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AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANIZATION

SIXTH
REPORT
1974–1975

PRICE £1.00

SIXTH REPORT 1974–1975

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SOME FACTS ABOUT WRO

WRO is one of eight institutes belonging to and directly controlled by the Agricultural Research Council. It was set up in 1960 to serve as a national centre for applied research and information on weeds and weed control, with particular emphasis on herbicides. Its principal aim is to serve British agriculture but from its inception it has played an active role in tropical agriculture in co-operation with the Ministry of Overseas Development (ODM). Its information role is international and is assisted by the Commonwealth Agricultural Bureaux (CAB). For 1974–75 ODA and CAB together provided about 12% of the institute's funds.

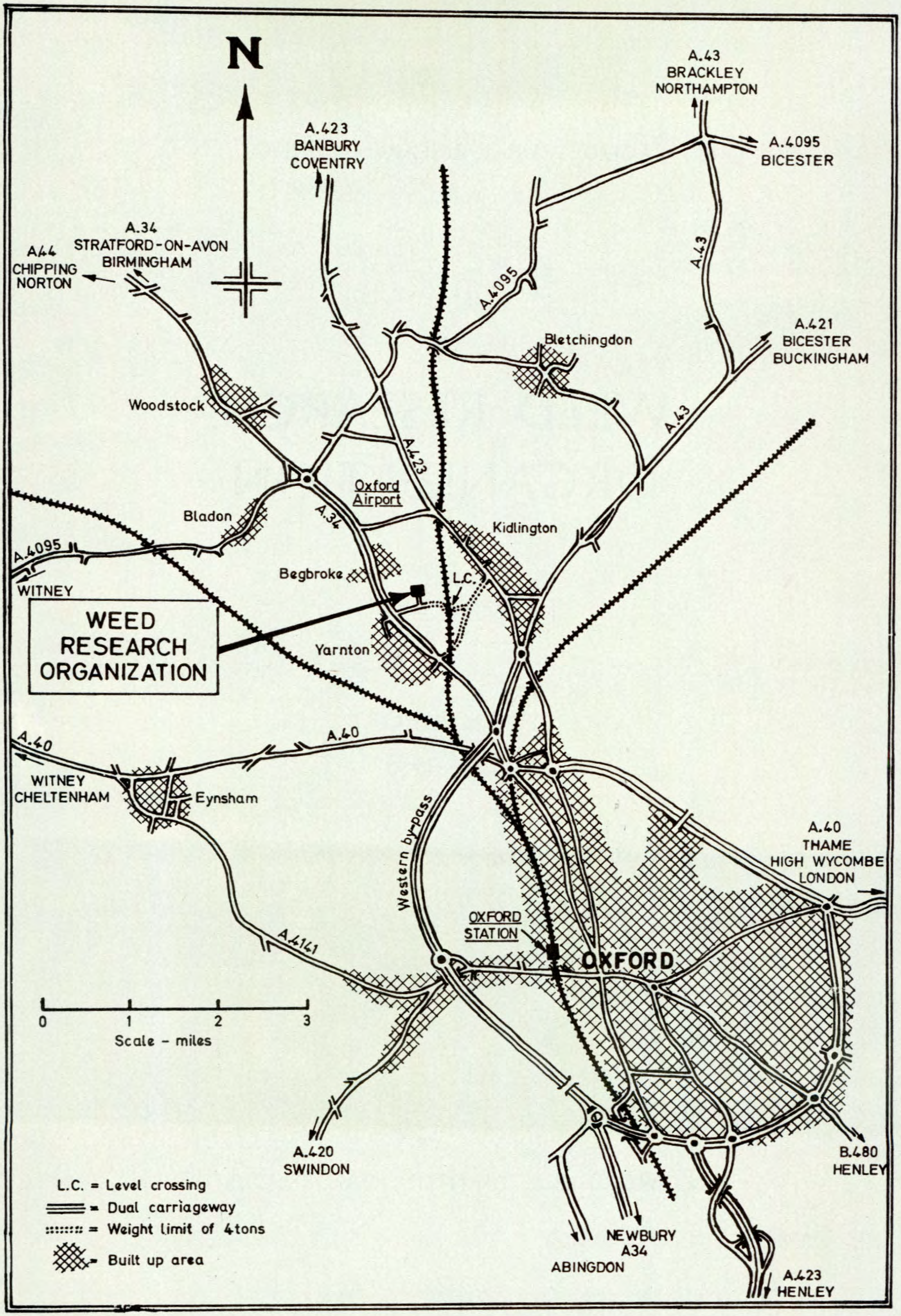
ERRATUM

Page 70. Figures 2 and 3 are transposed. The legend of Figure 2 refers to the lower histogram; that of Figure 3 to be the upper one.

ABBREVIATED TITLE

The abbreviated title of this report as given in the *World List of Scientific Periodicals New Periodicals Titles (1960–68)* is:

Rep. Weed Res. Org. 1974–75(1976)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WITNEY
Begbroke
L.C.
WEED
RESEARCH
ORGANIZATION
Yarnton
A.40
A.40
WITNEY
CHELTENHAM
Eynsham
Western by-pass
A.40
THAME
HIGH WYCOMBE
LONDON
OXFORD
STATION
OXFORD
A.4141
0
1
2
3
Scale - miles
A.420
SWINDON
B.480
HENLEY
L.C. = Level crossing
= Dual carriageway
= Weight limit of 4tons
= Built up area
NEWBURY
A34
ABINGDON
A.423
HENLEY

Contents

This 5-row tool frame assembly of components has been used to develop the WRO technique of one-pass re-seeding of old pasture. Each unit simultaneously applies a narrow band of growth-suppressing herbicide, removes a strip of turf down the centre of the band leaving a slot 2–3 cm wide and deep, into which is sown seed, fertilizer and slug pellets. (See article on p. 68).

DIRECTOR'S INTRODUCTION

This report covers the period 1 January 1974 to 31 December 1975. Its purpose is to convey an impression of the contribution made by the Weed Research Organization (WRO) during the two years to weed science and to British and overseas agriculture. Topical facts about the institute are also included. The information provided is necessarily condensed and selective. Readers wishing for more detail are invited to contact the Information Department. Visitors to Begbroke are always welcome by appointment.

The energy crisis and the research programme

The energy crisis during the 1973–74 winter coincided with a world shortage of certain commodities used in the manufacture of herbicides. The result was a shortage of some products and price increases affecting all. Awareness by farmers of their dependence on chemical methods of weed control and of the escalating size of their spray bills was heightened and it became apparent that WRO ought to strengthen its endeavours to find more economical and efficient ways of using herbicides. Some success to this effect has been obtained through two different but complementary approaches.

The first aims to determine the main factors which influence the performance of individual herbicides in the field and to devise ways to improve their efficiency. A major boost to this part of the programme has been given by the construction of a new controlled environment laboratory which includes three large walk-in growth rooms. (p. 44) The laboratory will be commissioned during 1976 and will be of great help in providing information to advise herbicide users and manufacturers how to obtain the optimum performance of herbicides under different weather conditions.

Herbicide performance can also be much influenced by the method of application. There would be many advantages to the user if the large volume of water now used for spraying could be reduced from the present level of about 200 l/ha to say 10–20 l/ha (1–2 gal/ac). The WRO programme on controlled droplet application (CDA) of herbicides at very low volumes by special spinning disc systems has made encouraging progress and is described in detail on p. 75.

A further potentially useful development which interlinks with those already mentioned has been the striking enhancement of activity of several herbicides by the use of cheap additives such as ammonium sulphate or other formulation changes (p. 83). Such work is not without its hazards in that inadvertently enthusiastic reporting in the farming press has led to an understandable but premature interest by some farmers anxious to cut costs of expensive herbicides as soon as possible. It is not always realised that it takes considerable time and effort to build up sufficient experience before new herbicide technology can be recommended with confidence for practical use. The manufacturers interests and responsibility have also to be considered. Too early and incautious uptake by farmers or contractors may lead to disappointing results and/or crop damage with resultant disappointment and financial loss, possible infringement of the Pesticide Safety Precautions Scheme and embarrassment to manufacturers. Herbicide suppliers cannot be expected to accept responsibility unless the treatment features as a label recommendation.

Research by WRO aimed at the development of long-term systems of integrated weed control practices based on a detailed analysis of the weed problem involved provides the second approach to greater economy in the use of herbicides. An early example was the development by WRO of successful programmes for the control of couch grass in intensive cereal systems with only minimal or without use of herbicides (see 3rd and 4th WRO Reports). More recently a tremendous effort has been made and continues to be made to study the wild oat problem in great depth with the object of predicting the response of field or whole-farm populations to managerial options available to the farmer. Much progress has been made in developing a factual basis for advice to farmers how to plan and carry out long-term programmes of wild oat control at minimum cost and with maximum flexibility in cropping practices (p. 47). A rational long-term approach to weed control based on a detailed knowledge of the response of the weed to agronomic practices and to climatic and soil conditions not only makes good sense but can lead to major economies in the use of herbicides.

Wild oat research

Wild oats feature in many places in this report, a reflection not only of their importance but also of the major involvement by WRO. This spans a wide range of activities which together make up a co-ordinated programme to which most of the research groups contribute. The following list gives some idea of the scope of the programme: preparation of a book reviewing the extensive world scientific literature on wild oats (p. 41); basic studies on the biology of wild oat plants and seeds (p. 10) and of wild oat herbicides (p. 7); practical research on herbicide application techniques and herbicide mixtures and formulations (pp. 7 and 8); the study of wild oat population dynamics and the development of long-term systems of control (p. 47); field studies of the response of wild oats to farm practices (p. 56); active participation in the National Wild Oat Advisory Programme (p. 37). Much of this programme has been undertaken in collaboration or consultation with the Agricultural Development and Advisory Service, (ADAS) and the manufacturers of wild oat herbicides.

Early in 1974 the introduction of more stringent seed purity standards, when the UK joined EEC, posed a serious threat to British producers of rye-grass seed on account of widespread contamination by wild oats and lack of suitable control measures. After representation to the Agricultural Research Council (ARC) by the National Farmers Union (NFU) and the seed growers associations the problem was judged sufficiently acute for WRO to mount a crash programme to investigate in collaboration with ADAS and the National Institute of Agricultural Botany (NIAB) the potential value of herbicides (p. 21). From one point of view this was a disturbing development in that other research on grassland weeds had to be brought to an immediate halt but was salutary as an example of the versatility and willingness of WRO to assist the industry at short notice, without additional funds and at considerable disturbance to the research staff and their programme.

Herbicides in grassland

Another project which has attracted much attention has resulted in the development of a technique for the economical introduction of improved grass species or clover into unproductive swards by direct sowing with an experimental machine built at Begbroke called the one-pass-seeder—(p. 68). The technique is of particular interest at the present time because of the high cost of conventional reseeding. When combined with use of novel selective herbicides it is thought to offer much scope for better sward management.

Diversion of research effort

At WRO, as at other institutes, the past two years have been marked by a rapid escalation of administrative work caused by increasing central control, greater professionalism in the management of staff and research and in the democratic consequences of trade union activity. Admirable as most of these developments are in themselves, when taken together they inevitably involve much time of the senior scientific staff so that the resulting adverse influence on the output and quality of research must be a cause for concern. The problem has been exaggerated during this particular period by intense activity on the part of the Joint Consultative Organization (JCO) sponsored by ARC, MAFF, and the Department of Agriculture and Forestry, Scotland (DAFS), to advise on requirements for research and development in agriculture and food. Many papers covering a wide range of weed control topics have been prepared by senior members of WRO at the request of JCO Committees or Working Parties. The burden imposed by this work has detracted from research. The reaction of the staff involved has been that the exercise has been of interest and value in bringing people, information and viewpoints together but should now be scaled down. Fortunately, the close contacts WRO has built up over the years with ADAS, the industry and other research workers in the field of weed and crop science has made the job of undertaking the required reviews relatively painless and no major new requirements for research unknown previously to WRO have come to light.

The extent to which the WRO research programme has been adopted by the Ministry of Agriculture, Fisheries and Food (MAFF) in its commissioning of research undertaken by ARC is note-worthy. Of the 41 officially listed research (as distinct from service) projects comprising the WRO programme, no less than 36 (88%) have been included in commissions and are therefore now sponsored by MAFF. They represent 65% of the total cost of WRO research.

