous species during crop establishment (Haggar and Bastian, 1976; Haggar and Passman, 1978; Griffiths, Hammond and Edwards, 1978). Other work (Haggar and Kirkham, unpublished) has showed that these benefits to ryegrass production can persist into the second harvest year.

However, at present the choice of herbicides for this purpose is limited, so breeding ryegrass varieties tolerant of existing herbicides is a valuable alternative approach. Faulkner (1975, 1976 and 1978) showed that some indigenous species could be controlled selectively by paraquat in stands of two strains of paraquat-resistant perennial ryegrass. This led to increases in both ryegrass yields and digestibility of the herbage harvested.

The aim of the work reported here was to confirm the paraquat tolerance of Stormont Causeway perennial ryegrass compared to other varieties, and to quantify the relative susceptibilities of several indigenous species which commonly invade ryegrass pastures. The effects of paraquat on white clover, and the possibility of varietal differences in susceptibility were also investigated.

METHOD AND MATERIALS

Experiment 1. Response of Melle and Stormont Causeway perennial ryegrass to paraquat

Plants of Melle and Stormont Causeway perennial ryegrasses were sprayed with paraquat at 0.1, 0.2 and 0.4 kg a.i./ha on 25 November 1977. Each variety was grown separately in 10 cm diameter pots containing sandy loam soil mixed with potting compost. Twenty-eight pots of each variety were sown giving 7 replicates of 4 treatments including unsprayed controls. Plants were grown in a glasshouse where the temperature was maintained between 14 and 18°. Two weeks after sowing plants were thinned to 5 per pot, and sprayed 10 days later.

The herbicide, formulated as 'Gramoxone', was applied in water at a volume rate of 321 l/ha through a single 8002 Spraying Systems fan nozzle at a pressure of 2.05 bars. A laboratory pot sprayer was used which moved at a constant speed over the pots. The mean number of leaves per plant at spraying was 2.9 for Stormont Causeway and 2.4 for Melle, and some plants of each variety had just begun to tiller.

Forty-five days after spraying the numbers of plants surviving in each pot were recorded. Plants were then cut off at ground level, the aerial parts dried in an oven at 100°C for 14 h, and dry weights per pot recorded.

Experiment 2. The relative susceptibilities of four white clover varieties to paraquat

In this experiment plants of white clover varieties Blanca, S.100, Grasslands Huia and Kent Indigenous were grown in a glasshouse and sprayed with paraquat at 0, 0.15 and 0.3 kg a.i./ha on 18 October 1979. The growing medium and glasshouse conditions were the same as for Experiment 1, except that 18 cm diameter pots were used.

Seventy-two pots were sown to give six replicates per variety of each treatment. Plants were thinned to five per pot 20 days after sowing and sprayed 39 days later. Growth stages at spraying were assessed by counting the number of petioles per plant on 30 plants of each variety. Mean numbers per plant were Blanca 19.0, S.100 16.6, Grasslands Huia 19.5 and Kent Indigenous 24.9. Spraying procedure was the same as for Experiment 1.

Pots were harvested 25 days after spraying and harvesting procedure was the same as in Experiment 1.

Experiment 3. The effect of paraquat on pure stands of two perennial ryegrass varieties, white clover and three weed species grown in the field

The experiment was sited on well drained sandy clay loam soil overlying Oxford clay. The area had been sterilized by injection of liquid methyl-bromide on 18 May to prevent weed invasion.

The experiment was of plaid design with four paraquat treatments imposed across pure stands of the test species. On 30 June 1978 main plots measuring 4 x 2 m of each of the following species and cultivars were sown separately by hand: perennial ryegrass cvs. Stormont Causeway and Talbot, each at 22 kg/ha; white clover (cv. Blanca) at 12 kg/ha; *Poa annua* and *Agrostis stolonifera* each at 15 kg/ha and *Stellaria media* at 24 kg/ha. There were three replicates of each species.

On 28 July paraquat was applied at three doses, 0.15, 0.3 and 0.6 kg a.i./ha with one strip in each replicate left unsprayed, giving four 1 x 2 m herbicide plots per species main plot. The herbicide was applied in 337 l/ha of water at a pressure of 2.05 bars, using an Oxford Precision Sprayer fitted with two 6502 fan nozzles.

Mean tiller number at spraying was 4 per plant for the ryegrasses and 3 for *P. annua* and *A. stolonifera*. There was an average of 3 petioles per plant for white clover and 3 runners with a total of 22 to 28 leaves per plant of *S. media*.

Plots were harvested on 1 September. The herbage from within a 1 x 0.5 m quadrat was cut to a mean height of 1.5 cm from each plot, dried in an oven at 100°C for 14 h and the dry weights recorded.

RESULTS

Experiment 1 - perennial ryegrass

Stormont Causeway showed considerable tolerance of paraquat compared to Melle (Table 1). Plant numbers of Stormont Causeway were reduced only by the highest dose when losses amounted to only 14%. By contrast all treatments reduced Melle plant numbers very significantly ($P < 0.001$), the highest dose killing all plants.

Table 1

Numbers of surviving plants of two perennial ryegrass varieties 45 days after spraying with paraquat (Expt. 1)

Paraquat (kg a.i./ha)	Stormont Causeway	Melle
0.0	5.00	5.00
0.1	5.00	3.14
0.2	5.00	1.29
0.4	4.29	0.00
SE	±0.18	

Foliage yields, expressed as a percentage of control pots showed a very significant difference between varieties for each dose ($P < 0.001$) (Table 2). At the highest dose Stormont Causeway was reduced by 42% whilst the yield of Melle was negligible.

Table 2

Foliage yield of Stormont Causeway and Melle perennial ryegrasses 45 days after spraying paraquat at 3 doses, expressed as % of unsprayed controls (Expt. 1)

Paraquat (kg a.i./ha)	Stormont Causeway	Melle
0.1	79.9	41.2
0.2	76.1	4.9
0.4	58.4	0.8
SE	±4.19	

Experiment 2 - white clover

Paraquat caused considerable damage to all varieties at both doses (Table 3). Foliage dry weights, expressed as a percentage of unsprayed controls, were significantly lower for Kent Indigenous than any other variety at both doses ($P < 0.01$). At the lower dose Grasslands Huia was also significantly reduced compared to Blanca, the most tolerant variety ($P < 0.05$).

Table 3

Foliage yield of 4 white clover varieties 25 days after spraying paraquat, expressed as % of unsprayed controls (Expt. 2)

Paraquat (kg a.i./ha)	Blanca	S.100	Grasslands Huia	Kent Indigenous
0.15	29.4	25.3	19.5	2.6
0.30	17.5	12.7	15.0	1.8
Mean	23.4	19.0	17.2	2.2
SE variety means		±1.38		
SE dose x variety means		±2.62		

Experiment 3 - perennial ryegrass, white clover and weeds

Stormont Causeway perennial ryegrass was more tolerant than any of the other species tested, whilst Talbot perennial ryegrass was the most susceptible. A dose of 0.15 kg a.i./ha gave good control of both *P. annua* and *S. media* with a fairly modest reduction of 22% for Stormont Causeway (Table 4). Though *A. stolonifera* was slightly less susceptible to this dose than the other weed species the reduction in yield was significantly greater than that shown by Stormont Causeway ($P < 0.001$); and it was at least as susceptible to higher doses as the other species.

