AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANISATION

First Report 1960-1964

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The Weed Research Organisation

J. D. Fryer

Chemicals are playing an ever increasing part in our lives, yet one of the most remarkable achievements of chemistry in this century is little known outside agricultural and scientific circles. For the first time in the history of man, it has become possible to grow crops which are kept free from weeds with little mechanical or manual effort and with no disturbance of the soil. The contribution towards more food at low cost that this development offers is incalculable. Wherever there is a need to conserve or control vegetation with the minimum of labour, these chemical weedkillers, nowadays called 'herbicides', have a vital role to play.

The Weed Research Organisation (W.R.O.) was set up by the Agricultural Research Council (A.R.C.) in April, 1960, as the official centre in Britain for research and information on the technology of weed control. Although primarily concerned with the needs of British agriculture and horticulture, the Organisation also plays a significant and increasing role overseas and its interests range over the whole field of weed control. The emphasis is, and is likely to remain, on herbicides, but other methods of weed control are also considered.

The object of this report is to summarise the progress achieved by W.R.O. during the first four years of its existence and to describe its role and structure. It is hoped that this introductory article and the detailed accounts which follow will throw light on an organisation which, because of its youth and novelty, may so far have remained unknown, or obscure, to many.

Origins

The revolutionary discovery of the synthetic plant growth regulators, now well known as MCPA and 2,4-D, occurred during the war years. At the end of the war, when these chemicals first became available in commercial quantities as selective weedkillers, farmers in Britain and elsewhere, short of labour and being urged to produce more food, were quick to realise the advantages of these new tools and lost no time in treating large areas of cereals and other crops.

Chemical firms in Europe and America started a massive search for other active compounds and so began a flow of new herbicides which, some 18 years later, still shows no sign of abating.

In 1950, the A.R.C.-financed research team that had been responsible for extensive field investigations on the new weedkillers during the 1940's was reorganised as the A.R.C. Unit of Experimental Agronomy. It continued to operate at the University Department of Agriculture in Oxford under the leadership of Professor G. E. Blackman. Soon after the formation of the Unit it became clear that a small research team situated in a university department could not continue indefinitely to fill the need that had developed as a result of the rapidly increasing importance of chemical weed control. Permanent and enlarged facilities were required for field experimental work and for laboratory and office work which could not be provided by the University. Accordingly, the A.R.C. decided to set up a permanent centre for its weed research activities. In due course, sanction was given to acquire land and to develop a new organisation.

When Begbroke Hill Farm was eventually purchased in 1960, the Unit of Experimental Agronomy split into two. One half consisting of the research workers concerned with the chemistry and physiology of herbicidal action, together with the work on new crops, remained with Professor Blackman at Oxford. The other half, whose interests lay in the more practical aspects of weed control research, moved to Begbroke and formed the nucleus of the new Weed Research Organisation, under the directorship of Dr. E. K. Woodford, who had been Assistant Director of the Unit.

Dr. Woodford remained at Begbroke until September, 1964, when he was appointed Director of the Grassland Research Institute at Hurley. It was largely as a result of his far-sightedness and persistence that the W.R.O. came into existence and he forged many of the links which today serve to connect W.R.O. so effectively with other weed control interests, not only in Britain, but throughout the world. His stimulus and pioneer spirit will be long remembered by all who were associated with him during this exciting period of weed control history.

At the time of writing (January, 1965) the number of staff at Begbroke is around 70, the renovation of the old farmhouse and buildings is virtually complete and the new laboratory and greenhouse block has been in full operation for about two years. The farm land has been laid out to provide on a rotational basis some 40 acres for arable experiments each year and as much permanent grassland as is required. The first phase of establishment is over. The second phase of consolidation and further development has now begun.

Role and Organisation

The Weed Research Organisation is an Institute of the Agricultural Research Council, who provide finance directly from the agricultural research funds made available by the Treasury through the Department of Education and Science. A substantial grant towards the cost of maintaining W.R.O. is also made to A.R.C. by the Ministry of Overseas Development. Unlike the larger State-aided agricultural research institutes the administration and the research policy of W.R.O. are wholly under the control of A.R.C. All the staff are employed directly by A.R.C. with the exception of certain officers attached to W.R.O. from the Ministry of Agriculture, Fisheries and Food and the Ministry of Overseas Development.

The role of W.R.O. must be viewed against the background of the thriving agriculture and horticulture which exists today in Britain as this country's greatest single industry; also against the revolutionary developments which are essential in the agriculture of less developed countries if they are to play their part in meeting the needs of a rapidly growing world population.

In Britain there is a vigorous chemical industry, a part of which is devoted to the discovery and development of new herbicides. This is true also of other European countries and in particular of the United States of America. The latter uses chemical methods of weed control to a greater extent than any other country, easily leading the field in the discovery and utilisation of new herbicidal chemicals.

During the past ten years, numerous chemicals from commercial firms in many countries have become available in Britain for experimental evaluation as herbicides. In most instances, the firms or their agents undertake enough research and development to ensure their efficient and safe use. The amount of work they do is related to the scope for financial return and the requirements of the official safety and approvals schemes of the Ministry of Agriculture, also to the facilities and staff available. Some new herbicides, particularly from abroad, are accompanied by the bare minimum of information and research experience relevant to conditions in this country. Others are introduced with a wide background of experience gained from extensive field and laboratory research both in this country and overseas, undertaken by research teams of the firms concerned.

Variations in the standard and extent of the research and development work underlying the introduction by commercial firms of new herbicides into British agriculture and horticulture are difficult to avoid. Tight controls and regulations might unify the standard of information provided by the manufacturers to accompany each new herbicide, but would stultify progress and eliminate many useful treatments. In any case, no firm can reasonably be expected to investigate all aspects of each new herbicide that it discovers. For these reasons, it is very desirable that countries in which there is a major requirement for herbicides are served by adequate official research and development work. Such work provides an independent assessment of the merits, properties and possible hazards of new herbicides and may well show up new uses, as well as problems, overlooked by the manufacturers. In addition, those who carry out the work form a pool of interested and experienced herbicide specialists able to advise on the many technical problems liable to beset the administrators responsible for the safe use of herbicides and other pesticidal chemicals.