Liaison activities

Since weed research is not an end in itself but a means to more efficient crop production, it is essential that WRO maintains effective liaison with research workers in other institutes, in universities, agricultural colleges, the advisory services and the diverse branches of the agricultural industry. Such liaison often proves mutually beneficial and the advantages of having in WRO a focal point for all who are interested in weeds and weed control are often commented on favourably. Some information about WRO liaison activities will be found on p. 35. Attention is drawn particularly to the long-standing co-operation between WRO and ADAS which aids both the integration of ARC and ADAS work on weed control and liaison with manufacturers and distributors of agrochemicals.

Inauguration of Advisory Group

One of the most welcome events of an eventful period has been the appointment by the Agricultural Research Council (ARC) of a Science Advisory Group to advise the Director on the institute's programme. This development, which is common to all eight ARC institutes, should prove most helpful. The scope of research undertaken by WRO is exceptionally wide for a small institute, ranging from scientific investigations on aspects of plant growth and the mode of action and ecological consequences of herbicides to field research on cropping systems and tillage practices. Virtually all weeds and crops grown in Britain have to be considered. It is impossible for the relatively small number of research staff at WRO to be specialists in all the many scientific disciplines involved or in all the intricacies of the agricultural industry. The new Advisory Group will greatly enlarge and strengthen the expertise available to the institute and will open up new links with other research groups which it is hoped will be mutually beneficial.

The Advisory Group to WRO consists of the following members who all serve in a voluntary capacity:

Professor A H Bunting	Reading University (Chairman)
Professor J T Braunholtz	ICI Plant Protection Division
Professor R N Curnow	Reading University
Professor R W Edwards	University of Wales Institute of Science and Technology, Cardiff
Professor J P Hudson	
Mr J G Jenkins	Farmer
Professor F T Last	Institute of Terrestrial Ecology, Midlothian
Mr J J North	Agricultural Development and Advisory Service
Professor W D P Stewart	University of Dundee

Acknowledgements

I should like to take this opportunity to record my appreciation of the help, advice and generous support given over many years to WRO and myself by members of ARC Headquarters and by the Council. It is also a pleasure to acknowledge the help of many colleagues who have contributed to this report, particularly John Hardcastle who has had the

major task of compiling and editing it. I continue to be impressed by and deeply grateful for the loyalty and dedication shown by WRO staff in pursuing the objectives of the institute.

J D FRYER
Director

PROGRESS REPORT

REVIEW OF RESEARCH

WILD OATS IN CEREALS

The inter-relationship of the many factors which contribute to the effective control of wild oat in cereals has become more clearly defined in recent years and, as indicated in the article on p. 47, it is now possible to visualise various packages of control measures which would, in 3–4 years, reduce any farmer's wild oat problem to manageable proportions. Nevertheless, just as the National Wild Oat Advisory Programme (p. 37) must continue to persuade all farmers of the seriousness of the weed and the need to achieve the most effective control possible in a variety of situations, so must research continue on the various facets of the problem. During the past two years, high priority has continued to be given to wild oat research by WRO and some recent advances in our knowledge are described here and in the two articles appearing on pp. 47 and 57.

Wild oat herbicides in 'tank-mixes'

One problem of recent years has been the antagonism which can occur between wild oat herbicides and those used to control broad-leaved weeds. This can seriously reduce the degree of wild oat control achieved. In particular the effectiveness of the new wild oat herbicide, difenzoquat, is very much reduced if applied in a 'tank mix' with herbicides like mecoprop and dicamba. However, over the last three years, the results of a programme undertaken in liaison with the manufacturers have shown that the antagonism is very much less if esters rather than salt or amine formulations of the broad-leaved weed herbicides are used.

New wild oat herbicides

A new compound, 4-(2′, 4′-dichlorphenoxy)-α-phenoxypropionic acid methyl ester, which controls wild oat and to a lesser extent blackgrass in winter and spring cereals, became available for research during the period under review. Experiments in 1975 indicated that, although very effective when applied in the early months of the year, it was less active against tillered wild oats later in the season. Its effectiveness was also reduced by 'tank mixing' with salts of dichlorprop or mecroprop. However, a mixture with bromoxynil, ioxynil and dichlorprop effectively controlled both wild oats and broad-leaved weeds. Work on this aspect is continuing along with studies of other promising new wild oat herbicides, such as flamprop-methyl.

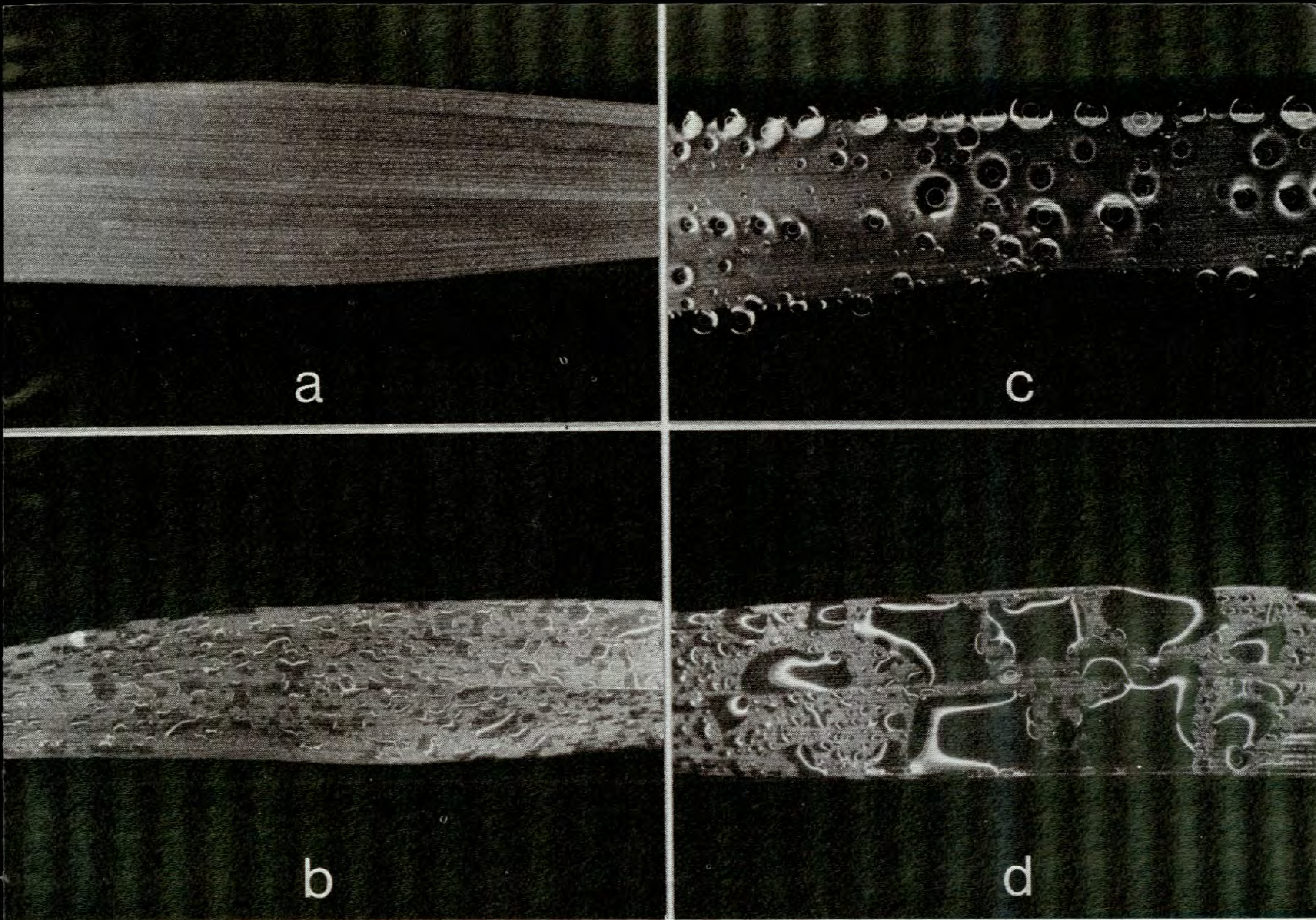
Effect of rain and dew on wild oat herbicides

Part of the project on the effect of environmental factors on herbicide performance is concerned with rain and dew.

In pot experiments the foliage of wild oat plants was wetted with simulated rain applied with a laboratory pot sprayer either before or after herbicide application. The amount of herbicide retained on the plant was estimated by adding dye to the spray solution. Other application factors such as volume and formulation remained the same. After the spray deposit had dried the leaves were harvested and the dye washed off and determined spectrophotometrically.

Wetting the foliage before herbicide application may have no adverse effect. An aqueous solution of difenzoquat incorporating 0.5% surfactant and an emulsified formulation of benzoylprop-ethyl, with and without dye, were applied at 200 l/ha to dry and to wet wild oat plants. Neither the amount of dye retained nor the control of the wild oats with these herbicides was affected by the presence of water on the foliage. These results indicate that possibly the common farming practice of avoiding spraying herbicides when foliage is wet is too cautious. However, it should be borne in mind that retention of the spray depends on features of the plant such as form and leaf surface characteristics and spray factors including volume, drop size and concentration of surfactant and, in the case of wet plants, the amount of water on the foliage. Consequently other species/herbicide situations require careful evaluation. Also in the field, water deposited as dew could exceed that obtained in the laboratory and subsequent spraying could lead to run-off. Application to wet foliage is most likely to succeed at low and very low volumes, and achievement of the latter by controlled drop application might possibly increase the number of days suitable for spraying.

Simulated light rain after difenzoquat application removed herbicide without reducing control. Subjecting treated plants to simulated rainfall of 0.5, 1.0 and 2.0 mm/h immediately after herbicide application indicated that over 50% of the herbicide may be removed from the leaves without reducing the phytotoxicity of the herbicide. The rain, although washing off some of the herbicide, redistributed the rest over the leaf surface. Dye recovered from plants cut into sections, showed that most was lost from the middle and tip of the leaf and least from the base/ligule



The effect of the presence of water on a wild oat leaf on the retention of sprayed herbicide: (a) a dry leaf; (b) a dry leaf sprayed with dye solution; (c) a wet leaf; (d) a wet leaf sprayed with dye solution.
The amount of dye retained was the same in both (b) and (d).

area where in some instances the quantity of dye exceeded that on dry plants.

Subsequent experiments in which single drops of herbicide were applied indicate that the magnitude of the herbicide effect can differ with the position of the drop on the target plant. The most sensitive area is that of the ligule and leaf base of the last fully expanded leaf. Re-distribution of herbicide from the point of impact to these more sensitive positions may explain why applications to wet foliage, or a light rainfall or dew following spraying, gives better results. Loss of performance could result if the rainfall is sufficiently heavy to remove the herbicide from the area of the leaf base and ligule.

Dormancy of wild oat seed

The ability of wild oat seed, once returned to the soil, to remain dormant and viable for a number of years contributes greatly to the success of this weed. It is important, therefore, to find out the effect of natural environmental factors upon dormancy and viability. One of the factors investigated has been water stress during the period from the emergence of the panicles from the flag leaf sheath until seed harvest. In a preliminary experiment the germination percentage of seed produced under dry conditions was 11% greater than that of seed produced when soil moisture was not limiting. Another factor investigated was temperature. Plants were grown at either a constant 15°C or 20°C during the period of flowering and seed setting. The germination percentage of seeds produced at 20°C was 39% higher than that of seeds produced at 15°C. These results suggest that hot dry summers like 1975 may substantially reduce the dormancy of wild oat seed returned to the soil. Further research is in progress.

Because germinating seeds are vulnerable to control measures it would obviously be advantageous if the onset of dormancy in wild oat seeds could be prevented or diminished before the seeds were shed. Reports from elsewhere suggested that certain herbicides, if they did not kill wild oat plants completely, did at least reduce the dormancy of seeds that were returned to the soil. The effect of applying sub-lethal levels of herbicides to parent wild oat plants has therefore been investigated.

A preliminary test showed that benzoylprop-ethyl at 0.38 kg/ha applied at the 5–6 leaf stage of wild oats reduced dormancy in the seeds by 12%. During 1974 benzoylprop-ethyl was applied to wild oat plants at 0.2, 0.4 and 0.6 kg/ha, either when the first node was visible or when the panicles were just emerging from the flag leaf sheath. The seed was collected when ripe and stored dry for 4 months, when dormancy and viability were tested. At the 1-node stage no treatment had any effect on seed dormancy although viability was somewhat reduced but, at the later stage, there was a reduction of both viability and dormancy. Seeds from the main stems of untreated plants gave only 8% germination while comparable seed from plants treated with 0.6 kg/ha benzoylprop-ethyl gave 34% germination; from tillers, the comparable figures were 9 and 43%. The main conclusion is that the reduction in dormancy of wild oat seeds produced by survivors of an application of benzoylprop-ethyl could be a useful bonus to the farmer.

