AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANIZATION

FOURTH REPORT
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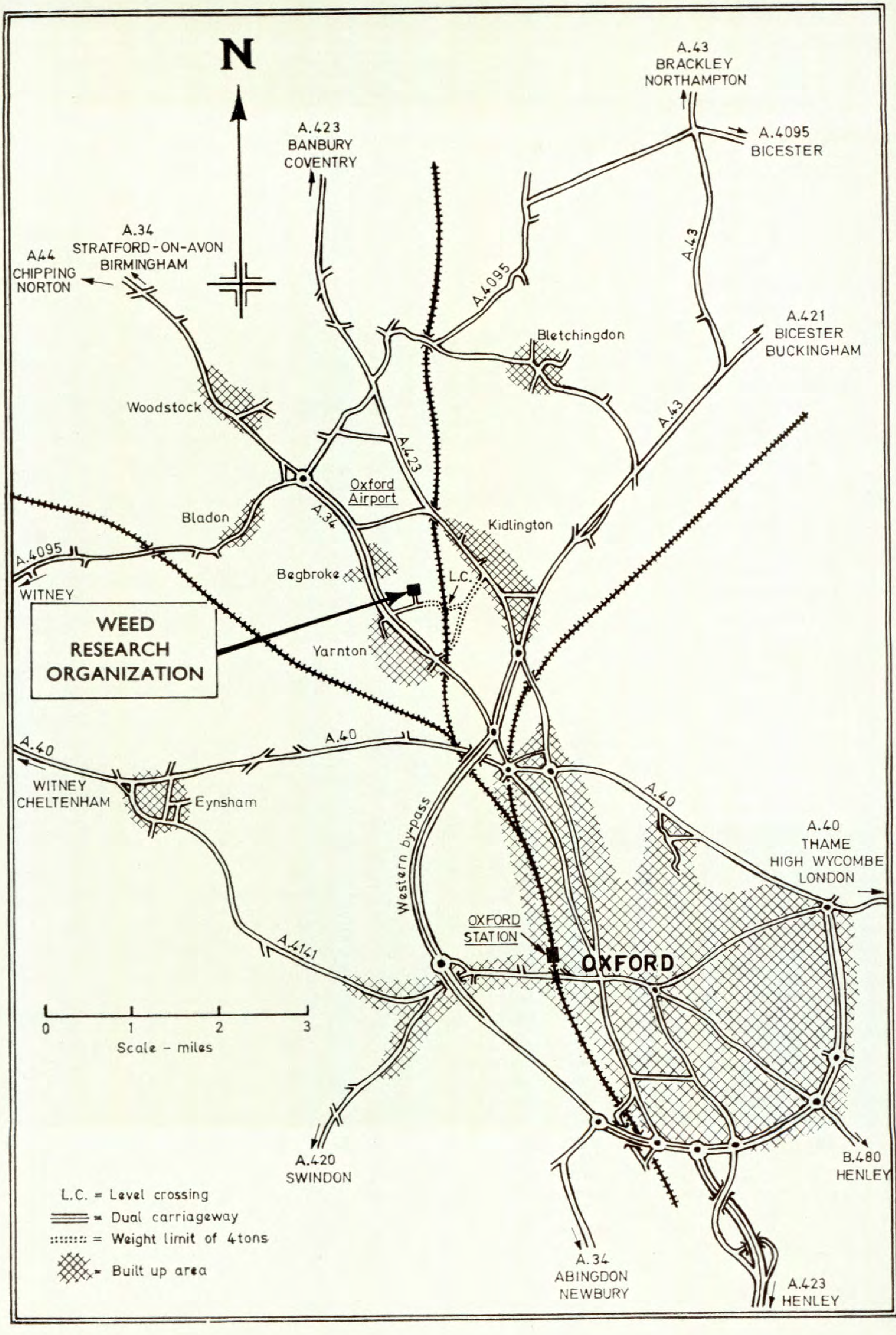
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HENLEY

Contents

Members of a WRO field team spraying one of the plots in a herbicide evaluation trial. The independent appraisal of the activity, selectivity and persistence of new herbicides produced by industry is an aspect of WRO research important to every farmer and grower.

Report of the Director

INTRODUCTION

The Weed Research Organization (WRO) celebrated its 10th anniversary in April 1970. Springing from one of the ARC's Units—the Unit of Experimental Agronomy in the University of Oxford's Department of Agriculture—it is an example of an institute that has had a brief solely for applied research to find answers to practical problems. In addition it has developed a self-made role as a centre for information and liaison. Although receiving no finance from the Ministry of Agriculture (MAFF) it was set up by the Agricultural Research Council (ARC) only after joint discussions with the Ministry had taken place and one of its functions was to provide technical 'back-up' to MAFF's agricultural and horticultural advisors faced with technical problems of herbicides and weed control. Much of the research programme is planned in consultation with MAFF specialists and carried out with their assistance on private farms or on the Ministry's Experimental Husbandry Farms and Horticulture Stations.

WRO is one of the 10 British research institutes directly controlled by the ARC and is mainly financed by funds made available by the Treasury through the Department of Education and Science. A grant from the Overseas Development Administration of the Foreign and Commonwealth Office supports additional research and advisory work on behalf of developing countries in the tropics. Another grant from the Commonwealth Agricultural Bureaux partially supports the production of the journal *Weed Abstracts* by the Information Section.

ROLE OF WRO

The principal object of WRO is to carry out applied research on weed problems and methods of weed control. Particular emphasis is given to chemical techniques. Although industry has been mainly responsible for the discovery and development of herbicides and plant growth regulators, escalating costs place increasingly severe restrictions on the amount and orientation of research and development that can be done by the parent firm and its associated companies. Much of the R and D effort available is aimed at ensuring efficient use in markets that can be economically exploited without too high a risk and obtaining information to meet the requirements of official safety and approval schemes of the countries concerned.

It has always been important for there to be an independent assessment of the properties of herbicides and their potential benefits and risks. At the present time increasing financial pressures on industry and a growing awareness of the large scale of herbicide usage by the public make the need for government-sponsored research both on herbicides and on alternative methods of weed and vegetation control more important than ever before. Such research is essential if the potential benefits of these remarkable chemicals are to be fully exploited and any risks associated with their use are to be understood and kept to a minimum.

The importance of herbicides as a sector of Britain's agricultural chemical industry is well illustrated by data issued by the Board of Trade. In 1970 total sales of pesticides by the larger manufacturers in Great Britain amounted to £38.7 million. Of this total herbicides accounted for £26.4 million or 68%, an increase of 12% on the corresponding figure for 1969. In contrast, sales of all other pesticides only increased by 6.5% in the same period, sales of insecticides actually falling by 5%.

ORGANIZATION OF RESEARCH

The main research programme of WRO is shared between two Departments, each comprising several sections. The Department of Weed Science undertakes research on the interactions between herbicides, plants and soils to assist in the development of new techniques of weed control, improve the reliability of existing methods and to detect and, if possible, solve incipient problems. In recent years that part of the programme concerned with the biology of weeds and the nature of weed/crop competition has become increasingly important. The Department of Weed Control has the task of assessing through surveys and research the technical nature and economic significance of weed problems and of difficulties encountered by farmers and growers in utilizing existing control measures. It undertakes research to widen the range of control options available and to provide producers with the necessary information to allow the most efficient to be selected to suit individual requirements. The Department also has a major role in investigating new possibilities in crop husbandry made possible by chemical methods for controlling vegetation.

The Overseas Section contributes to the research programme by evaluating the activity and selectivity of new herbicides in a wide range of tropical crops and weeds and investigating aspects of herbicide usage and weed biology of general importance in the tropics which can be conveniently studied in the glasshouse or laboratory.

INFORMATION AND LIAISON

In addition to its research functions, WRO serves as the main centre for information relating to weed research throughout the world. It helps also to provide liaison in Britain between all concerned with weeds and herbicides. A two-way exchange of information with the Agricultural Development and Advisory Service (ADAS) and the farming and horticultural community is greatly facilitated by the attachment of two ADAS officers to WRO: one an agricultural and the other a horticultural specialist. Close contact with the chemical companies concerned with herbicides is also vital and is assisted by the secondment to WRO of the officer responsible for recommending approval of new herbicides under the MAFF Agricultural Chemicals Approval Scheme.

Keeping in touch with R and D carried out within the agricultural industry, at universities and elsewhere as well as with commercial and regulatory aspects is also extremely important and is helped by the active participation of WRO in the affairs of the British Crop Protection Council (BCPC), an independent organization aimed at promoting the science and practice of crop protection through the co-operation of those concerned in industry and in farming, official and research circles. The organization of the programme of the biennial British Weed Control Conference and the preparation and editing of the BCPC Weed Control Handbook, now in its sixth edition, provide regular opportunities for the discussion and presentation of the most up-to-date information on all aspects of weed science including those applicable to the non-agricultural sector. Above all, these activities, with WRO taking the initiative and serving as a focus, help to foster a co-operative spirit between everyone concerned and to break down the barriers that sometimes exist between commercial and official interests.

THIS REPORT

The third biennial report of WRO was published in March 1969. Due to a change of policy this present report covers a span of three years—the period from 1st January 1969 to 31st December 1971. A new format has been used in which individual reports from research sections have been abolished. These could no longer provide a satisfactory account of the many intersectional activities now featuring in the programme and have been replaced by an extended Director's Report which highlights selected topics of research considered to be noteworthy. Supported by a number of review articles aimed at placing some of the WRO research and achievements in perspective plus a few pages of essential records, it is hoped that this report will be more readable and interesting than its predecessors and will give a better idea of the purpose and achievements of the institute. Further reports will be issued biennially.

THE RESEARCH PROGRAMME

INTRODUCTION

Every three years detailed proposals for the research programme with estimates of staff, equipment and facilities required are submitted to ARC Headquarters. These are considered by members of a Visiting Group in consultation with scientific and administrative staff of the Council's secretariat during a two-day visit to Begbroke during which senior staff are invited to discuss their work. The Group then submits a report to Council and this, together with the institute's proposals, serves as a blueprint for all concerned for the next 3-year period. The last Visiting Group exercise took place in May 1970. Members were: Professor P. W. Brian, F.R.S. (Professor of Botany, University of Cambridge), Chairman; Professor S. H. Crowdy (Professor of Botany, Southampton University); Sir Emrys Jones (Director General of ADAS); Mr. J. S. Martin (farmer and a Council member of ARC); Professor R. L. Wain, C.B.E., F.R.S. (Professor of Agricultural Chemistry, Wye College). The Group were accompanied by Mr. D. J. Parkinson, O.B.E., Professor Helen Porter, F.R.S., Dr. D. Rudd Jones and Dr. C. C. Webster, C.M.G., of the ARC secretariat.