The Weed Research Organisation is unique in being the first major institute to be set up solely to serve the present day requirement for independent research and information on herbicides. Its main function is to undertake research concerned with the practical use of herbicides, but of equal importance is the fact that it provides a focus for weed control interests in this country. Information is collected and made available to all who seek it. Through its liaison activities with official organisations and with Industry and also through the British Weed Control Council, close touch is maintained with all concerned with the weed control field.

The organisation of W.R.O. is briefly described in the remainder of this introductory article. More detailed information together with an indication of the progress made can be found in the reports prepared by the individual Sections.

Research

Five research sections have been set up at Begbroke. The largest of these is the Evaluation Section. This has as its main task the collection of samples of new herbicides and the investigation of (a) their selective action on a wide range of plants, (b) factors influencing their phytotoxicity, and (c) other properties. Particular emphasis is given to herbicide/soil relationships. The work is done in the laboratory, greenhouse or field as appropriate. At the present time, much thought is being given to how the evaluation programme should be developed within the resources of the Section to provide information on as wide a range of properties as possible. The aim is in due course to produce technical reports on the herbicides examined supplementing the data sheets published by most manufacturers, and providing an independent assessment of the principal factors to be taken into account when considering practical usage.

This Section is also responsible for the evaluation of herbicides for specific weed control situations. However, abundance of chemicals (more than 100 at the present time) has created a major problem, since it is impossible for a relatively small team to undertake comprehensive evaluation of all of them. Priorities are difficult to assess and liable to change rapidly. With each new chemical many exciting avenues of research open up, only a few of which can be followed if the evaluation programme is to be maintained.

It is the job of another research team—the Agronomy Section—to take on for development results of practical significance achieved by the Evaluation Section or by other research workers, also to consider new achievements by industry and to study how these may best benefit the farmer. It is becoming increasingly realised that herbicides, with their unique property of selectively killing weeds without soil disturbance, may permit changes in traditional systems of crop husbandry which have been built up around the need to control weeds by non-chemical methods. Such changes can result in increased yield and efficiency. Chemicals and cultivations may have to be combined and related to whole cropping systems. Plant spacing, fertiliser requirements and crop varieties may need to be changed and long-term effects on the soil considered. Special implements may have to be developed to take advantage of the flexibility in crop production methods made possible by modern weed control techniques. This is a vast subject and usually outside the scope of the commercial firms that develop herbicides. It involves close liaison and collaboration with other research stations, the Ministry of Agriculture Experimental Husbandry farms, the N.A.A.S. and the farming community. The Agronomy Section is at present organised into three highly mobile teams, one dealing with arable crops and two with grassland. As in the case of the other research sections, experiments are carried out at Begbroke, other research stations, or on commercial farms, whichever is the most suitable.

The Horticultural Section of W.R.O. has a similar function to the Agronomy Section except that it deals with horticultural crops and pays more attention to problems of evaluation raised by the specialised nature of fruit and ornamental crops. Vegetable crops are considered only in the primary evaluation work, any interesting results being passed to the National Vegetable Research Station for further study by the latter's weed research team. The Horticultural Section also has a special interest in soil-applied herbicides and their problems, in view of their increasing importance in horticulture.

The two remaining research sections have a dual function of providing specialised knowledge and facilities to back up the main herbicide programme, also to carry out research work in more detail than is generally possible in the other sections.

The Botany Section is concerned with aspects of the biology of annual and perennial weeds, also with weed seed behaviour. This is a field of activity that has received inadequate attention in the past. A better knowledge of our common weeds is badly needed to assist in developing methods for their control.

The Chemistry Section also has a 'service' role. It has the task of developing analytical procedures for the determination of herbicides in plants and soils and then employing them in studies undertaken in collaboration with one of the other sections. In addition, the Chemist has his own research programme on the physico-chemical behaviour of herbicides in soil—a subject fundamental to their reliable and safe use.

Three other research activities falling outside the main research sections need to be mentioned.

1. Under an arrangement with Reading University, W.R.O. accepts post-graduate students for a 2 or 3-year research programme on weeds, herbicides or related topics for an external M.Sc. or Ph.D. degree. At present, three students are working at Begbroke, one from Ceylon, one from the Sudan and one from the U.K. Visiting research workers are also welcome, provided room can be found for them and at present there is a senior research officer from Israel undertaking a year's study-training on a British Council Scholarship.

2. An Experimental Officer is working under the author on the long-term effects of herbicides in the soil. A field experiment was started in 1963 in which four herbicides are applied at regular intervals to soil with and without a crop with the intention of following any changes in soil properties, crop yields and quality, soil microfauna and microflora, etc., which may result. The experiment is being undertaken in collaboration with specialists in other research organisations.

3. The work outlined above refers almost exclusively to the use of herbicides in agricultural and horticultural situations. Of the many other uses for herbicides, three in particular deserve mention—forestry, aquatic weed control and total (non-selective) weed control. Forestry weed problems are dealt with by the Forestry Commission and are not studied by W.R.O. Total weed control also falls outside the terms of reference of W.R.O. and research on the subject is virtually confined to commercial firms specialising in this subject. No research on aquatic weeds is carried out at present by W.R.O., but there is a research worker on the staff undertaking a two-year survey of aquatic weed control practices and requirements, with special reference to the ecological implications of different control measures.

Information

In such a rapidly moving subject as weed control, and because the spate of new chemicals and published results of experience with them continued unabated through the 1950's and shows no signs of slackening during the present decade, it is impossible for individual workers to keep abreast of more than a fraction of the extensive literature now being published. There has therefore developed the need for an official information centre, where the world literature is studied and abstracted and which has personal contacts with the leading organisations and personalities in the field. The W.R.O. Information Section is acknowledged as the most important source of information on weed control research and technology and *Weed Abstracts* which it produces for publication by the Commonwealth Agricultural Bureaux is the only abstracting journal devoted to this subject.

Liaison

In order to fulfil its role as the official centre for weed research, the W.R.O. has to be closely linked with other government organisations.