Other factors influencing dormancy of wild oat seeds and the emergence of seedlings that have been investigated were position of the seed in the placeholder

placeholder

Early competition from broad-leaved weeds

Previous work with winter wheat has shown that controlling wild oats and blackgrass during the winter months is likely to give higher yields than delaying control until the late spring, particularly where the infestation is dense. In three further experiments with this crop, the wild oats were accompanied by overwintering broad-leaved weeds. Chlortoluron or isoproturon applied in early January controlled both the wild oats and most of the species of broad-leaved weeds present and raised yields by amounts ranging from 4–5½ quintals/ha above the level achieved when only the wild oats were controlled by the use of barban. All the plots were sprayed in April for routine broad-leaved weed control, so the additional yield clearly resulted from the removal of competition from broad-leaved weeds between January and April.

These results emphasise the importance of autumn or winter spraying of broad-leaved weeds in winter cereals, particularly where large numbers of seedlings emerge with the crop. Further experiments are currently in progress to investigate the early competition from broad-leaved weeds, wild oats and blackgrass, using various combinations of herbicides for specific weeds.

REDUCED CULTIVATIONS FOR CEREALS

Change in status of weed species

The third of a series of annual progress reports on the WRO/Letcombe Joint Tillage Project, published alternately in the reports of the two institutes, appears on p. 62. In addition to the joint project, WRO has a number of other activities which contribute to the progress of this important subject.

WRO has recently increased its studies of weed performance and weed control in the absence of cultivation, and has also been increasingly called on to assist other organisations in controlling the weeds in their experiments on the growth of cereals by reduced cultivation. In consequence of these activities there is an accumulation of knowledge of weed reaction to cultivation based on detailed assessments and observations. The experiences have been consolidated in Table 1. The likely change in importance of a number of species as a result of a change from conventional plough-based systems is indicated thus: + indicates an increase in importance; − a decrease; = negligible change.

It should be stressed that many of these weeds are favoured by cereal monoculture regardless of cultivation regime so that the changes indicated

Table 1. Effect of different tillage systems on the status of individual weeds

	Mainly spring sowing		Mainly autumn sowing	
	Tine cult. systems	Direct drilling	Tine cult. systems	Direct drilling
Rhizomatous (couch) grasses	—	+	=	+ +
Arrhenatherum elatius	=	+ +	+	+ +
Convolvulus arvensis	=	+	=	+
Cirsium arvense	=	+	=	+
Alopecurus myosuroides	—	—	+	+
Avena fatua	+ +	—	+	+
Avena ludoviciana	—	—	+	+
Poa species	=	+	+	+ +
Stellaria media	=	=	=	+
Matricaria & *Tripleurospermum* species	=	=	=	+
Most annual broadleaved weeds	—	—	—	— —

are likely, in the short term, to be changes of degree only. Even a (— —) rating may not indicate any financial saving to the farmer as the population may still need to be treated, even though reduced in numbers. Conversely a rating of (+) or (+ +) does not indicate that ploughing is satisfactory (as a couch control measure for instance), merely that direct drilling is likely to exacerbate an existing problem.

Decomposition of straw

The direct drilling of cereals is associated at present with the burning of straw to leave a clean surface, a practice which may give rise to fire hazard and aerial pollution. WRO has been studying the natural breakdown of straw in the absence of incorporation into the soil by cultivation. The experience of the winter of 1974/75 was that substantial breakdown occurred such as to leave less than 20% of the original dry matter present at the time of sowing spring barley, and thus there was little obstacle to establishment of the crop. However, the situation in the previous autumn when wheat was sown showed that little breakdown had occurred since cereal harvest and, therefore, that successful direct drilling without burning will depend on an improved understanding of the relationship between straw present and successful cereal establishment.

Recent laboratory work has also shown that paraquat applied to straw, at a rate equivalent to that used in the field, markedly reduced the decomposition of straw when buried in the soil. This treatment also appeared to promote a different population of micro-organisms to that which develops during the decay of untreated straw. Spraying paraquat on to soil before burying untreated straw did not affect its degradation. Treatment of straw with ammonium nitrate at a rate equivalent to 12 kg/ha largely overcame the effect of paraquat and the straw then decomposed at a near-normal rate. Spraying glyphosate directly on the straw or on to soil prior to burying straw, had no effect on its decomposition.

Minimum tillage case studies

As part of its contribution to the ARC/ADAS meeting on reduced cultivation and direct drilling in January 1975, WRO undertook case studies on 70 cereal farms covering 21,705 ha. In addition to providing much background information about land, manpower, machinery etc. the replies showed that the farmers were active in changing their systems in pursuit of economy of cultivation. More than half of the fields recorded as in cereals in autumn 1973 were prepared without ploughing; the traditional approach was, however, more common on land prepared for spring cereals. Grass and other weeds topped the list of subjects regarded by the farmers as the most important cultural problems requiring research.

POTATOES

Controlling ground-keeper potatoes with herbicides

It is difficult to kill ground-keeper potato plants with post-emergence herbicides because of their vigour and the size of their food reserve. Research at WRO, supported by the Potato Marketing Board, has shown that most of the herbicides in common use are ineffective, but two chemicals, glyphosate and aminotriazole, will kill potato plants provided that they have sufficient foliage to ensure adequate uptake. In addition, these two herbicides will either kill, or prevent from sprouting, any daughter tubers present at the time of spraying.

The main drawbacks to the commercial use of glyphosate and aminotriazole are their lack of selectivity and the long period over which potato plants emerge, which makes the timing of treatments very difficult. Thus to ensure good control, farm applications would have to be deferred until late May. Crops could be planted soon after treatment with glyphosate but, because of the residual activity of aminotriazole, planting would have to be further delayed for some weeks. A more practical use for either of these herbicides would be in cereal stubbles in the autumn. After the cereal harvest, many volunteer potato plants regrow and provide a suitable target for herbicide treatment. Experiments now in progress will determine the practicability of stubble treatments with glyphosate and aminotriazole for the control of groundkeepers.

Incorporation of metribuzin into potato seedbeds in organic soils

For the last two years the WRO Fenland Team, in collaboration with the staff of the Arthur Rickwood Experimental Husbandry Farm, has investigated the performance of metribuzin incorporated into a potato seedbed. Incorporation of metribuzin into organic soils has a number of advantages over conventional surface application, including the longer period of residual activity which aids the control of late germinating weeds such as fat hen (*Chenopodium album*). Another is the reduction of herbicide loss from the top of the ridge. This is especially important for varieties like Maris Piper, the foliage of which falls over and exposes the top of the ridge. Furthermore, because metribuzin is recommended only to be used pre-emergence with Maris Piper, no advantage can be taken of this herbicide's foliar activity. The extended residual activity following incorporation is thus of particular benefit to this variety. Finally, when metribuzin is incorporated, there appears to be less possibility of damage to subsequent crops, perhaps due to the greater dilution of the herbicide in the soil.

The work in the last two season has concentrated on Maris Piper because it is an important variety in the fens of East Anglia. The tuber yields obtained with incorporated applications of metribuzin were comparable with those after pre-emergence applications, and from 'weed-free' controls maintained with paraquat and hand-weeding. The final stage of this work will be a number of farm-user trials in 1976.

WEED CONTROL IN GRASS AND FODDER CROPS

The present programme can be broadly divided into work on the biology and control of individual problem weeds and work on novel methods of sward maintenance and improvement based on herbicides. One example of each category is given here and a full account of WRO research on a new, cheap and rapid technique for renovating old pasture is given in the article on p. 68.

Weed control achieved in a crop of Maris Piper potatoes with a pre-emergence, incorporated application of metribuzin. The control plot on the left was untreated.

Dalapon, ryegrass persistence and cattle performance

A field experiment to determine the effect of applying low doses of dalapon on the ryegrass content of a deteriorating ley was concluded in 1974. Plots which had been treated with 2.8 kg/ha dalapon in alternate years over a 4-year period retained their initial 50% content of ryegrass whereas, on the unsprayed plots, the ryegrass content fell as low as 20%. Improved animal performance from beef cattle was recorded from the dalapon-treated plots, mainly in the spring of the year following treatment. Without the herbicide, ryegrass decline could only be arrested by using a high stocking rate which led to a poor individual animal performance.

Productivity of indigenous sward grasses

Although the high productivity of individual strains of perennial ryegrass is well documented, there is a lack of comparable data on the productivity of some of the commonly occurring indigenous grasses which often form components of old ryegrass swards. The seasonal variation in productivity of pure stands of Yorkshire fog (*Holcus lanatus*) creeping bent (*Agrostis stolonifera*), red fescue (*Festuca rubra*), rough meadow-grass (*Poa trivialis*) and ryegrass (cv. S23) was measured during the first year of a recently concluded 3-year study.

Under conditions of high fertility (400 kg nitrogen/ha annually and frequent irrigation) the daily production of dry matter by rough meadow-grass followed the familiar two-peaked pattern of perennial ryegrass, albeit at a lower level after flowering. By comparison, red fescue and creeping bent grew more uniformly throughout the year; Yorkshire fog, like red fescue, reached its productivity peak after mid-summer. Cut monthly, all four indigenous grasses had a higher mean nitrogen content than perennial ryegrass and, with the exception of red fescue, digestibilities were also comparable.

During the second year, when the amounts of nitrogen and water applied were lower, Yorkshire fog and red fescue produced the greatest amount of spring growth but the high digestibility of perennial ryegrass meant that its harvesting could be delayed to obtain the most forage of a given D-value. Creeping bent produced the greatest re-growth after the grasses were cut in early August and red fescue produced most after cutting in September.

The dry-matter response to nitrogen, applied at either 60 or 180 kg/ha in three split applications, was recorded in the final year. After the first nitrogen application, indigenous grasses, with the exception of creeping bent, responded well especially after flowering. Though the response of perennial ryegrass was consistently high (at least 20 kg DM/kg N) throughout the summer, it yielded least of all the grasses at the low nitrogen level. It is concluded that, whereas perennial ryegrass performs well at high levels of nitrogen and moisture, the other indigenous species have advantages, especially during mid-season, when these factors are limiting.

In another experiment, dry matter production from pure stands of S 23 perennial ryegrass, red fescue, Yorkshire fog and creeping bent, plus that from different percentage combinations of each of the indigenous species with perennial ryegrass, was recorded from grazed plots over a 2-year period. The results showed that the performance of the mixtures was generally as good as that of the pure stand of perennial ryegrass and there was little evidence of any short-term decline in dry matter yield as the proportion of indigenous grasses increased. This confirms previous work with mixtures of perennial ryegrass and rough meadow-grass.

Wild oat control in herbage seed crops

As a result of the introduction of the more stringent EEC maximum permitted levels of wild oat contamination in herbage seeds, a crash programme was started in 1974 in conjunction with NIAB and ADAS to determine the tolerance of the available wild oat herbicides exhibited by common species and cultivars of herbage seed crops. This complemented the parallel ADAS investigation into the efficiency of these herbicides for controlling wild oats.

After two years' work, difenzoquat and ethofumesate have emerged as being the most promising. Difenzoquat sprayed at rates below 3 kg a.i./ha has not damaged ryegrass, meadow fescue or cocksfoot varieties. Ethofumesate has only checked meadow fescue and cocksfoot slightly at 5 kg a.i./ha, three times the normal rate. Both herbicides effectively control wild oats.

Of the other herbicides tested, benzoylprop-ethyl, chlorfenprop-methyl and flamprop-isopropyl have also been safely applied to ryegrass and meadow fescue cultivars. Timothy and cocksfoot are less tolerant.