Table 4

Foliage yields of Stormont Causeway and Talbot perennial ryegrasses, Blanca white clover, and three weed species expressed as % of unsprayed controls (Expt. 3)

Paraquat (kg a.i./ha)	Stormont Causeway	Talbot	Blanca clover	*P. annua*	*S. media*	*A. stolonifera*
0.15	77.8	5.5	85.8	17.5	10.5	32.0
0.30	59.4	0	31.8	2.4	3.9	1.6
0.60	18.8	0	8.1	0.4	3.1	0.2
Mean	52.0	1.8	41.9	6.8	11.3	5.8
SE dose x species means			±4.79			
SE species means			±2.76			

Blanca white clover was slightly more tolerant of 0.15 kg a.i./ha than Stormont Causeway but was significantly more susceptible to 0.3 kg a.i./ha ($P < 0.05$). ED 50's for these two species, calculated by computer prediction, were 0.24 and 0.35 kg a.i./ha respectively. Yields of the other species were too low on sprayed plots to allow ED 50's to be predicted.

DISCUSSION

These results confirm some of the findings of Faulkner (1975, 1976 and 1978) and suggest that paraquat could be used for weed control during the establishment of paraquat-resistant ryegrass swards. But if clover is to be included in the seed mixture choice of variety might be important.

No attempt was made to explain the differences in susceptibility between clover varieties, but their relative growth habits may be significant. Blanca has larger more erect leaves than the other varieties, whilst Kent Indigenous has the smallest leaves and a more prostrate growth habit.

The two herbicides approved for grass-weed control in ryegrass seedbeds are methabenzthiazuron and ethofumesate. Paraquat would be cheaper and relatively clover safe, and can be used effectively from early spring to late autumn (Faulkner, 1978). However, one disadvantage of paraquat compared with the others is its lack of persistence.

Both P. annua and S. media are able to germinate and make growth at low temperatures (Wells, 1974; Lyre, 1957). In other work (Kirkham and Haggar, unpublished), ingress of both species occurred until mid-December in an autumn sown ley and started again during late February. Moreover, it has been shown that competition from indigenous species during the first few weeks after sowing ryegrass can significantly hinder its establishment (Gibson and Courtney, 1976; Haggar, 1979); so early weed control is necessary if this is to be prevented.

Thus a sequence of two or more applications of paraquat might be needed to achieve efficient weed control with maximum benefit to the crop. However, since the weeds would be small on each occasion, correspondingly low doses could be used with minimal risk of crop damage. Thereafter paraquat could be used on a regular basis, say annually, to keep the sward free of invading species.

Elliott and Allen (1964) reviewing work with paraquat on established grasses, including standard ryegrass varieties, suggested that selectivity might be enhanced by manipulating the surfactant concentration. Preliminary studies by the author, as yet unpublished, suggest that increasing the concentration of wetting agent can enhance selectivity for Stormont Causeway, but the susceptibility of white clover (cv. Grasslands Huia) may also be increased.

Acknowledgments

I would like to thank Dr R.J. Haggar for his help and advice, C.J. Standell for her help with field and glasshouse work, and C.J. Marshall for his advice on the statistical analysis of the results.

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CONTROL OF WEED GRASSES AND STELLARIA MEDIA IN GRASS WITH ETHOFUMESATE

By J.A. Goldsworthy, L.G. Duke and R. Whitehead

Fisons Limited, Chesterford Park Research Station,
Saffron Walden, Essex, U.K.

Summary Data is presented from 15 timing trials over two years, where ethofumesate gave reliable control of Stellaria media, Poa annua and volunteer cereals. Optimum results were from earlier timings (October and December) when weeds were small, growth was slow and adequate moisture was available to activate the herbicide. Yield data from the second production year of leys, treated shortly after sowing, are reported showing that increases in output can continue eighteen months after treatment, reflecting the importance of controlling weed ingress at establishment. Seven newly sown ryegrass swards treated with ethofumesate have also been investigated and the results reported, showing the beneficial effects in the first production year particularly on ryegrass output.

INTRODUCTION

The use of ethofumesate (as a 20% e.c.) in grass crops has been widely reported and has recently been reviewed by Duke and Whitehead (1980). Initial work concentrated on grass seed crops, particularly ryegrass, where the ability to selectively control annual grass weeds such as Alopecurus myosuroides and Avena spp. (Hammond et al, 1976) is of particular importance to growers. More recent work (Griffiths et al, 1978) has concentrated on grass grown for forage, where control of annual grass weeds and Stellaria media can improve establishment (in terms of tillers/m^2) and subsequent output.

The trials described in this report follow up the work reported by Griffiths and Hammond (1978) with the objectives of providing data on the effect of spray timing on weed control, evaluating the effect on output 18 months after treatment and increasing the data available on output in the first season of production following treatments with ethofumesate.

METHOD AND MATERIALS

In the autumns of 1978 and 1979, timing trials (eight and seven respectively) were laid down throughout England on newly sown ryegrass. Treatments of ethofumesate (2.0 kg ai/ha) at various times from October to April were replicated 4 times on plots at least 9 x 1.83 m using Drake and Fletcher knapsack sprayers applying about 200 l/ha. Weed control was assessed visually at least one month after the final time of application.

Assessments of effects on output in 1979, after treatment eighteen months previously with 2.0 kg a.i./ha ethofumesate were carried out on two of the sites described by Griffiths and Hammond (1978). These sites received the same fertiliser regime as in their first year and were cut twice (Sites 1 and 2, Table 1).

Further trials on output in the first year of production were laid down in 1978 and 1979 using 2.0 kg a.i./ha ethofumesate as described previously by Griffiths and Hammond (1978), except six replications were used and fertiliser treatments were varied slightly to fit in with the farmer's practice.

Details of spray date and cutting dates are summarised in Table 1. The 20% e.c. formulation of ethofumesate was used throughout the trials.

Table 1

Details of spray and cutting dates

Site	Date sprayed	Dates cut
1. Leics.	29/11/77	11/6/79, 19/7/79
2. Salop	1/12/77	18/6/79, 23/7/79
3. Buntingford	2/3/79	14/6/79, 16/7/79
4. Felixstowe	10/1/79	31/5/79, 6/7/79
5. Wing	28/2/79	6/6/79, 9/7/79
6. Cuffley	6/11/79	27/5/80, 17/7/80
7. Ampthill	8/11/79	23/5/80, 8/7/80
8. Enfield	29/10/79	22/5/80, 15/7/80
9. Newmarket	29/10/79	6/6/80, 26/7/80

RESULTS

1. Timing trials

The mean levels of weed control of the predominant weeds for the two seasons are presented in table 2; the March timing was included only in 1979/80.

Table 2

Mean weed control (%) of weeds in ryegrass sprayed at different times in two years ('78/'79, '79/'80)

Weed	Year	October	December	February	March	April	No. of trials
Stellaria media	'78/'79	100	100	89	-	96	3
	'79/'80	100	100	100	100	100	2
Poa annua	'78/'79	98	100	91	-	95	4
	'79/'80	99	99	98	79	83	4
Volunteer cereals	'78/'79	94	84	71	-	66	2
(Wheat & barley)	'79/'80	96	92	94	70	-	5

These trials confirm the high level of control of the commonest weeds of newly sown grass which can be achieved with ethofumesate, particularly when sprayed early (i.e. October-December). Later spraying, although often producing good results (particularly on *Stellaria media*), does tend to be less reliable.

2. Carry-over effects

Two sites from the 1977/78 trials (Sites 1 and 2, Table 1) were yielded in their second year of production and the yields are presented in Table 3.