The National Agricultural Advisory Service (N.A.A.S.) in Britain does not employ weed control specialists as part of its advice structure. Advisory work on weed control is undertaken by the district, county and regional officers concerned with general aspects of crop and grassland husbandry. The officers of N.A.A.S. are served by two Liaison officers who are based at Begbroke and who have access to all the research work and information available to W.R.O. members. One is concerned with weed control in agriculture and the other with horticultural weed problems. Theirs is a dual function—to help the advisory officers and to advise W.R.O. of practical problems requiring investigation.

A third Liaison Officer of the Ministry of Agriculture attached to W.R.O. is a member of the Agricultural Chemicals Approval Organisation (A.C.A.O.). It is his job to advise A.C.A.O. on the official approval of new herbicides. Begbroke makes an ideal centre on which to base his activities, since he has access to the research work and information services of W.R.O., a valuable supplement to the experimental work carried out by the commercial firms seeking approval. With increasing emphasis on safety aspects, it seems likely that collaboration between W.R.O. and the official safety and approval schemes for pesticides in Britain will continue to grow. It should perhaps be emphasised here that none of the work undertaken by W.R.O. is done expressly for the Ministry of Agriculture's Safety and Approval schemes.

The liaison activities of W.R.O. also extend overseas. Developments in weed control processes that have transformed crop production in the more advanced countries have had little impact on agriculture in the so-called developing countries. Herbicides have a great part to play, but they are little understood and their potentialities often unrealised. Agricultural experts in these countries increasingly need advice on how to make use of these new chemical tools. Tropical weeds, crops and conditions are often not included in the test programmes of the manufacturers and recommendations must be worked out by means of properly conducted field experiments performed under local conditions.

The Weed Research Organisation has an Overseas Liaison Officer to provide assistance to enquirers from abroad. By means of tours sponsored by the Ministry of Overseas Development, he sees for himself the problems and conditions of these areas and meets the people responsible for introducing modern techniques of crop production into the agriculture of their country. The work is as yet in its early stages, but in view of the potential role of herbicides in the tropics and the leading position of W.R.O. in practical experience and in providing information, there seems little doubt that the overseas role of W.R.O. both as a training centre and as a research and information centre of tropical weed problems will develop as it becomes more widely known.

Closely allied to this endeavour is the production at Begbroke of 'PANS C' a tropical weed control journal sponsored by the Ministry of Overseas Development as a further contribution to Britain's programme of technical aid in this field. The Editor of this journal, who is employed by the Ministry, is attached to the Weed Research Organisation.

Finally in this brief survey of W.R.O. it is worth drawing attention once again to the links which its members maintain with other research institutes, with herbicide specialists of commercial firms in Britain and elsewhere and with the many sections of the agricultural industry in Britain Liaison is greatly assisted by the British Weed Control Council (B.W.C.C.). The B.W.C.C. Weed Control Handbook is edited at Begbroke. Several W.R.O. members as well as the N.A.A.S. and A.C.A.O. Liaison Officers spend much time in helping to prepare this publication, into which are incorporated many of the research results gained at W.R.O. Connections with other research workers in Europe are continually strengthening with the aid of the European Weed Research Council (E.W.R.C.) whose official journal *Weed Research*, one of the leading scientific journals directed to this new subject, is edited at Begbroke. It should be emphasised that the greatest importance is attached by the scientific staff of W.R.O. to the exchange of ideas and information on all aspects of the subject.

From this brief account of the place of W.R.O. in Britain's agricultural research service and of the way in which the work is organised, it is hoped that the reader will have acquired at least an impression of this new and little known organisation.

As to the future? So long as the pressure of man on his environment continues to increase, research will be needed to improve the efficiency of production from the land. Herbicides will have a vital part to play and will often play a key role in providing a weed-free environment. Increasing use of chemicals, however, inevitably brings associated problems, one of which is public anxiety concerning possible side effects. This is a challenge to the research worker and demands that he should bring forth enough information to demonstrate not only to his fellow scientists but also to the man in the street, the relative benefits and possible hazards of these new tools. While much of the work will have to be done by the chemical industry, a great deal must remain the responsibility of the official research services. The staff of Weed Research Organisation are looking forward to playing their part in meeting this challenge.

The Development of Chemical Weed Control in Potatoes

J. G. Elliott

Farmers have been accustomed to controlling the weeds in their potatoes by cultivation, for which the machinery and expertise has long been available. Such was the situation in the early 1950's when chemicals started to be developed for weed control in other crops. Suggestions by research workers that chemicals might be used in potatoes met with little enthusiasm from agronomists and advisory workers at this time. However, complete harvesters were coming into use in increasing numbers and bringing with them new problems. One in particular concerned the inability of such machines to distinguish between soil clods and potatoes, the final separation having to be achieved by hand. Research on soils indicated that appreciable numbers of clods were formed by the passage of tractors over the land during the life of the crop. Since the primary purpose of the tractor operations was considered to be weed control, thoughts turned to the use of chemicals instead. So it was that in 1959, the A.R.C. Unit of Experimental Agronomy was approached as to the possibility of developing the use of chemicals for this purpose.

With the creation of the new Weed Research Organisation in 1960, it was possible to put potatoes high on the list of priorities. Field experimentation started in 1961 and has continued until this day; indeed, it is likely to go on for many more years. The greenhouses were not operational in 1961, so virtually the whole investigation was carried out in the field by the arable team (Leader: T. I. Cox) of the Agronomy Section.

From the start it was apparent that this was not a subject that would be worked on in isolation. The research staffs of chemical firms and of other State organisations were interested and contemplating active research. In the event, careful planning has been necessary each year to make the W.R.O. programme complementary to that of others. This process has been helped by the formation in 1962 of the A.R.C. Working Party on The Chemical Control of Weeds in Potatoes, which has responsibility for co-ordinating official research on herbicides and their agronomic implications for the potato crop.

Chemical weed control in potatoes is one of the most exciting and fast-moving research projects that the writer has experienced. Farmer interest, and therefore demand for research, has grown with a speed and intensity that is unusual, even in the world of herbicides. In the space of four years, progress has been made to the point at which a selection of different herbicides has become commercially available to farmers during the past season. In this situation of increasing complexity, the Weed Research Organisation holds a key position as a centre for impartial research and as a clearing house for reliable information on the chemicals and their performance.