No major changes were proposed to the 1970 Visiting Group but some valuable strengthening of some existing projects was agreed. The programme has become increasingly 'problem-orientated' as the result of a conscious effort to deploy the resources available on a few really important topics rather than spread the net ineffectively over too wide

A Letcombe Laboratory member of the Joint WRO/Letcombe Cereals Tillage Project assesses the effect of various tillage treatments on soil compaction.

a field. Much of the programme is now concerned with difficult grass and perennial weeds and with herbicide/soil relations. As the number of specific problems tackled has become whittled down so the depth and breadth of the research needed for the remainder has increased. Inter-departmental and inter-sectional programmes are now the rule rather than the exception and collaboration with other research institutes or organizations having experience or facilities complementary to those of WRO has become increasingly vital. Particularly notable during the period under review has been the development of truly joint research projects shared between WRO and its sister ARC institute the Letcombe Laboratory near Wantage. One of these (see p. 16) has for the first time brought into the programme of WRO a topic that has only slender connections with weeds and herbicides. The production of crops by reduced or even without soil cultivation stems directly from the ability of herbicides to control weeds without soil disturbance and has already allowed enormous economies in a wide range of agricultural and horticultural crops. However, many problems still remain which can only be solved by a better understanding of the basic relationships between crop growth and soil conditions, a subject fundamental to the whole of agriculture. The joint WRO/Letcombe tillage project is aimed at finding out how cereals react to specific soil conditions created by different tillage practices and makes good use of the complementary skills of the two institutes. It is part of a wider programme on this topic sponsored by ARC, the need for which was highlighted by the Ministry of Agriculture's recent report—'Modern farming and the soil'. Other collaborative projects are indicated in the list on p. 102. It is a pleasure to take this opportunity to thank the many colleagues at the institutes concerned, those in ARC Headquarters and members of our Visiting Group for lending support to these projects.

Because of the importance attached by the Directors of both institutes to this and to another joint Letcombe/WRO project on the availability and fate of herbicides in soil—as examples of reduced autonomy of institutes and pooling of resources to serve a common cause—it has been agreed that the names of members of the joint co-ordinating committees will be published in each institute's report (see p. 102). The two institutes also share a Joint Statistics Section. Its members are based at Letcombe but regularly visit Begbroke to advise on statistical problems and to undertake data-processing on behalf of WRO staff.

CONTROLLING WILD OATS

Wild oats (*Avena fatua* and *A. ludoviciana*) are causing unprecedented concern in the United Kingdom and are spreading into previously uninfested areas of Scotland and Northern Ireland. The biological, climatic and economic factors responsible for this explosive increase in wild oat populations and the current status of control measures are described on pp. 50–7. Much effort is currently being devoted by WRO to wild oats over as wide a front as possible. The programme is being contributed to by many of the research teams and joint research projects are under way with Rothamsted Experimental Station and the ARC Letcombe Laboratory, ADAS and others. Some of the more significant findings during the past three years are mentioned below.

The activity of tri-allate granules

The discovery by WRO of the post-emergence activity of the wild

A WRO experimenter applying tri-allate granules. The present approved recommendations for the use of the granular formulation for pre- and post-emergence control of wild oats in cereals are largely based on WRO research.

oat herbicide tri-allate, when formulated as a granule, was mentioned in the Third Report. Since then further research in the field and the greenhouse by members of the Herbicide Evaluation Section has established the importance of several factors which may influence the effectiveness of this formulation. First, it has been established that there is little or no effective entry of tri-allate into the plant through the root system. The main route into emerged plants appears to be through the stem at, or just below, the soil surface. Movement of the tri-allate from the granule to the plant can occur entirely in the vapour phase.

Second, the increased action of tri-allate on emerged wild oat plants when applied as granules rather than in the conventional spray emulsion has been explained on the basis of the reduced rate of vapour loss of tri-allate from granules under moist soil conditions (see also p. 46).

Third, the results of 46 field experiments have already demonstrated the relatively long period over which the granular formulation can be used to control wild oats in both winter and spring wheat or barley, extending from immediately after drilling to early post-emergence. However, after the 2.5-3.0 leaf stage the resistance of the wild oats increases and the effect of the herbicide is markedly reduced.

It is on the basis of WRO research and the manufacturer's own development programmes that approved recommendations for the use of tri-allate granules by the farmer as either a pre- or post-emergence treatment have now been made.

Herbicide application glove

The hand-roguing of wild oats, although an unwelcome procedure, is a vital step in eradication or control programmes. In an attempt to speed up this time-consuming and expensive operation a special glove has been developed by the Herbicide Evaluation Section with which the operator can apply controlled amounts of herbicide to panicles of individual wild oats in a crop (see page 52). This glove has been patented through the National Research and Development Council, a manufacturer has been licensed and it is hoped that it will be available commercially in the near future. In addition to the control of wild oats, the glove has a potential for the direct selective application of herbicides to other problem weeds of agriculture and horticulture both in the UK and overseas and also in the home garden.

Weed competition

Studies on the mutual competition between wild oats and spring cereals have formed a major part of the programme of the Botany and Agronomy Sections. The object is to obtain data which will allow the principles of the interaction to be understood and advice to be given about the potential reduction in crop yield by a given infestation. At the present time farmers have little guidance as to the level of expenditure on herbicides likely to be justified in terms of increased crop yields or on how the timing of wild oat control affects the yield response. Recent work in Canada has suggested that damage to the crop occurs at a very early stage, perhaps even before the crop emerges, but WRO field experiments have indicated that serious competition begins to occur rather later, probably at about the two-leaf stage. This suggests that pre-emergence and early post-emergence control measures such as the conventional use of tri-allate or barban and tri-allate granules are all equally suitable in reducing or preventing yield reductions. Further work is required to confirm this.

Crop competition

With both wild oat and couch grass (*Agropyron repens*) work by the Botany and Agronomy Sections has provided evidence of the crucial competitive role of crop plants in controlling weed development. Field experiments by the Agronomy Section have yielded much information on the suppressive effect on both species of spring wheat, barley and field beans, also on the effects of variety, row width and seed rate of barley. In many respects there has been a marked similarity between the two weeds. Both develop much more strongly in field beans than in wheat or barley. Generally the most competitive crop of all has been spring barley and, with this crop, the most powerful factor within a farmer's control has been seed rate. In each of 3 successive years, doubling the seed rate of barley from 80 lb/ac to 160 lb/ac has approximately halved the number of wild oat seeds produced from a given weed population. The weight of couch rhizome recorded at cereal harvest has been similarly reduced.

Since crop-weed competition is a dynamic process, any factor which reduces weed performance in this way also reduces the effect of the weed on crop yield. Thus, in some of these experiments, crop yield has been unaffected by change in seed rate in the absence of weeds but, in the presence of wild oat, has been significantly greater at the high seed rate. There are a number of factors to be considered in deciding on optimum seed rate, mostly unrelated to weed control, but these results indicate the adverse consequence of reducing crop seed rate on land infested with grass weeds.

By contrast, changing plant arrangement by reducing crop row width from 8 in. to 4 in. has had only limited and not entirely consistent results on weed growth. A limited range of spring barley varieties including prostrate and erect types has also been tested and the variation in competitive ability found to be relatively small. However, if plant breeders achieve increased yield potential from cereal varieties with a short erect habit of growth and relatively sparse tillering, the advantages that are gained may have to be set against increased weed growth or a more stringent demand for weed control.

Wild oat seeds in cereal stubble. Late harvests increase the number of seeds entering the soil; early harvests increase the contamination of crop seed and straw.

The fate of wild oat seed

One of the factors determining the fate of seeds of wild oat has been found to be the time at which they are shed from the parent panicle relative to crop maturity and harvest. Shedding occurs over a period of 3-4 weeks and is usually about 80% complete by the time of crop harvest. However, the process is very dependent on the speed of maturity of both crop and weed and on the period between crop maturity and harvesting, which may be considerable. In limited observations on farm crops the extremes encountered were (i) a winter barley crop in which only 16% of the wild oat seed had shed before crop harvest in mid-July, and (ii) a spring barley crop in which 95% of the seed had shed before harvest in mid-August. It is now quite certain that, irrespective of harvest date, the bulk of wild oat seed finds its way to the soil surface.

These results obtained by the Agronomy Section have several practical implications. The earliest shed seeds have a period of 3-4 weeks in which the alternate flexing of their awns may propel them into cracks in the soil and under clods. The later that shedding occurs in relation to harvest, the greater the numbers of seed recovered in the grain or straw. Seed in a straw swathe may be vulnerable to burning but seed in straw that is baled represents a potent source of contamination wherever the straw is used. Some attention has been paid to this problem and the numbers of seed found have ranged from 4-304 seeds/lb of baled straw. It has been concluded from the results of this study that any crop in which wild oats are present will give rise to contaminated straw.

CONTROLLING COUCH

A significant feature of the past few years has been the acceptance by a large number of farmers of the need for a systematic approach to the control or containment of true couch grass (*Agropyron repens*) and the very similar black bent (*Agrostis gigantea*) which is also generally referred to as 'couch', 'wicks' or 'wickens'. Moreover it is now no longer exceptional for farmers to accept the need to integrate the harvesting of one crop with land preparation for the next. The intensive perennial grass weed programme of WRO, supported by work of colleagues in ADAS, has played a leading part in reducing the status of this problem by providing the cereal farmers with explanations for actions which in the past have been less convincingly a matter of judgement. Dry weather in three successive autumns has, of course, also helped. Much of the relevant work of the Botany and Agronomy Sections was reviewed in the WRO Third Report. Of particular value were the investigations of patterns of rhizome growth following fragmentation which showed the need for an early start to control, also for straw disposal and stubble break-up by cultivation to be planned as a part of the harvest programme.