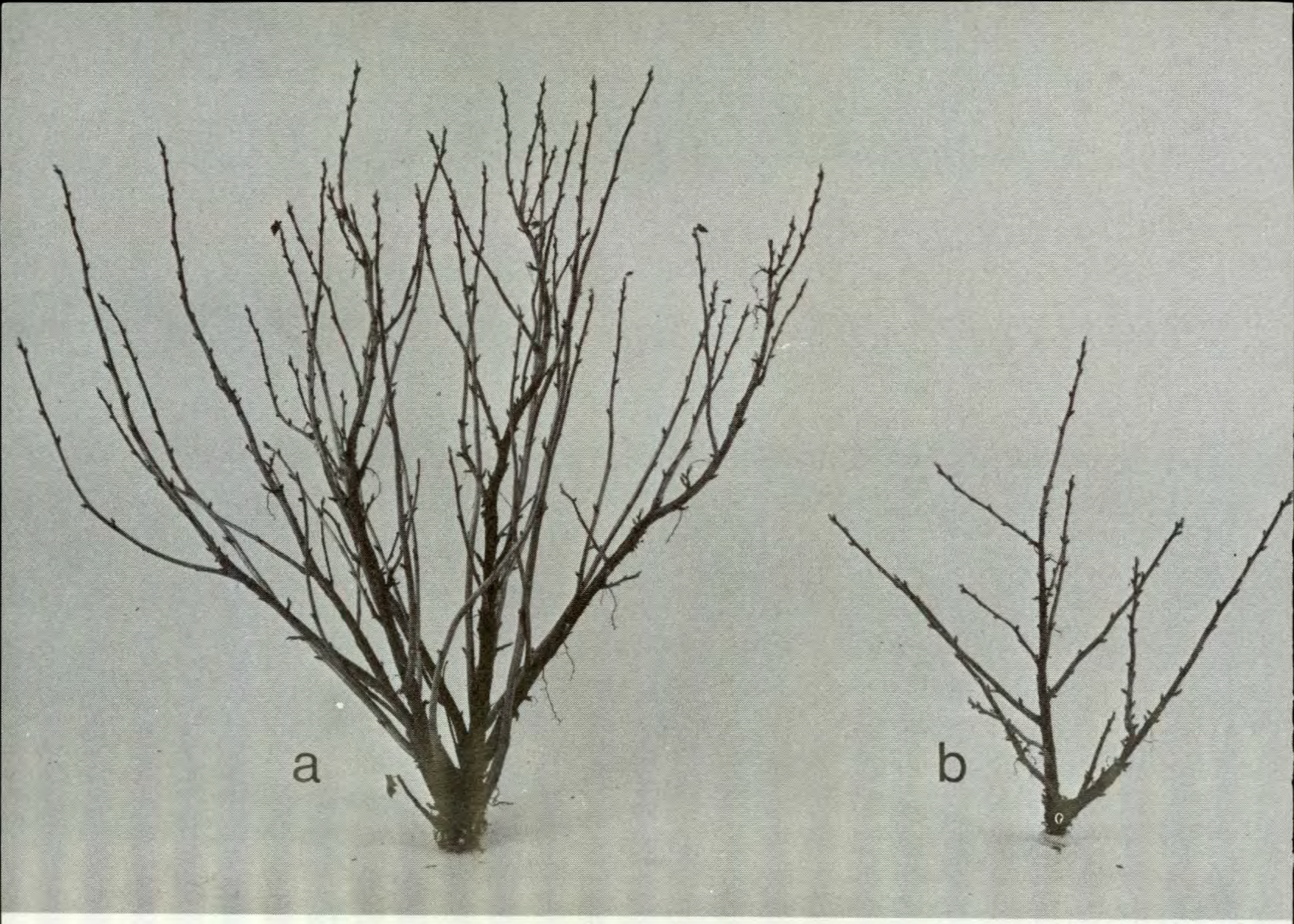
These results require proving over a wider range of field situations before firm recommendations can be made.

WEEDS IN PERENNIAL CROPS

Most of the annual and many of the perennial weeds of fruit and ornamental crops can be controlled by use of herbicides. New problems arise when species that are not adequately controlled increase in number or when herbicides previously thought reliable cause damage in crops. Thus, the work on controlling bindweed reported in detail in the Fifth Report has continued as has that on methods of determining the crop tolerance of soil-acting herbicides. More recently work has begun on the effects that annual weeds have on crop establishment and special attention has also been given to herbicides for strawberries.

Weed competition in young apples and blackcurrants

Herbicides are widely used in newly planted fruit crops even though many of the treatments are not recommended by the agrochemical industry. Growers are prepared to accept the risk of crop damage for the



The effect of weed competition on growth of two-year-old blackcurrant bushes. Bush A was kept weed free for two years; bush B was subject to weed competition in the first year but kept weed free in the second year.

benefit of removing weed competition. But in most cases the grower does not know the relative importance of weeds at different times of the year and therefore what standard of weed control needs to be achieved to obtain optimal growth of the crop.

At Begbroke the presence of annual weeds in the year of planting can reduce the extension growth of apples and blackcurrants by up to 60%. Weeds germinating early in the season and not removed until June or July were more damaging than weeds germinating later in the season and allowed to remain. Crops checked in the first season also produced less extension growth in the second season, even though they were then weed free. The effect was not confined to vegetative growth. Reduced growth of apples in 1974, the year of planting, was followed by a reduction in fruit bud development in 1975. This could result in a reduction in fruit yield in 1976. In blackcurrants, the reduction in yield in 1975 was proportionally greater than the reduction in extension growth in 1974.

Many questions remain unanswered but the results obtained so far indicate clearly the benefit of controlling annual weeds at the beginning of the season. Nevertheless, it is important that the benefit from removing weed competition is not offset by herbicide damage. A safe soil-acting herbicide, giving only two or three months weed control, may therefore be preferable to a more effective herbicide which is less safe to the crop. Work is continuing on both weed competition and herbicide tolerance aspects of the problem.

Soil mosture and herbicide safety

Soil-acting herbicides continue to form the basis of annual weed control in most fruit and ornamental crops. The safety of these treatments is usually dependent on soil factors which prevent too much herbicide coming in contact with, and being taken up by, roots. While some promising herbicides have been selected by means of the sand-culture technique described in the Fifth Report, their field performance is often influenced by distribution in the soil and this is largely dependent on soil moisture.

The importance of soil moisture has been demonstrated by the response of newly-planted strawberries to lenacil. Damage to the crops was more closely related to the amount of rainfall than to the amount of lenacil. On plots that were kept dry after spraying there was very little damage from three times the recommended dose. On plots that received normal rainfall (15 mm) there was a moderate amount of damage. On plots that received normal rainfall plus 60 mm of 'artificial rain' in the 3 weeks after spraying, damage was severe even at the recommended dose.

These results with this normally successful commercial treatment highlight the variable performance of soil-acting herbicides and the need for methods of testing new herbicides that will predict field performance at different levels of soil moisture.

WATER WEEDS

The aquatic weed research programme is aimed at finding new ways of controlling weeds in freshwater which are acceptable to all water users in Britain. The studies cover mechanical, chemical and biological methods and include the effects the new techniques have not only on weeds but also on other organisms in or dependent upon the water. Herbicides receive most attention but a herbivorous fish, the grass carp, also has an important position in the programme and shows considerable promise. At the same time close liaison is maintained with scientists outside the WRO and with those bodies and individuals whose primary concern is the practical control of excessive weed growth in water.

Weed control methods surveyed

Data collected in a survey of weed control methods from land drainage areas in England and Wales during 1973 were summarised and published in WRO Technical Report No. 35. The survey showed that many of the 267 Internal Drainage Boards are using herbicides, but a lack of technical knowledge sometimes causes errors. There is a need both for the education of operators to ensure that they use the chemicals safely, and also for research into development of safer techniques. This was endorsed at the British Crop Protection Council's symposium held in Oxford in January 1976 in which WRO had a major role (p. 42).

Ecological effects of controlling 'blanket 'weed

In recent years there has been a pressing need to find algicides to kill the large filamentous algal 'blanket' weeds which float on the surface of lakes and drainage channels. Two triazines, terbutryne and cyanatryne, have been developed for this use and, in co-operation with the two companies concerned, WRO has provided basic information on their behaviour and ecological effects. Much of this information has been collected from one lake over a four year period. As recorded in the Fifth Report, the lake was treated with terbutryne in the spring of 1973 and samples were then taken regularly to monitor the persistence of herbicide residues and their effects on non-target organisms and some environmental factors. Although the 'blanket' weed and all submerged vascular plants were killed there is still a flourishing population of zooplankton, rudd and trout. However, the triazines seriously reduced dissolved oxygen levels in the water immediately after application and work is continuing to find ways of overcoming this.

Yellow water lily control

One example of the way in which aquatic herbicide use may be made safer is the technique which has been developed for controlling the wild

Part of a lake formerly covered with yellow water lily, 18 months after treatment with glyphosate. The sprayed strips are still clearly defined.

yellow water lily. This weed can infest rivers and lakes and is difficult to remove mechanically because it has a robust rhizome buried in the mud. It has been shown that the two herbicides, glyphosate and asulam, when applied to the surface of floating leaves, are readily translocated down the long petiole to the rhizome which then dies. The effects are not always noticeable until the following spring. The main advantages of this technique are that selected patches of water lilies can be treated without affecting the remainder, and that there is very little herbicide contamination of the water. Though these herbicides have not yet been cleared for this use under the Pesticide Safety Precaution Scheme, the chemical companies concerned are actively interested and it is hoped that clearance may be forthcoming.

HERBICIDE RESEARCH

The current enormous cost of the R and D involved in the marketing of a new herbicide has undoubtedly contributed to the reduction in the number of new products received by WRO for investigation. This, together with the more effective and reliable screening procedures now possessed by the pesticide industry, has allowed a change of emphasis in the institute's programme and enabled more resources to be diverted to research aimed at improving the performance of herbicides. However as a result of negotiations with the Forestry Commission in 1975, funds will be available from 1976 to enable WRO expertise in herbicide evaluation to be applied to a greater exploitation of chemical weed control in forestry.

Currently much activity is deployed in three interrelated areas. Recent work in the first of these, the effects of environmental factors on herbicide performance, has already been mentioned on page 12. Work in the other two areas, the improvement of methods of herbicide application and research into herbicide formulation, are described in the articles on page 76 and page 83 respectively. Apart, therefore, from the account of the work with the new herbicide 'antidotes' described below, the remainder of this section is devoted to the more basic studies aimed at providing a greater understanding of the interrelationship between plants, herbicides, the soil and its microflora which should lead to the more effective and safer use of herbicides.

The role of herbicide antidotes

For many years the pesticide industry has responded to the need to increase the level of control of a particular weed, or extend the range of weed species controlled in a particular crop, by producing a succession of new herbicides. There are, however, alternative approaches and one which has been investigated recently by WRO is the use of so-called crop protectants or antidotes. Attention has been focussed on the two protectants that are in commercial usage namely 1,8-naphthalic anhydride (NA) and *N*,*N*-diallyl 2,2-dichloroacetamide (R 25788). The use of these compounds enables certain herbicides to be employed which otherwise might cause some damage to the crop. They are applied as a dressing to the seed of the crop prior to planting. Alternatively, the second compound may be applied in a 'tank-mix' with the herbicide. The crop then shows enhanced tolerance of the herbicide while the weed control effect is unimpaired. This technique has already enabled EPTC to be used with success for weed control in maize in North America.

The antidote project at WRO was designed to answer three questions.

The first, pursued jointly with the Tropical Weeds Group, was whether maize could be protected from herbicides other than EPTC. The second was whether temperate crops could similarly be protected against amide herbicides and thiocarbamates like EPTC. The third was whether it was possible to improve the soil-dependent safety of some soil-applied herbicides to the crops in which they are used.

The successful protection of maize against the herbicide perfluidone enabled the Tropical Weeds Group to suggest a solution to the problem of controlling *Rottboellia exaltata* (p. 32). Less success attended the application of the same technique to temperate crop/weed problems. Such protection as was achieved was unreliable and further progress evidently depends upon a knowledge, not yet available, of the mode of action of protectants.

New methods of herbicide analysis

During the past two years a rapid method for the estimation of dalapon by the gas liquid chromatography (GLC) of its n-butyl ester has been devised, and modified GLC methods have been developed for methabenzthiazuron, trifluralin, propyzamide and chlorpropham. Routine use is now made of high pressure liquid chromatography for the analysis of the uracils and isoproturon. For other ureas and triazines, procedures have also been developed which, in some circumstances, have advantages over GLC methods.

Behaviour of glyphosate in the soil

Recent WRO research has attempted to discover why glyphosate is generally inactive when applied to the soil. The only soil property correlated with glyphosate adsorption found in a study of nine soils was an empirical inorganic-phosphate-sorption index. The results are consistent with the suggestion of workers at Michigan that inorganic phosphate can exclude glyphosate from sorption sites. However, the extent of adsorption, though higher, was of the same order as that of diuron although the two were not related. Hence, inactivation solely by an adsorption process does not provide a satisfactory explanation.