The Agronomy Section's approach to the potato project in 1961 was to split it up into a number of aspects which required investigation and then to concentrate on those that were important and unlikely to be pursued in detail by other organisations. The work and progress in each of these will now be described.

The Evaluation of Herbicides

The preliminary examination of all sources of information produced a list of 54 chemicals worthy of field screening on potatoes. These were applied in a variety of ways to Majestic potatoes at Begbroke in 1961. In the light of experience gained in that first year, 20 chemicals were carried through for further testing in 1962, and this number was reduced to 8 in 1963. Those that fell by the wayside did so for reasons of poor weed control, toxicity to the crop or more general considerations. The chemicals that emerged at the end of the three years were:—

contact foliar herbicides:	dinoseb, diquat, paraquat
foliar/soil-acting:	desmetryne, linuron, prometryne
soil-acting:	EPTC, trietazine.

All these herbicides required to be applied before the emergence of the potatoes, none being sufficiently selective when used on the potato foliage.

This three year programme was invaluable in concentrating interest on the promising chemicals, and in providing an independent assessment of the worth of those currently being investigated by chemical firms. As early as 1961 it was evident that it would be necessary to use herbicides which act through the soil if the crop was to be kept free of weeds over the necessary period of about 12 weeks. Indeed, such chemicals had already shown promise in the evaluation programme. In view of this, work was started in 1962 to study the possible toxicity to potatoes that might occur.

The Tolerance of King Edward Potatoes to Soil-Acting Herbicides

The variety King Edward was chosen because circumstantial evidence had indicated it to be more sensitive to herbicides than Majestic. A programme of yield experiments has been carried out for three years on different soil types as follows:—

Soil	*Site*
Fen	Messrs Sears Bros., Manea, Cambs. (1 year only)
Sand	Exp. Husb. Farm, Gleadthorpe, Nottinghamshire
Silt	Exp. Husb. Farm, Terrington, Norfolk
Medium loam	Exp. Husb. Farm, Martyr Worthy, Hants (2 years only)
Sandy loam	W.R.O., Begbroke Hill, Oxford

In these experiments the main soil-acting or foliar/soil-acting chemicals were applied in high doses and mixed into the soil before the potatoes were planted, the intention being to ensure the presence of the chemicals in the rooting zone. Other applications were made to the soil surface.

This trial series is being written up at the present time. Briefly, the main results are as follows:—

1. When mixed into the soil at rates up to 6 lb/ac, only EPTC failed to produce toxicity in potatoes.
2. The chemicals were generally most active on sandy soils and least active on the fen soil.
3. The toxicity of the chemicals increased with increasing dose. At similar rates, linuron, desmetryne, prometryne and trietazine produced approximately the same degree of toxicity.

It must be emphasised that these experiments were designed to produce damage in order that the reaction of the crop might be measured. The normal commercial practice of applying these herbicides at doses of 1–2 lb/ac to the soil surface prior to potato emergence would be much less drastic than mixing in an overdose; indeed, the commercial practice appears largely without effect on the potato. However, the experiments showed that King Edwards are not inherently tolerant to these soil-acting herbicides, and the avoidance of damage depends on the protection provided by the soil cover. Caution is necessary in using high doses on sandy soils.

In 1964 the Agronomy Section investigated the possibility of damage on sandy soils in a slightly different manner, using overhead irrigation in an attempt to wash the chemicals into the potato root zone and thereby induce damage.

During the period 1962–4, the W.R.O. has been able to emphasise the aspect of crop tolerance because of the co-operation of the National Agricultural Advisory Service. Each year suggestions have been made for weed control trials to be carried out by the Service's officers in various parts of the country; and the information on weed susceptibility that has been gained has been returned through the N.A.A.S. Liaison Officer at Begbroke Hill. In this way an overall picture of chemical performance against weeds has been built up.

The activities that have been described so far were largely concerned with the development of herbicides. Equally important is the agronomy of weed control in potatoes and this subject has also received attention during the past four years.

The Agronomy of Weed Control

An integral part of the development of a new technique is its comparison with the old-established practice to which it is to be an alternative. In the case of potatoes, this involved comparing the crop grown without soil disturbance (with herbicides used for weed control) with a similar crop grown with the soil disturbance of normal cultivation. Experiments of this type were carried out at Begbroke Hill in 1962 and 1963.

The results were rather startling. After the best of the herbicide treatments, that is to say the one (in this case paraquat) that controlled the weeds without adverse affect on the crop, the Majestic potatoes grew with visibly more vigour than those that were cultivated, and yielded 4 tons/ac more of ware potatoes (16·2 versus 12·2 tons/ac). Since it was unlikely that the herbicides had stimulated crop growth, it seemed apparent that the cultivations had had an adverse effect. As these results could have important implications, the experiment was repeated in slightly different form in 1963. The variety King Edward was used and the cultivations were kept to a minimum consistent with weed control (four tractor passes). The same differences in growth occurred, and this time the herbicide treated crop outyielded the cultivated crop by 1·4 tons/ac. In 1964, the entire commercial acreage of potatoes on Begbroke Hill Farm was sprayed just prior to emergence with a mixture of 1 lb paraquat plus 1 lb (active ingredient) linuron per acre, the soil being left undisturbed between planting and harvesting.

These experiences and those elsewhere have called into question the value of cultivation in potatoes, and the subject is currently receiving much attention, with experiments being done by research and advisory workers, and farmers themselves throughout the British Isles. As might be expected the results are often contradictory. However, one hard fact has been established, namely that the potato plant is sensitive to cultivation. The belief handed down to us that the soil in which the potato grows could be disturbed with impunity is incorrect. Ahead lies the research that will define the optimum soil environment requirements of the plant. This however, is a subject outside the scope of a weed research organisation.

A small amount of work has been undertaken, partly in co-operation with the National Institute of Agricultural Engineering, on new systems of planting and growing potatoes. The Organisation has associated itself actively so that an assessment can be made of any changing requirements in weed control that might be dictated by the new techniques.