Table 3

Yield (kg/ha DM) over two cuts from treated (T) and untreated (UT) areas of two sites eighteen months after treatment

		Leics.	Salop.	Mean	S.E.+
Total	T	7985	8955	8470	
	UT	7098	8154	7626 **	± 170
Ryegrass	T	7626	7125	7376	
	UT	6313	6470	6392 **	± 156
Timothy	T	-	1719	1719	
	UT	-	1471	1471 NS	± 94
Poa spp.	T	359	106	232	
	UT	734	210	472 **	± 10

** $P < 0.01$
NS $P > 0.05$

+ Trials contained an additional treatment, therefore T is based on 12 degrees of freedom.

These two sites show that beneficial effects from ethofumesate can persist into the second production year. This is particularly evident with the output of the major sown species, ryegrass: in the first year the ethofumesate-treated areas averaged 36% more ryegrass DM yield than the untreated areas (Griffiths and Hammond 1978), and in the second year they averaged a 15% increase.

3. First year yields

Yields were taken from seven sites altogether, 3 in 1978/79 and the remainder in 1979/80. The results are presented in Tables 4 and 5.

Table 4

Yield (kg/ha DM) over two cuts from treated (T) and untreated (UT) areas, 1979

		Buntingford	Felixstowe	Wing	Mean	S.E.+
Total	T	8171	9817	8926	8971	
	UT	7579	9693	8091	8454 *	± 176
Ryegrass	T	8165	9799	8588	8851	
	UT	5653	8205	4599	6056 **	± 171
Alopecurus myosuroides	T	0	0	194	65	
	UT	68	816	2955	1280 **	± 9
Volunteer barley	T	2	-	82	42	
	UT	1994	-	324	1159 **	± 28
Stellaria media	T	0	-	0	0	
	UT	71	-	60	66 **	± 1
Poa spp.	T	0	0	0	0	
	UT	43	4	37	28 **	± 1

* P < 0.05

** P < 0.01

+ Trials contained an additional treatment and therefore T value is based on 30 degrees of freedom.

Table 5

Yield (kg/ha DM) over two cuts from treated (T) and untreated (UT) areas, 1980

		Cuffley	Ampthill	Enfield	Newmarket	Mean	S.E.
Total	T	12135	13471	13250	9607	12116	
	UT	11350	13512	14165	8618	11662 N.S.	± 175
Ryegrass	T	12058	13466	13250	9118	11973	
	UT	10455	12235	12572	7515	10694 **	± 139
Alopecurus myosuroides	T	-	0	-	-	0	
	UT	-	548	-	-	548 **	± 68
Volunteer barley	T	32	0	-	0	11	
	UT	361	477	-	3	280 **	± 39
Stellaria media	T	0	0	0	-	0	
	UT	499	12	567	-	359 **	± 35
Poa spp.	T	0	0	0	351	88	
	UT	11	26	12	756	201 **	± 18

NS P > 0.05
** P < 0.01

Trials from both years show interesting increases in output, particularly of ryegrass. Newmarket and Cuffley are unusual in that by the first cut the infestations of Poa annua and Stellaria media had virtually died out (helped by the very dry May in 1980), and much of the Poa annua at the former site was recorded in the second cut and thus constituted a fresh germination.

DISCUSSION

1. General

The results presented in this paper support those already reported of ethofumesate use in grass (Griffiths and Hammond, 1978). They show that high levels of weed control with excellent crop safety are possible using ethofumesate, producing useful effects on output.

2. Timing trials

These trials confirm extensive commercial experience showing that, used over a very wide time period (October-February/March), ethofumesate produces a high level of weed control. However, they also show that for optimum results three factors should coincide: the weeds should be small, growth should be occurring (but slowly) and the ground should be moist and remain so to ensure that initial foliar uptake is complemented by root uptake. Provided these criteria are met, reliable control can be achieved over a considerable period; however, use over 5 seasons suggests that these conditions tend to occur in the late autumn and early winter. The flexibility in timing that ethofumesate offers means that even the most difficult land can be treated at some time to give satisfactory results.

3. Carry-over effects

The significant increases in output shown in table 3 suggest that removal of weed competition early in the life of a sward affects not only the first production year but also the second. This indicates that the reduction in number of ryegrass plants/m^2 and number of tillers/plant that weed competition causes (R.J. Hagger, personal communication) can fundamentally affect the potential of a sward. Current efforts to regard grass as a crop with targets for establishment and production, like some arable crops, (J.G. Elliott, personal communication) are therefore justified.

4. First year yields

The effects on output shown in Tables 4 & 5 indicate a range of response to ethofumesate treatment. Sites with the highest weed levels (or highest levels over the autumn/winter/early spring period as at Cuffley and Newmarket) show substantial improvements in ryegrass output and effects on total output. Sites such as Ampthill, Enfield and Felixstowe, with lower weed levels, show correspondingly lower effects, as would be expected by analogy with weed competition in cereals.

Ethofumesate can thus provide the means of removing weed competition in establishing ryegrass-based swards with resulting improvements in output. No herbicide, however, can maintain sward productivity without complementary management. Weed invasion must be discouraged by maintaining an optimum environment for the sown species (with attention to drainage, pH and NPK status) and avoiding overgrazing and poaching. With suitable management, long-term benefits seem possible and a reduced rate of sward deterioration (as reported by Morrison and Idle, 1972) an achievable goal.

Ethofumesate is currently recommended in the UK for use on establishing leys for the control of annual weed grasses and Stellaria media and for the control of Poa annua, Stellaria media, Hordeum murinum and Bromus spp. in established grass. It is approved under the Agricultural Chemicals Approved Scheme for this purpose.

Acknowledgements

The authors wish to thank Mr. Chris Hammond, Mr. Dave Gilbert, Mr. Andy Eccles and Fisons Technical Officers for their work on this project. Also the many farmers on whose fields the work has been carried out.

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THE USE OF SEQUENTIAL HERBICIDE TREATMENTS TO CONTROL POA TRIVIALIS IN TWO PERENNIAL RYEGRASS CROPS GROWN FOR SEED

A.K. Oswald

ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford OX5 1PF

Summary Single applications of dalapon, ethofumesate and TCA in November or April were compared with sequential treatments involving the same herbicides applied in November and February or November and April for the control of *Poa trivialis* in two perennial ryegrass crops grown for seed.

The sequential treatments were more effective in reducing numbers of inflorescences than the single treatments. Ryegrass seed yields were, however, affected.

The work suggests that sequential application of herbicides is a potentially effective method of controlling *P. trivialis* in ryegrass seed crops. However, investigations on optimum doses necessary for satisfactory weed control and tolerance of a wider range of ryegrass cultivars are now required.

INTRODUCTION

The economic significance of *Poa trivialis* in perennial ryegrass crops grown for seed was indicated by Budd and Shildrick (1968). Cultural and chemical control methods were available but these were not dependable and the problem continued (Oswald and Haggar, 1980). Although the main peak in emergence of *P. trivialis* is in September with a smaller peak in May (Oswald and Haggar, 1975), the weed is able to germinate during mild spells throughout the winter (Oswald, unpublished information). It was thought that the possible reason for failure to control the weed was that herbicides applied as single treatments in autumn or spring could not control effectively the continuous weed emergence. Hence it was decided to test the efficacy of dalapon, ethofumesate and TCA applied as sequential treatments compared to single applications for the control of *P. trivialis* in two perennial ryegrass seed crops.

METHOD AND MATERIALS

Details of sites, management and crop and weed growth at spraying on the two experiments are shown in Table 1.

Treatments

Details of the herbicide treatments, which were in three replicates with plots 7.5 m x 2.5 m, are shown in Table 2.

All treatments were applied in 30 l/ha aqueous spray solution at 2.1 bar pressure with Tee jets fitted to a 2.5 m boom on an Oxford Precision Sprayer. Treatments 8 and 9 were applied as a tank mix.