The role of cultivations

The importance of cultivation in systems of couch control has long been recognized in the minds of farmers and advisers, though largely in terms of desiccation of the rhizomes. It is now clear, however, that the key role of cultivations is the fragmentation of the rhizomes to stimulate their dormant buds into an active and therefore vulnerable

Post-harvest cultivation of cereal stubble for couch control at WRO. The aim is to fragment the rhizomes to stimulate dormant buds into active growth, rendering them vulnerable to subsequent cultivations or sprays.

state. What has been lacking has been the means to exploit economically and effectively this Achilles Heel.

Although the value of the rotary cultivator has been well recognized it has generally been used to make two or three passes at very slow speed. Fail* in his original work reported instances of good results from a single pass, but the fear has persisted that one cultivation would do no more than spread and worsen an infestation as indeed it can do if no appropriate follow-up action is taken.

In a series of experiments conducted by the Agronomy Section in the wet autumn of 1968 a single rotary cultivation set to give a very coarse chop and followed after an interval by ploughing, reduced shoot emergence of couch grasses by an average of 80% the following spring. Other more recent experiments have given a similar result.

Tined and disc cultivators have been similarly investigated. The former can give good results by disrupting the rhizome system provided it is operated at high speed and at a shallow depth. Many farmers make the mistake of working too deep and too slow, or they fail to move all the ground even with two passes. Discs suffer from uneven penetration of the surface but can also be most useful at high speed in follow-up cultivations.

The research programme has also included the herbicide TCA, which has shown a remarkable surge of extensive use by farmers during the past few years after having attracted relatively little attention for some twenty years. In the wet conditions of 1968 activity was high and, although the best control of couch was obtained from combinations of cultivation and herbicides, there was no difference between TCA worked in by cultivation and TCA applied after cultivation. In subsequent, drier years activity has been slightly higher following incorporation. In most of these experiments, the cultivation effect and the herbicide effect appeared to be independent; there was no evidence of an interaction when results of cultivations and herbicides applied separately and together were compared.

Since the publication of the Third Report the technique of couch control by repeated applications of paraquat at low dose has also been developed and shown to be a useful technique in a variety of farming conditions and to be particularly valuable when the weather is too wet to permit cultivations.

It can now be reported that, with the availability of a range of herbicides and with increased confidence in the role of cultivation, based on principles elucidated by WRO research, many farmers have been able to evolve for themselves economical systems of perennial grass weed control. Whilst favourable weather has undoubtedly helped, there is no reason why these systems should not stand up to the test of a series of wet autumns if farmers are prepared to make modest use of herbicides, instead of letting the couch grow, when the land is too wet for cultivation.

New herbicides

Rhizome production by couch grasses is normally at its peak in late summer and autumn. In a cereal system herbicides can be used then to control couch without risk of crop damage. Dalapon, TCA and aminotriazole have been used for many years with varying success and at considerable cost. In the hope of finding alternative treatments the Herbicide Evaluation Section has examined many new herbicides supplied by industry. The most interesting newcomer in the past three

* (See opposite) FAIL, H. (1956). The effect of rotary cultivation on the rhizomatous weeds. *J. agric. Engng Res.*, *1* (1), 68–80.

years has been a chemical originating from Japan, sodium 2,2,3,3-tetrafluoropropionate (Orga 3045). This has given good control of couch when applied at doses in the range 2-4 lb/ac either pre- or post-emergence in spring or autumn. In field experiments best results came from application to the cereal stubble after cultivation in the autumn. In one case an ensuing spring barley crop gave, in consequence, a 12% yield increase.

Effect of environment on herbicide performance

The activity of a number of herbicides with some potential for controlling couch grass has been examined under a range of climatic conditions in the controlled environment laboratory of the Herbicide Evaluation Section in the hope that optimum conditions of use can be prescribed and attention drawn to conditions when application is likely to give poor results. Particular attention has been paid to activity at low autumn temperatures as couch continues to grow in all but the coldest weather.

Most of the herbicides tested had an equal or lower performance at 6°C compared with 16 and 26°C. The exceptions were maleic hydrazide and paraquat the long-term effects of which were greatest at low temperature.

This result with paraquat was followed up in field experiments made during the autumn and winter. In one instance even treatment of frost-covered couch plants was highly effective. In addition to low temperature, autumn application of paraquat is favoured by other environmental factors including short days, low light intensity and high humidity.

In both growth cabinets and field experiments the contact action of paraquat developed more slowly at low temperatures, regrowth took longer to appear and production of chlorotic leaves continued for a longer time. Autoradiographs of couch plants in which a single leaf was treated with ^{14}C-labelled paraquat indicated that at high temperature, almost all the paraquat was confined to the treated shoot while at low temperature the herbicide moved into other shoots and rhizomes. It is when small quantities of the chemical move in the plant, at concentrations below those required for cell destruction, that the other manifestations of damage occur. In developing tissue, chlorophyll formation is impaired and chlorotic leaves are formed, draining the food reserves of the plant. Furthermore, in recent experiments, where

Frost-covered, paraquat-treated couch grass. The performance of this contact herbicide has been shown to be considerably enhanced at low temperatures.

paraquat solution was fed into the cut end of a detached couch rhizome, it was found that less than 1 ppm of paraquat would permanently prevent the growth of buds thereon.

This work confirms the view that the enhanced performance of paraquat at low temperature is associated with increased mobility of the chemical in the plant. Further experiments are now in progress examining combinations of paraquat with other chemicals in the hope of improving its mobility, and its potential for couch control, still further.

Chemicals and bud dormancy

When couch rhizomes are fragmented by cultivation dormancy of the rhizome buds is temporarily broken and some shoots grow to form new plants. The remainder are quickly suppressed by natural growth inhibitors, a process often described as apical dominance. The Botany Section has been studying the effect of various chemicals on the dormancy of rhizome buds and shoots to see whether it can be broken or its re-imposition prevented. So far two chemicals, 'Ethrel' and chlorflurecol-methyl, have proved active in the laboratory. Both chemicals can interfere with the dominance system in rhizomes. Shoots continue to grow which not only helps to exhaust food reserves in the rhizome but could, in the field, make them more vulnerable to control measures.

GRASS WEEDS IN GRASSLAND

The current situation regarding weed control in grassland is reviewed in the article on p. 66. As the authors rightly point out, this has not been a field remarkable for the swift adoption of new techniques but it can now be reported that the pioneer work by WRO on the use of dalapon for sward improvement is at last receiving recognition. Recent research by the Agronomy and Herbicide Evaluation Sections on herbicides for the selective control of weed grasses in grassland is briefly reviewed elsewhere and so is not dealt with here.

Weed status of rough stalked meadow grass

Most intensively managed ryegrass pastures are invaded by rough stalked meadow grass (*Poa trivialis*) at some stage after sowing. Competition experiments have been started by the Agronomy Section to establish whether the presence of meadow grass either augments or limits total seasonal production from ryegrass pastures. Early results from microswards, made up of monocultures and mixtures of the two species, indicate that meadow grass produces less dry matter than ryegrass, particularly after flowering and whenever soil moisture is limiting. Under the conditions of the experiments mixtures containing equal proportions of the two species produced approximately 70% of the yield of the pure ryegrass. These early results support the belief that meadow grass can be considered an undesirable species in ryegrass swards.

MINIMUM TILLAGE AND CROP ESTABLISHMENT

Research on tillage might seem out of place in an Institute primarily concerned with weeds; there are, however, good reasons for the association of the two subjects. Weed control has long been one of the more important objects of cultivation. Chemical herbicides that control weeds without soil disturbance allow a re-examination of the traditional practices of soil cultivations: a particularly appropriate activity at the present time because of the increasing scarcity and rising cost of farm labour and recent fears that, on some soils at least, problems of soil structure are making themselves felt.

Cereals

As part of a joint research programme with the ARC Letcombe Laboratory, the Agronomy Section started in 1968 a programme concerned with the tillage requirements of cereals. The first large scale field experiment using normal field equipment was carried out on sandy loam soil at Begbroke Hill to investigate the influence of reduced tillage on root and shoot development of spring barley. Subsequently the programme was extended to include barley grown on chalk and on clay, and experiments are about to start on winter wheat grown on sandy loam and clay. A further winter wheat experiment on chalk will follow. The programme will thus eventually include studies of two cereals on three soils.

The treatments which are common to all experiments are:

Mouldboard ploughing Deep tined cultivation Shallow tined cultivation	After these three different primary cultivations, the soil surface in each case is worked down to a suitable tilth
No cultivation	

Each experiment runs for at least three harvests in order to assess any short-term cumulative effects and an indication of the influence of weather.

A characteristic of the experiments is the very detailed nature of the assessments that are made on both the aerial and subterranean performance of the crop plants. Extraneous factors such as weed competition that might differentially affect the crop are avoided and all managerial treatments apart from cultivation are kept uniform.

The results so far may be summed up thus: while only minor differences in the vegetative growth of aerial parts of the cereal plants have occurred there have been substantial differences in root growth (deep-rooting being associated with deep cultivation) but all the crops have yielded as well as adjacent commercial crops and differences in grain yield between treatments have, on the whole, been insignificant.

When economy of cultural input is equated to output the optimal primary treatment appears to have been shallow tined cultivation.

Field experiments of the type just described have unavoidable sources of variability, of which the two most serious are the compaction caused by wheels and the possibility of variable depths of implement penetration when controlled by tractor hydraulics or land wheels.

To eliminate these an experimental area at Begbroke Hill has been provided with concrete tracks laid in the soil. An MF 165 tractor has been equipped with row-crop wheels set at 104 in. centres so as to travel on the tracks. Equipment necessary for cultivation, sowing, fertilizing, spraying, irrigating etc., has been developed for use on the tracks. In addition to guiding the wheels the tracks also provide a datum level for controlling the penetration of implements. A mobile scaffold allows assessment of soil or crop without placing wheels or feet on the ground. One advantage of the technique is that it uses mostly mass-produced equipment and is, therefore, relatively cheap to set up.

The current investigation based on the 'tracks' is also part of the joint cereal programme with the Letcombe Laboratory. It involves a critical study of root and shoot growth of spring barley under stress conditions caused by specially compacted or very loose seedbeds under both wet and dry conditions.