The Current Programme

The questions about how best to grow potatoes and whether or not they should be cultivated have created so much interest and experimentation by others, that the Organisation is changing the emphasis of its programme so as to avoid duplication. More attention is now being given to improving methods of weed control, both by chemicals and cultivation. Particular attention is being given to the control of perennial grasses and to annual weed control on fen soils, in co-operation with the Bridgets and Arthur Rickwood Experimental Husbandry Farms, respectively.

Because cultivation implements are equally effective against most annual weeds, there has been no need in the past to build up a comprehensive picture of the weeds that occur on potato soils. This omission is now being rectified by means of information collected from Advisory Officers in England, Wales and Scotland. Information on potato varieties and the soils on which they grow is being received from the Statistical Section of the Potato Marketing Board.

Weed Seeds in the Soil

R. J. CHANCELLOR

Weeds have been with man ever since he first tried to grow certain plants to the exclusion of all others. Many agricultural operations today are influenced directly or indirectly by the need to take account of weeds. The advent of chemical methods of control has not only increased the yield of farm crops, but is also beginning to influence and change many of the time-honoured husbandry practices used in growing them. Yet despite these great changes, there remains one weakness in man's increasing mastery over weeds and that is the great store of dormant weed seeds buried in the soil.

THE POPULATION OF WEED SEEDS

The greatest density of plants recorded for a single weed species at Begbroke Hill is 119 seedlings of *Matricaria recutita* (wild chamomile) per square foot, which is equivalent to a population of five million to the acre. Yet this high figure represented only a small proportion of the total number of viable seeds remaining in this soil. By taking soil samples from the area and keeping them for three years in conditions suitable for seed germination, it was found that these 119 seedlings represented only about 4% of the total viable seed population of this species, which therefore amounted to 125 million per acre. Even when the seeds of other species present were added, the total number was still far short of the figure of 364 million viable seeds per acre, which is the highest population so far recorded anywhere. Yet even this figure is far below that of the number of seeds originally shed from the weeds into the soil. In one experiment at Begbroke the number of seeds produced by a dense weed stand approached 5¼ thousand million per acre. However, these astronomical numbers are never fully realised in terms of resultant plants, because many of the seeds are either eaten or decay rapidly. It has been found by H. A. Roberts at the National Vegetable Research Station and confirmed at the W.R.O. that if replenishment is prevented, the decline in numbers of a mixed seed population in the soil is about 50% per year, i.e. the population has a 'half-life' of one year. This means that the weediest field at Begbroke will still contain over 145,000 viable weed seeds per acre in 1975 provided no further seeds are shed into the soil before then. Methods of speeding up the exhaustion of these vast reserves of seeds would therefore appear to be a logical step towards the reduction of arable weed problems.

Most annual weeds have only one generation in each growing season. Their seeds are thus the vital link between one generation and the next and the sole reason why annual weeds are perennial nuisances. The varied behaviour of their seeds is a remarkable demonstration of adaptation to an environment more fraught with vicissitudes than most. Despite the importance of the subject, relatively little is known about the behaviour of weed seeds in the soil. A study programme was therefore started in 1962 to investigate certain aspects of the biology of weed seeds with the ultimate aim of evolving methods of hastening the natural rate of decline of seeds in the soil and to look for weak points in the life-cycles of individual species that could be exploited for their control. As a result it became known as the 'Achilles Heel' programme.

Periods of Seedling Emergence

The first aspect to be investigated was the periods of the year when weed seedlings emerge from the soil. There were known to be two general groups of annual plants, the summer annuals and the winter annuals, so described from the period of the year that the majority spend in the green or leafy phase. The summer annual, which germinates in the spring, passes the summer months in leaf, flowers and finally dies in the autumn. The winter annual, in contrast, germinates in the autumn and passes the winter in leaf, to flower in the following spring or early summer. In order to find out the germination periods of a number of weed species, three experiments were laid down in arable fields at Begbroke Hill during 1962. In them plots of bare soil have been maintained by hand-weeding at the end of every calendar month, at which time every seedling is also identified and counted. The results show that many, if not most, of the important weeds at Begbroke behave both as summer and winter annuals, i.e. they are not limited to one type of behaviour alone. However, a certain number of weeds germinate only in the spring, e.g. *Polygonum persicaria* (persicaria) and *Polygonum convolvulus* (black bindweed) and a very few germinate only in the autumn e.g. *Aphanes arvensis* (parsley piert). There is another group of plants that can germinate in quantity in virtually any month of the year, depending on the weather. An example of this is *Senecio vulgaris* (groundsel), which in three adjacent fields showed in 1962 three different peak periods of germination. Differences in micro-climate between the fields were obviously important here. Other weeds that appear to behave similarly are *Poa annua* (annual meadowgrass) and *Capsella bursa-pastoris* (shepherd's purse). They are occasionally called the 'Horticultural

Annuals' for they often share this type of habitat and it may well be that their success under horticultural conditions can be attributed as much to their germination behaviour as to the brevity of their life-cycles. Finally, there is the anomaly of *Veronica hederifolia* (ivy-leaved speedwell). This species behaves as a winter annual, but germinates much later than other weeds in this group and in consequence often passes the depths of winter in the cotyledon stage. In less severe weather it can also germinate throughout the winter from October to May, so it does not readily fall into the other groups which normally have pauses between the autumn and spring germination peaks. In view of its short life-span it might perhaps be described as a winter-germinating spring annual.

Within each group there are considerable differences between species in the duration of their germination periods. *Juncus bufonius* (toad rush) and *Gnaphalium uliginosum* (marsh cudweed) are notable for the brevity of their periods of germination. At the other end of the scale, *Papaver rhoeas* (corn poppy) and *Matricaria recutita* (wild chamomile) can germinate to some extent in virtually every month of the year, providing conditions are not too extreme, though winter totals are generally fairly low. Those weeds that have shorter periods of germination are less important agriculturally, while those that have longer periods are, as might be expected, the more important ones.