Table 1

Details of experiment sites, management and stages of plant growth at spraying

Location	Stoke Charity, Hants	Bullinghope, Hereford
Crop	Perennial ryegrass cv. Monta	Perennial ryegrass cv. Wendy
Pre-spray management	Crop direct drilled on 2 September 1978 after spring barley. 20 kg/ha N + 50 kg/ha P_2O_5 + 50 kg/ha K_2O in seedbed	Crop undersown in spring barley in April 1978. 50 kg/ha N + 50 kg/ha P_2O_5 + 80 kg/ha K_2O in seedbed
Post-spray management	100 kg/ha N split in March and April applications	125 kg/ha N split in April and May applications
Crop growth and height at spraying		
3 November 1978	-	Established plants, 5-7.5 cm
17 November "	Plants tillered, 5-10 cm	-
7 February 1979	-	as on 3 November 1978
14 " "	As on 17 November 1978	-
25 April "	-	Plants 5-10 cm
27 " "	Plants 5-12.5 cm	-
Weed growth and height at spraying		
3 November 1978	-	Mature plants and seedlings present, 5-10 cm
17 " "	Mature plants and seedlings present, 5-10 cm	-
7 February 1979	-	As on 3 November 1978
14 " "	As on 17 November 1978	-
25 April "	-	As on 3 November 1978
27 " "	Some plants flowering, 7 cm	-

Inflorescences of *P. trivialis* were counted within four 30 x 30 cm fixed wire quadrats on each plot on 4 July (Experiment 2) and 10 July 1979 (experiment 1). The quadrats were placed 1.5 m apart diagonally across the plots leaving a 0.9 m discard at each end.

The same fixed wire quadrats were used to measure the yield of ryegrass seed on 18 July (experiment 1) and 9 August 1979 (experiment 2). All fertile tillers present in each quadrat were harvested using hand shears when the moisture content of the ryegrass seed was approximately 40%. The seed was dried by air draught to approximately 14% moisture content before threshing. It was then cleaned to 97% purity using a mini Petkus cleaner. The amount of clean seed from each plot was weighed. Germination tests were carried out on the seed samples using the procedure laid down by the Official Seed Testing Station (OSTS, 1976).

RESULTS

The number of P. trivialis inflorescences

All treatments, except the single application of ethofumesate on experiment 2, reduced the number of inflorescences when assessed in July 1979 (Table 2). The sequential applications were more effective than the single applications but otherwise there was no significant difference between the effects of these individual treatments.

Table 2

Effects of single and sequential herbicide treatments on the number of inflorescences of Poa trivialis present in two perennial ryegrass seed crops

No.	Herbicide	Dose (kg ha^{-1} a.i.)	Month of spraying	No. of inflorescences/m^2 Expt 1 10 July 1979 (log x)	No. of inflorescences/m^2 Expt 2 4 July 1979 (log x)
1	Untreated	0	-	121 (1.85)	303 (2.39)
2	Ethofumesate	2.0	November	39 (0.99)	283 (2.34)
3	Dalapon	2.2	April	26 (0.82)	11 (0.43)
4	TCA	7.5	November	28 (0.93)	32 (0.93)
5	Ethofumesate Dalapon	2.0 1.1	November April	3 (0.20)	44 (0.87)
6	TCA Ethofumesate	7.5 1.0	November February	18 (0.52)	9 (0.56)
7	TCA Dalapon	7.5 1.1	November April	22 (0.57)	2 (0.09)
8	TCA + Dalapon	4.4 + 0.8	November	56 (1.44)	23 (0.68)
9	TCA + Dalapon	5.7 + 1.0	April	23 (0.87)	45 (1.23)
Mean of single treatments		2, 3 and 4		31 (0.95)	109 (1.53)
" " sequential "		5, 6 and 7		14 (0.43)	11 (0.43)
Log S.E. between treatments 1-9				±(0.17)	±(0.18)
S.E. between means of treatments 2,3,4 and 5,6,7				±6.3	±33.5

Ryegrass seed yield and germination

Seed yields were generally lower on experiment 2 than on experiment 1, probably due to a thinner ryegrass crop and a greater level of competition from P. trivialis on that site prior to treatment (Table 3).

All the treatments in experiment 1 yielded less than the untreated controls but the differences were not significant. Ethofumesate caused least damage.

Yields varied on experiment 2, but again differences did not reach significance.

There was no effect on germination of the seed.

Table 3

Effects of single and sequential herbicide treatments used to control Poa trivialis on the clean seed yield (kg/ha) and germination (%) of two perennial ryegrass seed crops

No.	Herbicide	Dose (kg ha^{-1} a.i.)	Time of spraying	Expt 1 18 July 1979 kg/ha	Expt 1 18 July 1979 %	Expt 2 9 August 1979 kg/ha	Expt 2 9 August 1979 %*
1	Untreated control	0	-	2098	97	727	96
2	Ethofumesate	2.0	November	1899	96	748	97
3	Dalapon	2.2	April	1145	92	591	97
4	TCA	7.5	November	1569	96	374	100
5	Ethofumesate Dalapon	2.0 1.1	November April	1822	96	898	99
6	TCA Ethofumesate	7.5 1.0	November February	1581	96	478	99
7	TCA Dalapon	7.5 1.1	November April	1707	96	474	96
8	TCA + Dalapon	4.4 + 0.8	November	1834	97	549	97
9	TCA + Dalapon	5.7 + 1.0	April	1560	93	864	97
			S.E.	±208	±1.68	±155	±2.01

*Means of 2 replicates only due to malfunction of germination test.

DISCUSSION

The results of these experiments illustrate the possible use of sequential herbicide treatments for the control of P. trivialis in ryegrass crops grown for seed.

The sequences gave 85-99% control of P. trivialis inflorescences which was significantly better than the effects of the single applications or tank mixes. The sequence of ethofumesate in November followed by dalapon in April was of particular interest. This treatment caused reductions in weed inflorescences of 97 and 85% on the two experiments and stood out as being the least damaging to the crop in terms of seed yield and germination. The other sequences, as well as the other treatments involving dalapon and TCA, were unreliable.

Crop damage was probably due to the high chemical doses used. These had been applied because earlier work had shown that ryegrass crops would tolerate TCA at 10 kg/ha a.i. (Oswald, 1978) and dalapon at doses up to 2.8 kg/ha a.i. although results were variable (Oswald, 1980). The value of dalapon for use in ryegrass seed crops is therefore likely to be as a sequential application in April at a dose lower than 2.8 kg/ha a.i. So far the inclusion of second applications at reduced doses has proved promising but it is now relevant to investigate the effectiveness of sequences when both treatments are lowered, both from a crop tolerance and an economic viewpoint. In this respect timing of applications is also important and more detailed work is required to identify the best time during the autumn, winter or spring for treatment in relation to crop and weed growth.

The need to investigate the tolerance of a wider range of ryegrass cultivars, particularly to the sequential treatments is also indicated. Although ethofumesate is safe to spray on over 150 different cultivars (Hammond et al., 1976), dalapon has been shown to be more damaging on S.23 than S.24 (Charles et al., 1978, Oswald, 1980). Tolerance to dose of TCA is also required as recorded knowledge of the effects of this herbicide on ryegrasses is limited.

Acknowledgments

The author wishes to thank the farmers for providing the land, P.G. Smith and Miss C.J. Standell for field and laboratory assistance and C.J. Marshall for advice on analysis of results.

