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the combination of herbicides and cultural measure in many farming situations. More elaborate 'models' could be produced but Fig. 2 illustrates the possibilities. It also illustrates the degree of interaction between cultural practice and the use of herbicides which must be considered when planning management systems.

In practice, weed populations are unlikely to follow absolutely consistent trends even if management is constant. Fig. 2 shows that reduction in populations by herbicides is likely to be a fairly long-term process at best, so that small diversions from the expected behaviour of the weed could result in major differences at the end of a 4–5 year treatment plan. Any practical management system must therefore be sufficiently flexible to accommodate variations which cannot be predicted, because of climatic or other causes of atypical behaviour by the weed.

WILD OAT MANAGEMENT SYSTEMS

Wild oat populations fall into three broad categories as far as management is concerned.

1. If the population exceeds 10–20 plants/m² there is a considerable risk of yield loss with cereals, whilst less competitive crops will almost certainly be affected. The only logical decision is to use a herbicide. At very high populations one role of the herbicide must be to safeguard crop yield. However, the longer term requirement of a systematic reduction in seed production is also important.

2. At low populations (less than 500 plants/ha), hand-roguing is possible and advisable.

3. Intermediate populations, or low populations if hand-roguing is impracticable, present the most severe problems of management. Annual routine herbicide treatment cannot be economically justified at low population levels but some action must be taken to avoid build up of the weed.

One possibility would be to treat all crops in which the weed population has reached the suggested threshold level of 10–20 plants/m². The simplicity of this concept is deceptive; this threshold will vary from crop to crop. In spring barley the same level of yield response has resulted from very different wild oat populations, varying by a factor of over five. Even if we were able to prescribe such levels, it is extremely difficult to assess wild oat numbers critically in the short period of time available before treatment so that spraying decisions based on the concept of threshold levels must be of limited value.

A more rewarding approach is to plan a systematic reduction of the wild oat population, *either* down to hand-roguing levels *or* to some 'safe' level, possibly of the order of one plant (10 seeds)m^2. Such a safe population level would have to be maintained by systematic herbicide use but at lower cost than the initial reduction. The steps involved in such an approach are described below. Central to the proposed system is an initial survey of weed populations and an annual re-assessment. The impracticability of monitoring wild oat populations in spring has been discussed, and this is most marked at low population levels. In contrast, wild oat populations can be measured and their distribution mapped relatively easily in July when the panicles emerge above the crop.

A PROPOSED SYSTEM

The strategic plan

(a) Map the wild oat populations in July.

(b) Identify the rotation of cropping and cultivations or, if no set rotation is followed, establish a pattern of cultural practices to minimize seed production and maximise seed loss from the soil. Make changes where possible and desirable. Plan to reduce or avoid the entry of seed on to the farm.

(c) Use the available knowledge of wild oat population dynamics to estimate the potential for wild oat population increase on the farm and on individual areas.

(d) Herbicide use, cropping and cultivation should be integrated to achieve the overall aim of the system, e.g. rapid population decrease, maintenance of already low populations, etc.

Tactical re-appraisal

(a) By annual re-surveying of wild oat seed production, the gap between theory and practice can be recorded and contingency action taken if necessary.

(b) New herbicides and new approaches can be incorporated into the plan.

RESEARCH INTO PRACTICE

The system described above was developed in a study of a 500-acre 'model' farm. The exercise produced a 5-year programme of cropping, cultivations and herbicide use to optimise control of wild oats and other grass weeds. This approach is now being developed jointly with the

Oxfordshire Division of the Agricultural Development and Advisory Service in order to incorporate the outlined system and the knowledge of wild oats on which it is based into a practical body of recommendations which can be applied on any farm.

ACKNOWLEDGEMENTS

This paper has drawn on the results of much WRO research, mainly by the staffs of the Annual Crops and Botany Groups. Special thanks are due to the Grasshoppers Club, a group of farmers who financed the employment of G. Strickland for a period of 3 years and whose contribution has been referred to in this article. G. Strickland provided much useful information on loss of wild oat seeds from stubbles, on the decline of soil seed reserves and on the costs and efficiency of hand-roguing.

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Effects of herbicidal control of wild oats on the grain yield and quality of cereals

J. HOLROYD, B. J. WILSON and P. AYRES

The extent and nature of the effects of weeds on crops are dependent on many factors such as the weather, the soil, the time and density of sowing of the crop, the number and time of emergence of weeds and, if a herbicide is used, the time of their removal. All these factors are relevant to the use of herbicides to control wild oats (*Avena fatua*) in cereals.

Winter cereals now tend to be sown relatively early in the autumn and, as a result, autumn-germinating weeds like wild oats often become relatively large and consequently more competitive before the onset of the winter. At WRO we have been studying the effect on the grain yield and quality of winter wheat and barley of removing autumn-germinating wild oats with herbicides at different times.

YIELD

The yield of a cereal is governed by three main parameters: the number of fertile tillers, the number of grains per ear and the weight of the individual grains. All three may be influenced by weed competition but the period over which this occurs determines which of the three is most affected.

As a general rule, competition at an early stage of development will reduce the number of fertile tillers and, to a lesser extent, the other components but competition at later stages will cause a greater reduction in the number and weight of individual grains in the ear.

Winter wheat, because of its long period of growth, is generally considered to be a resilient crop. Yield is normally expected to be satisfactory if the plant population in the early spring is adequate and competitive weeds are removed in April. However, our experiments at four sites in 1974–75 have shown that it can be advantageous to control weeds in winter wheat in the autumn or early winter.

Wild oats were present on all the sites: at relatively low populations (16–25 panicles/m^2) at harvest at Bucknell, Eastleach and Hinton but in large numbers (435 panicles/m^2) at Swalcliffe. Though broad-leaved weeds were almost absent at Bucknell they were present in moderate numbers on the remaining three sites.

Table 1 Effect on yield of winter wheat of removal of wild oats with difenzoquat (mean of 3 doses)

Date	Percentage increase in yield or yield components over unsprayed control			
		Components of yield*		
	Yield	(a) fertile tillers	(b) grains /ear	(c) grain wt
Swalcliffe				
Dec/Jan	102	20	59	6
April	46	6	32	5
May	6	4	6	−3
June	7	1	8	−1
Bucknell, Eastleach and Hinton (mean of 3 sites)				
Dec/Jan	9	3	6	0
April	6	0	6	0
May	1	−5	6	1
June	−1	−3	1	2

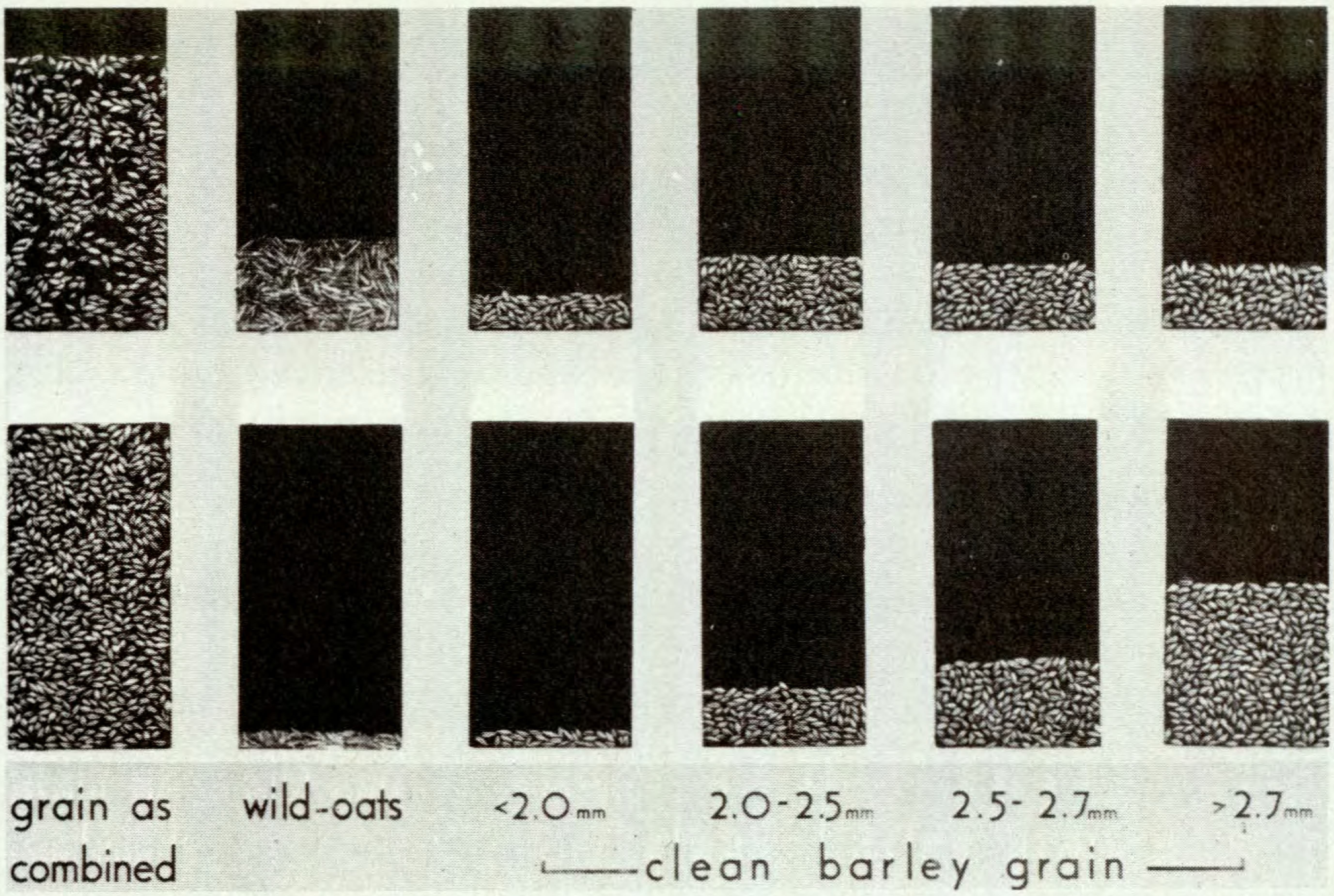
In one series of experiments, plots were treated with difenzoquat at doses of 0.75, 1.0 and 1.25 kg a.i./ha in December/January, April, May or June. Crop yield and the components of yield (numbers of fertile tillers and grains/ear, individual grain weights) were measured at harvest.

Wild oat control was generally excellent on all the plots except those treated in April where it was only moderate. However, it is evident from Table 1 that yield responses to the two earliest treatments were greater than those to the later treatments with the Dec/Jan treatments giving the greatest yield increase. As might be expected, the responses were most marked at Swalcliffe which had the highest wild oat population.

The reactions of the three components of yield show that, although there was a 20% increase in the number of fertile tillers in response to herbicide treatment in December/January, the most marked percentage increase was in the number of grains per ear. At this time, the winter wheat had only 3–4 leaves† and it is interesting to speculate whether removal of the wild oats even earlier would have given a more pronounced increase in the number of fertile tillers. There was relatively little effect on the individual grain weights and, in fact, at Swalcliffe competition at the later stage resulted in the least reduction in grain

*The data in the Table are percentage differences between treated and untreated plots so that, in theory, the sum of the percentage differences of the components should equal the total percentage yield loss. In practice this is not achieved because of the different techniques used in determining the figures.

†At present, this use of difenzoquat falls outside the manufacturer's label recommendations.



The effect of treatment with wild oat herbicides on the quality and yield of winter barley. Each panel shows the proportion of seed of the different types harvested from the control (top row) and treated (bottom row) plots.
In this experiment few wild oats had shed seed before harvest so the harvested grain from the untreated plots was severely contaminated with wild oat seeds. Competition from the wild oats had also reduced the average size of the grain.

weight. However, it is possible that the 1975 drought interacted with the herbicide treatments to reduce the benefit of the late removal of wild oat competition

Winter barley also responds to the early removal of wild oats, particularly where these emerge in the autumn. In an experiment in 1973–74 at Bourton-on-the-Water, barban and difenzoquat increased the yield of barley by 58% and 55% respectively when applied in the autumn but only by 12% and 44% when applied in the spring. The untreated control plots had approximately 200 wild oat panicles/m² at harvest.

QUALITY

Cereal quality is a composite of many factors, the importance of which depends on the intended use of the grain. However, in general, the larger the grain size and the cleaner the sample, the higher the quality.

Grain size

Table 1 shows that the effects on grain size were negligible at the three sites where the wild oat populations were relatively low, while at Swalcliffe where the oat population was high, the earlier the wild oats were removed, the heavier the individual grain weight.

In 1973 in the winter barley experiment, grain samples were sieved and split into four size fractions: >2.7 mm, 2.5–2.7 mm, 2.0–2.5 mm, and <2.0 mm. Autumn treatment with barban and difenzoquat increased the proportion in the >2.7 mm fraction by 24% and 25% respectively. Spring treatment with barban had a relatively minor effect on grain size although treatment with difenzoquat had a more marked effect.