The Effects of Cultivation on Emergence

A series of cultivation treatments was superimposed on top of these monthly weeding experiments. Some plots were cultivated by digging every month after the monthly weeding, some were dug every three months, others once a year and still others were never cultivated at all. Surprisingly, these cultivation treatments yielded the most interesting results. For example, it was found that for most of the serious arable weeds, the more the soil was cultivated the more seedlings emerged. This was interpreted initially as simply the result of each cultivation bringing to the surface fresh supplies of non-dormant seeds. It was then discovered that other weed species, especially those less important agriculturally, did exactly the opposite, i.e. the fewer the number of cultivations the greater the number of seedlings that emerged. The group that responded to more frequent cultivations by increased germination was called the Arable Weed Response Group because it contained many serious arable weeds. The other group, which contained less important arable weeds and which had the opposite germination behaviour, was called the Inverse Response

Group. In addition, there was an Intermediate Group which appeared to prefer neither too few nor too many cultivations and as this group contained a diversity of weed species, it may indicate that the factor (? aeration) that stimulates or depresses germination of the other two groups is not of prime importance to this group. It has therefore been suggested that the germination responses of species to cultivation may well determine how serious they are as weeds, or even whether they become weeds at all.

Dormancy

Perhaps the most important factor in weed seed behaviour and indeed survival is dormancy. The causes of dormancy are many and it has been aptly said that some seeds are shed dormant, some acquire dormancy, while others have dormancy thrust upon them. An embryo may not grow because the soil is too cold or too dry, that of another species may not grow because the seed coat is impervious to oxygen and water, while others may not grow through immaturity or biochemical inhibitions. Dormancy carries the seed of summer annuals over the winter, enabling the seedlings to emerge at the beginning of the next growing season when they have a better chance of survival. However, some seeds have more prolonged dormancy which enables them to survive longer periods of unfavourable conditions. Seeds of arable weeds may thus be able to survive long periods under permanent pasture. It is a further remarkable adaptation to environment that a number of species not only have dormancy to tide over the cold period, but often also require the chilling of the winter to break this dormancy and to allow growth once the winter is over. One farming operation that aids and abets dormancy is ploughing. By burying seeds it imposes dormancy on them and, moreover, places them in conditions under which they can retain their viability for long periods. Left on the surface, they would germinate or perish much more quickly.

To reduce the population of seeds in the soil as suggested earlier, would require that ways of eliminating dormancy in all its various forms be found. This is unlikely to be feasible in practice. To take but one example, a common cause of dormancy is the presence of an impervious seed coat which keeps out the oxygen and water necessary for germination. In the laboratory, such seeds can be made to germinate by filing, chipping or pricking them, but it is obviously impossible to employ such methods on a field scale.

It is, of course, possible to kill dormant seeds in the soil by using soil fumigants. Such treatments are, however, very expensive and uneconomic on a farm scale. The use of other more usual types of herbicide has also been explored, but so far without success. Even if such chemicals could be discovered, there would still remain the problem of distributing them through the soil so as to reach all seeds. Recent experiments at Begbroke using radioactive and fluorescent tracers have shown that no implements at present available to farmers can mix surface-applied chemicals to plough depth satisfactorily.

Depth of Germination

The problem of the depth to which soil-acting herbicides should be incorporated has led also to studies being made of the depth from which seedlings emerge in the field at Begbroke and other locations. In these studies, seedlings of each of eighteen weed species were dug up in arable fields after they had germinated naturally and measurements taken of the depth of the seed from which the seedling originated. The measurements were repeated where possible in peat, clay and sandy soils, in spring and autumn and duplicated in two successive years. It was found that 98% of all seedlings measured had germinated from depths of less than two inches, which implies that any treatment of dormant seeds need only be effective to that depth to achieve control in the following season's crop. However, seeds lying dormant at deeper levels would remain and make herbicidal treatments an annual necessity.

Conclusion

It is obvious from these and other studies that the behaviour of annual weeds and their seeds is very variable, both as between one species and another and within any one species. This is especially notable in the most serious weed species and is an important factor in ensuring their survival and indeed their success. Although a given treatment might prove effective in depleting the seed reserves of a single species in the soil, it seems unlikely at present that any panacea will be forthcoming to get rid of all weed seeds. Effective reduction can therefore only be achieved by a policy of attrition over a period of many years.

Soil-Applied Herbicides

R. J. HANCE

In recent years, increasing attention has been paid to the development and use of herbicides which are applied to the soil. Present indications are that this trend will continue.

Normally, soil-applied herbicides have no immediate direct contact with their target plants, so that their performance can be greatly influenced by soil characteristics and weather conditions. Since plant behaviour also depends to some degree on these factors, the possible interactions between them are clearly both numerous and complicated.

Chemicals applied to the soil can be selective in their effects, in which case they may be applied before sowing, after sowing but before crop emergence, or after emergence, or they can be used non-selectively so as to control all vegetation.

Pre-sowing application. Such treatments are used to control perennial weeds which are otherwise difficult to control selectively in the growing crop, or to control annual weeds which germinate at the same time as the crop. If the crop is not very tolerant of the chemical the margin of safety at rates high enough to give adequate weed control may be narrow, depending on dose, time of application and rate of inactivation in the soil.

Pre-emergence application. Except where the crop is tolerant of the chemical, pre-emergence treatments depend on the presence of a high herbicide concentration near the soil surface and the use of crop plants whose seeds germinate at a safe distance below the surface zone. In this situation, factors affecting the mobility of the compound are of paramount importance.

Post-emergence application. This type of treatment, though less common in agricultural practice, is frequently used in perennial horticultural crops. Chemicals used in this way are usually toxic only to plants in the early seedling stages, whilst the maturer crop plants are unaffected.

Total weed control. An ideal total weedkiller would be a chemical which killed the existing vegetation, became distributed throughout the germination zone and was persistent. For practical purposes, the last two requirements are mutually exclusive, as materials which distribute themselves well are usually easily leached and thus lack persistence. For this reason combinations of chemicals are frequently employed.

A major advantage of soil-applied chemicals, is that they provide weed control over long periods, perhaps for the whole growing season.

If longer persistence occurs, it may be necessary to sow a tolerant crop in the year after treatment. As van der Zweep[1] has observed, such procedures are defeatist in that the chemical dictates the cropping practice.

Frequently the selectivity of soil applied herbicides is low, so that there is a danger that a given dose may either produce crop damage or fail to provide adequate weed control. In order to reduce this danger, a better understanding is required of the factors which control the persistence and mobility of such chemicals in the soil. Such information is also desirable in view of the current public interest in pesticide residues of all kinds.