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NOTES

DIRECT DRILLING OF GRASS AND CLOVER INTO CHEMICALLY DESTROYED SWARD

W.I.C. Davies
Agricultural Development & Advisory Service, Bryn Adda, Penrhos Road, Bangor, Gwynedd.
M.V. Jackson
ADAS, Government Buildings, Westbury on Trym, Bristol.
J. Johnson
ADAS, Government Buildings, Coley Park, Reading.

Summary Grass and clover seeds were direct drilled at 4 sites into swards desiccated by glyphosate and paraquat to provide varying intervals from 0 to 28 days between spraying and drilling. Two drills were compared at one site and calcium peroxide treatment of seed was investigated at another. Burning off of the sward after herbicide treatment was also investigated.

Increasing the interval between spraying and drilling seed had a consistent and marked effect resulting in improved seedling establishment. Drill type had a marked effect and calcium peroxide treatment of seed also improved establishment. Burning off of the sward was also beneficial. The likely effect of toxins produced by the decaying sward are discussed.

INTRODUCTION

As a method of reseeding, direct drilling of grass and clover into chemically destroyed sward has had mixed results. In 1975 it was concluded that insufficient experimental work had been carried out on direct drilled grass to draw any general conclusions as to its effectiveness, (Davis and Cannell 1975). More recent work with paraquat and glyphosate (Cromack et al 1978) on a number of sites showed that direct drilling gave a poor initial establishment of grass on all sites and only produced a satisfactory sward at half the sites whereas rotovation and drilling of seed gave a good establishment at all sites. General observation by ADAS suggested that most establishment failures were in situations where the desiccated sward was dense leaving considerable surface trash. Earlier work by Squires and Elliott (1972) showed that the presence of surface trash reduced the establishment of Lolium multiflorum and breakdown products of previous crop residues, such as acetic acid (Lynch 1978) or tannins and phenolic compounds (Habeshaw 1980) have been associated with inhibitory effects on seed germination.

Work with rice has indicated that coating seed with calcium peroxide has resulted in improved establishment in water logged conditions (Nakamura 1976; Ota et al 1971) and peroxides have also improved establishment of other crops (Coumans 1974).

It was therefore decided in 1978 to carry out a trial to investigate further the factors affecting establishment of direct drilled grass and clover following sward desiccation with paraquat and glyphosate. This was extended to a national series of trials in 1979.

METHOD AND MATERIALS

Four sites were established, two in Gwynedd (1978 and 1979) one in Somerset (1979) and one in Surrey (1979). Site details are given in Table 1.

Table 1

Site Details

Site reference		A Talybont Gwynedd 1978	B Talybont Gwynedd 1979	C Wiveliscombe Somerset	D Guildford Surrey
Sward type		Long term grass	Long term grass	Short term grass Sown 1977	Long term grass
Pre spray use		Grazing and cutting	Grazing and cutting	Grazing and cutting	Intensive paddock grazing
Sward Components:					
Ryegrass spp.		36	11	26	68
White Clover		2	0	1	3
Other grasses		59*	70*	64**	4
Broad leaved weeds		3	12	2	3
Bare Ground		0	7	7	22
Drilling date		6/9/78	24/8/79	30/8/79	3/9/79
Drill type	(i)	Rotoseeder	Moore Unidrill	Bettinson	Moore Unidrill
	(ii)	Bettinson			
Row width	(i)	12.7 cm	12.0 cm	17.8 cm	12.0 cm
	(ii)	12.0 cm			
No. of passes		Two	Two	Three	One
Soil type		Silty loam	Silty loam	Silt loam	Sandy clay loam

*mainly Holcus lanatus **mainly Poa annua and P. trivialis with some Agrostis tenuis and A. stolonifera

Swards at each site were allowed to grow and topped as necessary to provide a sward of about 10 - 12 cm at spraying. Weight of herbage dry matter to ground level was assessed at spraying.

The following basic treatments were applied at all sites.

Chemical: Paraquat 1.7 kg a.i./ha
Glyphosate 1.44 kg a.i./ha (1.8 kg a.i./ha site A)

Spray timing: 14 days before drilling
7 days before drilling
same day as drilling (1 day before drilling site C)

The following additional treatments were also applied

Chemical: Glyphosate 0.9 kg a.i./ha - 14, 7 and 0 days - Site A
Glyphosate 1.44 kg a.i./ha - 14 days - burnt 7 days later - Site D
Glyphosate 1.44 kg a.i./ha - 14 days - rotovated 7 days later - Site D
Paraquat 1.7 kg a.i./ha - 14 days - burnt 3-7 days later - Sites B, C and D.
Paraquat 0.9 kg a.i./ha - 14 days + 0.6 kg a.i./ha - 7 days - Site D

Spray timing: 28 days before drilling (both chemicals) Site D
21 days before drilling (both chemicals) Site B

All chemicals were applied with an Oxford Precision Sprayer at 2 bars pressure using 200 - 450 l/ha water.

Layout:

At site A two types of drill were used as an additional treatment. A split plot design was used with drill type as main plots and chemical/timing treatments as sub plots, with 2 replicates.

At site B half the seed was coated with 60% calcium peroxide concentrate applied at 25% by weight. There were four replicates with randomised blocks of chemical/timing treatments. Seed treatment was confounded with replicates, two with treated seed and two with untreated.

At site C a split plot design was used with number of days between spraying and drilling as main plots and chemical treatments as sub-plots, with three replicates.

At site D the chemical/timing treatments were randomised per block, with 3 replicates.

A long term seeds mixture with a predominance of late heading perennial ryegrass was sown to a depth of 1-2 cm at each site at a seed rate of 30 - 35 kg/ha. White clover was included at sites A, B and C and Timothy at sites C and D. Slug pellets were broadcast and at site D chlorpyrifos was used to prevent frit fly attack.

RESULTS

Spraying was carried out in satisfactory weather at all sites but heavy rain following spraying of 14 day treatments at site C necessitated respraying of glyphosate treatments.

The amount of surface trash above ground level recorded at spraying is shown in Table 2.

Table 2

Mean weight of herbage (kg/ha d.m) cut to ground level at each spraying

Spray Interval	Site A	B	C	D
28 days	-	-	-	3750
14 days	1389	616	-	2770
7 days	1312	449	3380	3960
0 days	1307	843	3337	3345

Assessments were based on quadrat areas of $1m^2$ or less and showed considerable variation from plot to plot. However differences between sites were much greater than within sites. At site D further assessments were made at drilling and at 28 days after spraying for each treatment. These indicated very little total loss of trash dry matter in the first three weeks after spraying. After four weeks 47 to 79% of the original trash dry matter was still harvestable but in the burnt treatments this was only 2 to 9%.

Establishment of sown species was recorded at intervals after drilling. Table 3 shows effect on establishment after four weeks where different drills were used at site A.

Table 3

Number of grass seedlings per m^2 site A

Chemical	Days before drilling	Rotoseeder Drill	Bettinson 3D Drill
		mean S.E.	±117.7
Glyphosate 1.8 kg a.i./ha	14 days	599	594
Glyphosate 1.8 kg a.i./ha	7 days	366	125
Glyphosate 1.8 kg a.i./ha	0 days	467	170
Glyphosate 0.9 kg a.i./ha	14 days	609	306
Glyphosate 0.9 kg a.i./ha	7 days	390	168
Glyphosate 0.9 kg a.i./ha	0 days	342	222
Paraquat 1.7 kg a.i./ha	14 days	689	84
Paraquat 1.7 kg a.i./ha	7 days	633	99
Paraquat 1.7 kg a.i./ha	0 days	413	67
	mean S.E.	±119	±121

The rotoseeder had a greater cultivation effect and assessment of debris ground cover four weeks after drilling showed 41% cover after the rotoseeder and 74% after the Bettinson. There was evidence of some seedling damage particularly in the Bettinson treatments attributed to pick up of paraquat from the debris.