Cleanliness of harvested grain

The number of wild oat panicles present in the crop at the time of harvest and the size and ripeness of the seed in these wild oat panicles all have a marked effect on the number of wild oats which contaminate the grain. All these factors are affected by herbicide treatment and by the time of harvest. In the winter barley experiment at Bourton-on-the-Water the harvested grain from the untreated plots contained over 17% by weight of wild oats whereas that from the crop treated in the autumn with barban contained less than 2%, and that treated with difenzoquat contained less than 1%. Spring treatment with difenzoquat also reduced contamination to less than 2% but barban in spring had little or no effect upon the high proportion of overwintered wild oats at an advanced stage of growth.

Winter barley, being one of the earliest harvested cereals, does suffer a greater risk of contamination than other cereals because relatively few wild oat seeds have shed at harvest and much of the seed appears in the harvested grain.

Winter wheat is harvested later than winter barley by which time more of the wild oats have shed and contamination of the grain is generally less substantial. However, a wild oat herbicide applied late in the life of a wheat crop can sometimes aggravate the problem particularly if the wild oats re-tiller and produce secondary panicles. These secondary panicles are less mature and thus much of their seed may be harvested with the grain.

CONCLUSION

The main conclusion from this work is that autumn or early winter herbicide control of grass weeds, can produce a worthwhile bonus in the yield and quality of cereal grain which may not be obtainable from spring treatment.

There must, however, be one qualification. This work has been done during the present succession of mild winters and should there be a return to colder, harder weather the number of surviving autumn-germinating wild oats and the effect of controlling them may be less.

Further progress in minimum cultivation for cereals

A report on the WRO/Letcombe Joint Tillage Project*

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in collaboration with

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The Joint Tillage Project has now been in progress for seven years and it is therefore inevitable that the original agronomic background to the experiments has changed. When they started in 1969 experience had shown that in some circumstances direct drilling could be successful and in others could result in failure. The reasons for failure were often unknown. Since 1969 there has been a considerable increase in the area of direct-drilled crops and therefore an increase in general experience but detailed investigations on the relationship between crop growth and soil conditions have remained few.

The link between soil conditions as modified by cultivation and the grain yield of a cereal crop is a tenuous one which is all too little researched and understood. A greater understanding of this link and the factors influencing it would enable more farmers to grasp the opportunity of reducing soil cultivations made possible by the advent of herbicides.

The two institutes by collaboration have deployed their complementary resources and expertise on tillage and weed research to enable many new facts and experiences to come to light. The Joint Tillage Project, which has so far spanned some 7 years of field work, continues to investigate the growth of winter wheat and spring barley in response to ploughing (P), deep and shallow tine cultivation (DT & ST), and direct-drilling (DD) on three contrasting soils, a clay loam, a sandy loam and a silt loam over chalk. A feature of the experiments is the very detailed measurements of soil and crop that are made. The purpose of this brief report is to describe the progress during 1975, a year which was full of interest because of the extremes of weather.

The late summer of 1974 was very wet and there was great difficulty in burning straw and carrying out the various cultivations for the sowing

*By agreement between WRO and ARC Letcombe Laboratory, a report of the past year's progress in the joint project is published each year, appearing alternately in the reports of the two Institutes. This report reviews the results for the 1975 cropping season.

Direct drilling of the clay loam soil with spring barley in April 1975. At this time the natural crumb structure developed on the surface gave good seed cover after harrowing.

of winter wheat. The early spring of 1975 was also wet, creating difficulties in the sowing of spring barley on the clay loam soil; thereafter the weather became extremely dry for the remainder of the summer, leading to an easy harvest but also difficulties in preparing the ploughed land particularly in autumn 1975. Since the agronomists in charge are now familiar with obtaining good crops in normal weather, the extremes of climate were valuable in testing the systems.

SPRING BARLEY EXPERIMENT ON CLAY LOAM

Following the autumn ploughing or tine cultivation of the appropriate plots and further seedbed work in spring, the whole area was sown to barley (cv. Julia) on 22 April 1975. As in previous years the highest bulk

Table 1 Soil and crop data from the spring barley experiment on clay loam soil, 1975

	Date	DD	ST	DT	P	SE(±)
Penetrometer at 7.6 cm (kg cm^{-2})	1.5.75	7.0	6.7	4.8	4.5	0.3
Plants/m^2	5.5.75	155	185	144	131	12.8
Plants/m^2	23.7.75	250	294	264	270	10.6
ears/m^2	23.7.75	642	616	622	592	14.0
1000 grain wt (g)		36.4	37.9	36.8	38.9	0.46
yield of grain (t/ha, 85% d.m.)		4.30	4.50	4.44	4.14	0.10
yield of straw (t/ha, d.m.)		4.69	4.51	4.81	4.47	0.11

density in the surface 0–5 cm layer of soil was observed in the DD plots. At 5–10 cm, DD and ST plots had a higher bulk density that DT or P plots and also a greater resistance to penetration with the cone penetrometer (Table 1). Although the start of crop emergence was later on the ploughed soil than with the other treatments, the difference soon disappeared and the plant populations for all treatments were similar when measured on 5 May and 23 July. There were significantly more ears/plant on the direct-drilled plots than on those that were cultivated and in consequence a tendency towards more ears/m^2 which did not, however, achieve statistical significance. However, plants in the cultivated plots had a slightly higher 1000 grain weight which provided compensation. Thus there was no significant difference in grain yield between treatments, though that of the ploughed plots tended to be lower than the remainder.

WINTER WHEAT EXPERIMENTS ON THREE SOILS

Clay loam

For the first time in the series a wet autumn in 1974 nearly caused a departure from the practice of sowing all the treatments the same day. The DD and ST plots were capable of being drilled but the P plots would not bear traffic. However, the land dried out sufficiently for all sowing to be completed on 31 October. On 28 November significantly more plants had emerged on the P plots than on the others but the difference soon disappeared. The final populations of plants and ears/m^2 were very similar, and there was no significant difference between the grain yields which were in the range 5.16–5.43 t/ha though there was a suggestion that the deeper the cultivation the less was the yield (Table 2). Thus the technique of direct-drilling on this soil stood up very well to a most extreme cropping year containing an excessively wet autumn, a cold spring and a very hot dry summer.

Table 2 Soil and crop data from the winter wheat crops experiments on three soils, 1974–75

	Date	DD	ST	DT	P	SE(±)
Clay loam						
penetrometer at 7.6 cm (kg cm^{-2})	3.11.74	7.1	7.6	5.7	4.9	0.2
plants/m^2	28.11.74	71	66	68	104	8.6
plants/m^2	21. 7.75	153	137	142	171	8.2
ears/m^2	30. 7.75	337	310	324	337	14.2
yield of grain (t/ha, 85% d.m.)		5.43	5.37	5.19	5.16	0.09
Silt loam						
penetrometer at 7.6 cm (kg cm^{-2})	2.12.74	6.2	5.6	2.9	4.3	0.5
plants/m^2	23.12.74	67	57	47	50	9.2
plants/m^2	17. 7.75	175	164	178	171	10.8
ears/m^2	29. 7.75	423	413	386	446	6.3
yield of grain (t/ha, 85% d.m.)		6.60	6.64	6.44	7.00	0.13
Sandy loam						
penetrometer at 7.6 cm (kg cm^{-2})	5.12.74	10.0	7.1	3.8	5.3	0.8
plants/m^2	25.11.74	66	126	114	100	11.9
plants/m^2	2.12.74	161	200	207	177	12.1
plants/m^2	13. 5.75	178	176	172	167	7.6
ears/m^2	16. 7.75	321	332	325	369	7.8
yield of grain (t/ha, 85% d.m.)						
after oats		4.33	3.88	3.99	4.99	0.22
after wheat		4.08	4.42	4.43	4.26	0.17

Silt loam overlying chalk

This was the first experimental crop of winter wheat on this soil. A wet autumn does not have the same significance on a free-draining chalk as on a clay, and there were few difficulties or differences in sowing and establishment over the winter. The average plant population was similar on all treatments at the end of July but there were fewer ears/m^2 on the DT plots than on the DD and ST plots which had less than the P plots. In consequence, the yield of wheat on the DT plots was lower than that on the P plots and the other two treatments were intermediate (Table 2).

Sandy loam

The wheat on the direct-drilled plots was slow to emerge in autumn compared with the other treatments but in time it caught up, and there was no difference in the plant populations on 13 May 1975. Thereafter the treatments suffered differentially from the competition of volunteer cultivated oats. Part of the experimental plan to suppress disease in this

Overhead view of the clay loam soil, direct-drilled in the spring, cracking along the line of drilling (from left to right) in the dry summer of 1975. This did not occur in the same soil direct-drilled the previous autumn.

experiment had involved alternating winter oat with winter wheat. In the wet harvest of 1974 many oat seeds were shed and the ensuing plants proved difficult to control. The yields of wheat after winter oats and after winter wheat are shown separately in Table 2. The pattern of yield reduction after oats mirrors the counts of oat plants, indicating a reduction in wheat yield due to competition, while the yields in the absence of oats indicate that there was probably little difference between the treatments.

WEEDS*

On all the experiments the populations of broad-leaved weeds were relatively low and there were no problems over controlling them. The position with the grass weeds, particularly the annual grasses, was

*Contributed by G. W. Cussans and S. Moss.

different. Reference has already been made to the cultivated oat as a weed in winter wheat on the sandy loam soil; blackgrass (*Alopecurus myosuroides*) was a continuing menace to be combated in the winter wheat on the clay loam. In spite of using a herbicide the blackgrass population on 21 March 1975 was 106 plants/m^2 on the direct-drilled plots compared with 163 on the shallow cultivated plots and 65 on the ploughed. Few wild oats appeared in the spring barley on clay loam but these were rather more numerous on the direct-drilled than on the ploughed plots.

The common thread running through these experiences is that the ploughed plots usually tend to be the cleanest in respect of grass weeds. Ploughing alone does not lead to a weed free situation, nor even to a low grass weed population; but when allied to other measures of weed control including herbicides it has provided the cleanest crop. However, the effort and cost of ploughing is a high price to pay for the relative improvement in weed control.

CONCLUSION

The experiments continue to demonstrate the practical feasibility of producing cereals by direct-drilling or reduced cultivation on these three contrasting soils. The land sown to autumn wheat without cultivation and, to a lesser extent, that sown to spring barley continues to show a good surface structure. The condition is easily destroyed by wheeled traffic. How right was Professor W. E. Russell, for these particular soils, when he wrote 10 years ago that 'if it were possible to sow and harvest a crop without ever going on the land, the crops themselves would maintain the sort of tilth and pore space distribution needed for a seedbed and for seedling growth' (Russell, 1966). Many of the problems confronting the practitioners of direct-drilling are man-made in the sense that they stem from man's past actions (cultivated oats as a weed for example) or are created by machines. What man has fashioned wrongly he can re-fashion. Here is the challenge of the future.

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A two-stage approach to sward renewal

R. J. HAGGAR, N. R. W. SQUIRES and J. G. ELLIOTT

During the last 25 years periodic ploughing and reseeding of British grassland has led to a widespread replacement of old grass by sown swards. But, despite these large-scale efforts at improvement, over 80 per cent of swards in the UK are still dominated by indigenous species like common bent (*Agrostis tenuis*). This suggests that the majority of sown swards quickly revert back to their original composition; a recent survey by the Grassland Research Institute has confirmed that, on average, indigenous grasses outnumber sown grasses within five years from sowing (Morrison & Idle, 1972).

LIMITATIONS OF CURRENT METHODS OF RESEEDING

Many grassland farmers are not in a position to carry out further reseeding work, being unable to afford the high cost of conventional reseeding, which has more than doubled in recent years. Moreover, most of these farms are based on family labour, giving priority to the needs of livestock at the expense of field work. On such farms, which are usually heavily stocked, it may be difficult to set aside fields for ploughing and reseeding. In addition to the disruption to forage supplies, there is the risk of complete failure of the seeds to establish a new sward during a period of drought.

There are yet other farmers for whom conventional reseeding is not feasible. Either their land is too wet or steep for cultivation or their farms are too small and isolated to justify the purchase or hire of appropriate machinery.

Hence, if farmers in these grassland areas are to exploit the higher productivity of improved varieties of herbage species, it is essential to provide methods of establishment more suited to their circumstances and to develop more reliable ways of maintaining the higher productivity, once achieved.

At present, direct-drilling grass seed into killed swards does not offer a practical alternative to ploughing and reseeding, largely because of poor reliability and high cost. The nearest successful approach is based on rotary cultivation and reseeding.