Grass and fodder crops

In grassland, tillage research at WRO has concentrated on the germination and establishment of crop seeds in the unconventional soil surface left by herbicide spraying. The environment of a sprayed sward involves three main materials: mineral topsoil, vegetative mat and dead trash. In considering direct seeding of crops into such swards it is necessary to determine the extent to which each component of the seedbed needs to be modified (if at all) to provide a healthy environment for seed germination and establishment. A micro-plot technique has been developed to allow the study of the behaviour of individual seeds or seedlings.

During the past 18 months comparisons have been made in field experiments of the performance of ten crops on mineral soil which has received ploughing, shallow cultivation or no disturbance. The results have been consistent: in the absence of substantial trash and mat all the crops have germinated and established as well without cultivation

Tillage investigations without 'wheelmarks'. This experimental site at Begbroke is provided with concrete 'tracks' to avoid the soil compaction caused by tractor wheels and enable accurate control of implement penetration.

as in the cultivated seedbeds. The programme is now moving on to consider the effects of dead vegetation on the soil surface.

The rapid decomposition of a killed sward is essential to the success of reduced cultivation techniques of crop establishment. The Microbiology Section examined the decomposition of young ryegrass grown in the greenhouse and sprayed with dalapon, aminotriazole and paraquat. Untreated grass dying slowly and grass killed by heat were also included, the latter to simulate the rapid killing action of paraquat. All were incubated under laboratory conditions optimal for decomposition. Paraquat-treated grass decayed more slowly than heat-treated grass. The possibility that paraquat treatment can significantly reduce decomposition through an effect on the saprophytic microflora involved in degradation of plant materials is under investigation.

Hogweed (*Heracleum sphondylium*) is resistant to simazine and can seriously affect the yield of blackcurrant and other bush fruit crops. Effective control has been achieved in WRO experiments.

HORTICULTURAL WEED CONTROL

In addition to the research on the persistence of certain herbicides in the soil, which is reviewed in the article on p. 58, the Horticulture Section has devoted considerable attention to the control of those perennial species which now constitute the major weed problem facing fruit growers.

Bindweed

Bindweed (*Convolvulus arvensis*) occurs widely in arable situations but it only thrives in the absence of competition from other vegetation. At Begbroke Hill transplants growing in weed-free conditions have spread 20 feet in a single season but similar plants, when in competition with blackcurrants, have made hardly any growth after three seasons. It would appear that the proliferation of this weed is a result of the practice in fruit culture of creating large areas of weed-free ground which are not disturbed for long periods.

In tree-fruit crops several growth-regulator herbicides (MCPA, 2,4-D, 2,4,5-T and MCPB) have been used on a considerable scale against bindweed. The shoots are usually killed during the season of treatment but major reductions are seldom achieved. Few comparative studies on the herbicides have been made and the conditions under which the best results from each can be obtained are not at all well known. The object of the research programme of the Horticulture Section has, therefore, been to determine the most effective herbicide in preventing regrowth in the year of treatment and in subsequent years and to define the conditions under which the optimum results can be obtained. The research to date has indicated that MCPA and 2,4-D are more effective than 2,4,5-T and MCPB. In the case of 2,4-D, dosage does not appear critical in the range 2-8 lb/ac but timing is important and treatment in mid-summer has proved the most effective. High doses (12 lb/ac) of MCPA, 2,4-D and 2,4,5-T applied to the soil surface have not resulted in any adverse effects on four cultivars of apple but pears have been damaged, sometimes severely, by root-uptake from similar treatments. The cultivar Conference is more susceptible in this respect than Williams. 2,4-D is more damaging than 2,4,5-T and MCPA. Although the results have indicated that there is only slight risk of damage to Conference at the minimum dose needed for weed control (2 lb/ac), it would seem sensible to use one of the safer alternatives since 2,4-D has caused damage to commercial crops.

There is less scope for using growth-regulator herbicides in bush fruit. In these crops the performance of the soil-acting herbicides chlorthiamid and dichlobenil has been investigated in field experiments. In gooseberries it has been shown that both can give sufficient control of bindweed to keep bushes free, at least until after fruit picking. Such control is worthwhile because the presence of the weed on the bush tends to increase the picking time and, therefore, the cost of this operation. Gooseberry and to a lesser extent blackcurrant have on occasions developed leaf-margin chlorosis following application of chlorthiamid and dichlobenil. These symptoms, thought to be due to a breakdown product of the herbicides, can also occur in the year following application. The symptoms in gooseberries were not associated with a reduction in yield and doses of chlorthiamid five times those recommended have not affected growth or yield of blackcurrants.

In collaboration with the Chemistry Section, gooseberries treated with dichlobenil and chlorthiamid at rates up to 35 lb/ac (3.5 times the commercial dose) have been examined for residues. No significant trace of the parent herbicide was found but the breakdown product 2,6-dichlorobenzamide was present in quantities of up to 0.45 ppm. In addition, treatment with these herbicides was shown to increase the vitamin C content of gooseberries though it had no effect on that in blackcurrants.

Hogweed

Hogweed (*Heracleum sphondylium*) is an example of a very common wild plant that flourishes in fruit crops, notably blackcurrant, which are subject to herbicides and non-cultivation. The Horticulture Section has given emphasis to control measures for initial infestations which may consist of a few isolated plants. Cutting 3 in. below the soil surface gives an immediate kill of shoots and prevents the regrowth of even mature plants. Localized application of chlorthiamid or dichlobenil is effective and simple but these chemicals must be applied before mid-May if further seeding is to be prevented. Small seedlings can be controlled with paraquat. Infestation can be prevented at an early stage by such methods. However, if the weed is allowed to spread it can have a serious effect on crop yield. It cannot be controlled by any of the overall treatments at present recommended in blackcurrants but for other fruit crops there is a choice of herbicides. Both terbacil and bromacil have given good control when applied pre- or post-emer-

The herbicide asulam has consistently given good control of bracken in WRO and ADAS experiments, like the one being sprayed here.

gence. Aminotriazole has given good control when applied post-emergence.

CONTROL OF BRACKEN

Bracken (*Pteridium aquilinium*) has always been a problem to the hill farmer and forester. However, owing to the low value of hill land, and many technical problems in the effective and safe use of herbicides, chemical methods of bracken control in grazing land in Britain have so far made little progress and chemical manufacturers do not pay much attention to this plant in their search for new herbicides.

At WRO however, interest in bracken and a small amount of experimental work have been a feature of the programme for many years. As a result of work in 1967 by the Herbicide Evaluation Section the pronounced activity of asulam first came to light. This finding was followed up by a series of field experiments by WRO and ADAS, the results of which have been consistently promising. The herbicide has to be applied during the period between full frond emergence and the onset of senescence when doses of 2-4 lb/ac active ingredient can give very good control for at least 2-3 years. ADAS, the Scottish Colleges of Agriculture, the manufacturers and WRO are now all involved in a development programme and there is likely to be an approved recommendation for this use by the summer of 1972.

WOODY WEEDS

The Herbicide Evaluation Section's project on the effect of herbicides on woody plants which may be troublesome as weeds has had two main objectives. First, new compounds and certain established herbicides have been tested for activity against woody species: as with bracken, manufacturers seldom screen herbicides specifically for activity on such plants. Second, research has been undertaken to increase the effectiveness of those herbicides already in use.

A total of eighteen new chemicals and twenty-three agricultural herbicides have now been applied to five standard test species—pot-grown privet, poplar, willow, beech and Norway spruce—using a range of doses applied to foliage or soil. Some new compounds have been found to be very phytotoxic to woody plants but of greatest interest are the results obtained with the old-established herbicides mecoprop and dichlorprop. These relatively cheap compounds have proved to be at least as phytotoxic towards certain woody species as 2,4,5-T, the main active chemical in many well known proprietary scrub control products. Even MCPA, a herbicide which is generally inactive towards woody plants, has been found unexpectedly effective as a foliage treatment for poplar and willow.

The ability of various additives to enhance the activity of established herbicides has also been examined. Particularly interesting results have been obtained with certain organo-phosphorous compounds. Early in the programme tri-*S*-butyl phosphorotrithioate, a cotton defoliant, was found to act as a synergist in mixture with water-soluble growth-regulator herbicides. More recently tributyl phosphate and technical mixtures of acid butyl phosphates, cheap and of low mammalian toxicity, have also been shown to increase the effectiveness of these herbicides. Tributyl phosphate is known to increase the phytotoxicity of aminotriazole as well. Such synergistic additives may well provide the key to a new range of cheap efficient herbicide formulations for woody weed control.

Synergistic enhancement of the activity of mecoprop salt on guava (*Psidium guajava*) by tributyl phosphate. Cheap, low toxicity additives of this kind may provide the key to a new range of woody weed herbicides.

AQUATIC WEED CONTROL

The programme for the Aquatic Weeds Section is reviewed annually by the ARC Technical Committee on Aquatic Weeds whose membership includes representatives of research organizations, MAFF and other authorities with a wide interest in the biology and management of freshwater.

One of the main objectives in the period under review has been to increase the efficiency of dalapon, one of the few herbicides cleared by the Pesticides Safety Precautions Scheme for safe use in aquatic situations and widely used to control the major emergent water weeds. Dalapon has been recommended for a number of years but results have not always been satisfactory and regrowth has often occurred in the year following spraying. The reason for this was considered likely to be the poor translocation of the herbicide in the plant, a process associated with the movement of photosynthates. Since many perennial grasses build up food reserves in their rhizomes and roots after flowering it was thought that the time of application of dalapon might be critical in influencing movement to the perennating organs. A series of field experiments started in 1968 has shown that the susceptibility of reeds and sedges to dalapon does indeed increase towards the end of the growing period but more so with some species than with others. For instance, the sedge (*Carex riparia*) which flowers in the spring was completely eliminated by dalapon applied after the beginning of July, while in the case of the summer-flowering reed mace (*Typha angustifolia*), the best results were achieved by spraying in September.

The project undertaken in collaboration with the Salmon and Freshwater Fisheries laboratory of MAFF to study the use of the herbivorous Chinese grass carp for the control of submerged aquatic weeds has been continued and the preliminary findings reported. The results have been promising but more information is required on the behaviour of the fish, the stocking densities and the effect on other species.