Establishment of sown grasses at other sites 4 weeks after sowing is shown in Table 4.

Table 4

Number of grass seedlings per m^2

Chemical	Days before drilling	Site B	Site C	Site D
Glyphosate	28	-	-	711
Glyphosate	21	402	-	-
Glyphosate	14	252	677	302
Glyphosate	7	236	482	235
Glyphosate	0	186	166	139
Paraquat	28	-	-	656
Paraquat	21	403	-	-
Paraquat	14	313	334	349
Paraquat	7	184	246	227
Paraquat	0	108	120	190
Glyphosate + rotovate	14	-	-	568
Glyphosate + burn	14	-	-	442
Paraquat + burn	14	505	538	507
Paraquat	14 + 7	-	-	427
	mean S.E.	±39.9	±88.1	±184.2

At site C comparison with earlier assessments showed plant counts to be highest about 3 weeks after sowing with some loss of plants in most treatments in the fourth week. This was not apparent at sites B and D and later readings at the latter showed that plants were still establishing in the period 4 to 6 weeks after sowing, probably due to the dry autumn conditions delaying germination. Stellaria media developed in the 28 and 14 day treatments at site D and was controlled by ethofumesate in November.

Botanical assessments were made at various intervals through the autumn and the following spring. The ground cover of sown species in the autumn followed the same pattern as the seedling counts as shown in Tables 5 and 6.

Table 5

% Ground Cover sown species - site A 6.12.78

Chemical	Days before drilling	Rotoseeder Perennial ryegrass	Rotoseeder White Clover	Bettinson Perennial ryegrass	Bettinson White Clover
Glyphosate 1.8 kg a.i./ha	14	29	2	18	3
Glyphosate 1.8 kg a.i./ha	7	18	3	9	2
Glyphosate 1.8 kg a.i./ha	0	21	3	10	3
Glyphosate 0.9 kg a.i./ha	14	35	5	20	6
Glyphosate 0.9 kg a.i./ha	7	19	4	14	5
Glyphosate 0.9 kg a.i./ha	0	27	6	20	7
Paraquat 1.7 kg a.i./ha	14	39	5	9	4
Paraquat 1.7 kg a.i./ha	7	33	7	7	3
Paraquat 1.7 kg a.i./ha	0	28	4	3	3
	mean S.E.	± 2.3		± 3.4	

Table 6

% Ground Cover sown species sites B,C and D

Chemical	Days before drilling	B (19.12.79)	C (28.11.79)	D (13.12.79)
Glyphosate	28	-	-	53
Glyphosate	21	62	-	-
Glyphosate	14	37	66	37
Glyphosate	7	23	61	33
Glyphosate	0	21	24	26
Paraquat	28	-	-	62
Paraquat	21	61	-	-
Paraquat	14	52	39	40
Paraquat	7	21	22	27
Paraquat	0	11	3	18
Glyphosate + rotovate	14	-	-	50
Glyphosate + burn	14	-	-	45
Paraquat + burn	14	55	59	46
Paraquat	14 + 7	-	-	42

Further botanical assessments in early spring showed an improved cover of sown species on all treatments particularly the poorer ones but the pattern shown in the autumn was still evident.

Three of the centres were fertilised in spring and closed off for yield assessments.

Table 7

Yield of dry matter (t/ha) Site A 26.6.79

Chemical	Days before drilling	Rotoseeder	Bettinson
		mean S.E. ±0.45	
Glyphosate 1.8 kg a.i./ha	14	6.16	5.42
Glyphosate 1.8 kg a.i./ha	7	4.96	5.13
Glyphosate 1.8 kg a.i./ha	0	5.77	4.22
Glyphosate 0.9 kg a.i./ha	14	4.88	5.02
Glyphosate 0.9 kg a.i./ha	7	5.82	5.72
Glyphosate 0.9 kg a.i./ha	0	5.21	5.49
Paraquat 1.7 kg a.i./ha	14	5.18	4.39
Paraquat 1.7 kg a.i./ha	7	6.08	3.65
Paraquat 1.7 kg a.i./ha	0	5.33	4.34
	mean S.E.	±0.53	±0.38

Table 8

Yield of herbage dry matter tonnes/ha sites B and D

Chemical	Days before drilling	B 24.6.80	D 1st Cut (13.5.80)	D 2nd Cut (23.6.80)	D 3rd Cut (6.8.80)
Glyphosate	28	-	5.65	4.32	4.33
Glyphosate	21	6.90	-	-	-
Glyphosate	14	6.99	5.10	4.42	4.16
Glyphosate	7	5.34	4.31	5.14	3.87
Glyphosate	0	4.88	4.10	5.31	4.00
Paraquat	28	-	5.96	4.25	4.60
Paraquat	21	7.22	-	-	-
Paraquat	14	7.58	5.30	4.78	4.29
Paraquat	7	6.84	4.34	5.08	4.02
Paraquat	0	5.26	4.61	5.34	4.41
Glyphosate + rotovate	14	-	5.58	4.13	4.53
Glyphosate + burn	14	-	5.22	4.52	4.38
Paraquat + burn	14	7.33	5.41	4.33	4.58
Paraquat	14 + 7	-	5.08	4.96	4.46
	S.E. mean	±0.74	±0.23	±0.17	±0.16

At site D the lower yielding treatments at first cut became the higher yielding treatments at second cut.

The effect of coating seed with calcium peroxide at site B is shown in Table 9.

Table 9

Effect of seed coating with calcium peroxide

Chemical	Days before drilling	% increase in no of seedlings/m^2 at 4 weeks	Difference from untreated seed in % cover sown species 19.12.79
Glyphosate	21	18.2	-5.5
Glyphosate	14	105.2	+20.0
Glyphosate	7	-18.2	-4.5
Glyphosate	0	40.3	-2.5
Paraquat	21	37.9	-8.5
Paraquat	14	58.5	+9.5
Paraquat	7	59.8	+18.5
Paraquat	0	115.7	+16.5
Paraquat + burn	14	23.6	-2.0

Botanical assessments 8 weeks after sowing showed a better cover of sown species after seed coating in every treatment but by December the uncoated seed had improved in some treatments. Yield assessments in June showed no advantage to coated seed except for the paraquat 14 and 7 day treatments where a 10 and 19% increased yield was recorded respectively.

DISCUSSION

A clear pattern emerged from all sites where increasing the interval between sward desiccation and drilling seed increased seedling establishment. On the two sites where longer intervals than 14 days were included it appears that there was a continued improvement in establishment. The results from site A show the marked effect of choice of drill and the considerable advantage of the minimal cultivation from the rotoseeder over the narrow slit created by the Bettinson where the old sward debris is in close contact with the developing seedling. The pattern of establishment was similar for both glyphosate and paraquat but at site A (Bettinson) and site C establishment was poorer after paraquat. There was evidence of some seedling damage possibly attributed to pick up of herbicide from the decaying sward. Whilst this could play a part in influencing seedling establishment there is no evidence to suggest that glyphosate can be picked up from the decaying sward. The pattern emerging is therefore more likely to be the effect of toxins produced from the decaying sward affecting seed germination and establishment, the concentration of these decreasing as the interval between spraying and drilling increases. Burning of the decayed sward considerably improved establishment after both chemicals and treatment of seed with calcium peroxide also produced a marked effect on early establishment. The calcium peroxide could be helping to overcome the inhibitory effects of the toxins on germination.