Soils were incubated in the laboratory with ^{14}C-labelled glyphosate. One soil evolved 50% of the radioactivity as $^{14}CO_2$ in 40 days but two others were much slower. After 63 days, less than 18% of the radioactivity had been released by one soil and only 3% by the other. This is not conclusive evidence that decomposition is not rapid, and no determination of residual unchanged glyphosate could be made because an adequate analytical method was not available. Nevertheless, the results do suggest that degradation is unlikely to be a major cause of the inactivity of soil-applied glyphosate.

Results of experiments with plants grown in culture solution at WRO and elsewhere indicate that, for root applications, effective concentrations of glyphosate are 5–300 times higher than those of soil-acting herbicides. Thus, it is likely that the inactivity of glyphosate in the soil is the result of a low intrinsic toxicity when applied to the root, reinforced by a moderate degree of adsorption.

Soil tilth, moisture content and herbicide availability

Soil tilth and moisture content at the time of application might be expected to influence subsequent herbicide availability. Wettable powder formulations of metribuzin and simazine were sprayed, in the laboratory, on to two soils at two moisture contents, air dry and 12%, and two particle sizes, less than 0.5 mm and more than 2.5 mm. Soils were wetted to above field capacity after various time intervals and the herbicide concentrations in the soil solution monitored for 48 hours. With metribuzin, dry coarse crumbs gave higher solution concentrations immediately after wetting than fine crumbs but, with simazine, the differences were small. Application of metribuzin to moist soil generally produced higher solution concentrations after wetting than application to dry soil, irrespective of particle size. Simazine, however, tended to show higher concentrations after application to dry than to damp soil.

A tentative explanation is possible, based on the different solubilities of the two compounds. Metribuzin is about 400 times more soluble than simazine so a larger proportion of it would be in solution in the sprayed liquid. Dissolved material can be adsorbed and there were probably more available sites in the fine particles than in the coarse. This difference would be less important for simazine because most of it would be present in the spray as undissolved solid and hence unavailable for adsorption. Dissolved metribuzin would be carried into the internal pores of dry particles with the mass flow of spray solution and hence, on wetting, less would be available to move into the bulk solution from an initially dry soil than from one that was damp. By contrast, simazine particles might be mechanically excluded from the internal pores of dry soil but following application to a moist soil a little more could dissolve with soil water and hence become adsorbed in the period before wetting.

Herbicide degradation at depth in the soil

Since the numbers of micro-organisms decline with depth in the soil there is a possibility that herbicides leached into the soil, below the plough layer, may persist and subsequently pollute ground water. A laboratory study has shown that soil from depths down to at least 50–60 cm is still capable of degrading linuron. With one soil the rate of degradation was about half that obtained with soils from the top 10 cm but, with another, there was essentially no difference.

Methods of testing herbicides on the soil microflora

It is recognised that repeated treatment of soil with herbicides may have adverse effects of practical significance on the soil microflora. As a result there are growing pressures to introduce standardized ways of assessing these effects. An organization such as WRO can play an important role in obtaining and collating the basic information essential to the establishment of any test programme. Recognising this, the scope of the Institute's work has been widened considerably during the last two years. It now involves investigations of the effects of herbicides on several different groups of organisms, soil enzymes and soil physiological processes. The effects of environmental factors and of crop plants on soil-herbicide-micro-organism interactions are also being examined.

A major objective of the programme is the development of reliable, valid methods of testing the effects of herbicides on the soil microflora, particularly methods which are suitable for use by the agricultural chemicals industry. Many of the techniques available at present are relatively crude, time consuming and expensive. Furthermore, there is a serious risk that they may either not disclose or, conversely, may exaggerate the effects of a herbicide. Consequently, considerable efforts are being made to minimise this risk and to rationalise the approach to testing effects of herbicides on the soil microflora. In this context particular attention is paid to those aspects of soil microbiology which are important to soil fertility.

Soil conditions modify effects of herbicides on micro-organisms

During the last two years the gross effects of twelve herbicides on the population and activities of the soil microflora have been examined. Previous work has shown that some herbicides can have adverse effects on the microflora in the Begbroke soils. Some of these effects, for instance, a reduction in nitrogen mineralisation, could impair the ability of soil to grow crops. However, the effects so far observed have only occurred at high concentrations of herbicides, much greater than those likely to occur in the field after normal herbicide use.

Nevertheless, workers elsewhere have demonstrated that some herbicides used at field rates can cause adverse effects on the soil microflora. It has been suggested that, in such instances, environmental factors may have affected the microbial response to the herbicides. This possibility has been investigated using high concentrations of dalapon. The results indicate that both soil moisture and temperature can effect the response of soil micro-organisms. Thus, in one of the soils studied, dalapon stimulated the mineralisation of soil organic nitrogen less in moist than in dry conditions. In this soil, dalapon was most rapidly degraded in moist conditions. In a second soil, moisture had no effect on nitrogen mineralisation but dalapon was rapidly degraded in dry conditions. Similar experiments at two temperature levels showed that temperature interacted with soil moisture to modify the effects further.

Clearly, environmental factors can have a major effect upon the response of micro-organisms to herbicides. This must obviously be taken into account when assessing the effects a herbicide may have on the soil microflora and its biochemical activity.

Herbicide effects on the microflora of plant roots

Plants are associated with a dense, highly active population of micro-organisms which live in the soil adjacent to the roots or on the roots themselves. The numbers and types of organisms on the roots are governed, in many respects, by the plant itself. Changes in plant health and growth rate are among the factors which can influence the microbial population of the root. Usually micro-organisms live harmoniously with roots, or indeed may be beneficial, as with the legume-nodule bacterium symbiosis. If however, an imbalance in the microflora occurs, harmful effects to the roots may result. Imbalances may arise as a result of damage to the plants, or from changes in the physiological activity of the plant. Some herbicides, if used at other than the recommended rate or stage of crop growth, can produce either of these types of effect. For example, misuse of mecoprop can produce root abnormalities, and some damage to root tissues, in cereals.

Recent work at WRO has examined the possibility that the misuse of mecoprop on wheat (cv. Sappo) might result in a microbial imbalance on the roots and thus harm the plant. It was found that the root abnormalities caused by application of mecoprop at the wrong stage of plant growth were indeed associated with large increases in the numbers of micro-organisms on the root. In particular, those organisms living within the root tissues were stimulated. At normal field rates, these effects of mecoprop were of short duration and the plant recovered by producing new roots with a normal microflora. However, at an application rate four times higher than normal, the effects were prolonged, microbial imbalance on the roots more severe, and the plant growth and yield reduced.

The results suggest that it was the plant that was directly affected by mecoprop and that the microbial changes measured arose from alterations to plant growth, particularly to that of the root. It seems likely therefore, that misuse of some herbicides may entail the risk that harmful micro-organisms are encouraged to grow on plant roots with the attendant possibility that crop growth may suffer. Further research on this topic is in progress.

STATISTICS

The staff of the WRO/Letcombe Laboratory Joint Biometrics Group divide their time approximately equally between the two Institutes and least one member of the Group is normally present at WRO on most days. A tele-type at WRO is linked by private telephone line to the ICL 4–70 Computer at Rothamsted Experimental Station, on which most statistical analyses are now carried out. Extensive use is made of the Rothamsted Genstat statistical programme.

Many fewer analyses of microbiological experiments were carried out in 1975 following the reorganisation of the work of this Group but more effort was devoted to the results of experiments concerned with the effects of environment on the activity of herbicides. Some progress has been made in the development of a mathematical model of the fluctuations in wild oat seed populations from year to year, on the application of modelling to calculating—from experimental results—the likely economic benefit of different systems of weed control, and an investigation into the scale of sampling necessary in field experiments.

OVERSEAS ACTIVITIES

ODM TROPICAL WEEDS GROUP

The research activities of this group at WRO have been curtailed in consequence of changes in policy when the three-year contract was renewed with the Ministry of Overseas Development (ODM) in 1975. However, evaluation of new herbicides on tropical species has continued in the glasshouses revealing compounds likely to be of value in the establishment of tropical legume crops. The liaison and information activities of the group have been augmented by the appointment of a part-time information officer.

a b c d e

Effect of the crop protectant napthalic anhydride (NA) on the activity of the herbicide perfluidone applied at 3 kg/ha, both on maize and the weed *Rottboellia exaltata*: (a) maize treated with perfluidone; (b) maize protected with NA and treated with perfluidone; (c) untreated maize; (d) *Rottboellia* treated with perfluidone; (e) untreated *Rottboellia*.

Research at WRO and overseas

The recent discovery elsewhere of so-called herbicide antidotes (p. 26) suggested a possible solution to two particularly difficult weed problems, *Rottboellia exaltata* in maize, and wild rice (*Oryza punctata*) in rice. Antidotes applied to the crop seed in each case have made it possible to use herbicides which would not normally be safe in those crops: perfluidone in maize and alachlor in rice. Further work with alachlor in rice by staff of the Commonwealth Development Corporation in Swaziland suggests that the technique will prove useful in the field.

Work on the parasitic *Striga* species, serious weeds of tropical cereals, has thrown further light on mechanisms of resistance in sorghum varieties.

A variety with an apparent mechanical resistance to attachment is being studied further by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India. ICRISAT is also making use of techniques developed at WRO for the selection of *Striga*-resistant sorghum lines.

At the request of ODM, the Director visited Arusha, Tanzania in April 1974 to assess the weed research programme of the Tropical Pesticides Research Institute (TPRI) led by P. J. Terry ('home-based' officer at WRO) and supported by ODM Research Scheme R 2557. He also visited research staff of the Cotton Research Corporation at a number of centres in East Africa. Shortly before his visit, it was learned that the East African Community had decided not to request an extension of the ODM support for weed science work at Arusha thereby bringing to a close more than 20 years of close collaboration between WRO (formerly ARC Unit of Experimental Agronomy) and TPRI involving the appointment of an expatriate botanist at Arusha. However, due to the unexpected resignation of the two graduate members of the TPRI team, the Community requested the return of P. J. Terry for a further year. The research scheme was concluded in November 1975 on completion of a programme aimed at developing methods of controlling weed sedges in East African crops.

Glyphosate was the most successful herbicide evaluated and significant increases in crop yield were obtained when *Cyperus* species were controlled with this product. Repeated application of glyphosate over a two-year period in a coffee plantation maintained by zero-tillage techniques gave excellent control of *Cyperus rotundus*, and parchment coffee yields were increased by 15%. Annual crops also benefitted from controlling weed sedges. This was achieved by applying glyphosate to the weeds before the first cultivation of the season. In ideal conditions, subsequent regrowth of *Cyperus* was considerably reduced and this method is particularly promising for irrigation schemes where management techniques can be adapted to achieve optimum times of herbicide application and cultivation.

Studies have also been made on the distribution and biology of weed sedges in East Africa. Several species are of widespread or localised importance but methods of controlling them are not identical. It is important therefore to assist farmers and agronomists to distinguish between weed sedges which, to the untrained eye, look very alike.

Liaison with overseas countries

The head of the Tropical Weeds Group, in his capacity as ODM Liaison Officer, visited Kenya, Tanzania, Zambia, Swaziland, Indonesia, India, Saudi Arabia, Bahrain, Ghana and Nigeria to advise on a variety of weed problems and to maintain personal contact with workers in those countries. Close liaison was also maintained with a large number of workers in these and other countries through correspondence and the opportunities afforded by their visits to WRO.

In October 1975, the Director visited Indonesia on behalf of ODM to advise on a request for assistance in the development of mechanical methods of clearing water hyacinth and floating islands of vegetation from Rawa Pening Lake in Central Java, an important source of hydro-electricity and irrigation water.

OTHER ACTIVITIES

European Weed Research Council/Society

As President of the European Weed Research Council (EWRC) the Director has played a leading role in the transformation of the Council into a Society with open membership and a potential for making a major contribution to weed science in Europe. The Council which was established in 1960 consisted of one national representative from each of some 26 countries. It achieved much valuable work but was limited by the restricted membership, lack of participation by industry, and a weak organizational structure.

A steering committee chaired by the Director of WRO was set up by the Council in 1973 to organize and arrange the replacement of EWRC by EWRS. The Society operated provisionally during 1975 under the direct control of the committee which involved a heavy load falling on WRO and on Dutch colleagues at Wageningen. At an international symposium on the status, biology and control of grass weeds in Europe, sponsored by EWRC/S in association with COLUMA and held in Paris in December 1975, the new society was ratified and the EWRC dissolved. At present the secretariat of EWRC is shared between WRO and CABO (Centre for Agrobiological Research) Wageningen. At the time of writing more than 550 members have joined the Society and a programme of technical activities is being developed.