When a herbicide is applied to the soil it becomes exposed to a number of inactivation processes. These are usually considered to be: volatilisation; photochemical alteration; chemical reaction (non-biological); biological decomposition; leaching; and adsorption onto soil colloids. These processes will clearly be influenced by soil characteristics, climatic conditions and the chemical and physical properties of the herbicide.

Volatilisation

Hartley[2] has calculated that a herbicide with a molecular weight of about 180 and a vapour pressure of about 10^{-4} mm Hg could be lost from the soil surface by evaporation at a rate of some 24 lb/acre/month. On this basis, even a non-volatile material such as monuron, which has a vapour pressure of 5×10^{-7} mm Hg at 25°C, may suffer significant losses in this way. With a compound such as EPTC which has a vapour pressure of the order of 0·15 mm Hg losses may be substantial.

In practice, movement of the chemical into the soil and adsorption on soil surfaces will greatly reduce such losses. However, this reduction may be offset to some extent by the upward movement of herbicide in solution. Evaporation of water at the soil surface causes water to move upwards by capillary flow. Dissolved herbicide will thus be moved to the surface where it can also evaporate. This process has sometimes been confused with steam distillation, which it is not. Hartley has coined the term 'wick' evaporation for this phenomenon.

Photochemical Alteration

It has been shown that in aqueous solution or in dry, thin layers, some herbicides, notably the ureas and triazines, undergo alteration when

[1] van der Zweep, W., Persistence of some important herbicides in the soil. In "Herbicides and the Soil". ed. Woodford E. K. & Sagar G. R. Blackwell, 1960.

[2] Hartley, G. S. Herbicide behaviour in the soil. In "The Physiology and Biochemistry of Herbicides", ed. Audus L. J. Academic Press, 1964.

exposed to ultra-violet light. This process has not, however, been unequivocably demonstrated in the field, as under these conditions it is difficult to distinguish between accelerated evaporation and photochemical decomposition.

Chemical Decomposition

Many herbicides contain groups which are susceptible to hydrolysis. At normal soil pH values, such processes will be slow, but at the surface of soil colloids, particularly the organic colloids, the local pH may be appreciably lower than the bulk pH of the soil and hydrolysis could then occur with significant speed.

Little is known of the extent to which herbicides undergo oxidation or reduction in the soil. However, it is reasonable to suppose that the molecular distortion imposed when a molecule is adsorbed may lead to increased susceptibility to oxidation by atmospheric oxygen.

In some cases decomposition is essential for a herbicide to be effective. A good example is 2,4-dichlorophenoxyethyl hydrogen sulphate (2,4-DES), which is not itself phytotoxic. This compound is hydrolysed in the soil to 2,4-dichlorophenoxyethanol, which is subsequently oxidised to the active 2,4-dichlorophenoxyacetic acid (2,4-D).

Biological Decomposition

When added to the soil, an organic substance, such as an organic herbicide, is attacked by those organisms that can utilise it as a nutrient source. Such a process is characteristically preceded by a lag phase of slow decomposition, during which time organisms which can metabolise the compound develop and multiply. Thereafter, decomposition is much more rapid, the rate being determined largely by soil conditions such as water content, temperature, pH, mineral nutrient supply, aeration and organic matter content. Microbiological breakdown appears to be one of the most important decomposition processes that occur in the soil.

A second pathway of biological loss is by crop removal. A crop may absorb a herbicide and then proceed to degrade it to harmless substances. An outstanding example is the ability of maize to remove large amounts of simazine and atrazine from the soil by this process. This may be a significant source of loss. It must also be remembered that some herbicide is used up in the course of destroying weeds, although this is likely to be important only in the initial clearing of a weedy area.

Leaching

Leaching of a herbicide may enhance its effectiveness by moving it to areas where susceptible plants root or germinate, or the converse may occur if leaching moves the chemical out of the desired area. This process may also remove the herbicide altogether from the top soil and thus give rise to further problems if the chemical ultimately reaches water supplies used for irrigation or drinking.

The extent of leaching is largely determined by the water-solubility of the compound, the quantity of water moving through the soil and those soil-herbicide interactions, particularly adsorption, which tend to retard movement.

Adsorption

Adsorption is the process by which a dissolved substance becomes concentrated on the surface of a solid with which it is in contact. The colloidal fraction of soil has an enormous surface area, so this phenomenon is of importance in the soil-water-herbicide system. Adsorption influences the activity of a herbicide both directly, by removing the chemical from solution, and indirectly through its effect on the other processes of inactivation discussed earlier.

The colloids of soil include organic and inorganic materials, the inorganic fraction being largely composed of clay minerals and hydrated oxides of iron and aluminium. The soil colloidal surface contains both negatively and positively charged sites, although in the normal soil pH range, the overall effect is of a net negative charge. Such sites are usually more numerous on the organic fraction than on the inorganic fraction. The sites attract oppositely charged ions which may be displaced or exchanged for other ions, thus giving rise to the well known ion exchange phenomena which are important in the mineral nutrition of plants. Some herbicides are ionic and therefore can participate in ion-exchange reactions. Paraquat and diquat are examples of cationic herbicides which may be held by this process. Under acid soil conditions (below about pH 5), the triazines may also be adsorbed significantly in this way. Similarly, anionic herbicides such as dalapon and 2,4-D may be held at exchange sites, though positively charged sites are less numerous than negative sites. The adsorption of such anions is inhibited to some extent by the fact that since the soil colloids bear an overall negative charge, simple electrostatic repulsion will tend to prevent these herbicides from approaching colloidal surfaces.

Molecules which are essentially uncharged, such as the ureas and the triazines (the latter at pH values above 5–6) are also adsorbed. It is thought that such chemicals are held by short-range forces such as hydrogen bonds and the van der Waals forces.

The Chemistry Section of W.R.O. has been engaged on an investigation of some of the factors involved in adsorption, with particular reference to the substituted urea herbicides. The work has been carried out with three objects in view:—

(i) To attempt to correlate the structure of urea derivatives with the extent of their adsorption.

(ii) To compare adsorption by different soil types.