Ground cover of sown species in late autumn closely reflected the pattern of early seedling establishment and, despite the compensatory effect of tillering, differences between treatments were still evident the following spring. First cut yield assessments showed significant differences ($P < 0.05$) between treatments at both sites A and D indicating that tillering had not completely overcome the poor early establishment. However where three cuts were taken over the season at site D differences in total seasonal yield were not significant.

It is concluded that the interval between sward desiccation and drilling has a marked effect on establishment of sown species.

Further investigation is required of the inhibitory factors involved and on the role of calcium peroxide in overcoming these effects.

Acknowledgements

Our sincere thanks are due to the ADAS Agronomy support staff who have carried out these trials, to the farmers who provided sites and facilities on their farms and to the contractors who carried out the direct drilling. Thanks are also due to La Porte Industries Limited for their supply of calcium peroxide and for coating the seeds.

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EFFECTS OF BAND-SPRAY WIDTH AND SEED COATING ON THE ESTABLISHMENT OF SLOT-SEEDED GRASS AND CLOVER

N.D. Boatman, R.J. Haggar and N.R.W. Squires

ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford, OX5 1PF

Summary In an experiment to test the effect of varying the width of band-spray when slot-seeding Italian ryegrass, perennial ryegrass or white clover, the number of grass plants establishing increased with band-spray width. Clover establishment was also increased by the use of a band-spray, but the relationship with band width was less marked.

Two further experiments are described which investigated the effect of seed coatings incorporating inocula of *Rhizobium*, mycorrhizal fungi or fertiliser, on establishment and growth of white clover. In a pot experiment inclusion of fertiliser in the coating reduced emergence but increased growth thereafter. Emergence was also reduced in the field but growth was not stimulated and final yield was reduced. Inoculation with symbiotic micro-organisms did not affect growth. Possible interpretations of the results are discussed.

INTRODUCTION

Clover and grass seed can be introduced into permanent swards, as a first stage in pasture improvement, by the technique of slot-seeding (Squires, Haggar and Elliott, (1979) but no work has been done on the effects of varying band-spray width.

Seed inoculation of legumes with *Rhizobium* is well established in New Zealand (Mackinnon *et al*., 1977) and new coating techniques have increased survival rate of rhizobia and improved reliability (Lowther and McDonald 1973). More recently yield responses have been obtained by pelleting ryegrass and clover seed with inoculum of mycorrhizal fungi (Powell 1979). In Great Britain benefits have been obtained on hill land from inoculating white clover with *Rhizobium* (Mytton, 1975) and mycorrhizal fungi (Hayman and Mosse, 1979). It was thought that inoculation might increase survival and early growth of white clover by ensuring early nodulation and mycorrhizal infection. The incorporation of fertiliser in the seed coating to boost early growth was also studied.

METHOD AND MATERIALS

Experiment 1 Band-spray width

The experiment was sited on a matted *Agrostis/Festuca* permanent pasture at Begbroke Hill (for details of sward and management, see Squires, 1976). On 22 April 1977, slots 2.5 cm wide x 2.5 cm deep were cut 30 cm apart with the 6 row WRO slot-seeder (Squires and Haggar, 1979). Then the following band-spray treatments (all glyphosate at 1 kg a.i./ha) were applied over the slots, using a hand-pushed interrow sprayer with a single nozzle containing a Spraying Systems 8001E jet operating at a pressure of 2.1 bar and a height of 30 cm, but rotated at various angles from the direction of travel:

Band-spray width (cm)	Angle of jet	Volume rate (l/ha)
4.5	16°	1512
6.5	23°	1019
8.5	31°	778
12.5	49°	529
16.5	90°	401

A plaid design was used with four blocks. Main plots were 3 m long and 30 cm wide, and were split into 3 sub-plots for sown species. Three days after cutting the slots seeds of Italian ryegrass cv. Sabalan, perennial ryegrass cv. Melle and white clover cv. Blanca were sown by hand at 1.5 cm intervals in the slot. Slug pellets were applied at 5 kg/ha. Rain occurred during sowing, so seed was sown onto damp soil, which had a reasonable tilth. Numbers of seedlings per 30 cm length of row, selected at random, were counted 14, 20, 27, 35 and 52 days after sowing.

Experiment 2 Seed coating of white clover, pot experiment

Samples of white clover seed (cv. Blanca), treated with various coatings, were obtained from Coated Seeds Ltd of Christchurch, New Zealand, as follows:

Treatment number	Type of coating
1	Commercial "Prillcote" pellet plus *Rhizobium*
1A	As 1 minus *Rhizobium*
2	Granulated with soil inoculum of the mycorrhizal fungus *Glomus tenuis* plus *Rhizobium*
2A	As 2 minus *Rhizobium*
3	Granulated with soil inoculum of *Glomus fasciculatus* plus *Rhizobium*
3A	As 3 minus *Rhizobium*
4	Granulated with sterile soil only plus *Rhizobium*
4A	As 4 minus *Rhizobium*
5	Granulated with slow release fertilisers (P, Mg, Ca, S) plus *Rhizobium*
5A	As 5 minus *Rhizobium*
6	Untreated seed (control)

Seeds were sown in 9 cm pots containing soil taken from the permanent pasture described above. They were kept in a glasshouse which was maintained at a mean temperature of 17°C and mean relative humidity of 51%. There were 8 replicate pots for each treatment, with 10 seeds per pot.

After 22 days, numbers of seedlings in each pot were counted and thinned to one per pot, the remaining plant being chosen at random. Leaf number and spade leaf area were also assessed and a second assessment of leaf number made 57 days after sowing. The plants were then harvested, and root and shoot dry weights measured.

Experiment 3 Seed coating of white clover, field experiment

Slots were cut on 19 June 1978 with a Gibbs slot seeder, using a 7.5 cm band-spray of glyphosate at 1.5 kg a.i./ha, and coated seed shown by hand at 2 seeds per 1.5 cm. Site details were as in experiment 1, and treatments as for experiment 2. A randomised block design with 4 replicates was used, each plot consisting of a 2 m length of slot. Slug pellets were applied at emergence and the experiment was mowed at 3-4 weekly intervals and irrigated whenever necessary.

Plant numbers were counted after 17 and 36 days. At the second assessment leaf numbers were also counted for 10 randomly selected plants in each plot. After 4 months, a harvest was taken: two swaths 30 cm long were cut along the slot in each plot at a height of 2 cm above the soil surface and the herbage bulked. The clover was separated out, dried and weighed.

To check that the Rhizobium inocula were still viable, cell counts were made by the plate count method (Vincent, 1970) on samples of each seed treatment incorporating rhizobia.

RESULTS

Experiment 1 Bandspray width

Table 1

Number of plants per 30 cm row at 20 and 52 days after sowing as influenced by width of glyphosate band-spray at 1 kg a.i./ha (Experiment 1)

Crop		Band-spray width, cm	Days from sowing 20	52
Italian ryegrass		0	13.0	4.8
		4.5	13.8	14.8
		6.5	22.8	17.2
		8.5	21.0	20.0
		12.5	22.0	27.7
		16.5	19.0	24.0
	Mean for band-spray width		19.8	24.0
	Regression coefficient+			1.25
	S.E.			± 0.479
Perennial ryegrass		0	11.3	5.0
		4.5	15.0	14.7
		6.5	20.0	22.0
		8.5	12.3	23.5
		12.5	14.3	19.0
		16.5	11.5	37.7
	Mean for band-spray width		14.6	23.3
	Regression coefficient+			1.65
	S.E.			± 0.299
White clover		0	13.0	4.0
		4.5	18.0	8.0
		6.5	11.5	6.8
		8.5	13.0	8.7
		12.5	12.5	14.0
		16.5	17.8	11.5
	Mean for band-spray		14.5	9.8
	Regression coefficient+			0.52
	S.E.			± 0.322

+ for linear regression of plant number on band-spray width

On unsprayed plots, plant numbers of all three species reached a maximum 20 days after sowing (Table 1), accounting for about 30% of the seed sown, but after 52 days the surviving plants represented only about 12% of the seed sown. However, with band-spraying (width meaned), survival values at 52 days were increased to 24%, 58% and 60% for white clover, perennial ryegrass and Italian ryegrass respectively.