International Weed Science Society

On the occasion of the annual conference of the Weed Science Society of America (WSAA) held in Washington in February 1975, a decision was taken to form an International Weed Science Society (IWSS). This was the outcome of a recommendation made at the first FAO International Weed Conference held in Davis, California in 1970. The Director of WRO who had been in close touch with regional and national weed societies and similar organizations in many countries attended the meeting and became a member of the steering committee charged with the responsibility to bring IWSS into existence. The object of the Society is to co-ordinate and encourage the activities of national and regional weed science groups and to provide an information centre for industrial weed specialists and affiliated members throughout the world. The secretariat of the Society is located at the International Plant Protection Centre, Oregon USA.

FAO

The Director accepted an invitation to become a member of the FAO Expert Committee on Pesticides in Agriculture and attended meetings of the Committee and of the FAO *ad hoc* Government Consultation on Pesticides in Agriculture and Public Health held in Rome in April 1975. At these meetings it was agreed that the international use of the term 'pesticide' ought in future to include herbicides and that much benefit could stem from more active involvement of FAO in weed science. It is expected that a full time senior weed specialist post will shortly be added to the secretariat of the FAO Plant Protection Service. This is a much needed and long overdue appointment.

LIAISON AND INFORMATION

As explained in the Fifth Report, WRO as a specialist institute for weed science has to meet many demands for participation, assistance or leadership in many activities which tend to conflict, sometimes seriously, with research. The involvement of the scientific staff in the important information and liaison functions of the Institute has now been appreciably reduced (but by no means eliminated) by the appointment early in 1974 of a full-time officer to the Information Department to assist with some of the activities described in this section. Nevertheless, it has remained necessary for several senior members of staff voluntarily to continue to devote a considerable amount of their leisure time to activities beneficial to weed science in the UK and overseas.

LIAISON

Contacts with other organizations

Individuals in many other organizations than WRO undertake weed research and related work. WRO staff are encouraged to take the initiative in promoting liaison which may range from infrequent discussions or correspondence to regular organized meetings leading to co-ordinated research programmes. Examples of such organized groups are: the ARC Weed Control in Fruit Working Group; the Weed Control in Herbage Seeds Working Group; and the two-day annual meetings at Begbroke on aquatic weed control. Annual or biennial liaison meetings are held with several research organizations including: Grassland Research Institute, National Vegetable Research Station, Plant Breeding Institute, Processors and Growers Research Organization and National Institute of Agricultural Engineering. There is periodic liaison between individual members of staff and research workers in many universities, particularly at Oxford, Reading, Bath, Wye, Sheffield, Strathclyde and University College of North Wales, Bangor. Close contacts exist with workers at the three Scottish Colleges, the Northern Ireland Ministry of Agriculture, Belfast, Norfolk Agricultural Station, the Forestry Commission and also with all the principal research stations of the agrochemical industry.

Close links with ADAS

With the recent and very welcome encouragement given to closer collaboration between the Agricultural Research Service (ARS) and ADAS and to the integration of programmes, WRO has found itself in the fortunate position of having its own long-established and effective machinery for liaison with the advisory service. The ADAS liaison unit at Begbroke consists of an agronomist and horticultural specialist who, in addition to their principal function of providing technical advice to their colleagues and others, provide invaluable links between WRO staff and members of ADAS, promote development work on weed control topics by ADAS, help WRO to find experimental sites on private farms and advise on practical problems requiring WRO research. In addition, WRO staff maintain personal links with many Directors and staff of the Ministry's Experimental Stations. The WRO/ADAS Liaison Group meets twice a year at Begbroke under the chairmanship of the Head of the Department of Weed Control and is an important forum for discussing weed control problems and possibilities for collaborative work. In December 1975 the biennial ADAS Agronomists Conference was held at Begbroke and provided a valuable opportunity for a two-way exchange of information and ideas.

The National Wild Oat Advisory Programme

A special word about this important programme is in order because of the precedent that it may set. In the programme MAFF, ARC, chemical industry, merchants, NFU and many other organizations have combined in a joint effort to challenge and defeat the menace of this widespread weed. WRO has been an active contributor by working within the programme to provide technical knowledge about the weed and its control. The programme now provides a means for the rapid dissemination of research knowledge in a way that is most gratifying, a precedent for future collaboration by organizations and a true reward for the considerable work by WRO staff in support of the programme.

Assistance to the Agricultural Chemicals Approval Scheme

WRO has no formal requirement to supply information for the official approval of herbicides. Nevertheless the research programme provides much relevant information and this is freely made available to the ACAS Herbicides Liaison Officer who is seconded to the institute from the MAFF Plant Pathology Laboratory. The presence of this officer at Begbroke is also of great value to WRO on account of his intimate knowledge of new developments in herbicides, of practical problems of herbicide usage and his close contacts with the industry. The Director is a member of the ACAS Scientific Advisory Committee.

Liaison with the agrochemical industry

Much of the work of WRO is planned to be complementary to that of herbicide manufacturers and distributors and it is essential that the institute is kept well informed of developments within the industry. The large number of firms involved in Europe, North America and Japan makes this a difficult task which has not been made easier by the necessarily more selective approach by WRO towards the testing of new products. A systematic attempt is made each year to obtain technical literature on new and established herbicides. The glasshouse evaluation programme which continues to examine on a wide range of crops and weeds the more interesting new chemicals is a great help in keeping in touch. In the case of herbicides which play a major role in this institute's research programme, the research staff involved are encouraged to liaise closely with relevant specialists of the supplying companies. Members of the ADAS Liaison Unit at Begbroke have intimate contact with agrochemical firms in the UK and much useful information is made available to WRO.

The importance of communication between WRO and the industry cannot be overemphasised. To improve liaison a proposal was made during 1975 to the British Agrochemical Association that WRO should act as host for one day each year to representatives of BAA members to allow them to learn about and discuss this institute's programme and recent developments. This proposal was accepted and a Chemical Industry Day took place in early 1976.

In October 1975 over 70 herbicide specialists, mainly from agrochemical firms, participated in a one-day meeting organised by and held at WRO to review recent work on controlled droplet application of herbicides (see p. 76) and to have the chance to comment on the possible interest and co-operation of the industry in furthering future development of the technique.

The support of Learned Societies

A vital component of the research scene which is sometimes taken for granted is the network of learned societies which through their meetings and publications provide the main forum for the communication of research results both nationally and internationally. To continue to exist in these difficult inflationary times these societies desperately need the continued support of institutes and research workers. The staff of WRO attempt to assist whenever possible. Thus the British Grassland Society has been going through a difficult financial period which has necessitated considerable reorganization. During the past two years senior members of WRO have participated in the considerable work of an appeal on behalf of the Society, a complete reorganization of the Society's publications and a re-appraisal of the Society's procedures for meetings. Another senior member of staff has participated in the organizational structure of the Pesticides Group of the Society of Chemical Industry. The Association of Applied Biologists has a member of WRO staff on its Council and the Organization has contributed to the successful launching of a Weed Group within the Association.

Renovation of old pasture was a major feature of Weed Workshop '75. Here some of the 800 visitors hear about the high productivity achieved in the WRO 'beef from grass' enterprise.

Liaison with agricultural merchants

'Merchants Days', now held annually at WRO with the collaboration of the British Association of Grain, Seed, Feed and Agricultural Merchants (BASAM), have proved a particularly popular and effective means of liaison with the technical staff of agricultural merchants. Held every February, the objective is to bring participants up-to-date with current thinking on weed control and with the latest WRO research on which it is based. Over 80 merchants visited WRO on each occasion in 1974 and 1975.

Weed Workshop '75

Perhaps the outstanding achievement in human contact in the period reviewed was the Weed Workshop which occurred on two days in July 1975. The scientific staff of WRO prepared lectures, demonstrations and, with the help of the information staff, more than 50 new exhibits of progress in research which were described to the press on the day before and then offered to visitors during the two days. More than 800 farmers, advisers, technologists and research workers attended. Helped by brilliant sunshine the event was a great success.

INFORMATION AND PUBLICATIONS

In addition to its liaison function WRO is the recognised national centre for the dissemination of information on weed research. The specialist library, current awareness and information retrieval services, provided to assist the research staff, are also available to all weed scientists in the UK. In 1974–75 the demand for these services was greater than ever and over 1150 enquiries were answered and 24 new annotated bibliographies on weed science topics were prepared. Over 1200 requests for the latter were received. Some 114 journal and conference papers and 7 Technical Reports emanating from WRO research were published in 1974–75; a full list appears at pp. 00–00. In the same period the world-wide mailing of nearly 500 copies of the half-yearly lists of recent WRO publications resulted in requests for 6000 reprints, 600 Technical Reports and 1600 copies of the WRO 5th Report. Sales of the 1972 edition of the popular booklet *Chemical Weed Control in Your Garden* topped 25,000 in 1975 and there were 50 subscribers to the weekly *Current Awareness List*.

CAB Abstracting Journals

The reputation of WRO as an international information centre for weed science remains firmly based on the journal *Weed Abstracts* which has presented a continuous digest of the world's weed research for 25 years. Its compilation by staff of the Information Department is partially financed by the Commonwealth Agricultural Bureaux, which is wholly responsible for its printing and distribution. Over 6000 abstracts were published in 1974/75 while, of a total circulation of 1300, subscriptions in 1975 accounted for 1000 copies. Indeed, *Weed Abstracts* showed the highest percentage increase in subscriptions of any CAB journal in the period reviewed.

A new monthly abstracting journal, *Plant Growth Regulator Abstracts,* commenced publication in 1975. One of a series of new ventures by CAB in response to specialist demand, the content of *PGRA* consists of relevant abstracts culled from other CAB journals and collated by the editor of *Weed Abstracts*. Over 150 subscriptions have been taken out to date.

Weed Research

The Director and the Head of the Information Department continued to serve as honorary Chairman and Secretary, respectively, of the 16-strong international Editorial Board of *Weed Research*. Published by Blackwell Scientific Publications, some 117 research papers appeared in this official journal of the European Weed Research Council in 1974/75 while circulation increased to 1053.

Wild Oats in World Agriculture

Purposeful direction of research into the control of wild oats, the most serious cereal weed problem in the UK, has been hampered by a lack of any recent comprehensive review of the voluminous, world-wide, scientific literature on the subject. With the encouragement of the former ARC Technical Committee on Cereal Research, and financial assistance both from ARC and the Home-Grown Cereals Authority, a review was put in hand early in 1973. By late 1975 more than 1300 literature references had been critically reviewed by a panel of authors drawn mainly from WRO but also from Rothamsted, WPBS and NIAB, under the general editorship of Dr. D. Price-Jones. This major contribution to the appraisal of present, and the development of future, research on wild oats is scheduled to be published during 1976 by ARC as a 250-page book of 12 chapters.

Weed Control Handbook

The production and editing of the *Weed Control Handbook* continues to be based at WRO with active participation by the institute's staff, amongst many others. The *Handbook*, which is issued by the British Crop Protection Council and published by Blackwell Scientific Publications, Oxford, consists of two volumes covering respectively: principles of weed biology and weed control, and recommendations for weed control practice. The text, which is based on information from some 130 contributors, is under the voluntary joint editorship of the Director and the ACAS Herbicide Liaison Officer based at Begbroke.

CONFERENCES

Twelfth British Weed Control Conference

Once again, WRO staff were heavily involved in the organization of the scientific programme of this biennial conference, sponsored by the British Crop Protection Council, which took place in Brighton in November 1974. The Head of the Department of Weed Science chaired the Programme Committee on which six other members of staff also served in a voluntary capacity. At 1636 conference attendance was the largest ever recorded, 44% of the participants coming from overseas. Contributions emanating from WRO research accounted for 14% of the total of 149 papers presented.

EWRC/EWRS Symposium on the Status, Biology and Control of Grass Weeds in Europe

Several members of WRO contributed papers to, or attended, this very successful International Symposium held in Paris in December 1975. An attendance of over 460 not only provided a fitting conclusion to the activities of the European Weed Research Council, of which the Director has been the sixth and last President since 1973, but also served to inaugurate the new European Weed Research Society. The Society has similar objectives to the former Council but provides opportunities for membership by individual weed scientists.

BCPC Symposium on Aquatic Herbicides

The Head of the Aquatic Weeds Group at WRO was chairman of the committee which organized this successful symposium, sponsored by the British Crop Protection Council, in Oxford in January 1976. It was attended by 106 invited participants from regional water boards, internal drainage authorities, chemical industry and official and university research establishments engaged in aquatic weed control. Ten papers were presented and discussed and, in a final session, Mr. J. D. Fryer surveyed the current objectives, cost-effectiveness and safety of aquatic herbicides and made recommendations for the better training and education of those engaged in using them.