The provision of a laboratory and a greenhouse in 1969 made possible the initiation of several new projects on chemical control of aquatic plants in which increasing emphasis has been placed on submerged vascular plants and filamentous algae. From these studies data have been obtained on herbicide persistence, dissolved oxygen and pH levels and changes in plankton and periphyton populations as well as on the weeds themselves.

Work was started on the biology and control of one of the most troublesome filamentous algae, *Vaucheria dichotoma*. Methods for identification and culturing it in the laboratory has been worked out and preliminary studies of the effect of a range of herbicides on it have been completed. These will now be followed by larger-scale field experiments on its control.

APPLICATION OF HERBICIDES

Some attention has been given to the ways in which changing the physical characteristics of the spray application may influence the phytotoxicity of herbicides. In a joint research programme with the National Institute of Agricultural Engineering the Herbicide Evaluation Section has been making a detailed study on the effect of droplet size on the retention of spray on the plant and on the effectiveness of a small range of herbicides contained in drops of different dimensions. The project is still in its early stages but from the practical point of view there already is hope that it may prove possible to reduce substantially, without loss of effect, the volumes of liquid in which herbicides are applied and hence to improve the logistics and economics of the spraying operation.

ANALYSIS OF HERBICIDES

The Chemistry Section has continued to provide the analytical service essential to the work of the other Sections. This has required the development of several new methods of analysis. During the last three years procedures have been devised for the analysis of 2,4-D, simazine, dichlobenil, diuron and diquat in water samples, for 2,4,5-T and picloram in woody plants and soil and for tri-allate in cereals. In addition a thin-layer chromatographic system has been produced for the identification of the substituted ureas. An alkali flame ionization detector has been constructed for the measurement of nitrogen compounds and is now in routine use for triazine analysis by gas chromatography.

A manual of these analytical methods for herbicide residues, devised or refined at the WRO, has recently been published in the form of a Technical Report.

Work of a more speculative nature has been undertaken to evaluate the potential of polarography for herbicide residue analysis. The behaviour of thirty-eight compounds that were likely to be polarographically active has been surveyed and of these twelve showed potentially useful responses.

HERBICIDES AND THE SOIL

Whilst WRO primarily exists to undertake applied research on methods of weed control for the benefit of agriculture and horticulture in Britain, in order to obtain the essentially practical results of interest to the agricultural industry research of a more fundamental nature must often be pursued concurrently with applied research. This is nowhere more evident than in research on the inter-relationships of herbicides and soils undertaken to achieve greater reliability and an understanding of possible undesirable side effects. The necessary variety of approach is well illustrated by the projects described here.

Weed control in organic soils

A two-man team from the Herbicide Evaluation Section was established at the Arthur Rickwood Experimental Husbandry Farm of MAFF in 1968 to undertake a joint ARC/MAFF project to develop more effective herbicide treatments for the serious weed problems on the highly organic soils of the fens. A particularly valuable outcome of this project has been a practical method of extending to peat soils the application of the herbicide lenacil, commonly used in mineral soils for the pre-emergence control of weeds in sugar beet.

When applied to the surface of fen soils, in the conventional way, lenacil is often ineffective due to adsorption by the organic matter. However, it has been found that if the surface application is incorporated with the soil, with careful attention to depth and thoroughness of mixing, a satisfactory level of weed control can be achieved. A special machine, christened a 'rotobar', has been devised at WRO to mix the herbicide into the top 2 in. of soil. Treatments using this machine have been found to be more effective than when other machinery such as a standard rotary cultivator or reciprocating harrow has been used for incorporation. The practical recommendations for lenacil use on sugar beet weeds in fen soils now being made by the manufacturers are a direct consequence of these investigations by the WRO team.

The effects of continuous use of herbicides

There have been numerous references made in recent years in the communications media to the possibility that the ever-increasing use of herbicides may have an adverse effect upon soil fertility and upon crop health, yield and quality. In anticipation of such concern, some long-term experiments specifically designed to provide objective information on this subject were laid down at Begbroke in 1963. Four common herbicides—MCPA, tri-allate, simazine and linuron—were chosen to represent the important phenoxyacetic acid, carbamate, triazine and urea 'families' of herbicides. These herbicides were applied every year to the same plots, in crops in which they could be used at the normal time and rate of application. Thus MCPA and tri-allate were applied to plots of barley and wheat, simazine to maize, and linuron to carrots. Uncropped plots also received annual applications of the same herbicides but at higher rates of application and more frequently. In other respects both treated and control plots in the

The plots of wheat, carrots (left centre) and maize (background) in the long-term experiment at WRO in which nine annual applications of four common herbicides at the recommended rates have had no adverse effect upon the crops or soil.

cropped and uncropped parts of the experiments received comparable treatment.

A progress report on the first six years of these experiments was published in 1970. This and subsequent papers have attracted considerable publicity as the first authoritative conclusions concerning possible effects of repeated herbicide use on soils and crops. Briefly summarized, the conclusions are as follows:

1. There has been neither build up of herbicide residues in the soil nor have microbial activities been affected.
2. Soil fertility has not been impaired.
3. There has, in general, been no adverse effect upon the growth, health or produce of the crops.

These experiments, which have been carried out in collaboration with a number of commercial, university and official research organizations, are being continued.

The effect of herbicides on the soil microflora*

The number of chemicals tested by the Microbiology Section for possible effects in the soil has increased to over thirty. In a few cases, the constituents of a particular herbicide formulation have been studied separately. The response of the several microbial activities examined has varied according to the specific chemical compound and its concentration, the soil type, and further unknown factors.

At concentrations of 200–500 ppm, over 100 times higher than those obtained generally in soil following normal use, most of the tested herbicides markedly inhibited mineralization of nitrogen and CO_2 evolution. At 50 ppm or less few chemicals had any adverse effect (see p. 76).

Nitrification in soil supplemented with ammonium sulphate was significantly depressed by a number of herbicides including some which had little or no effect on mineralization of nitrogen as a whole. This suggests that many herbicides can, at appropriate concentrations, curtail the profuse development of young populations of nitrifying bacteria following the addition of ammonium sulphate to soil. Suppression of nitrification at concentrations below 200 ppm was rare though it was recorded for barban at 50 ppm. In a few instances, certain herbicides have had greater effects on CO_2 output and on oxygen uptake than on mineralization of nitrogen; for example, both linuron and asulam lowered CO_2 output at 50 ppm and in exceptional circumstances asulam did so even at 5 ppm. Effects on population counts were also confined to high concentrations (200–500 ppm) resulting frequently in a decrease in fungal propagules and often associated with a profuse stimulation of bacteria. Cellulose decomposition *in situ* in the soil was adversely affected by linuron but only at high concentrations. The general impression from the work at WRO so far is that, at the concentrations of herbicide likely to occur in the field, adverse effects on the microflora are rare. However, they have been recorded by other workers.

The possibility that significant effects might be produced by breakdown products or metabolites rather than by the herbicide originally applied has received some attention. 3-Chloroaniline, 3,4-dichloroaniline (DCA) and sulphanilamide, probable derivatives of barban, linuron and asulam respectively, were found to behave similarly to the parent material in many respects but there were sufficient dis-

* A more detailed account of this work will be found in the review article on pp. 72–82.

A Ph.D. student, attached to WRO, setting up an experiment to measure the effect of different herbicides on the respiratory CO_2 production of soil micro-organisms.

similarities to justify further investigation. Thus, sulphanilamide and DCA had a very drastic effect on nitrification, a process affected far less by the parent herbicides. Barban delayed glucose utilization but enhanced phosphatase activity in the soil, which contrasted with the behaviour of 3-chloroaniline.

A recent study by the Chemistry Section has thrown further light on the potential importance of one such breakdown product (DCA). Soils from plots treated annually with linuron at about 8–9 lb/ac for 6–8 years (see p. 28) were examined and no 3,4-dichloroaniline was detected. However, traces of the chemical were found in soils treated on a single occasion with 100 lb/ac in the field or 100 ppm or more in laboratory incubation experiments. No tetrachloroazobenzene, a toxicologically undesirable potential derivative of dichloroaniline, was found in any of the soil samples from the field experiment or in soils treated with 500 ppm of linuron in the laboratory.

Decomposition and persistence of herbicides in the soil

Physico-chemical principles underlying the activity and persistence of herbicides in the soil, and the behaviour of tri-allate, have been a primary concern of the Chemistry Section in recent years. Some aspects are reviewed on pp. 44-9. Extensive field investigations to determine the persistence of simazine and other important herbicides used in fruit and ornamental crops which have featured in the programme of the Horticulture Section are described on pp. 58-65.

SURVEYS

A surveys officer was appointed to WRO in 1969 to fulfil a long-felt need to be able to obtain factual data—as opposed to opinions—on weed and herbicide usage problems.

Following a pilot survey in 1969, a major survey of the presence of wild oats (*Avena* spp.) in cereal seed drills in the United Kingdom was initiated by the Surveys Branch of the Agronomy Section and carried out during spring 1970 with the collaboration of six other official organizations.* Seven-pound samples were collected at random from 620 cereal drills at work and were analysed by the official seed testing stations. The proportions of samples found to contain seed of wild oat were: in England and Wales 19%, in Scotland 16%, and in N. Ireland 3%. The contaminated samples were widely distributed throughout England and Wales and in the North and East of Scotland.

Two surveys to obtain information on the distribution of the various species of wild oats in 1969 and 1970 were carried out with the help of students from Agricultural Colleges. In 1969, of 343 cereal fields inspected by students in 14 counties in England, 251 fields were found to be infested with wild oats to a greater or lesser extent. In 1970, of 342 cereal fields inspected in a number of areas in England, Scotland and Wales 207 were found to be infested.

Three firms of agricultural merchants in the North, the Midlands and the South of England co-operated with WRO by making four visits over a period of a year to each of 186 cereal fields on 93 farms. Data on the cultivations, crops, weeds and weed control were recorded. The information from this major survey is being summarized.

* ADAS; MAFF; Department of Agriculture for Scotland; Ministry of Agriculture for N. Ireland; Official Seed Testing Stations for England and Wales and for Scotland.

OVERSEAS ACTIVITIES

In April 1969, the activities at WRO financed by the Overseas Development Administration (ODA) were reorganized and a new Overseas Section was established with responsibility for overseas liaison and for an enlarged programme of research on tropical weed problems.