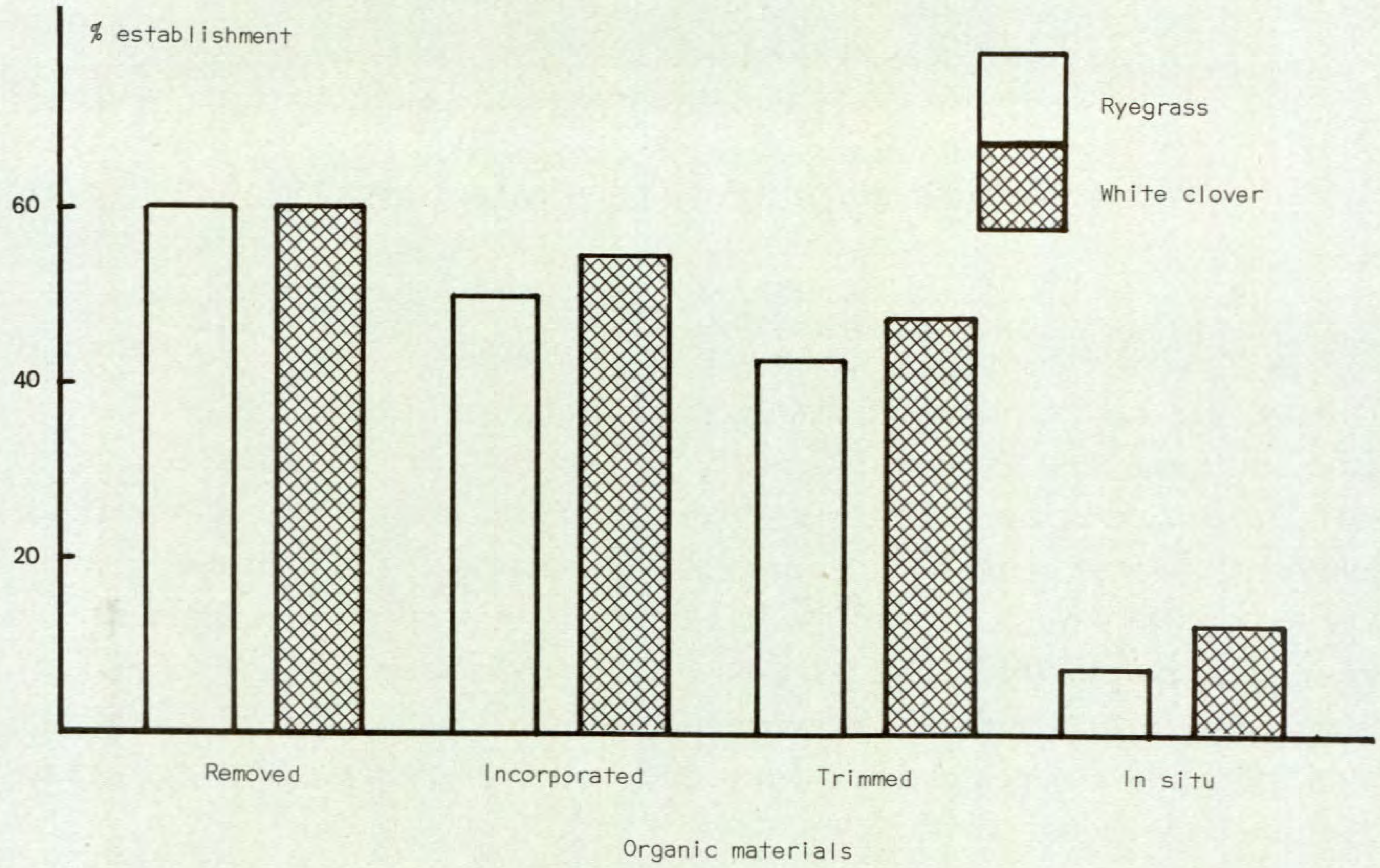

Fig. 1. The effect on herbage establishment of plant material on the soil surface.

The WRO approach to sward renewal

In endeavouring to overcome these dilemmas, and to provide a more flexible alternative to the present methods of reseeding, research at WRO has aimed at developing a two-stage approach to sward renewal. The first stage involves the establishment, in bands, of a threshold quantity of desirable species, with a minimum of disturbance to the existing sward. Subsequently, the introduced species are encouraged to spread by the exercise of suitable management, including the use of selective herbicides.

INTRODUCTION OF NEW SPECIES

The successful introduction and establishment of seed into existing swards depends on several factors, the most important of which are described below.

Provision of suitable conditions for germination

As swards get older, so the amount of surface litter and decaying root material tends to build up. This mixture of trash and mat has been shown (Fig. 1) to have an adverse effect on seedling emergence of direct-drilled crops, especially the small-seeded grasses and clovers (Squires &

Elliott, 1975). Although herbicide residues on the dead grass may occasionally be the cause of poor establishment, more often the overlying plant material prevents seedling emergence by sheer physical impedance.

It has long been known that the amount of harmful mat and trash can be reduced in various ways, including the use of fertilizers and lime. Alternatively, the organic matter can be processed mechanically or by-passed by pioneer cropping with a large-seeded fodder crop. But all these approaches can be costly, slow or difficult to organise. All that is required is to remove the organic matter from the immediate vicinity of the introduced seed. This can now be achieved by removing a strip in the track of the drill spout, thus exposing mineral soil at the bottom of a small trench.

In most areas sowing can take place at any time from April to September, providing a period of drought is avoided. When seed is sown in the bottom of the trench, burial is not essential so long as adequate contact is made with moist soils. Successful germination is not dependent on soil disturbance and there is ample evidence that seeds of grass and fodder crops drilled into uncultivated soil will germinate as well as seed in similar cultivated soil (Elliott & Squires, 1974). In practice, grass and legume seeds dropped into the mini-trenches germinate well in the moist microclimate, protected from the drying effects of wind and sun. Currently, the optimum depth and orientation of these trenches is being investigated (Fig. 2).

Provision of favourable conditions for establishment

Small seedlings can be very sensitive to competition from existing vegetation, both above and below ground. Seedlings establishing in depressions will inevitably encounter shading from surrounding plants, even when the sward is grazed closely. Such interference can be reduced by the use of an appropriate herbicide to check or kill the existing vegetation in the vicinity of the seedling (Fig. 3). This is particularly useful for slow establishing species such as white clover, though even Italian ryegrass responds favourably to suppression of grass competition.

The establishment and survival of seedlings drilled into existing swards is also very dependent on adequate supplies of nutrients, this being especially true with fertility-demanding species such as perennial ryegrass (Haggar, 1976a). Unless major nutrient deficiencies are rectified, no long-term improvement in botanical composition can be expected. The fertilizer requirements of species introduced into killed swards is currently being studied.

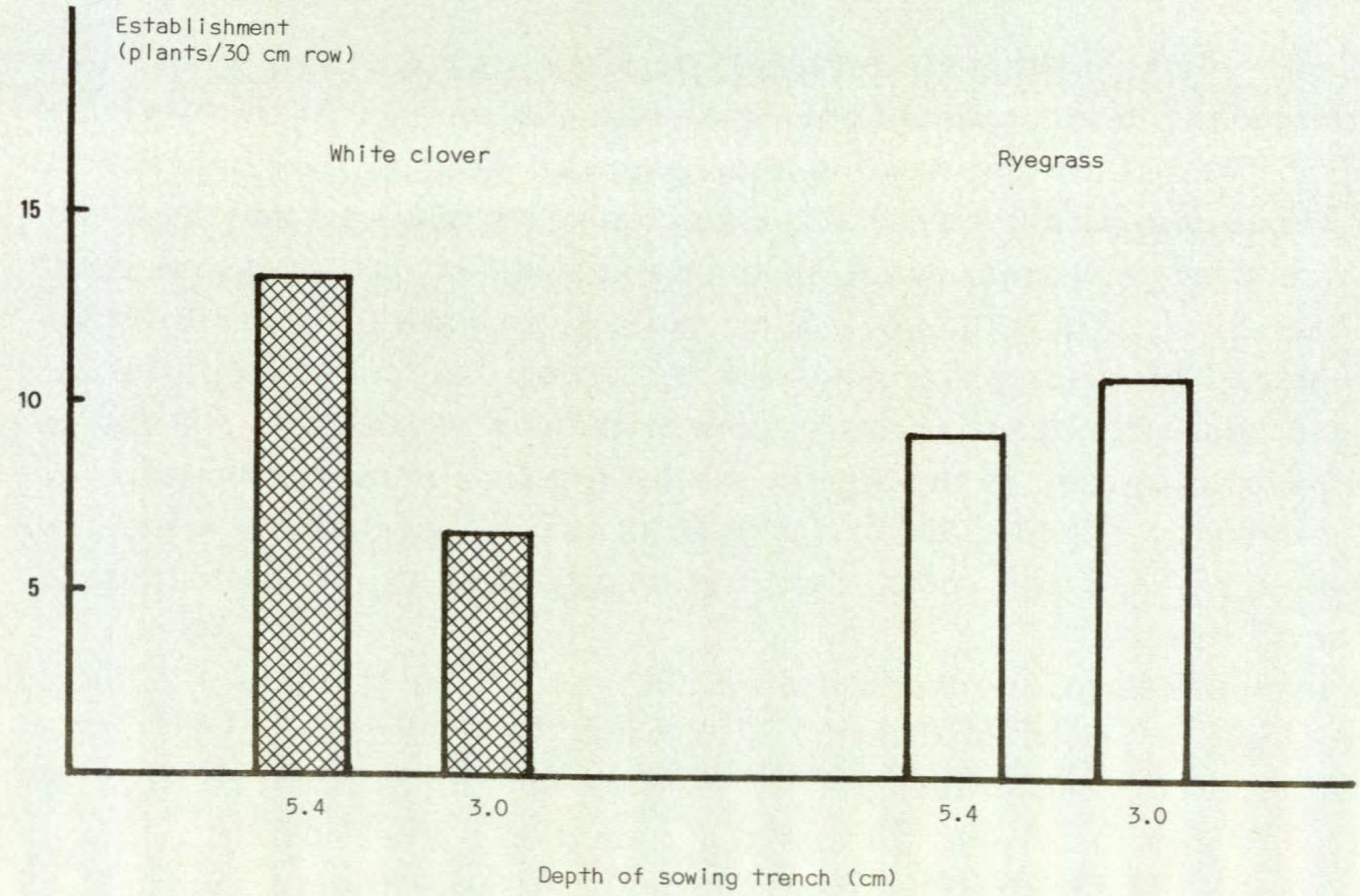

Fig. 2. The effect on herbage establishment of band-spraying on either side of the sowing trench.

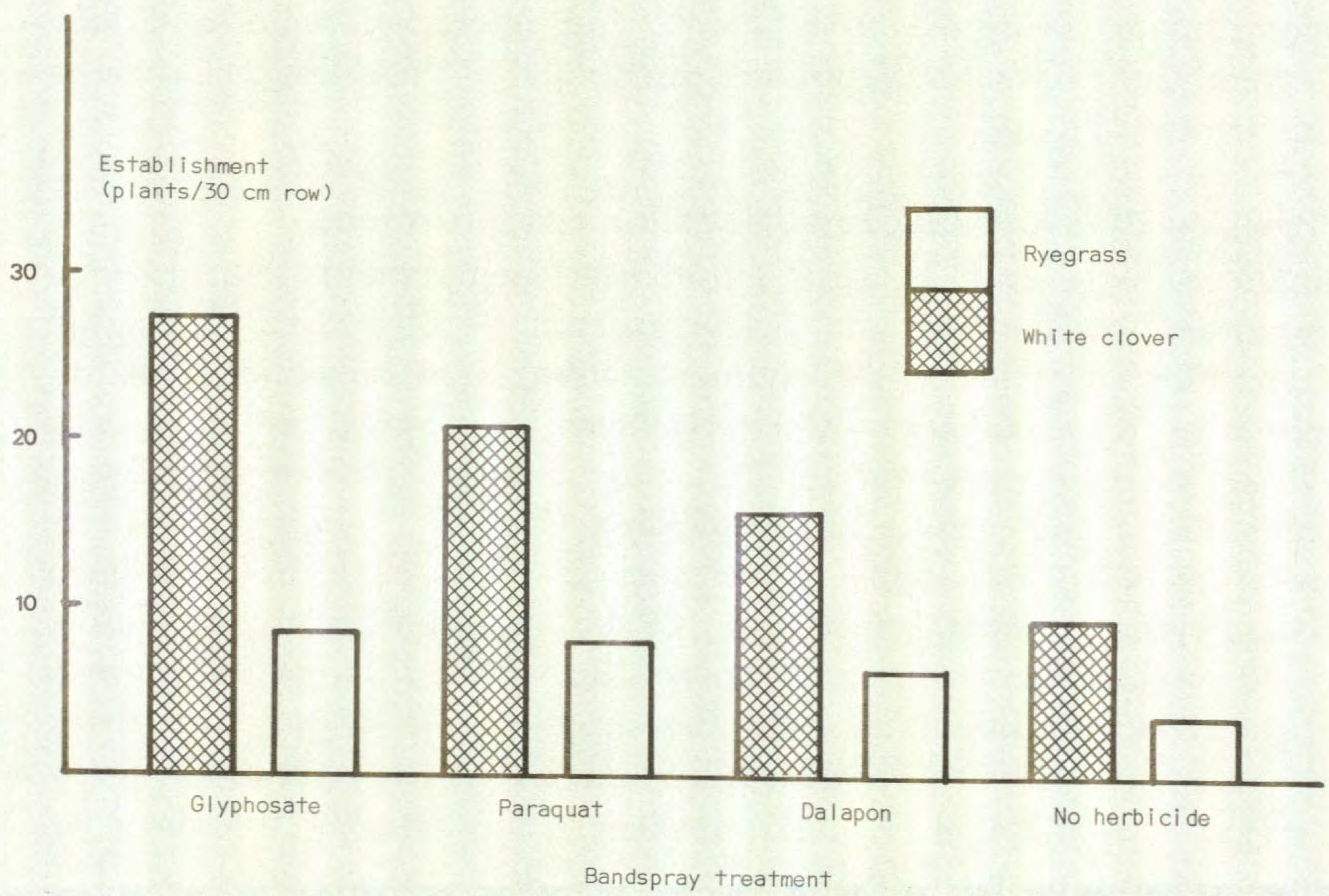

Fig. 3. The effect on herbage establishment of the depth of the sowing trench.