There was a significant relationship between plant number and band-spray width at 52 days for perennial ($P < 0.001$) and Italian ($P < 0.05$) ryegrass, with plant numbers increasing as band-spray width increased. There was also an indication that numbers of clover plants remaining was greater with wider band-sprays, but the regression was not significant.

Experiments 2 and 3 Seed coating of white clover

The only coating treatment which significantly affected early growth of pot-grown clover seedlings was inclusion of fertiliser (Table 2). Numbers of plants emerging were significantly reduced, but thereafter (at 3 weeks) a significant increase in spade leaf area, and a highly significant increase in leaf number per plant were recorded. It is thought unlikely that this increase was due to the lower numbers of plants as competition effects at this stage were probably negligible. After 8 weeks plants from this treatment still had larger leaves and weighed more than other treatments, though the difference was no longer significant. However there was a significant reduction in dry weight of plants grown from "Prillcote" pelleted seed. Presence or absence of Rhizobium inoculant did not affect plant growth at any stage.

Table 2

Effect of seed coating on white clover grown in pots (Experiment 2)

Treatment (see text)	Emergence + (plants/pot)	Spade leaf (area (mm^2)	Leaf number per plant 3 weeks	Leaf number per plant 8 weeks	Total dry weight (g)
1	4.8	48	1.6	23.2	3.15
1A	4.9	41	1.5	21.6	2.76
2	4.9	49	1.6	22.5	3.12
2A	4.1	56	1.5	26.0	3.18
3	5.3	55	1.7	27.8	3.48
3A	4.0	49	1.6	25.2	2.93
4	4.8	49	1.7	27.3	3.22
4A	4.1	48	1.6	25.3	3.17
5	3.1	76	2.3	29.8	3.90
5A	2.9	63	2.2	28.9	3.73
6	4.5	57	1.7	28.4	3.66
SED for comparing coating treatments (± Rhizobium) with control	0.85	61	0.09	N S	0.27

+ Emergence counts are means of 10 replicates. All other values are means of 8 replicates

The increase in growth obtained by pelleting with fertiliser was not repeated in the field experiment (Table 3). Plant numbers were again reduced in this treatment, resulting in a significant reduction in yield at harvest. No effect of the other treatments was detected.

Table 3

Effect of seed coating on clover slot-seeded into permanent pasture (Experiment 3)

Treatment	Plant Number 17 days	Plant Number 36 days	Mean leaf No. per plant 36 days	D.M. yield g/m slot
1	90	85	2.33	1.28
1A	81	74	2.25	1.78
2	82	77	2.17	0.89
2A	86	84	2.09	0.85
3	87	82	2.16	1.02
3A	98	93	2.06	1.23
4	92	83	2.10	1.19
4A	84	74	2.17	0.99
5	50	46	2.31	0.83
5A	78	70	2.11	0.56
6	81	71	2.24	1.44
SED for comparing coating treatments (± Rhizobium) with control	8.9	18.1	NS	0.373

NB All figures mean of 4 replicates

Rhizobium counts were adequate except when fertiliser was also incorporated (Table 4). There was some contamination of the granulated treatments, and the fertiliser treatment was badly contaminated with *Penicillium* spp. which probably accounted for the death of the rhizobia.

Table 4

Rhizobium counts and contamination of coated seed samples

Treatment	Rhizobium count (cells per seed)	Contamination
1. "Prillcote" + *Rhizobium*	13,000	Very little
2. *Glomus tenuis* + *Rhizobium*	228,000	Moderate, including Actinomycetes and Bacilli
3. *G. fasciculatus* + *Rhizobium*	222,000	As 2
4. Sterile soil + *Rhizobium*	53,000	Bad, including fungi, Actinomycetes and Bacilli
5. Fertilisers + *Rhizobium*	0	Very bad, mainly *Penicillium* spp.

DISCUSSION

The first experiment confirmed that band-spraying is an essential part of slot-seeding, not least with rapid-establishing Italian ryegrass (Squires, 1976; Squires, Haggar and Elliott, 1979) and showed that establishment can be increased by using a wider band-spray than the currently recommended 7 cm (Squires and Haggar 1979). Similar results have been obtained in an experiment involving red clover (D.W. Koch, unpublished data) where increasing band-spray width from 7.5 cm to 15 cm increased clover yields by 22% in the year of sowing. However, using a wider band-spray increases herbicide costs and causes a greater interruption to grass growth between the slots. The optimum band-spray width for each crop will therefore depend on the magnitude of the yield increase obtained and its relative value in economic terms.

The lack of response to inoculation with Rhizobium in experiments 2 and 3 was probably due to the high indigenous populations in the soil; large improvements in establishment have been obtained by inoculation in soils with low or ineffective populations, even though numbers of viable rhizobia per seed were considerably lower than in the experiments described here (Lowther and McDonald 1973). Either the indigenous populations are sufficiently effective or the introduced strain was unable to compete with them. Brockwell et al (1975) found that using inoculum with high cell counts increased the number of nodules formed by an introduced strain in the presence of large indigenous populations. However in a subsequent experiment (Boatman, unpublished data) no growth response occurred when large quantities of liquid inoculum were applied to ensure adequate populations of the introduced strain. It seems likely therefore that the indigenous strains were sufficiently effective.

The lack of response to mycorrhizal inoculation may be due to several factors. Powell (1979) reported that pelleting with effective strains of mycorrhiza (including Glomus tenuis and G. fasciculatus) increased clover growth in the presence of less effective native endophytes. However he used freshly pelleted seed and since pelleting with mycorrhizal inoculum is still in the experimental stage it is possible that the inocula used in the experiments now described were no longer viable at the time of sowing. Growing plants from treated seeds in sterilised soil to test the infective potential of the inoculum gave inconclusive results (Boatman, unpublished data). Also growth responses from mycorrhizal inoculation vary with strain used and soil type, and are often difficult to predict (e.g. Powell & Daniel 1978). More rigorous investigations of the potential for inoculation with mycorrhizal fungi in lowland soils might still therefore yield useful results.

There appears to be no obvious explanation for the apparent reduction in dry weight shown by plants grown from "Prillcote" pelleted seed in Experiment 2, and it seems likely to be an artefact since plants of this treatment gave the highest yield when grown in the field (Table 3).

The reduced emergence of seeds coated with fertiliser agrees with the results of Carr and Ballard (1979). Their data suggest that white clover is particularly susceptible to the effects of locally high concentrations of nutrients. However experiment 2 indicates that provision of fertilizer can benefit early seedling growth and placement in the slot close to but not in contact with the seed may be a better technique. This possibility is at present under investigation.

Acknowledgements

We are grateful to Mr G.M. Bennett of Coated Seeds Ltd and Mr J.M. Lloyd of Fruitgrowers Chemical Company Ltd for the pelleted seed, Mr G.I. Wingfield for Rhizobium counts, and Mr C.J. Marshall for assistance with statistical analyses.

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