The new programme includes, as hitherto, evaluation of new herbicides on tropical and sub-tropical crops and weeds in conjunction with the Evaluation Section. Several new species have been added to the 'tropical' range including jute, kenaf, sesamum and *Rottboellia exaltata* on which little published work has previously been available.

Work on tropical perennial weeds has continued and the discovery that asulam is active on *Imperata cylindrica* (lalang grass) is now being followed up by the manufacturers and by other workers in the field. High priority has been given to the biology and control of *Cyperus rotundus*: one aspect still being explored is the possibility of improving control by interference with tuber dormancy.

In November 1970 Dr. G. W. Ivens returned to WRO after secondment for four years to the UNDP/FAO Range Management Project in Kenya as Bush Control Officer. His objectives were to assess the importance of 'bush' as a factor limiting rangeland productivity and to evaluate control possibilities. In areas of low potential productivity burning was shown to be the most practical control method. In areas of higher potential productivity chemical control was considered practical and effective herbicide treatments were developed.

A picloram+2,4-D formulation was found to be more effective than 2,4,5-T on a number of *Acacia* species. On *Aspilia* and certain other shrubs 2,4-D alone gave satisfactory control. Stump or stem injection treatment with picloram+2,4-D was found the most economical method of using the chemical. Foliar treatment was needed for plants with a more bushy growth habit and promising results were obtained with mistblower application. Successful foliar spraying was shown to be very dependent on application at the most susceptible stage of growth and detailed studies to establish this stage were conducted on *Acacia drepanolobium* and *Tarchonanthus camphoratus*. Recommendations for the continuation of research and for practical treatments were made in a report issued by FAO.

Dr. Ivens returned from Africa to resume his appointment in one of the two 'home-based' posts sponsored at WRO by ODA. After a visit to Malaysia, Indonesia and Ceylon in the summer of 1971 to collect information on *Imperata cylindrica* and *Eupatorium odoratum* he was seconded to the University of Ibadan in November to establish an ODA-supported research project on the biology and control of these two species in Nigeria.

A second 'home-based' officer was appointed to the Section in 1971 and is now on secondment to the Tropical Pesticide Research Institute, Arusha, Tanzania in charge of a new weed research project jointly sponsored by the ODA and the East African Community. The programme includes herbicide evaluation and the biology and control of *Cyperus* spp; close liaison will be maintained between the project and WRO.

The Head of the Overseas Section has made five major overseas visits. Ghana, Ethiopia, and Saudi Arabia were visited by request of the local governments to survey the weed problems in general and advise on suitable research programmes. The USA and Tanzania were visited to attend, respectively, the First FAO International Conference on Weed Control and the Third East African Herbicide Conference. Nine other countries were also visited for liaison purposes.

LIAISON AND INFORMATION

LIAISON WITH ADAS

Keeping the weed control work at WRO and elsewhere under review the two ADAS liaison officers have acted as specialist advisers to their colleagues in the service. In consequence, weed control experiments carried out by ADAS regional field teams have carried forward developments initiated at WRO such as the use of asulam for bracken control, the effect of tri-allate granules on emerged wild oats and the detailed testing of the WRO prototype roguing glove. Furthermore, they have brought many field problems to the attention of WRO, recent examples being the increasing spread of blackgrass and concern at the reaction of cereals to common herbicides. The close links between WRO and ADAS that have always been a feature of WRO are greatly assisted by the appointment of these two officers, also by an ADAS/WRO Liaison Group which meets twice a year at Begbroke. As always, harmonious, personal contact between individual WRO and ADAS staff continues to be enormously important in fostering collaboration and good relations. In addition, a 3-day refresher course is held at Begbroke in alternate years for ADAS Crop Husbandry Specialists and periodic meetings are arranged between WRO and ADAS Horticultural Advisers.

LIAISON WITH ACAS

There have been no major changes in the arrangements in this country for the safety clearance and approval of herbicides sponsored by MAFF in collaboration with other Departments and the pesticide industry. Both remain voluntary but with a very high level of participation by firms. Whilst WRO has no official part to play in either procedure it serves as host to the ACAS Herbicide Liaison Officer and makes its results freely available to him. There is great benefit to WRO in this arrangement which helps to keep members of the staff in close touch with commercial developments and the technical staff of the chemical companies. At present there are some 440 herbicide products approved containing 66 different active ingredients, either alone or in mixtures.

LIAISON WITH AGRICULTURAL MERCHANTS

In addition to the co-operation which has existed for many years between WRO, NACAM* (now BASAM†) and ICAM‡, contacts with the technical staff of individual merchants have been much strengthened through the holding at Begbroke of two 'Merchants' Days' in 1970 and 1971 during which WRO staff and others provided an intensive refresher course in grass weeds and their control. Assistance to ICAM has also continued by participation of WRO staff as lecturers in ICAM courses.

INFORMATION AND PUBLICATIONS

The Information Section has continued to provide the specialist library, current awareness and information retrieval services essential to the efficiency of the research programme. In addition, by promoting the preparation and distribution of publications emanating from WRO research and disseminating the gist of the world's literature on weed research through the pages of *Weed Abstracts*, it has continued to strengthen the role of WRO as a centre for international liaison on weed research. The circulation of *Weed Abstracts*, published by the

* National Association of Corn and Agricultural Merchants.
† British Association of General, Seed, Farm and Agricultural Merchants.
‡ Institute of Corn and Agricultural Merchants.

Commonwealth Agricultural Bureaux, increased from 1,120 in 1968 to 1,260 in 1971, despite a 66% increase in price in 1970 for the majority of its subscribers. However, the continuing increase both in staff emoluments and the volume of literature to be abstracted necessitated requesting the 1970 Commonwealth Agricultural Bureaux Quinquennial Review Conference to consider augmenting the existing grant towards the cost of production of *Weed Abstracts*. It is with gratitude we record that the Review Conference agreed to double the existing grant for 1972-77 which will ensure that *Weed Abstracts* can continue to provide its readers with the comprehensive coverage of the world literature they have come to expect.

The associated information retrieval service has attracted nearly 500 enquiries in the last three years and some 30 annotated bibliographies on specific subjects have been published. Within the same period the total distribution of WRO publications has included nearly 500 bibliographies, 600 Technical Reports and over 3,000 reprints. A list of WRO publications for 1969-71 is given on pp. 89-95.

Since 1970 the Information Section has been increasingly involved in public relations activities, notably the co-ordination of exhibit design for Weed Workshop '71, arrangements for press and television coverage of WRO activities and looking after some of the 1000 visitors arriving at WRO each year. To assist in the dissemination of WRO research results and in public relations activities generally an additional Scientific Officer was appointed to the Information Section in October 1971.

Pest Articles and News Summaries

In addition to *Weed Abstracts*, WRO remains closely associated with several other publications of importance to weed scientists and agriculturalists. Thus it continues to accommodate the editor of the weed section of the quarterly journal *Pest Articles and News Summaries*, familiarly known to readers as *PANS*. Sponsored by the Overseas Development Administration, *PANS* provides current information on pest control throughout the developing countries. Since 1968 circulation has increased, in response to demand, from 1600 to 2600.

Weed Control Handbook

In 1969 the pace of development of methods of weed control, coupled with a sell-out of the 5th edition of the *Weed Control Handbook*, necessitated yet another major revision of the recommendations section

Some of the publications of importance to weed scientists with which WRO is closely associated and which have helped to establish its role as a world centre for international liaison on weed research.

and the issue of a revised reprint of Volume I. Financed by the British Crop Protection Council and published by Blackwells, the production of the 6th edition of Volume II of the *Handbook* was, once again, the joint effort of some 70 specialists from numerous organizations. The onerous task of editing was again undertaken by members of the WRO staff, a major part being played by the Herbicide Liaison Officer at Begbroke of the MAFF Agricultural Chemicals Approvals Scheme. The 6th edition of Volume II (Recommendations) of the *Weed Control Handbook* and the revised reprint of the 5th edition of Volume I appeared in September 1970.

Weed Control in the Tropics

An important new book, *Weed Control in the Tropics*, sponsored by ODA and published by Leonard Hill, appeared in September 1971. It was written by L. Kasasian of the Overseas Section and brings together, in one volume, a wealth of up-to-date information on modern methods of weed control for use in tropical crops based, not only on the long experience of the author, but also on an extensive review of the literature and of commercial technical publications. It should do much to satisfy an urgent demand in the developing countries.

CONFERENCES

Tenth British Weed Control Conference

This very successful conference, attended by over 1,200 delegates, was held at Brighton from 16th to 19th November 1970. Organized by the British Crop Protection Council, these conferences have become international in all but name and over 40% of those attending in 1970 came from overseas. Two senior members of the WRO staff served as chairman and vice-chairman of the Programme Committee and WRO staff contributed nearly 40 of the 180 papers presented. Copies of the Proceedings, in three volumes, are still available, price £7.50.*

Third International Symposium on Aquatic Weeds

This symposium, arranged by the European Weed Research Council, took place in Oxford from 5th to 8th July 1971. It was attended by 160 delegates, from 22 different countries. The symposium was organized for EWRC by a committee under the chairmanship of the Head of the Aquatic Weed Section assisted by the Secretary of WRO

* Apply to the Technical Officer, BCPC, Clacks Farm, Ombersley, Droitwich, Worcs.

and Dr. W. van der Zweep, Institute for Biological and Chemical Research on Field Crops and Herbage, Wageningen, Netherlands. The programme included 27 papers covering all the important aspects of the ecology and control of freshwater weeds. Copies of the Proceedings are available, price £2.00.*

PUBLIC RELATIONS

Two exercises in public relations at Begbroke have helped to heighten awareness of the contribution WRO research has made to British agriculture. The first, a Technical Field Day, was held in July 1969 when recent advances in the control of grass weeds of arable and pasture land were demonstrated. The second, called 'Weed Workshop '71', was held in July 1971 and focussed attention on four major topics of current interest, namely wild oats, perennial weeds, reduced cultivation and herbicides in the soil. Attendance at both was by invitation only. About 250 people attended the first event; over 400 attended the second, which was remarkable for the widespread publicity subsequently given by the national and technical press and television services to WRO work on wild oats and herbicide persistence (or lack of it!) in the soil.