Traditional methods of re-seeding, involving cultivation, do reduce the carry over of soil-borne pests so, with the new technique (see below), special precautions must be taken against a high incidence of wireworms, chafers and leather-jackets and it is common practice to protect seedling grasses and clovers from attack by slugs. Less is known about the possible damage caused by the foliage-dwelling pests such as aphids, leafhoppers, frit fly larvae, etc., so research into this has recently been started in collaboration with the Grassland Research Institute and Rothamsted Experimental Station.

WRO ONE-PASS SOWING TECHNIQUE

A new one-pass technique being developed at WRO attempts to meet all the requirements for successful establishment. The components of this technique are: the application of a narrow band of herbicide about 7 cm wide; the removal of a strip of turf in the middle of the sprayed band of about 2–3 cm wide and deep; the simultaneous sowing into the small trench of seed, fertilizer and slug repellent.

Although WRO is not attempting to produce a commercial drill it has assembled the various components necessary to the technique in order to carry out field experiments: these comprise a five row assembly mounted on a conventional tool frame and attached to a MF 135 tractor (see Frontispiece).

The likely cost of this technique was indicated by an experimental sowing of clover in rows 37 cm apart in old unfertilized pasture during summer 1975. The total material cost (herbicide, seed, fertilizer etc.) was about £19/ha. Assuming operating costs of £10/ha the total cost was about £29/ha, or about a quarter of the cost of overall reseeding.

Uses of the 'one-pass' technique

Permanent pastures are often slow to start growth in spring but Italian ryegrass, established by the 'one-pass' technique in the previous July or August, can overcome this limitation. Alternatively, by delaying sowing until mid-September, a significant increase in subsequent mid-summer production can be achieved at a time when grass growth is often at a premium. (N. R. W. Squires, unpublished data). Red and white clover can be introduced by the technique into all-grass swards and forage crops can be drilled without the need for overall spraying. The technique is particularly suited for patching swards that have been poached or topping up pastures that have become too thin.

The equipment, being flexible in use, cheap to assemble and low in tractor power requirement, is very suitable for the general needs of many grassland farms.

FOLLOW-UP MEASURES

Having introduced grass and clover from seed, follow-up measures are required to encourage the plants to spread. Traditionally, this has involved the combined use of fertilizers and close grazing, an approach which is slow, weather dependent and not always feasible, especially when grass management has to be sacrificed to animal management. Currently, we are investigating the use of selective herbicides to increase the desirable species from an initially low threshold level. Two examples serve to illustrate this point.

Clover encouragement

White clover can be changed from a minor to a dominant component in a mixed sward within four months simply by using a grass-suppressing herbicide in late winter to reduce the harmful shading by the grasses in early summer. Experiments at Begbroke have shown that carbetamide and propyzamide, applied in March at 2.0 and 0.6 kg/ha respectively, will produce at least a seven-fold increase in clover flower heads in the following July, the degree of change being determined by the chemical dose (Haggar, 1976b). Although the concomitant loss of early grass growth is considerable, this is largely offset by a substantial increase in production from mid-summer onwards. This compensatory growth can be most useful for beef grazing systems in which herbage intake increases with body weight as the summer progresses. Moreover, the increased clover content makes the sward less dependent on applied fertilizer nitrogen for maintaining productivity in the long term.

Ryegrass encouragement

The proportion of perennial ryegrass in a mixed sward can be increased by the employment of a selective herbicide like dalapon, in combination with appropriate levels of nitrogen to assist the ryegrass to occupy the spaces left by the killed weed grasses (Allen, 1969).

However, a single application of dalapon is not likely to provide a lasting control of the weed grasses. Under most practical systems of management, weed grasses are likely to re-invade in varying quantities, requiring the repeated use of dalapon in subsequent years.

To provide some quantitative data on the feasibility of ryegrass/weed grass manipulation by repeated applications of dalapon, a large-scale grazing trial was started in 1971 on a mixed sward containing about 50 per cent ryegrass. Except for the control plots, dalapon at 2.8 kg/ha was applied either annually or biennially (Haggar, 1974). Over a four-year period, dalapon applied every second year has maintained the ryegrass content at its original level while, without dalapon, the ryegrass has declined to about 14 per cent. It was also found that a high ryegrass content could be maintained by increasing the stocking rate by 25 per cent but this resulted in a considerable reduction in animal performance. Conversely, at stocking rates lower than the optimum, the herbicide treatment proved less effective in controlling the weed grasses. At the optimal stocking rate for good liveweight gain, ryegrass was only maintained in the swards by the use of dalapon.

CONCLUSION

Grassland improvement by this two-stage approach of seed introduction and species manipulation by selective herbicides should be considered as a supplement to sound grassland management and not as an alternative. It is axiomatic that the success of this approach will be dependent on the removal of any major soil deficiencies that might limit the productivity of the introduced species.

For 30 years high productivity in grassland has been equated with the sown ryegrass sward receiving high levels of nitrogenous fertiliser. This combination has proved particularly valuable for intensive dairy farmers and cereal/ley farmers on arable soils. The pastoral farmers of western and northern Britain were encouraged to follow a similar path to highly productive grass. Most did not respond, and of those that did, many encountered rapid sward deterioration. It can now be seen that the intensive ryegrass technique, requiring as it does high inputs of tillage, seeds, fertilizers and livestock, is not suited to the circumstances of many pastoral farmers. Their need is for dependable long-term swards with reliable output from modest inputs; for swards that can be improved from year to year because they are in ecological balance with the management environment. For such swards the combination of seed introduction and species control by herbicides can make a major contribution to higher productivity.

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Application of herbicides in very low volume sprays

W. A. TAYLOR and K. HOLLY

The spraying machinery used by the average farmer to apply herbicides today shows little evidence of major change or innovation in the course of the past 25 years. Machines have increased in size and new materials have been exploited in construction but the basic principle of forming a spray by pushing liquid under pressure through a hydraulic nozzle, generally a fan nozzle, remains unchanged. In particular, the volume of spray liquid applied per unit area has not been reduced and volume rates of the order of 200 l/ha are commonplace.

Current application practice has many disadvantages. Some derive directly from this large volume of carrier, generally water, which is used. On a day suitable for spraying much time is spent in ancillary tasks associated with provision of this carrier, notably in travel to and from the water source and in mixing with the active ingredient. The consequent weight of the loaded sprayer may also give rise to problems of wheel-marking and soil compaction. A recently introduced and publicised sprayer from the Continent weighs more than 10 t when loaded! Other disadvantages stem from the wide range of size in the drops produced by hydraulic nozzles. At one end of this range are the very large drops which may be inefficient for maximum herbicide performance. At the other end are the very small drops which can lead to danger from spray drift and hence to inability to spray on days which are otherwise suitable except that the wind speed is too high. This adds to the increasing difficulty experienced by large cereal farmers in accomplishing their spraying programmes within the correct stages of growth of crop and weeds.

RESEARCH USING ROTARY ATOMISERS

Application in very low volume rates of carrier per unit area with equipment capable of controlling drop size to within a narrow band has the potential to mitigate these disadvantages. The successful use of rotary atomiser sprayers for application of insecticides and fungicides at ultra-low volume rates stimulated consideration as to whether this type of spray equipment could be modified for the application of herbicides. In consequence, we started a programme of research at WRO to investigate this possibility, paying particular attention to the biological consequences of reducing volume rate with a spray of uniform drop size. At the same time the Spraying Department at the National Institute of Agricultural Engineering developed a complementary programme which, in part, involved joint experiments with WRO. The early stages of this work were referred to very briefly in the Fifth Report of the Weed Research organization for 1972–73. Since then, the programme of experiments has been pursued actively.

Ultra-low application of insecticides and fungicides is often highly successful because of the very large number of small drops that are produced, in spite of the meagre total volume, and the consequent large deposit of toxicant on target organisms. With herbicides, the necessity to avoid drift imposes a lower limit of at least 100 μm on drop size. The key issues then become those of ascertaining what drop size above that limit optimises retention by the target weeds, and of determining how far volume rate can be reduced with that drop size before biological performance decreases seriously. Clearly, there must come a point at which the number of drops per unit area becomes too few to ensure a sufficient number of points of contact with every weed in the population being treated.

For the application of herbicides at a controlled drop size in very low volumes to be taken up widely in practice it would need to be relevant to all types of herbicide. It was envisaged that lowering the volume rate would pose less problems for the application of herbicides acting through the soil prior to plant emergence than it would for the post-emergence spraying of herbicides depending on foliar entry. Therefore the research programme has concentrated most attention on foliage-applied herbicides. It was also anticipated that optimum drop size and the lower limit of volume to which reduction could safely be made without important sacrifice of performance would differ from herbicide to herbicide and with other circumstances of application. To elucidate the factors involved, both indoor experiments with pot-grown plants and field experiments in the natural agricultural environment seemed necessary.

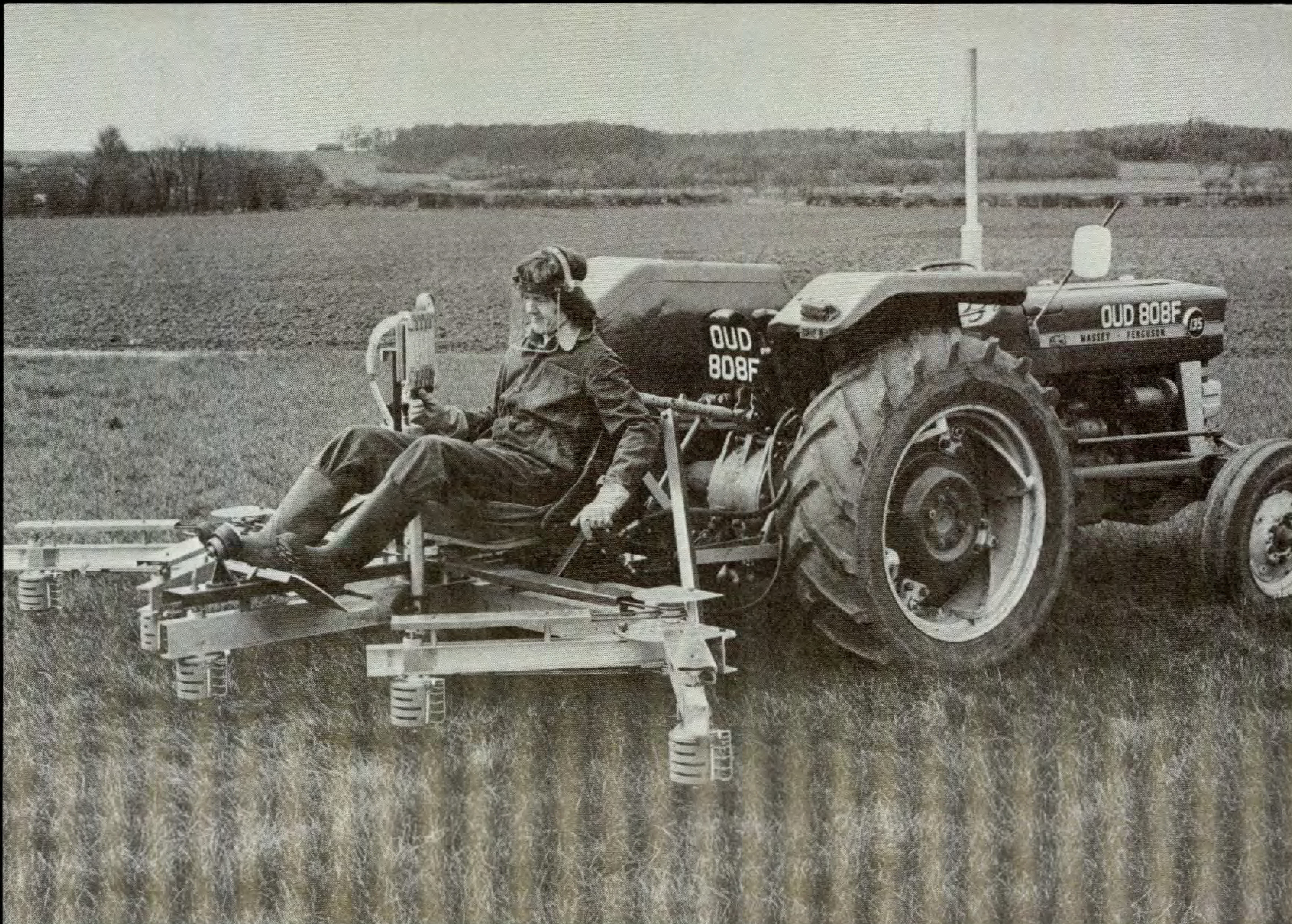
EQUIPMENT

The first requirement was to construct equipment for the experimental application of sprays of different uniform drop sizes over a range of volume rates. Initially a metal spinning disc unit enclosed in a cabinet as described by Byass & Charlton (1968) was used for all the glasshouse and laboratory studies. Recently this disc was replaced by a plastic disc of new design, bowl-shaped with a toothed margin, supplied by Edward Bals of Micron Sprayers Ltd. This disc is more versatile than previous ones available commercially in that it will break up a variety of liquids, including aqueous solutions, to form a curtain of uniform drops. The drop size depends primarily on speed of rotation. Plants to be treated travel on a conveyor belt system through a sector of the circle of vertically falling drops.