ADAS/ARC Joint Technical Meeting on Reduced Cultivation and Direct Drilling

Several members of staff participated in a residential technical meeting held at Reading University in January 1975 at which the current status and future development of reduced cultivation and direct drilling were discussed in depth. Some of the most valuable contributions were made by farmer protagonists of reduced cultivation, prepared to take the risks involved in putting into practice techniques not yet fully researched. The Proceedings of this technical meeting appeared in a special issue of *Outlook on Agriculture* (Vol. 8, 1975) while the meeting was reviewed in *ARC Research Review* (Vol. 1, (2), 1975).

DEMONSTRATIONS AND EXHIBITS

Research on minimum tillage, including that of the WRO/Letcombe Joint Tillage Project on cereal production, that of WRO on weed problems and that of Rothamsted on pest and disease problems featured in the 15-panel ARC corporate exhibit prepared for BP Landwork '74 and displayed at Bawtry in September 1974; this exhibit was again displayed at Brighton in November 1974 during the British Weed Control Conference. Also on the latter occasion, the Herbicide Group's research on the effects of environmental factors, formulation and controlled droplet application was a major feature of the BCPC Programme Committee's exhibit entitled 'Enhancement of Herbicide Efficiency'.

'Control your Couch' was the theme of a 5-panel display based on the findings of the Annual Crops, Botany and Perennial Crops Groups prepared for the ARC exhibit at the British Growers Look Ahead conference at Harrogate in March 1975. This was shown again at the Chelsea Flower Show in May 1975. The work of the Grass and Fodder Crops Group was featured in the prize-winning ARC corporate exhibit entitled 'Science in Grassland' presented at the National Grassland Demonstration in May 1975 and again at the International Dairy Event in September 1975.

EDUCATION, BUILDINGS AND ADMINISTRATION

EDUCATIONAL ACTIVITIES

A considerable time is spent by many members of the research and information staff, often outside working hours, in giving educational talks to visiting parties of students from schools, gardening clubs, polytechnics, technical colleges, colleges of further education, agricultural colleges and university departments, also to ADAS groups, technical staff of agrochemical manufacturers and distributors, to farmers and growers. Talks away from WRO involving much travelling or preparation time are avoided as far as possible unless some reciprocal benefit to WRO can be seen.

In October 1974 the Director accepted a three-year appointment as Visiting Lecturer to the Department of Biology, Strathclyde University and subsequently gave a series of lectures to 3rd year students specialising in crop protection. This has proved helpful in keeping up-to-date with the herbicide and weed research which is a specific feature of the Department's programme. The Head of the Aquatic Weed Group gives an annual lecture to students taking the MSc. course in applied hydrobiology at Chelsea College, London University.

Again, in 1974/75, the two-day introduction to the principles and practice of weed research was provided for the overseas plant protection workers taking part in the annual, ODM-financed, Silwood Park Pest Management Course. On both these occasions these visitors were joined by students of the ODM-supported Reading University course in tropical weed control. Several members of WRO staff also participated as lecturers on the latter course. In June 1975, two members of staff, sponsored by ODM, visited Bogor in Indonesia at the request of the SEAMEO* Regional Centre for Tropical Biology (BIOTROP) to participate in a workshop on research methods in weed science organized by BIOTROP and the Weed Science Society of Indonesia (WSSI). They also lectured to students attending a training course on pesticide ecology.

WRO was granted the status of an Associated Institute by Reading University in 1972 and this has been reflected in 1974–75 in the number of higher degree students conducting jointly supervised research at the institute. Both R. R. B. Leakey and G. J. Wells were awarded a Ph.D. in 1974, the former for his work on dormancy and dominance in rhizome buds of *Agropyron repens* and the latter for his ecological study of *Poa annua* in perennial ryegrass. A. L. P. Cairns is working on the mechanism of dormancy in *Avena* spp. and Miss C. Howe is studying the autecology of grass weeds of grassland. Miss S. El Hiweris, a former student of the Reading University tropical weed course, is now working on *Striga* spp. for a Ph.D. and often visits WRO to discuss her work. In addition, Ms. T. A. Watt is working for a D.Phil at Oxford University on the autecology of *Holcus lanatus* in grassland.

A number of 'sandwich' students have also carried out small research projects at WRO in fulfilment of their degree courses.

NEW BUILDINGS AND EQUIPMENT

A new building of about 300m² was completed in October 1975 to accommodate the existing and new equipment for the study of environ-

*SEAMEO—South East Asia Ministers of Education Organization.

Interior view of the new controlled environment building; two of the three Saxcil cabinets can be seen in the foregound while the three Vötsch walk-in growth rooms can be seen at the rear.

mental effects upon herbicide performance by the Herbicide Group. In addition to the existing Saxcil growth cabinets, three new Vötsch walk-in controlled environment rooms have been constructed, each of $11 m^2$ usable capacity. These are provided with three levels of illumination and automatically controlled and monitored temperature, aerial humidity and CO^2 content. There was excellent collaboration between the staffs of Ernst Vötsch Kälte and Klimatechnic KG and WRO to ensure effective design and installation of the rooms.

A mobile spraying cabinet permits plants to be sprayed with herbicides in the same environment obtaining in any growth room and without contaminating it with any herbicide vapours. In the course of time it is hoped to provide facilities to simulate rain, dew and frost and provide controlled root temperatures.

The technical requirements of the equipment made necessary a building higher than most others on the station but, despite the fact that it is basically an industrial type, concrete-framed building, the new structure harmonises quite well with the general appearance of the station and promises to be very functional.

The architects were Westwood, Piet, Pool and Smart of Weybridge, consulting engineers were R. W. Steel and Partners of Hatfield, and the main contractors were W. J. Lovell (Building) Ltd. of High Wycombe.

The other major item of equipment brought into use in 1974 was a UDS 6000 Word Processor or tape-operated typewriter. This has made an improvement to the quality of technical reports and scientific papers, successive drafts of which can now be reproduced in half the time and without the introduction of fresh typing errors.

ADMINISTRATION AND TECHNICAL SERVICES

The scientific work of the Institute continues to be ably supported by the Administration Department, under the leadership of the Secretary. The Department provides office and secretarial services and is responsible for accountancy, supplies and personnel matters. The technical services cover a photographic section, and workshops for engineering staff and the maintenance of buildings, plant, vehicles and equipment.

A notable addition to the staff has been the appointment of an electronics engineer who will not only service the controlled environment facilities, but also assist other staff with electronic problems.

The Secretary, as chairman of the Safety Committee, has been heavily involved with the preparation of safety policies and codes necessitated by the passing of the Health and Safety at Work Act.

Population dynamics of wild oats in relation to systematic control

G. W. CUSSANS

Wild oats (*Avena fatua*) have become a problem because they are well adapted to the repeated growing of cereals. In the past both WRO and industry have tended to concentrate on short term measures of control with the current crop/weed situation only in mind. However the cost of the wild oat herbicides at present available tends to limit their use to heavy infestations leaving light infestations uncontrolled. In recent years, therefore, WRO research has concentrated on a longer-term systematic approach in which the cropping, the husbandry practices and herbicide use are integrated to keep the weed control at minimum cost. To achieve this target one needs a considerable depth of knowledge on the changes in wild oat populations likely to occur as a result of the various systems of management, and the influence of herbicides upon such changes. Such information itself has to be based on detailed research on the wild oat and its reaction to agronomic and climatic factors, examples of which are reported elsewhere.

POPULATION DYNAMICS OF WILD OATS

Populations of wild oats can be measured by a number of methods, but the seed is the essential unit. Production and survival of seeds govern long-term population trends. In a single year, seed production is a multiple of seedling survival, number of fertile tillers and size of panicles. Seedling populations are, therefore, best expressed in terms of their potential ability to produce seed. Herbicides and cultural practices are best evaluated in terms of their effect on this potential. The life history of the weed may be presented as a simple population cycle. Each of a series of discrete but interacting steps or pathways is largely under the influence of a different set of environmental factors. Such a schematic population cycle is reproduced in Fig. 1.

Seed production

Crop competition. This is the major cultural factor controlling growth of wild oats. Poorly competitive crops, notably field beans and row crops allow greater seed production than cereals. The crop plant population

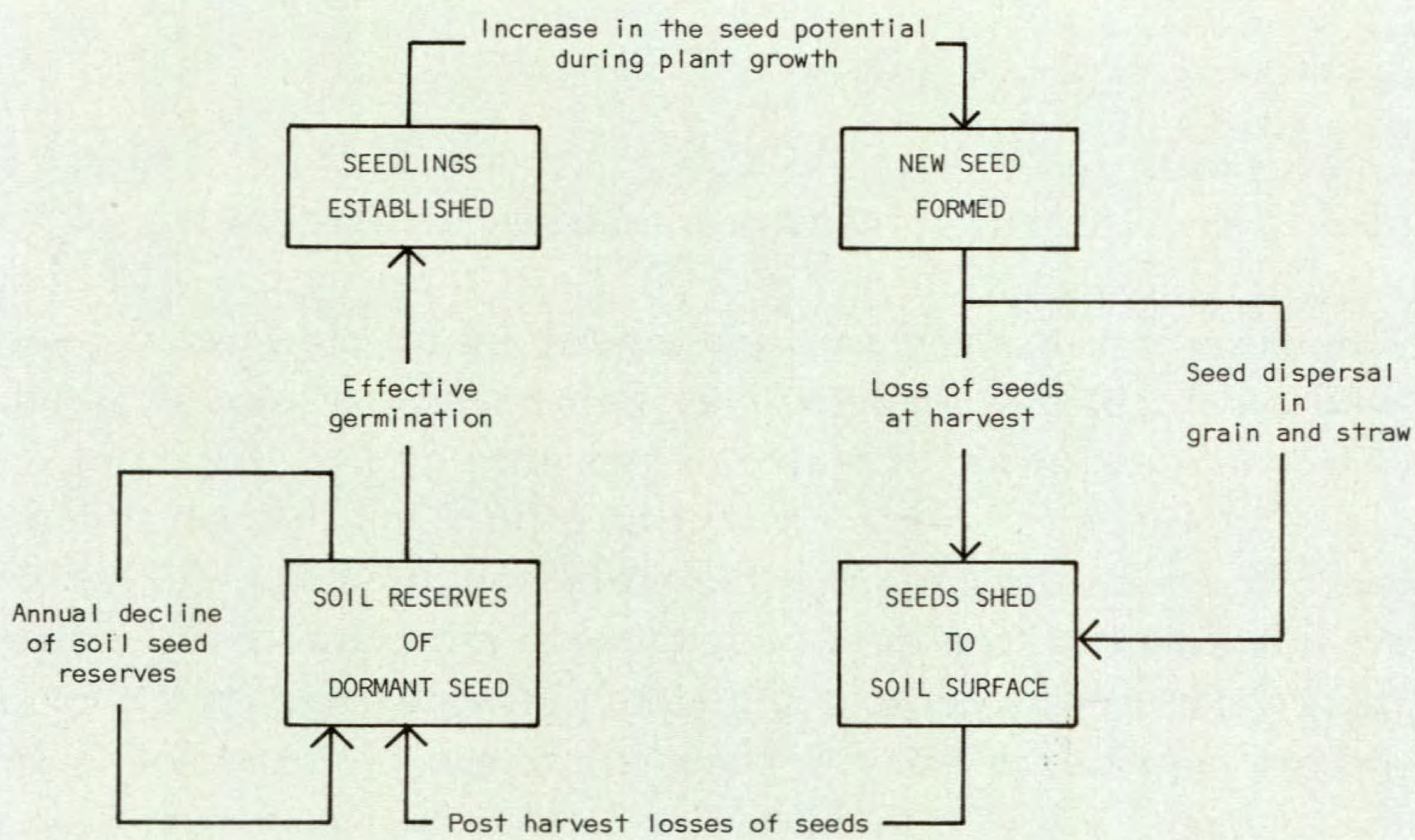


Fig. 1 A schematic population cycle for wild oats.

may also have a profound influence. In WRO experiments, varying the population of spring barley within the range commonly found on farms (200–400 seedlings/m^2) had a marked influence on wild oat seed production, an influence which varied from year to year. Reducing barley seedling density by approximately half had no effect in one experiment but increased wild oat seed production by between 55% and 100% in three others (Bate *et al* 1970, Cussans & Wilson 1975).