Excluding the attendance at such special events, well over 1,000 visitors a year have continued to come to WRO. The majority are individual scientists and specialists, but there have been increasing numbers of parties of farmers and growers, Young Farmers' Clubs, groups from universities and schools, and from a variety of local voluntary organizations. Virtually every Commonwealth country has been represented in the visitors' list, as well as many foreign countries.

TRAINING AND ADMINISTRATION

VISITING RESEARCH WORKERS

During 1969-71 it has been a great pleasure and of considerable benefit to the research programme to have at Begbroke, for periods of training and research ranging from a month to a year, weed control specialists from a variety of countries. These have included: Miss I. Alcada and Mrs. F. Rocha, Laboratorio de Fitofarmacologia, Oeiras, Portugal; Dr. J. D. Banting, Canada Department of Agriculture, Regina, Saskatchewan; Dr. S. Furuya, Central Agricultural Experiment Station,

* Apply to the Secretary, WRO, Begbroke Hill, Yarnton, Oxford, OX5 1PF.

Saitma, Japan; Mr. J. R. Moyer, Department of Soil Science, University of Saskatchewan, Canada; Mr. M. Soerjani, Treub National Biological Institute, Bogor, Indonesia; Ato Taye Teferedegn, Institute of Agricultural Research, Addis Ababa, Ethiopia; Dr. A. E. Dowidar, Ain-Shams University, Egypt.

The collaborative arrangements whereby students working for higher degrees conduct their experimental work at WRO under joint supervision, have been expanded to involve further Universities. From Reading University, Ph.D.s were awarded to M. Damanakis from Greece for his work on the absorption of paraquat on organic matter and its availability to plants and to E. Dhanaraj from India for his work on the response of *Agropyron repens* to dichlobenil. Currently two research students working for a Reading degree are at WRO, namely R. R. B. Leakey from University College of North Wales, investigating dormancy and dominance of buds and shoots on the rhizome of *Agropyron repens*, and G. J. Wells, Victorian Wheat Research Institute, Australia, studying the ecology of *Poa annua* in perennial ryegrass. P. Quilt from Bath University is on the point of completing his Ph.D. thesis on the effect of a barban formulation on some activities of soil micro-organisms. From Newcastle University J. Usoroh of Nigeria is working on the fate of linuron in soils and plants. Miss L. M. Boize has recently taken up a Science Research Council CAPS award; this will involve co-operation with BP Ltd. and Leeds University in work on the relationship between application methods for herbicides and biological activity.

Additionally, various sections of WRO have continued to make use of 'sandwich' students during the industrial training portion of their degree course, in order to conduct small research projects.

EDUCATION AND TRAINING COURSES

In addition to the research function of WRO an attempt is made, within the limits of the resources available, to assist a variety of education exercises. In July 1969, in conjunction with the British Council, a 2-week refresher course on current developments in weed research was held at WRO for weed specialists from fifteen countries. In June 1971 a somewhat similar 3-week International Course on Weed Control was organized by the International Agricultural Centre in the Netherlands in collaboration with the European Weed Research Council and WRO staff assisted by providing a number of lectures for the course.

The new office and service building for the field teams. Completed in 1969, this is the operations centre for nearly 300 WRO field experiments each year, both at Begbroke and at more than 170 sites throughout the country.

Each year WRO has acted as host for two days to 10–12 students on the Pest Management Course from Silwood Park. This 6-week course, financed by the Overseas Development Administration, is for personnel involved in operational or research work in plant protection, in developing countries.

In addition, members of the staff have provided numerous lectures, talks, and demonstrations to meetings of farmers and growers, to Young Farmers' Clubs, agricultural colleges, Women's Institutes, to schools and many others. Because of the need to convey balanced information on the role of agricultural chemicals to all sections of the community, invitations to address meetings or groups are seldom declined.

NEW BUILDINGS

The new office and service block for the field teams and the extension to the laboratories, to which reference was made in the Third Report, were occupied during the first half of 1969 and have provided much improved accommodation for research staff and also for visiting research workers. This additional space enabled some re-allocation of accommodation to be made in the converted farm buildings and house, providing much better facilities for the Information Section and the Administration Staff.

A new conference room was built in 1971, enabling long-needed improvements to be made to the staff restaurant, the original kitchen of which did not meet required standards in size or ventilation.

ADMINISTRATION

The reorganization of work within the Secretary's office, made possible on the move to fresh accommodation in 1969, has enabled the WRO Administration team to continue to improve the service which it gives to the research staff.

Late in 1971 H. Bywater, who had been Senior Photographer since March 1966, left and has been replaced by R. N. Harvey.

ACKNOWLEDGEMENTS

It gives me great pleasure to record my gratitude to all those whose support makes the existence and contribution of WRO possible, particularly to the Agricultural Research Council for providing funds so generously, and to our colleagues at ARC Headquarters who invariably react to our questions and difficulties in the most helpful way possible. I am also indebted to those members of the Overseas Development Administration who through finance and encouragement make it possible for WRO to play a part in weed control work in developing countries, also to the Commonwealth Agricultural Bureaux's Executive Council for their welcome decision to increase the subvention to WRO after the last Review Conference to enable our Information Section to carry on with the production of *Weed Abstracts*. Sir Thomas Scrivenor, Secretary of CAB, deserves special thanks for his efforts on our behalf.

As mentioned elsewhere in this report, WRO takes the initiative in many activities involving people in other organizations. My colleagues and I much appreciate the willingness with which others in the Ministry of Agriculture Fisheries and Food, the Department of Agriculture and Fisheries for Scotland, the Ministry of Agriculture for Northern Ireland, the chemical industry, universities, the Scottish Colleges of Agriculture,

ARC and other research organizations, also farmers and growers, are prepared so freely to give their help. The resulting dialogue is of the greatest value to WRO and I hope also to others.

I should also like to acknowledge the interest of our many collaborators and friends in the UK and in countries throughout the world where a common desire to learn about weeds and to find better means for controlling them provides a mutual bond.

I wish to thank very sincerely my colleagues in WRO for their unfailing loyalty, co-operation and enthusiasm. In particular I should like to mention Mr. J. G. Elliott and Dr. K. Holly who, as heads of the two research departments, have to bear the brunt of responsibility for planning and control of the research programme and who have had to accept an added burden during my many visits abroad during the past two years. I am also continuingly grateful to our Sectreary, Mr. B. A. Wright, for taking off my shoulders as much as possible of the non-technical administration of the institute with great efficiency, also for his attitude that it is the main job of himself and his colleagues in Administration to oil the wheels of the research programme.

Finally, I am very grateful to Mr. J. E. Y. Hardcastle, head of the Information Section, for all that he has done since joining WRO in October 1969 to develop information and P.R. work at Begbroke; also for his help in supervising the production of this report.

The Soil and Herbicide Activity

R. J. HANCE

Because soil acting herbicides are not applied directly to the target plant their performance is often less certain than that of foliar herbicides. It is therefore essential to understand what is likely to happen to a compound during the period between its application to the soil and its uptake by the plant if we are to improve the reliability of such materials. A herbicide molecule in the soil may be adsorbed to soil particles, it is exposed to degradative processes, it could be transported in solution or in the gas phase or it might be taken up by the host of living organisms in the soil. To some extent these processes are inter-related but this article will be largely confined to some recent developments in our understanding of the first two, adsorption and degradation.

ADSORPTION

The effect of properties of the herbicide

The great complexity of soil as an adsorbing medium offers a number of possible mechanisms by which herbicides may be adsorbed. A consideration of the relative importance of such mechanisms is outside the scope of this article, but the fact that there are several would immediately suggest that there is no single characteristic of a herbicide molecule which could be used to predict accurately its adsorption behaviour. Most soil acting herbicides remain virtually un-ionized under normal soil conditions and their adsorption is the result of a combination of relatively weak, non-specific attractive forces. Nevertheless it is possible, by taking into account such properties as molecule size and electron distribution, to calculate the probable adsorptive behaviour of a molecule (Lambert 1967, Hance 1969a, Briggs 1969). Such calculations are complicated and frequently are only valid for a limited range of compounds. There is an alternative, semi-empirical approach which is simpler and can usually be used to predict adsorption behaviour with sufficient accuracy to be of practical value. It is based on the premise that adsorption can be considered to be a consequence of the tendency of a molecule to move from an aqueous phase (the soil solution) to a non-aqueous phase (the soil surface). The more hydrophobic the molecule the more extensively it will be adsorbed. It is

A 'rotabar', based on a WRO specification, being used to incorporate a surface application of lenacil in a sugarbeet seedbed in the fens. In these highly organic soils, this technique prevents the inactivation of the herbicide by adsorption.

easy to estimate the hydrophilic/hydrophobic balance (HLB) of a compound by measuring its distribution in the two phases after it has been shaken with water and an immiscible non-polar solvent such as hexane, or it may also be determined by a chromatographic measurement (Hance 1967). Such an estimate of HLB has been found to correlate well with extent of adsorption for a number of compounds so that, if the adsorption behaviour and HLB of one reference compound are known, it is now possible to predict the adsorption of other compounds from a knowledge of their HLB's.

The effect of properties of the soil

From a detailed consideration of adsorption mechanisms it might be expected that the adsorption of most soil-applied herbicides would be related to the content of organic matter in the soil. This is in fact the case, although chronologically this relationship was deduced experimentally before sufficient theoretical evidence was available to predict it. The organic matter in mature soils seems to act in a similar fashion regardless of the conditions of climate, soil parent material and vegetation in which it was formed, so that the amount of organic matter in a soil usually provides a good indication of its sorptive capacity. However, there are exceptions, often among soils of low organic matter content, when clay minerals, if present in abundance, will also contribute significantly to adsorption.