For experiments in the field a vehicle-mounted machine was needed which would spray a swath, 2 m or so wide, with a uniform density of deposit both across and along the line of travel over a plot. A first attempt at such a machine was illustrated in the previous WRO Report, and this was used in the preliminary investigations. Subsequently a more versatile machine had been made in the WRO workshop. This has utilised the new bowl-shaped plastic disc mentioned above. Each spraying unit consists of five such discs stacked one above the other on a common shaft. There is a metered liquid feed direct to each disc in the unit. All discs except the lowest are shrouded in such a way that only two sectors of the circular drop pattern are emitted while the remainder is intercepted and fed down to supplement the direct liquid feed to the next disc below. The bottom disc is unshielded so that the residual liquid reaching it is distributed as spray. Five such stacks of discs are mounted in a boom arrangement, constructed so that the spacing between them can be adjusted. In this way a very uniform spray deposition can be produced across the line of travel. The biological performance thereof may be compared readily with that of a spray produced in the conventional way by a boom of hydraulic fan nozzles. The uniformity of distribution obtained with the former, even at volumes as low as 6 l/ha, is at least as good as with the latter. With this new machine the drop size may be adjusted between diameters of 150 to 350 μm; the volume rates may be varied between 5 and 120 l/ha; and spray liquids may be aqueous solutions, formulations in lipophilic solvents, or oil-in-water emulsions. The machine is described in more detail by Taylor, Merritt & Drinkwater (1976).

POT EXPERIMENTS

In the experiments on pot-grown plants many foliage-applied herbicides have now been examined for the effect of varying drop size and volume. These herbicides include MCPA, mecoprop, dichlorprop, dicamba, 2,3,6-TBA, a commercial mixture of dicamba-mecoprop-MCPA, benta-



The experimental sprayer built at WRO to test the effect on herbicide performance of applying sprays of different uniform drop sizes over a range of low and very low volume rates.

zone, a commercial mixture of bromoxynil and ioxynil esters, barban, difenzoquat and chlorfenprop. The weed species were those appropriate to the herbicide used and included seedlings of *Avena fatua*, *Polygonum lapathifolium*, *Raphanus sativus*, *Stellaria media* and *Tripleurospermum maritimum* at the 2-leaf stage or bigger. Those herbicides believed to have a moderate degree of mobility within the plant performed about as well when applied in the volume range of 5 to 45 l/ha at a drop size of 250 μm as they did when applied in a conventional spray at 200 l/ha. The biological performance of those herbicides generally regarded as having a contact action was appreciably poorer at very low volume rates. Thus the performance of bentazone on four dicotyledonous species was reduced markedly as volume rate was decreased and this reduction relative to conventional spraying was obvious even at 45 l/ha. A bromoxynil-ioxynil mixture showed the same type of reduction in effectiveness, starting at 45 l/ha and worsening with further decrease in volume.

Further experiments have established interactions between application volume, formulation and climatic conditions. It has been demonstrated experimentally that glyphosate can be more effective on *Agropyron repens* when applied in a spray of controlled drop size at a volume rate of about 15 l/ha than when applied conventionally and that this effect may be improved still further by the addition of ammonium sulphate (p. 83). Further experiments with the bromoxynil-ioxynil mixture demonstrated that the adverse effect of reducing volume rate might be less with oil-in-water emulsions than with oil solutions, though the emulsions tend to give a less uniform drop spectrum when applied by a spinning disc.

FIELD EXPERIMENTS

During the years since 1971 and with collaborative effort between Groups at WRO 39 field experiments have been conducted on various facets of application in very low volumes. From the indoor investigations barban, difenzoquat, the dicamba-mecoprop-MCPA mixture and glyphosate have been selected for inclusion in the more recent field experiments. Three volume rates, namely 5, 15 and 45 l/ha, together with three drop sizes (150, 250 and 350 μm) have been used. The agronomic situations have involved *Avena fatua* and dicotyledonous weeds in spring barley, and *Agropyron repens* in cereal stubble. Results with the wild oat herbicides and with the growth regulator mixture suggest that drop size within the limits tested is a far less important factor than volume rate. Reduction to 5 l/ha has certainly given inferior results. On the other hand results at 15 l/ha and 45 l/ha have been encouraging, suggesting that volume rates in this range are well worth more extensive investigation in field circumstances. The glyphosate experiments will not be assessed until the summer of 1976.

THE FUTURE

The experimental work to date has been promising in that it has demonstrated that experimental rotary atomiser sprayers can be used effectively for the application of herbicides under field conditions. Satisfactory control of weeds with the herbicide diluted in volumes substantially less than those used in contemporary practice has been obtained in a number of situations with different herbicides. At the same time, there is a clear indication that the process of volume reduction can be carried too far. The limits must be investigated and clearly understood. Much more experimentation will be required to define these limits with the more important herbicides in current usage in the range of practical situations in which they may be utilised. These extend widely over agricultural and horticultural situations, together with a diversity of potential 'out-of-crop' uses.

So far attention has been concentrated upon establishing that adequate weed control can be obtained. Reliability of performance now has to be verified under the full range of environmental circumstances encountered in Britain. Weeds are often shielded by crops and crop penetration studies with this type of application will have to be intensified. Furthermore, before such a major change can be accepted into commercial practice it must be substantiated that crop safety is not jeopardised in any way and that the final response in benefit from control of weeds in terms of yield or in other ways is as great as can be expected from traditional methods.

The intention of the Weed Research Organization is to pursue, with the help of others, the necessary research and development work as speedily as our resources allow. We are gratified that the work that has been done up to the present has drawn an encouraging response from many, including commercial interests, in the world of agrochemicals and agricultural machinery. The participation of numerous and diverse people is required before new machinery accompanied by appropriate recommendations on the labels of herbicide products can be placed in the hands of the user. Fruitful discussions on the way ahead have already been held with the advisory services and with industrial interests. There is, of course, a need for caution on the part of farmers and others against moving into large-scale attempts to apply herbicides in this way before an integrated package of recommendations on the biological, mechanical and chemical formulation aspects is available. However, we are confident that if the ongoing research continues to be promising, then the day is not too distant when novel spraying machinery for controlled drop application of herbicides in very low volumes will come into commercial usage with benefits to the user.

ACKNOWLEDGMENTS

It is a pleasure to record appreciation of the co-operation and interest of Edward Bals of Micron Sprayers and of Horstine Farmery Ltd.

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Preliminary results of research into improving herbicide performance by the use of additives

D. J. TURNER

At first sight it may be difficult to see how non-commercial research on herbicide formulation can help the farmer or grower. Chemical firms already spend much time and money on developing satisfactory formulated products for sale and use. Is this not enough? Recent research at the Weed Research Organization (WRO) has indicated that there may on occasions be scope for improvement. By the use of suitable additives, marked increases in the performance of some proprietary herbicide products have consistently been obtained in pot experiments. This promising indication is in no way a reflection on the capability of the manufacturers but of the overriding requirement in commerce to produce formulations which contain as high a concentration of the active ingredient as possible, are stable, easy to handle and store, and non-corrosive. Research into the possibilities of varying the efficacy of the active ingredient may in consequence receive little attention.

The role of additives to improve the performance of herbicides is not new. Manufacturers themselves sometimes recommend the use of extra wetting agents where herbicides are to be applied in high volumes of diluent or where the target weeds have waxy water-repellent leaves. In the USSR, phosphates and ammonium salts were being added to salt formulations of 2,4-D more than a decade ago (Chesalin, 1962, Makodzeba, 1962). In Europe and in North America, ammonium sulphate was recommended for use with dinitrophenol herbicides during the late 1960's (Crafts & Rieber, 1945). In recent years, however, relatively little research on additives has been undertaken. In the last two WRO biennial reports, preliminary results from a small project on this topic were reported. During the past two years the programme has been expanded in view of the increasing recognition of the economic savings and greater efficiency in the use of herbicides that may result from work of this nature.

WORK AT WRO

When constraints on herbicide performance are suspected it is logical to try to discover the limiting factors and then devise a suitable remedy. Sometimes this is possible, for example where surfactants and oils are used to remove leaf waxes and so promote herbicide uptake. In general, however, research on additives has been of an empirical nature and the mode of action of two important types of additives, ammonium salts and phosphates, is not yet understood. The WRO programmes with these compounds originated from chance observation of effects rather than from logical experimentation. Three types of additive are discussed here.

Surfactants and oils

Surfactants are commonly added by the manufacturer to formulated products to improve the spread of spray droplets on leaf surfaces or to emulsify or disperse constituent materials in water. The addition of extra surfactants to proprietary formulations sometimes improves activity, particularly where the herbicide is applied as a very dilute solution and the leaves of target plants are waxy and water-repellent. Some surfactants are specially effective when used with particular herbicides (Jansen, 1965). Bland & Brian (1975) have shown that certain surfactants improve the movement of paraquat in wheat and cocksfoot.

Oils too are a common constituent of formulated herbicides. Commercial blends of oil and surfactant are on sale to farmers for addition to such herbicides as atrazine, phenmedipham and pyrazon. The surfactant disperses the oil as an emulsion. With this type of formulation, the oil and the water are in separate phases and will eventually separate. Little work with emulsifiable oils has been carried out at WRO. However, other types of surfactant-oil-water mixtures have been examined in which the surfactants function as cosolvents to produce clear, apparently single-phase liquids. As well as being free from cloudiness, these mixtures differ from emulsions in that they do not separate on standing or when centrifuged. The process of using surfactants to make clear mixtures containing both oil and water, which is termed solubilization, can confer on water-soluble herbicides properties normally associated with oil-soluble materials, including an ability to pass readily through bark or thick leaf cuticle. A typical effect of a solubilized formulation on a woody species, *Rhododendron ponticum*, is shown in Fig. 1. In this experiment, glyphosate-in-oil at 4 kg/ha had lethal effects on the test plants, whereas the same dose as an aqueous solution had relatively little effect (Turner & Loader, 1974).

Solubilization of water-soluble herbicides into oil-based liquids has little advantage for treating most agricultural weeds. However, recent studies show that the addition of 10%–20% of solubilized oil to aqueous herbicide solutions can sometimes enhance activity. A mixture of oil and

Fig. 1. Effects of aqueous and solubilized glyphosate on *Rhododendron ponticum:* (a) no treatment; (b) aqueous glyphosate; (c) solubilized glyphosate.

surfactant, which will disperse in water to form a clear solubilized mixture, can be added to dilute aqueous herbicide solutions just before spraying, in the same way as emulsifiable oil additives. Research is still at an early stage but, in some circumstances, solubilized oils can have advantages over emulsifiable oil additives. An example using difenzoquat is given in Fig. 2. Application of the herbicide in aqueous solution to wild oats (*Avena fatua*) at 15 l/ha instead of at a more conventional volume rate of 150 l/ha considerably reduced its activity. However, incorporation of 10% of solubilized oil into the very low volume spray solution almost eliminated the difference between the two types of application. The addition of a similar proportion of emulsified oil had no such beneficial effect.