Relative time of emergence. The wide spread of time over which wild oat seedlings emerge means that individual plants do not have the same chance of survival in the face of crop competition. In spring barley, wild oats germinating with or just before the crop are the most likely to survive. They also produce the most seed. Later-emerging plants are progressively less successful; those that emerge after the four-leaf stage of the barley can suffer 50 to 100% mortality and any survivors produce only a few seeds per plant (Chancellor & Peters 1972, Peters N. C. B. & Wilson, B. J., personal communication).

The importance of time of emergence of wild oats appears to be even greater in winter wheat. There is commonly a flush of wild oat seedlings which emerge with the crop, followed by further emergence in mild spells during the winter period. There is also a spring flush of emergence in February to May. In every case we have studied, the earlier the plants emerged, the more seed they produced. Autumn germinating plants of wild oat have also been more frost resistant the earlier they emerged, being better established and well developed before the onset of winter (Holroyd 1972).

Soil type and climate. Observations suggest that wild oats suffer from moisture deficit during the summer more than the cultivated cereals. Conversely, with ample water the weed has the ability to grow on for a longer period than cultivated cereals which ripen more evenly. This suggests a greater potential for population increase on soils of high moisture capacity or in wet seasons but these responses have not yet been measured.

Herbicides. These have the greatest potential for reducing seed production. Unfortunately, much of the literature on the performance of herbicides records only their effects on seedling or panicle numbers. These data are of limited value as a measure of probable long-term effects.

Other factors. Some of these may be important, notably attack by frit fly. Soil pH, crop disease or any other factor which tilts the competitive balance between crop and weed can be of profound importance.

Table 1 Typical values for seed production/plant from WRO experiments

Maximum production, free of competition	:	c.2000
Range of mean values normally encountered:		
In spring barley	:	40–50
In winter wheat (autumn germinators)	:	80–100
In winter wheat (spring germinators)	:	10–30

Seed removed from the field of origin

In most cereal crops, with the exception of winter barley, the majority of wild oat seed is shed before harvest. The combine harvester does not remove all of the seed that remains so that, overall, only 2 to 10% is removed from the field in the grain and straw (Wilson 1970, and personal communication). Some very early-harvested crops like vining peas may remove more seed. Cereal crops grown for silage are, of course, excellent break crops because all the wild oat seed is removed from the field of origin and destroyed in the silage making process.

The wild oat seed removed in cereal grain and straw may be of relatively minor importance in influencing the population of the weed in the field of origin but it can be of profound importance if that grain or straw is taken on to land free of the weed. Straw used for feeding cattle at grass may be especially important, introducing wild oat seed to land that was previously clean.

The numbers of wild oat seeds brought into a heavily infested field with cereal seed, farmyard manure or in combine harvesters are small compared with the numbers already present, but they may be significant when introduced into previously clean fields.

Post-harvest losses of wild oat seed

Loss or mortality of the seed after shedding is variable but may be remarkably high. We have recorded losses of 10 to 75% and identified some of the causal factors.

Straw burning. This can destroy up to 30% of the seeds; the percentage is highest beneath the straw swathes and lowest between the swathes (Wilson & Cussans 1975). As well as killing seeds, burning affects the dormancy of many of those which survive; more seeds germinate in the autumn after burning. Where a spring crop is to be planted, this may be a further opportunity to reduce the wild oat population if the seedlings can be destroyed by ploughing or cultivation before the crop is sown. Conversely, these autumn germinators may significantly increase the wild oat population in an autumn sown crop.

Natural wastage. WRO work (Wilson 1972, Wilson & Cussans 1972, 1975) has established that there is a considerable loss of seeds from the surface of undisturbed stubble. This loss can be attributed in part to predation by mice and birds but mainly to other causes as yet unclarified. Because we cannot, as yet, account for the whole loss it is impossible to predict its magnitude, which has been on occasions as much as 75% of the newly shed seeds. However it appears to be the duration of surface exposure which is important, rather than the predominance of any single factor such as the bird or rodent population.

Effective germination

This is the part of the seed cycle that is most difficult to predict, although some of the mechanisms involved have been well researched. The relationship between seed reserves in the soil, seedling emergence and their subsequent growth is complex; for example the time of emergence of the seedlings relative to crop emergence may be as important as the total number of seedlings. We need, therefore, to introduce the concept of 'effective seedlings' which are successful because they emerge during the early stages of crop growth. Seedlings emerging earlier should be killed by seedbed cultivation and those emerging later will probably be suppressed by competition. We have, typically, recorded one effective seedling in spring cereal crops for every 10 viable seeds in the soil before planting.

The ratio is influenced by a number of external factors. Ploughing, by burying the seeds more deeply, reduces the number of seedlings and therefore increases the ratio. Cultivations, which keep the seed near to the soil surface, increase the number of seedlings and reduce the ratio of seeds to seedlings but they do not, surprisingly, appear to have the effect of causing earlier seedling emergence (Wilson & Cussans 1975; and personal communication).

Numbers and timing of seedling emergence are also affected by intrinsic variation in seed behaviour. The oldest or first seed of wild oat on a spikelet appears to have less dormancy than the subsequent seed(s) and is therefore most likely to germinate in the autumn. Indeed, WRO work suggests that the autumn germination of wild oat seedlings is almost entirely derived from freshly shed seed. After these non-dormant seed have germinated, the dormancy of the remaining seed declines with increasing age, so that the ratio of seed reserves to seedlings decreases (Wilson & Cussans 1975; Wilson, B. J.; personal communication).

With spring barley therefore the 10 : 1 ratio provides a convenient working hypothesis, suitable for a reasonably wide range of conditions, but markedly influenced by cultural factors and the past history of the weed population. With winter wheat, the relationship between seeds and seedlings is more complex. Autumn germination is influenced by timing and amount of rainfall (Whybrew 1964), but can be related reasonably well to the numbers of freshly shed seed and to cultural treatment. In WRO experiments the porportion of freshly shed seeds germinating successfully in the autumn has ranged from a minimum of 0.5% in ploughed plots to a maximum of 12% in plots where straw was burnt and the land shallowly tine cultivated.

The proportion of seeds germinating in spring has been variable. In some experiments there has been no spring emergence of seedlings; in others they have outnumbered the autumn germinators by a substantial margin. These differences must be related to the age structure of the seed population, to climate and to cultivation practices but more work is required to elucidate this.

The decline of seed reserves in the soil

After the loss of newly shed seed from the soil surface and the initial autumn germination, the other major period of seed loss is between February and June each year. Although seedlings are produced at this time of year, many viable seeds disappear without producing seedlings. If further seeding is prevented, conditions which favour germination should also maximise the decline of seed reserves. Under grass, when germination is presumably minimal, seed reserves appear to decline at about 50% per annum with a maximum survival of about nine years (Thurston 1966). In cultivated arable land, the decline appears to be much more rapid, of the order of 80% per annum (Wilson, B. J., Strickland, G., personal communication). Non-tilled arable land may be intermediate between grass and cultivated land. It also seems probable that seeds buried below cultivation depth may survive longer than seeds in the cultivated layer. An experiment is in progress to test these hypotheses.

SOME EXTRAPOLATIONS OF THESE DATA

Although our current state of knowledge is incomplete we can calculate some possible long term consequence of all the factors that have been described. As an example, Fig. 2 summarises our calculations of population changes assuming continuous spring barley cropping and the effects of cultivation reviewed earlier. Two levels of herbicide performance are assumed: the reduction of new seed formation by 80% or 95%.

In the absence of control measures, Fig. 2 shows calculated annual rates of population increase of $\times 2$ with mouldboard ploughing and $\times 5.4$ with early autumn cultivation, without ploughing. These increases are well withing the range which has been recorded in field studies (Selman, 1970; Wilson & Cussans, 1975). An annual rate of decline of the soil seed reserves of 80% has been assumed and the effect of three years without any seeding is then to reduce the population by 99%. The seed surviving from herbicide treatment delays the rate of decline appreciably; even a herbicide reducing seed formation by 95% in the most favourable

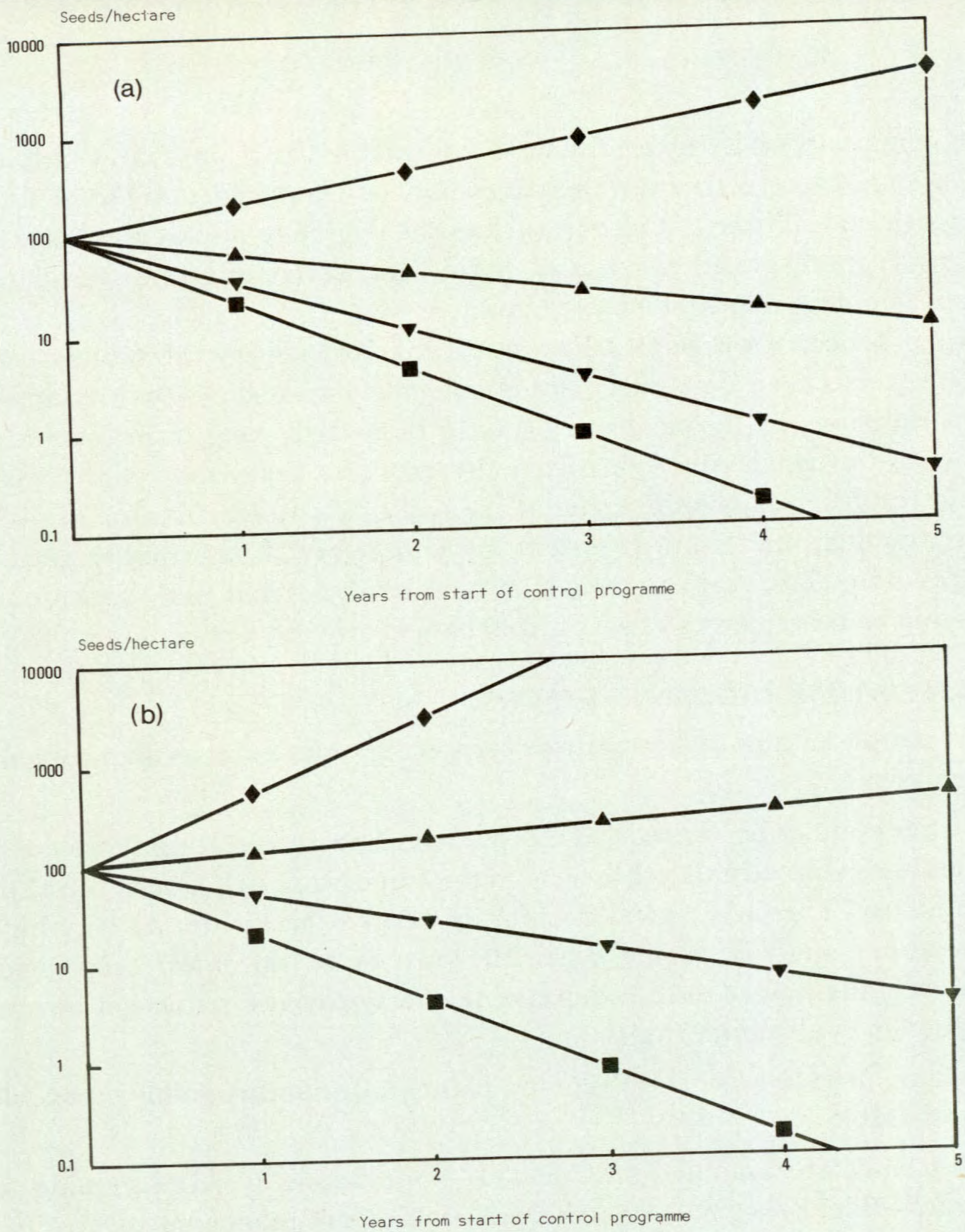


Fig. 2. Calculated changes in wild oat population, expressed as a logarithm of seed numbers per hectare in December over a period of 5 years. (a) Assumes mould-board ploughing in December each year and 70% mortality of freshly shed seed each autumn. (b) Assumes an early tine-cultivation system and 15% mortality of recently shed seed each autumn. ◆, no control measures. ▲, annual use of a herbicide reducing seed formation by 80%. ▼, annual use of a herbicide reducing seed formation by 95%. ■, complete elimination of seeding.

cultural system delays the achievement of 99% reduction of the seed burden by one year. In the least favourable cultural system, the delay is even more marked and a herbicide only reducing seeding by 80% would allow the population to increase.

These calculations suggest that the persistence of wild oat as a weed may be due not so much to persistence of its seed as to the inadequacy of

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