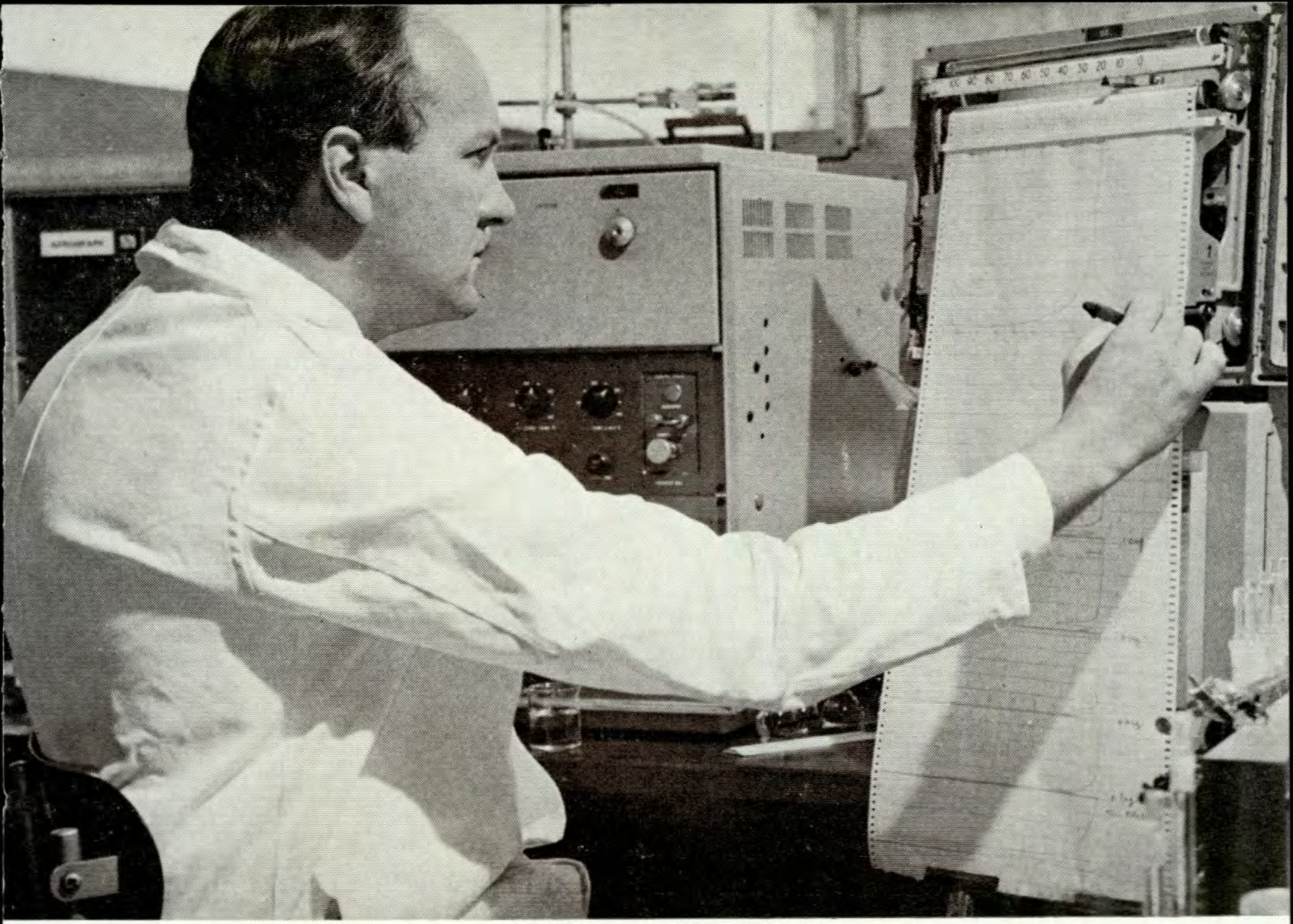
The use of adsorptive data to predict field performance

The adsorption properties of the soil, and hence the herbicide concentration in the soil solution, can be roughly predicted from its organic matter content. If it is assumed that only the herbicide in the soil solution is available to the plant then there should be a relationship between soil organic matter content and the amount of herbicide required to produce a given plant response in the field. Experiments to test this carried out at WRO (Hance *et al.* 1968) showed that such a relationship held in glasshouse experiments but not in field experiments on a range of soils containing 1.5-20.6% organic matter. It appears therefore that, in the field, the effect of climate on plant response can be more important than that of the soil. An additional factor is that the information about adsorption characteristics is largely based on laboratory experiments in which equilibrium conditions obtain. Later experiments have indicated that it is unlikely that such conditions occur in the field (Grover and Hance 1970).

Nevertheless, the general principle still seems to apply, that soils high in organic matter require higher rates of herbicide application than more mineral soils. However, in soils of low organic content, clays are important and many agricultural soils fall into this category. Consequently there are some current commercial dose recommendations based on soil texture, usually with the proviso that they be applied only to soils containing 1-5% organic matter.

Behaviour of volatile herbicides

This topic involves more than adsorption phenomena alone, but it is appropriate to consider it at this point. It is well established that vapour losses of volatile herbicides are greater from wet than from dry soils, the accepted explanation being that water competes with the herbicide



A WRO chemist using gas liquid chromatography to measure herbicide concentrations in a soil adsorption study.

for adsorption sites so that more adsorption of the herbicide occurs in the absence of water. If this is so then, at soil water contents above that required for the production of a mono-molecular layer on soil surfaces, the vapour pressure of the compound should be independent of water content. This has been demonstrated with some compounds, but with others vapour losses have increased as the soil water content increased beyond this point. In this laboratory, experiments with pure tri-allate, tri-allate granules and emulsifiable concentrate have also shown increases in tri-allate vapour pressure as the water content increased from a mono-molecular layer to field capacity, so it would appear that the competition theory is inadequate.

The formulation also has an effect as the tri-allate vapour pressure above soil treated with an emulsion was greater than that above soil treated with granules, presumably because tri-allate is more effectively adsorbed by the granule carrier than it is by soil. This is confirmed by a greenhouse experiment in which tri-allate disappeared faster from wet soil treated with emulsion than from a similar soil treated with granules. On a dry soil, however, tri-allate from the emulsifiable formulation appeared to be effectively adsorbed as losses were similar from both formulations. The persistence of tri-allate granules in a field experiment was consistent with the greenhouse observations and in addition appeared to be independent of tri-allate concentration in the granule (Hance *et al.* in preparation).

DEGRADATION

Organic molecules in the soil may be exposed to the activities of soil micro-organisms and also to such chemical decomposition processes as hydrolysis and oxidation or reduction. It is not easy to distinguish clearly biological from non-biological mechanisms without recourse to such artificial experimental conditions that extrapolation of the results to the field is of doubtful validity. However, there is now evidence that triazines (Armstrong *et al.* 1967, Harris 1967, Skipper *et al.* 1967) and dichlobenil (Briggs and Dawson 1970) are significantly degraded in the soil by chemical means. Other compounds can also be chemically decomposed to some extent (Hance 1969b). It also appears that specific sites in the soil are required for these reactions and that such sites are limited, as the rate of chemical decomposition decreases as the initial herbicide concentrations in the soil are increased. This work was extended in the WRO laboratories to ascertain if the size of the initial dose affected speed of breakdown of herbicides incubated with soil in conditions where both chemical and biological processes could occur (Hance and McKone 1971). This was found to be so for the chemicals studied which were atrazine, linuron and picloram, although the effect was not so great as when only chemical decomposition was allowed to occur. Studies are currently in progress to assess the significance of these observations in the field.

The effect of adsorption on the rate of decomposition is not clear from a study of the published literature. In a recent experiment in this laboratory (Moyer *et al.* in preparation) the effect on herbicide decomposition in soil of additions of charcoal or clay was studied, using atrazine, chlorthiamid and linuron. Added clay increased the persistence of all compounds. However, it did not always increase the extent of adsorption of the herbicide so it seems that the effect of clay was, at least in part, to reduce micro-organism activity rather than to reduce herbicide concentration in the soil solution. The presence of charcoal increased the adsorption of all the compounds. It increased the persistence of atrazine and chlorthiamid, but by a smaller factor than that by which adsorption was increased. Charcoal did not affect the persistence of linuron. It appears, therefore, that herbicides adsorbed on charcoal are at least partly accessible to soil microorganisms. The use of charcoal as a remedial measure in situations where unwanted herbicide persists thus offers the advantage that adsorption is increased, and hence plant availability reduced, rather more than the rate of dissipation is reduced. On the basis of this laboratory experiment 1000 lb/ac of charcoal mixed into a 3 in. depth could reduce the herbicide concentration in soil solution by something of the order of 3-50 times, yet still allow decomposition to occur at a rate probably not greatly lower than would take place in the unamended soil.

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Wild Oats

J. HOLROYD

Wild oats are the most important and widespread weed in Britain today, particularly where cereals are grown intensively. They are a serious problem in most areas of the world where wheat, barley or oats are grown. This brief review describes recent developments in research into their biology and control with special reference to work at WRO.*

BIOLOGY OF WILD OATS

Three species occur in Britain, but only two are of any consequence: *Avena fatua*, the spring wild oat and *A. ludoviciana*, the winter wild oat. *A. fatua* is the more abundant and is very widely distributed. *A. ludoviciana* is restricted almost entirely to central and eastern England. The third species, *Avena strigosa*, the black or bristle oat is the least common and is not a successful weed, probably due to its lack of seed dormancy. Because of its hardiness it is occasionally grown as a crop in the north of the country.

Germination of *A. fatua* occurs mainly in the spring between March and May, with a minor flush in the autumn, while that of *A. ludoviciana* occurs during the winter from October to March. Thus *A. ludoviciana* is a weed of winter crops and occasionally early-sown spring crops, whereas *A. fatua* is most generally found in spring-sown crops. Although plants of *A. fatua* that become established in the autumn are reputed to overwinter mainly in the milder areas of the country and then only if the winter is less severe than usual, recent observations by WRO staff suggest that they may be hardier than is currently believed. During the winter of 1970–71, plots were established in winter wheat crops at two very different sites, one in the Cotswolds at a height of 550 ft. and relatively exposed, and the other in the Thames Valley and sheltered. In these plots, plants of *A. fatua* were colour-coded for their stage of growth at intervals throughout the winter. Just before harvest they were assessed for their viability and seed production. The results showed that mortality during the winter decreased with age. A plant's chance of survival increased markedly as soon as the second leaf appeared. Those which had reached the three-leaf stage by mid-December suffered only minor mortality ($<20\%$) during the rest of

*Additional information on the wild oat research programme will be found on pp. 6–11.

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