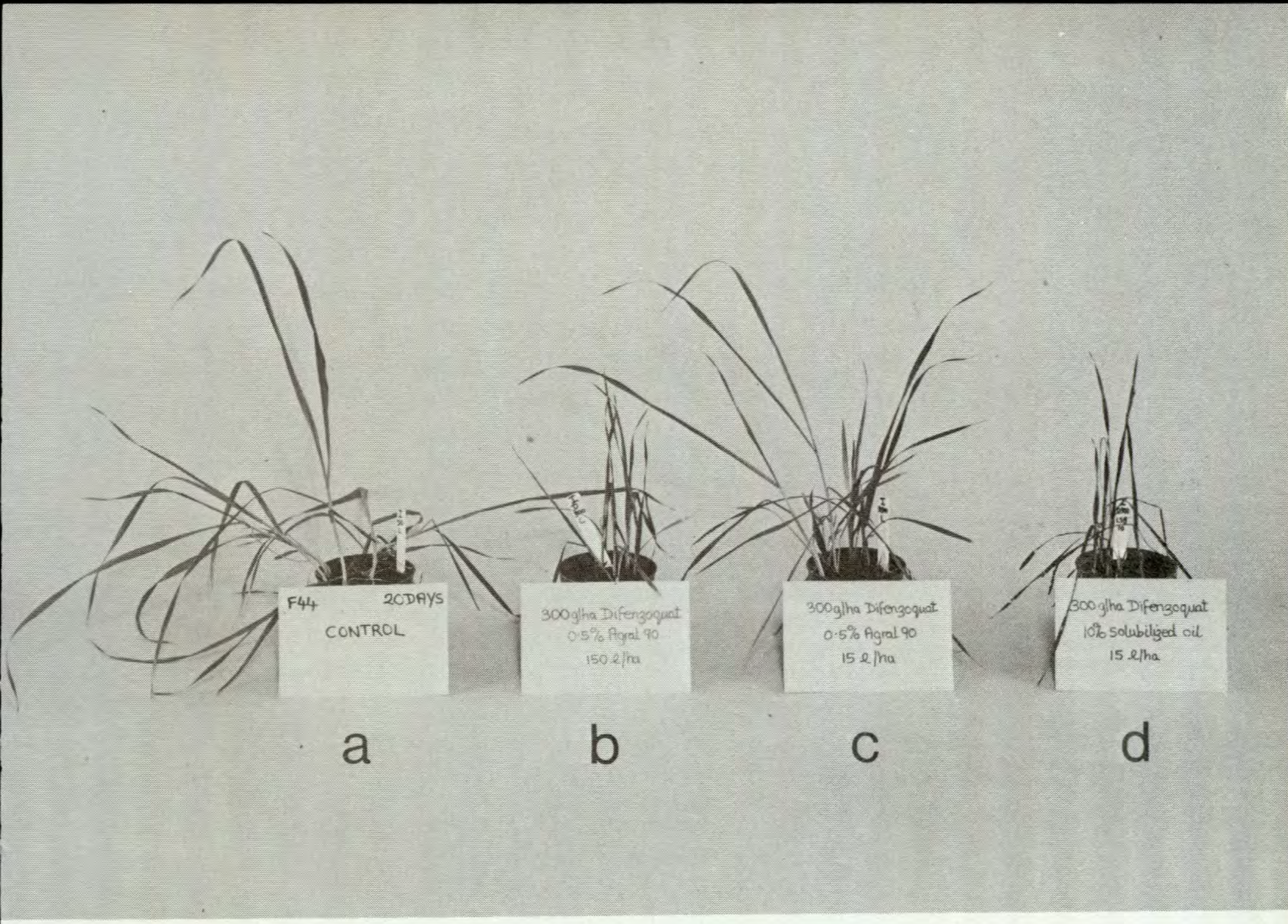

Fig. 2. Effect of added solubilized oil on difenzoquat activity on wild oats: (a) no treatment; (b) difenzoquat + wetter, at high volume; (c) difenzoquat + wetter, at low volume; (d) difenzoquat + solubilized oil, at low volume.

Ammonium sulphate and related salts

Early uses of ammonium salts in mixture with water-soluble foliage-applied herbicides have already been mentioned including the large-scale use of ammonium salt adjuvants with 2,4-D. Isolated reports of interactions between ammonium compounds and other foliage-applied herbicides have appeared from time to time but until recently no attempt has been made to study the effects systematically. When investigating the performance of herbicides against woody and herbaceous species at WRO, we discovered that ammonium salts can enhance the effects of many leaf-applied systematic herbicides including MCPA, mecroprop and dichlorprop salts, picloram, aminotriazole and glyphosate (Turner & Loader, 1972, 1975; Blair, 1975). Recently a contact herbicide, bentazone, has been added to the list. While activation of any herbicide may be of value, the results with glyphosate have aroused special interest because of the cost of this herbicide and because of its use in situations where effects on selectivity between crop and weed need not be considered.

Our research with glyphosate—ammonium sulphate mixtures is still in progress but results from nine experiments on pot-grown couch grass (*Agropyron repens*) are now available. Some of these experiments have involved very large plants, which were established in 30 cm pots during the previous season, and overwintered out of doors. Not all experiments have been assessed in the same way and there are, naturally, large differences in response to glyphosate, depending upon the dose used, the size of the plants and treatment, and the environmental conditions before, during and after spraying. However, the addition of a suitable concentration of ammonium sulphate to the spray solution has often increased activity by a factor of two or more, and sometimes by a much greater amount. In an outdoor pot experiment on well established plants the addition of 5% w/v ammonium sulphate to an 0.4 kg/ha spray treatment reduced the number of viable rhizome buds per plant 5 months later from 186 to 26. Another example of an effect of the additive is shown in Fig. 3. This experiment with well established pot-grown plants of couch grass was also conducted out of doors, the pots being sprayed in autumn and allowed to remain undisturbed until spring. When glyphosate alone was applied, a dose of 0.3 kg/ha in the equivalent of 150 l/ha suppressed regrowth but did not completely kill all the plants. However, when 4 kg/ha of ammonium sulphate (equivalent to 2.7% w/v concentration) was added to the spray solution, 0·1kg/ha of the herbicide was lethal.

Several field experiments with glyphosate/ammonium sulphate mixtures are in progress but only one of these, on couch grass established a year before treatment, has been completed. This study, reported by Blair (1975), showed that activation can occur in the field as well as in pot-grown couch. About three months after treatment, plants treated with 0.25 kg/ha glyphosate and 5 kg/ha ammonium sulphate had about the same weight of rhizome as plants treated with 0.5 kg/ha of the herbicide without additive. This result is encouraging but it must be emphasised that our experience under field conditions is still very limited, and it is not yet possible to judge the practical significance of the work.

Many pot experiments and two field experiments have been carried out with salt formulations of phenoxy herbicides such as MCPA, mecoprop and dichlorprop. In a series of eight experiments with pot-grown chick-

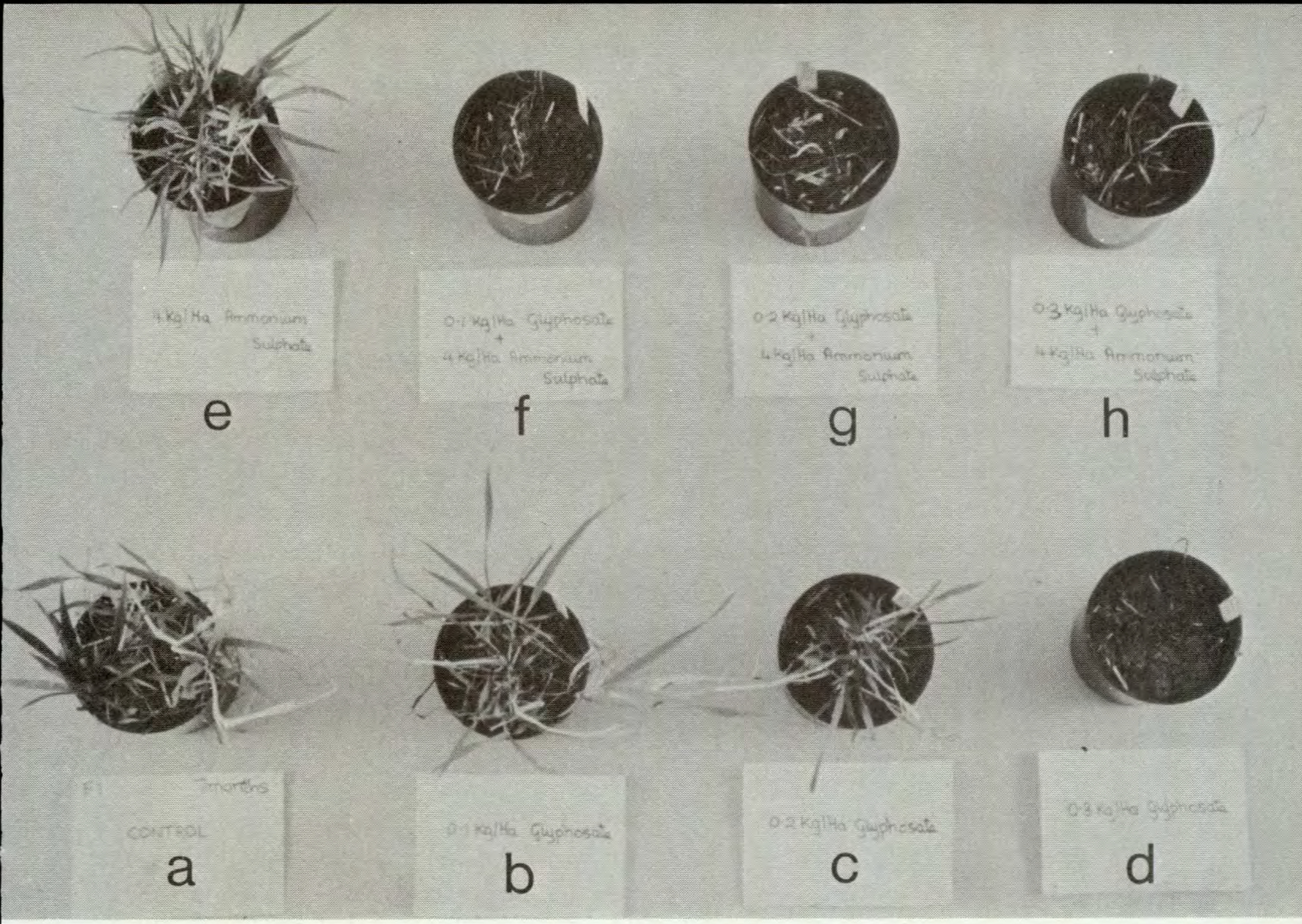

Fig. 3. Effect of ammonium sulphate on glyphosate activity on couch grass: (a) no treatment; (b, c and d) 0.1, 0.2 and 0.3 kg/ha glyphosate alone; (e) 4 kg/ha ammonium sulphate alone; (f, g and h) 0.1, 0.2 and 0.3 kg/ha glyphosate plus 4 kg/ha ammonium sulphate.

weed (*Stellaria media*), the addition of 3% w/v ammonium sulphate doubled the activity of dichlorprop. The additive also enhanced the effects of other herbicides which are active against the weed, including mecoprop, 2,3,6-TBA, benazolin and bentazone but did not appreciably change the herbicidal activity of MCPA, which normally has little effect on chickweed.

In two field experiments with dichlorprop salt, the addition of 2% or 8% w/v ammonium sulphate to spray solutions significantly increased effects on broadleaved weed species. On a site at WRO where the principal species was chickweed, 0·5 kg/ha of herbicide with either rate of additive had about the same effect as 1 kg/ha of dichlorprop alone. At an outside site, where a wider range of weeds was present including fat hen (*Chenopodium album*), cleavers (*Galium aparine*) and black bindweed (*Polygonum convolvulus*), activity was increased by about 60%. No adverse effects on the barley crop were observed. These results also are encouraging but should be treated with caution, particularly since the experiments were carried out in a very dry season (1975).

Very high concentrations of ammonium sulphate are sometimes antagonistic. However, within limits, the exact concentration of additive in spray solutions appears to be unimportant, levels of between 1% and 8% having approximately similar effects. As a rule we use 1% w/v for conventional volume rates (300 l/ha or over) and 5% for low or very low volume rates (75 l/ha and below). Recent work shows that ammonium sulphate can enhance glyphosate effects at very low volume as well as at conventional application rates. This is in itself an important discovery because the use of low or very low volume rates can markedly increase glyphosate activity (C. R. Merritt & W. A. Taylor, personal communication). In a recent pot experiment, 0.4 kg/ha glyphosate was applied to couch grass plants at 300 /lha or 75 l/ha, either alone or with 5% of ammonium sulphate. When the experiment was assessed 160 days later, the mean numbers of living buds on the rhizomes of treated plants were 114 and 17 respectively for the two high volume treatments and 20 and 10 respectively for the corresponding low volume treatments. The untreated control plants had an average of 268 viable buds.

Although ammonium sulphate has the advantage of cheapness and ready availability, other ammonium salts such as the phosphates, nitrate and citrate can also be used. So too can other sulphates including those of sodium and magnesium. As interactions occur between many inorganic salts on the one hand, and herbicides of diverse structures and modes of activity on the other, simple chemical action between additive and herbicide is unlikely to account for the increases in activity. The precise mode of action of these additives is still unclear but C^{14} tracer work at WRO shows that ammonium sulphate can markedly increase uptake through leaf surfaces. Thus, in an experiment with MCPA, the rate of herbicide penetration during a period of 24 h following treatment was increased by 0.5% ammonium sulphate, differences in uptake being evident only 10 minutes after application of MCPA to the leaf surface. The additive appears to have little direct effect on adsorption of the herbicide by leaf waxes or on translocation patterns or degradation. Studies by Poovaiah & Leopold (1975) suggest that the activity of ammonium sulphate may be due to its effects on the permeability of membranes which contain proteins.

Phosphate additives

Many inorganic and organic phosphates can enhance the activity of water-soluble leaf-applied herbicides. It is not known how these additives work but tracer studies suggest a different mode of action from ammonium sulphate. In particular, phosphate additives act more slowly and, unlike the ammonium salts, reduce the amount of herbicide which becomes adsorbed on the leaf waxes. Earlier research at WRO concentrated upon organic phosphates, esters such as tributyl phosphate and 'butyl acid phosphate' (Turner, 1972). In experiments in which glyphosate was applied to couch grass, this last additive more than counteracted the adverse effects of low humidity (Caseley, 1974). The result shows how formulation and environmental factors can interact. Recently, some cheaper inorganic phosphates have been examined. Among other materials, diammonium hydrogen phosphate has potential as an additive for phenoxy herbicide salts and for glyphosate. Its effects are partly due to its ammonium ion content but the phosphate part of the molecule is also synergistic. At concentrations of around 2% w/v, orthophosphoric acid is also a synergist but this material may not find practical uses because of its corrosive and caustic properties. Sodium salts of phosphoric acids increase the effects of a number of herbicides but have relatively little influence on glyphosate activity, probably because of the antagonistic effects of the sodium ions.

Other types of additives

In general, glyphosate appears to have a greater effect on plants when the spray solution in which it is applied is acid, rather than alkaline or neutral. We have for example observed that the effects of the herbicide can be increased by adding small amounts of citric, acetic or propionic acid. The use of these cheap, relatively non-toxic additives is being explored further. So also are the possibilities of three-way interactions between glyphosate, ammonium sulphate, and phosphate or acid additives.

THE PRACTICAL IMPLICATIONS

In some circumstances, the use of additives as described offers exciting possibilities for increasing the activity and reliability of foliage-applied herbicides. However, the evaluation of new techniques is a long process and it is not yet possible to recommend with confidence the practical large-scale use of these materials by farmers and growers. Since the results to date have already attracted publicity, it is best to conclude this article with a note of warning. Only a limited amount of field work has been undertaken and there are always possibilities of unforeseen effects. At present the addition of any extra material to a formulated product contravenes label recommendations and so absolves the herbicide manufacturer of responsibility for failure or crop damage. More widespread field testing is needed before the treatments which have been discussed are used on a practical scale and in most cases the implications of the formulation changes will have to be considered by the Agricultural Chemicals Approval and Pesticides Safety Precautions Schemes.

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LIST OF RESEARCH PROJECTS 1974–75

WEED CONTROL DEPARTMENT

Head of Department: J. G. Elliott

ANNUAL CROPS GROUP (Leader: J. Holroyd)

1. Herbicide treatments for the control of wild oat and blackgrass in cereals: J. Holroyd, M. E. Thornton.
2. Development of economic long term systems for the control of wild oats and blackgrass in cereals: G. W. Cussans, B. J. Wilson.
3. Effect of changes in tillage systems on the growth and control of unwanted plant material in cereals: G. W. Cussans, P. Ayres.
4. Growth of cereals in reduced tillage systems: J. G. Elliot, J. Holroyd, F. Pollard (Part of joint project with the ARC Letcombe laboratory and ADAS).
5. Growth and control of *Agropyron repens* and *Agrostis gigantea* in cereal and other cropping systems: G. W. Cussans, P. Ayres.
6. Effect of high organic matter soils on activity of herbicides: J. Holroyd, M. J. May.
7. Control of potato groundkeepers: G. W. Cussans, P. J. Lutman.
8. Cereal tolerance of herbicides: J. Holroyd, D. R. Tottman.

GRASS AND FODDER CROPS GROUP (Leader: R. J. Haggar)

1. Competition between cultivated grasses, legumes and weeds; autecology of grassland weeds: R. J. Haggar, T. W. Watt.
2. Herbicidal control of broadleaved- and grass-weeds; autecology of grassland weeds: R. J. Haggar, A. K. Oswald.
3. Systems of herbicide use and minimum cultivations for the establishment of grass and fodder crops: J. G. Elliott, R. J. Haggar, N. Squires.
4. Weed control in herbage seed crops: R. J. Haggar, A. K. Oswald.

PERENNIAL CROPS GROUP (Leader: J. G. Davison)

1. Fruit crop tolerance of soil- and foliage-applied herbicides: D. V. Clay, J. G. Davison.
2. Effect of important weeds on fruit production: J. G. Davison, J. A. Bailey.
3. Response of fruit crops to weed competition and herbicides in the year after planting: J. G. Davison, D. V. Clay.
4. Evaluation of new herbicides for the control of annual and perennial weeds in strawberries: J. G. Davison, D. V. Clay.

SPECIAL SERVICES

1. Survey information about weeds and weed control: J. G. Elliott, A. Phillipson.
2. Supervision, development and maintenance of application equipment for experimental use: M. E. Thornton.

WEED SCIENCE DEPARTMENT

Head of Department: K. Holly

HERBICIDE GROUP (Leader: K. Holly)

1. Evaluation of biological activity, selectivity and soil persistence of new herbicides: W. G. Richardson.
2. Evaluation of additives to improve performance of herbicides: D. J. Turner, M. P. C. Loader.

3. Improvement of methods for the application of herbicides: W. A. Taylor. (Part of joint project with National Institute of Agricultural Engineering).
4. Effect of environmental factors on the activity of herbicides: J. Caseley.
5. Development of experimental techniques and equipment for monitoring environment; establishment of controlled environment systems: R. Simmons.
6. Effect of environmental factors on the activity of growth regulators: J. Caseley.
7. Evaluation of antidotes and protectants to increase selectivity of herbicides: A. M. Blair.

CHEMISTRY GROUP (Leader: R. J. Hance)

1. Analysis of herbicides in soil, water and plant material: T. H. Byast.
2. Development of analytical methods for herbicides and their decomposition products: T. H. Byast, E. G. Cotterill.
3. Effect of herbicides on soil and crop quality: T. H. Byast.
4. Elucidation of criteria by which the ability of a soil to decompose herbicides may be predicted: G. Kempson-Jones.
5. Effect of repeated applications of MCPA, tri-allate, simazine and linuron on 'fertility' of soil: P. Smith.
6. Persistence in soil of paraquat applied repeatedly to plant cover or bare soil: P. Smith.
7. Persistence in soil of picloram applied annually: P. Smith.
8. Effect of high application rates upon the rate of decomposition of simazine and linuron: P. Smith.
9. Effect of repeated applications of glyphosate on fertility of soils and growth of cereals at Begbroke Hill: P. Smith.

MICROBIOLOGY GROUP (Leaders: formerly E. Grossbard; latterly M. P. Greaves)

1. Effect of herbicides and breakdown products upon microbial activity of soil: E. Grossbard, J. A. P. Marsh, H. Davies.
2. Effect of herbicides and breakdown products upon microbial populations and species composition in the soil: E. Grossbard, M. P. Greaves, G. I. Wingfield.
3. Development of techniques to measure microbial activity in the soil and the influence of herbicides thereon: E. Grossbard, J. A. P. Marsh, G. I. Wingfield, H. Davies.
4. Effect of herbicides and breakdown products on the microflora of the root region of plants: M. P. Greaves, G. I. Wingfield.
5. Effect of herbicides on decay of plant material in the soil: E. Grossbard.

BOTANY GROUP (Leader: R. J. Chancellor)

1. Periodicity of germination of weed seeds. Chemicals for breaking seed dormancy: R. J. Chancellor.
2. Vegetative regeneration of weeds: R. J. Chancellor.
3. Inter-action of factors affecting competition between crops and weeds: R. J. Chancellor, N. C. B. Peters.
4. Weed ecology: R. J. Chancellor.
5. Shoot development from rhizomes of couch. Effects of growth regulators on dormancy of rhizome buds: R. J. Chancellor.

EXTRA DEPARTMENTAL GROUPS

AQUATIC WEED AND UNCROPPED LAND GROUP (Leader: T. O. Robson)

1. Development of methods for the control of emergent weeds: T. O. Robson, P. R. F. Barrett.
2. Development of chemical methods of controlling submerged and floating vascular plants and algae: T. O. Robson, P. R. F. Barrett.
3. Assessment of potential of grass carp for the control of aquatic weeds: T. O. Robson, M. C. Fowler. (Joint project with MAFF Freshwater Fisheries Laboratory).

Aquatic weed and uncropped land group (*contd.*):

4. Herbicidal control of weeds in flowing water: T. O. Robson, M. C. Fowler.
5. Survey of methods of aquatic weed control developed by Internal Drainage Boards: T. O. Robson.

ODM TROPICAL WEED CONTROL (Leader: C. Parker)

1. New herbicide treatments for use in tropical crops against annual and established perennial weeds: C. Parker.
2. Growth and development of *Cyperus rotundus* with particular reference to tuber bud dormancy: C. Parker.
3. Biology and control of *Striga* spp. and *Orobanche* spp.: C. Parker.
4. Biology and control of weeds of East Africa, with emphasis on *Cyperus* spp.: J. Terry.

LIST OF PUBLICATIONS
1974–75

611* BAILEY, J. A. and DAVISON, J. G. The response to glyphosate of *Cirsium arvense, Heracleum sphondylium, Hypericum perforatum, Polygonum amphibium, Rumex obtusifolius* and *Urtica dioica* in orchards. *Proceedings 12th British Weed Control Conference*, 1974, 655–662.

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(Price includes surface mail; airmail £0.50 extra)

66. Selected references to the effect of herbicides on the protein content and quality of wheat and barley 1948–1973, (74 references), price £1.50.
67. Selected references to mistletoes (*Loranthaceae*) and their control 1955–1973, (266 references), price £5.25.
68. A review of methods of controlling *Cirsium arvense* (L.) Scop. 1962–71, (73 references), price £1.50.
70. Selected references to the occurrence, biology and control of *Acanthospermum hispidum*, 1961–1974 (25 references), price £1.00.
71. Selected references to glyphosate, 1971–1974, (35 references), price £1.00.
72. Selected references to the use of diuron as an aquatic herbicide 1960–1974, (78 references), price £1.50.

***A complete list is obtainable from the Librarian.**

73. Selected references to the chemistry and properties, physiological effects, usage and toxicology of asulam, 1964–1974, (115 references), price £2.25.
74. Selected references to the biology and control of hempiparasitic species of the Scrophulariaceae (excluding *Striga* spp) and Santalaceae, 1954–1974, (82 references), price £1.50.
75. Selected references to the biology and control of *Imperata cylindrica*, 1954–1965, (63 references), price £1.25.
76. Selected references to the control of *Rumex obtusifolius* and *R. crispus* in grassland, 1954–1974 (87 references), price £1.75.
77. Selected references to the biology and control of *Orobanchaceea*, 1973–1974, (66 references), price £1.25.
78. Selected references to potato haulm destruction 1964–1974, (35 references), price £1.00.
79. Selected references to the persistence of paraquat residues in the soil (replacing Annotated Bibliography No. 25 and part of Annotated Bibliography No. 3), 1958–1973, (110 references), price £2.25.
80. Weed control in lucerne (alfalfa) (*Medicago sativa* L.) a review of the world's literature 1962–1971 (89 references), price £1.75.
81. Selected references to the effect of herbicides applied to cereal crops of different growth stages, 1947–1974, (166 references), price £3.25.
82. Selected references to minimum cultivation in perennial fruit crops (replaces Annotated Bibliography No. 4), 1959–1974, (76 references), price £1.50.
83. Selected references to minimum cultivation in grassland and herbage crops (replaces Annotated Bibliographies Nos. 4, 4a and 57), 1959–1974, (138 references), price £2.75.
84. Selected references to minimum cultivation in cereal and field crops (replaces Annotated Bibliographies Nos. 4 and 57), 1959–1974, (246 references), price £5.00.
85. Selected references to weed control in upland rice, 1964–1974, (50 references), price £1.00.
86. Selected references to the biology and control of *Striga* species 1966–1974. A supplement to Bibliography No. 17, replacing Annotated Bibliography No. 56, (76 references), price £1.50.
87. Selected references to the effect of herbicides on the protein content and the quality of wheat and barley, 1955–1974, (98 references), price £2.00.
88. Selected references to the use of chemical crop protectants in conjunction with herbicides, 1962–1975, (72 references), price £1.50.
89. Selected references to the control of gorse (*Ulex europaeus*), 1940–1975, (79 references), price £1.75.
90. Selected references to the biology and control of wild beet and to herbicide damage to sugar beet, 1951–1975, (127 references), price £2.50.

STAFF OF THE ARC WEED RESEARCH ORGANIZATION

As at 31st December 1975

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Secretary
B. A. Wright, AMBIM

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Student
W. Thompson

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*Mrs. G. Yong
*Mrs. S. Jacques

Student
D. McWilliams

*Part-time.

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Farm Manager: R. J. Dale

G. T. Baden | F. A. Penfold | C. G. Woodhams

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Leader: K. Holly, B.Sc., Ph.D.

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J. C. Caseley, B.Sc., Ph.D.
D. Coupland, B.Sc. Ph.D.
M. P. C. Loader, B.Sc.
C. R. Merritt, MI.Biol.
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R. Porteous
R. H. Webster
J. A. Slater

*Part-time.

EXTRA-DEPARTMENTAL SCIENCE GROUPS

AQUATIC WEEDS AND UNCROPPED LAND GROUP

Head: T. O. Robson, B.Sc.

Scientific Staff

P. R. F. Barrett, B.Sc. Miss M. C. Fowler

Assistant

S. Hanley

ODM TROPICAL WEEDS GROUP

Head: C. Parker, M.A.

Scientific Staff

P. J. Terry, B.Tech. (Home based post)

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Miss A. M. Hitchcock *Mrs. A. K. Wilson, B.Sc.

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B. O. Bartlett, M.A., Dip. Math. Stat. C. J. Marshall, B.Sc.

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Editor, 'Weed Abstracts': W. L. Millen, B.A., A.L.A.

Information Staff

*Mrs. H. R. Broad, B.Sc.
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Ms N. Kiley, B.Sc.
J. L. Mayall
*Mrs. M. Turton, M.A.

Librarian: Mrs. B. R. Burton, A.L.A.

Indexer: Miss C. R. Deans, B.Sc.

Experimental Records: Miss K. P. M. Hedges

Assistants

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ADMINISTRATION DEPARTMENT

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Accounts Officer: L. G. Young

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Miss B. E Watson
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W. R. Charlton
J. A. Drinkwater
R. Foddy
W. Macklin
D. Porter
A. Warwick

Building Maintenance Supervisor: A. W. H. Gardner

C. Day A. Worth

Vehicle Maintenance Supervisor: P. A. Savin

P. Wickson

Electronics Engineer: C. J. Stent, B.A.

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Agricultural Development and Advisory Service Liaison

M. G. O'Keeffe N.D.A., N.D.Agr.E. (Agriculture)
A. G. Jones, C.D.H. (Horticulture)

Agricultural Chemicals Approval Scheme Liaison

R. J. Makepeace, B.Sc.

SOIL SURVEY OF ENGLAND AND WALES

R. Webster, B.Sc., D.Phil.
J. Hazelden, B.A.
Mrs. M. Cox
M. Jarvis, B.A.

CHANGES IN RESEARCH, INFORMATION AND TECHNICAL STAFF

NEW APPOINTMENTS

J. H. Fearon	HSO	Information	4.2.74
A. W. H. Gardner	PTO 4 (*on internal promotion*)	Administration	1.4.74
E. Cotterill	SO (*on internal promotion*)	Chemistry	1.4.74
Miss M. C. Fowler	SO (*on internal promotion*)	Aquatic Weeds	1.4.74
C. R. Merritt	SO (*on internal promotion*)	Herbicide	1.4.74
Mrs. M. Turton	HSO*	Information	1.8.74
M. P. Greaves	SSO	Microbiology	1.10.74
R. Foddy	PTO 4 (*on internal promotion*)	Administration	1.10.74
M. E. Rush	SO	Information	12.12.74
S. R. Moss	SO	Annual Crops	3.2.75
P. A. Savin	PTO 4 (*on internal promotion*)	Administration	1.4.75
C. J. Stent	PTO 3	Administration	15.12.75

*Part-time.

RESIGNATIONS

Dr. G. W. Ivens	PSO	Overseas	31.1.74
Mrs. E. M. Young	HSO*	Information (*Deceased*)	25.3.74
C. E. McKone	SSO	Chemistry	31.5.74
Dr. E. Grossbard	PSO	Microbiology	31.7.74
A. Phillipson	SSO	Weed Control Department	31.7.74
Mrs. B. Ellis	SO*	Information	27.9.74
M. E. Rush	SO	Information	28.2.75
M. L. Dean	SO	Overseas	1.4.75
Dr. G. F. Kempson-Jones	SSO	Chemistry	12.9.75
A. G. Strickland	HSO	Annual Crops	5.12.75

STAFF VISITS OVERSEAS

Overseas visits have been undertaken by members of staff in the period covered by this report as follows:—

March 1974	J. D. Fryer	Netherlands on behalf of European Weed Research Council (EWRC).
April 1974	J. C. Caseley	Germany to evaluate controlled environment rooms.
April/May 1974	J. D. Fryer	Tanzania to assess joint ODM/EAC herbicide research project at Arusha, and Italy for visit to FAO.
June 1974	J. D. Fryer	Netherlands, on behalf of EWRC.
	R. J. Haggar	USSR, to attend international grassland congress.
July 1974	R. J. Hance	Finland, to attend 3rd international congress on pesticide chemistry.
September 1974	T. O. Robson	Austria, to attend EWRC.
	P. R. F. Barrett	Symposium on aquatic weeds, sponsored by Duphar-Midox.
September/ October 1974	N. C. B. Peters	Netherlands and Germany, to meet research workers concerned with weed biology.
January 1975	R. J. Hance	France, on behalf of EWRC to attend programme committee meeting.
February 1975	J. D. Fryer	USA and Canada, to give lectures at Purdue and Guelph Universities and attend meeting of Weed Science Society of America, sponsored by Universities of Purdue and Guelph.
	J. D. Fryer	France to attend third international meeting on selective weed control in beet crops and meeting of EWRC,, sponsored in part by EWRC.
April 1975	J. D. Fryer	Italy to attend FAO meeting of experts on pesticides in agriculture.
	M. P. Greaves	Germany to discuss current research work in herbicide microbiology.
April/May 1975	R. J. Chancellor	Italy to foster continuing collaboration with Institute of Agronomy, Bologna University, sponsored in part by Bologna University.
	C. Parker	Ghana and Nigeria to advise on weed control problems on behalf of ODM.
June 1975	J. D. Fryer R. J. Hance	France on behalf of European Weed Research Society (EWRS) to attend programme committee meeting, sponsored by EWRS.

*Part-time.

June 1975 (*contd*)	J. G. Elliott	Netherlands to study progress on various research projects.
	T. O. Robson R. J. Hance	Indonesia to attend workshop on herbicide research methodology and Indonesian Weed Science Society conference on behalf of ODM.
August 1975	K. Holly	Russia to attend 8th international congress of plant protection, sponsored by British Crop Protection Council.
August 1975	J. C. Caseley	Germany to carry out acceptance trials on controlled environment rooms.
September/ October 1975	J. D. Fryer	Holland, Indonesia, Japan and USA to visit BIOTROP, attend 5th Asian-Pacific weed science society conference and meeting of International Weed Science Society, sponsored in part by ODM and Japanese Government.
November 1975	P. J. W. Lutman	Holland to discuss current research on control of volunteer potatoes on behalf of Potato Marketing Board.
December 1975	J. D. Fryer J. Holroyd G. W. Cussans D. R. Tottman J. C. Caseley R. J. Chancellor N. C. B. Peters A. M. Blair R. J. Hance	France to attend EWRC/EWRS symposium on grass weeds in Europe.

STAFF COMMITTEE SERVICE

Members of WRO have served on the following committees:—

Association of Applied Biology

Association of Drainage Authorities technical sub-committee

ADAS/WRO liaison group

Agricultural Research Council
- ARC working group on direct drilling and reduced cultivation
- Controlled environment users' meeting
- Library working party
- Computer users group
- Fruit weed control group

British Crop Protection Council (BCPC)
- Council
- Conference organising committee
- Education and communications committee
- Finance and general purposes committee
- Annual review of herbage usage
- Pesticides application committee
- Programme committee (weeds)
- Programme policy committee
- Recommendations committee (weeds)
- Symposium on aquatic herbicides
- *Weed Control Handbook* committee

British Grassland Society
- Executive committee
- Journal committee
- Programme committee
- Publication committee
- Working group on sward deterioration

British Standards Institution technical committee PCC/1
CAIN Tapes Project advisory committee
Cotton Research Corporation scientific advisory committee
Department of the Environment advisory group on *Sargassum muticum*
European Weed Research Council
- Executive committee
- Research group on aquatic weeds
- Aquatic weeds symposium organising committee
- Annual grass weeds group

European Weed Research Society
- Steering committee
- Programme committee for symposium
- Executive committee

FAO committee of experts on pesticides in agriculture
Herbage seed (weed control) working party
International Weed Science Society steering committee
JCO Arable Grass and Forage Board
- Cereals committee
- Plant science committee

Maize Development Association R and D committee
Ministry of Agriculture, Fisheries and Food
- ADAS pesticides committee
- Agricultural Chemicals Approval Scheme science advisory committee
- National Advisory Campaign on Wild Oat
  - Steering committee
  - Executive group
  - Bucks, Berks and Oxon co-ordinating group
- Pesticides analysis advisory committee—compatability panel
- Pesticides analysis advisory committee—formulation panel

National Academy of Sciences committee on the effects of herbicides in South Vietnam
National Institute of Agricultural Botany Official Seed Testing Station committee
National Institute of Agricultural Engineering
- Soil cultivation study group

ODM sub-committee on pesticide application overseas
University of Reading plant sciences joint committee
Weed Research editorial board

CO-ORDINATING COMMITTEES FOR THE JOINT RESEARCH PROJECTS OF THE ARC LETCOMBE LABORATORY AND THE WEED RESEARCH ORGANIZATION

JOINT CEREALS TILLAGE PROJECT

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Secretary:	J. G. Elliott	(WRO)
Members:	R. A. Cannell	(Letcombe)
	F. B. Ellis	(Letcombe)
	J. D. Fryer	(WRO)
	J. Holroyd	(WRO)

JOINT HERBICIDE PROJECT

Chairman:	J. D. Fryer	(WRO)
Secretary:	E. R. Mercer	(Letcombe)
Members:	R. J. Hance	(WRO)
	K. Holly	(WRO)
	R. Scott Russell	(Letcombe)
	M. G. T. Shone	(Letcombe)

RESEARCH WORKERS VISITING WRO

Research workers and trainees to whom it has been a pleasure to offer facilities at WRO during 1974 or 1975 have included: Professor R. Ashford (from University of Saskatchewan, Canada, on 1 year sabbatical leave); Professor J. D. Bandeen (from University of Guelph, Canada, on sabbatical leave for 6 months); Mr. Segun Lagoke (from University of Ibadan, Nigeria for 5 months on a Ministry of Overseas Development scholarship, working on the control of *Imperata cylindrica*); Dr. S. Matsunaka (from National Institute of Agricultural Sciences, Konosu, Japan, on sabbatical leave for 6 months); Mr. I. Moreira (from Institute of Agronomy, Lisbon, Portugal for 2 months study and discussion on the biology of weeds); Dr. J. V. Parochetti (from University of Maryland, U.S.A. for 3 months of a sabbatical leave); Dr. A. B. Radecki (from Agricultural University of Warsaw, Poland for 10 months on a Massey-Ferguson scholarship to study techniques of minimum cultivation); Dr. K. V. Ramaiah (from International Crops Research Institute for the Semi-arid Tropics, India for 2 weeks to study techniques with *Striga*); Mr. S. Ronoprawiro (from Gadjah Mada University, Indonesia on a 12 month Colombo Plan scholarship working on the biology and control of *Panicum repens*); Mr. S. T. Selamat (from Hasamuddin University, Indonesia for 4 months working on *Salvinia* as part of his M.Sc. in the Technology of Crop Protection at Reading University); Mr. Ranbir Singh (from Indian Agricultural Research Institute, New Delhi for 5 weeks after completion of the Reading University Tropical Weed Control Course); Mr. K. Y. Tan (from Federal Land Development Authority of West Malaysia for 3 weeks to study approaches to weed control and analytical techniques for herbicides); Dr. C. G. Waywell (from University of Guelph, Canada, for about 6 months while on sabbatical leave).

GLOSSARY OF CHEMICALS MENTIONED IN THIS REPORT

An asterisk (*) signifies a common name approved by the British Standards Institution.

alachlor*	α-chloro-2,6-diethyl-*N*-(methoxymethyl) acetanalide
aminotriazole	3-amino-1,2,4-triazole
asulam*	methyl (4-aminobenzenesulphonyl) carbamate
benzoylprop-ethyl*	ethyl *N*-benzoyl-*N*-(3,4-dichlorophenyl)-2-aminopropionate
bromoxynil*	3,5-dibromo-4-hydroxybenzonitrile
chlorfenprop-methyl*	methyl 2-chloro-3-(4-chlorophenyl)propionate
chlorpropham*	isopropyl *N*-(3-chlorophenyl)carbamate
chlortoluron*	*N*′-(3-chloro-4-methylphenyl)-*N*,*N*-dimethylurea
cynanatryne*	4-(1-cyano-1-methylamino)-6-ethylamino-2-methylthio-1,3,5-triazine
dalapon*	2,2-dichloropropionic acid
dicamba*	3,6-dichloro-2-methoxybenzoic acid
dichlorprop*	(±)2-(2,4-dichlorophenoxy)propionic acid
difenzoquat*	1,2-dimethyl-3,5-diphenyl-pyrazolium
EPTC*	*S*-ethyl *N*,*N*-dipropyl(thiocarbamate)
ethofumesate*	2-ethoxy-2,3-dihydro-3,3-dimethylbenzofuran-5-yl methyl-sulfamate
flamprop-isopropyl*	isopropyl(±)-2-(*N*-benzoyl-3-chloro-4-fluoroanalino)propionate
glyphosate*	*N*-(phosophonomethyl)glycine
ioxynil*	4-hydroxy-3,5-di-iodobenzonitrile
isoproturon	*N*-(4-isopropylphenyl)-*N*′,*N*′-dimethylurea
lenacil*	3-cyclohexyl-6,7-dihydro-1*H*-cyclopentapyrimidine-2,4-(3*H*,5*H*)dione
linuron*	*N*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea
MCPA*	4-chloro-2-methylphenoxyacetic acid
mecroprop*	(±)2-(4-chloro-2-methylphenoxy)propionic acid
methabenzthiazuron*	*N*-(benzothiazol-2-yl)-*N*,*N*′-dimethylurea
metoxuron*	*N*-(3-chloro-4-methoxyphenyl)-*N*,*N*-dimethylurea
metribuzin*	4-amino-6-t-butyl-3-(methylthio)-1,2,4-triazin-5(4*H*)-one
perfluidone*	4′-(phenylsulphonyl)trifluoromethylsulphono-*o*-toluidide
propyzamide*	3,5-dichloro-*N*-(1,1-dimethylpropanil)benzamide
simazine*	2-chloro-4,6-bisethylamino-1,3,5-triazine
terbutryne*	4-ethylamino-2-methylthio-6-t-butylamino-1,3,5-triazine
trifluralin*	2,6-dinitro-*N*,*N*-dipropyl-4-trifluoromethylaniline

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