(iii) To study the part played by organic matter, which field experience has suggested as perhaps the dominant factor.

Very simple experimental techniques have been employed. Solutions of test compound of known concentration were shaken overnight with soil samples, after which the supernatant liquids were removed and the final solution concentrations estimated by ultraviolet spectrophotometry or colorimetric procedures. Hence the amount of material adsorbed could be calculated. The results were evaluated with the aid of the empirical Freundlich isothermal relationship which may be written:—

$$\log \frac{x}{m} = \log k + \frac{1}{n} \log C$$

where $\frac{x}{m}$ = amount x adsorbed by weight m of adsorbent

C = concentration of equilibrium solution

k and n are constants, characteristic of the system.

This equation has no theoretical basis, but is useful for purposes of comparison. Figure 1 shows a typical graph in which $\frac{x}{m}$ has been plotted against C on logarithmic scales.

The behaviour of urea and nine of its derivatives has been studied. It appears that both *N*-alkyl and *N*-aryl substituents are important in determining the extent of adsorption. Increases in the chain-length of alkyl substituents and chloro- or chlorophenoxy- substitution in the aryl group produce increased adsorption. Water-solubility does not seem to be closely related to adsorption. The herbicides which have been tested may be listed in the following order of increasing tendency to be adsorbed: fenuron $<$ monuron $<$ monolinuron $<$ diuron $<$ linuron $<$ neburon $<$ chloroxuron.

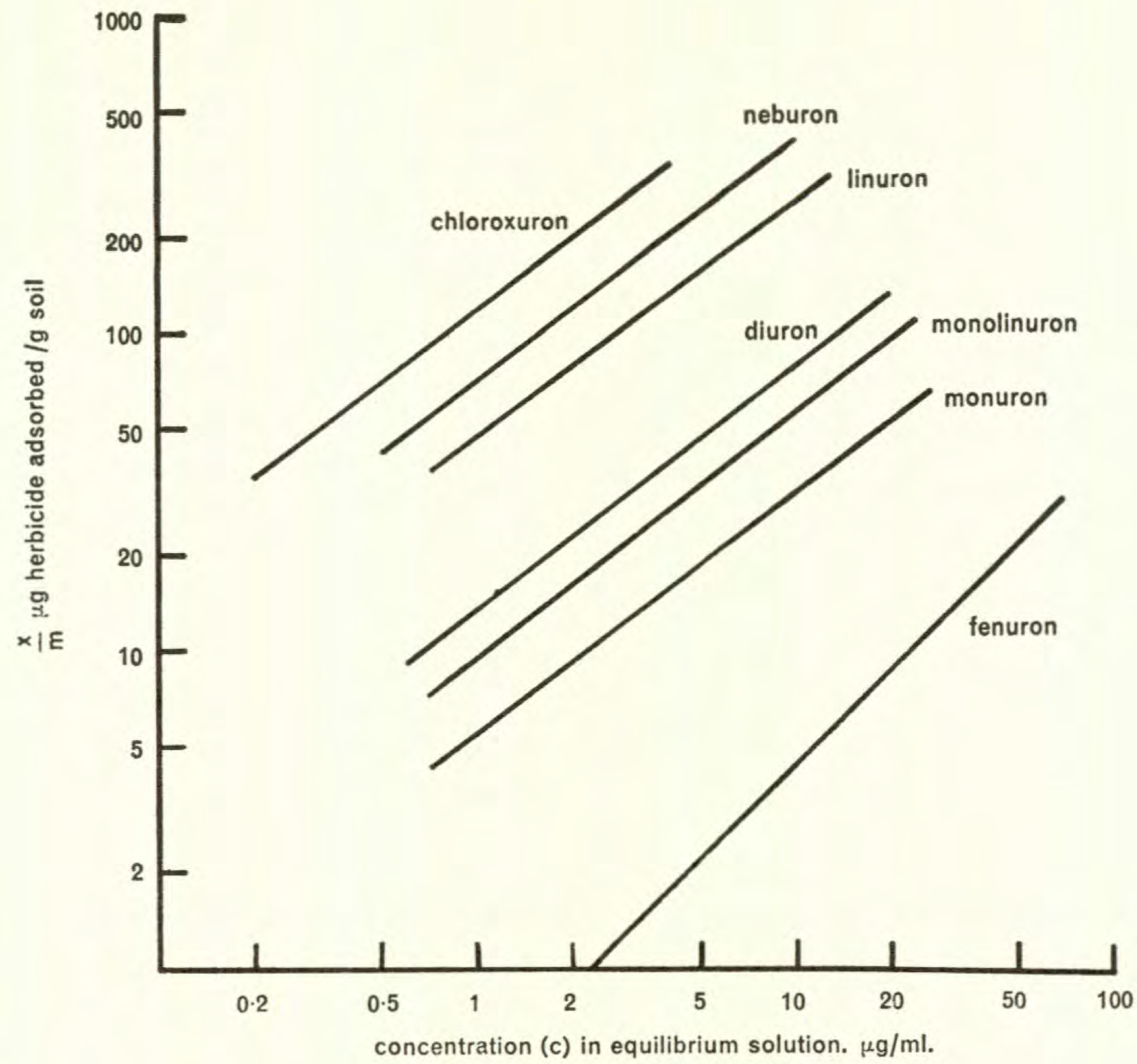


Fig. 1. Isothermal equilibrium adsorption of some substituted urea herbicides

The results showed one surprising feature. In theory, it might be expected that at the low concentrations used in this work, the quantity adsorbed would be directly proportional to the concentration in the equilibrium solution, in which case the slope of the lines in Figure 1 would be unity. In fact this was so only in the case of fenuron, the other compounds giving graphs of slope about 0·75. Because of this difference, fenuron is theoretically not comparable with the other herbicides. No explanation of this behaviour has yet been found.

Eleven British and nine East African soils were used in the investigation. The only soil property which was correlated with adsorptive power was organic matter content. Work with soils which had been oxidised with hydrogen peroxide to remove the organic matter indicated that the capacity of soil mineral matter to adsorb substituted ureas is low.

These investigations are currently being extended by the Evaluation Section, which is comparing the laboratory adsorption data with herbicide performance in pot experiments.

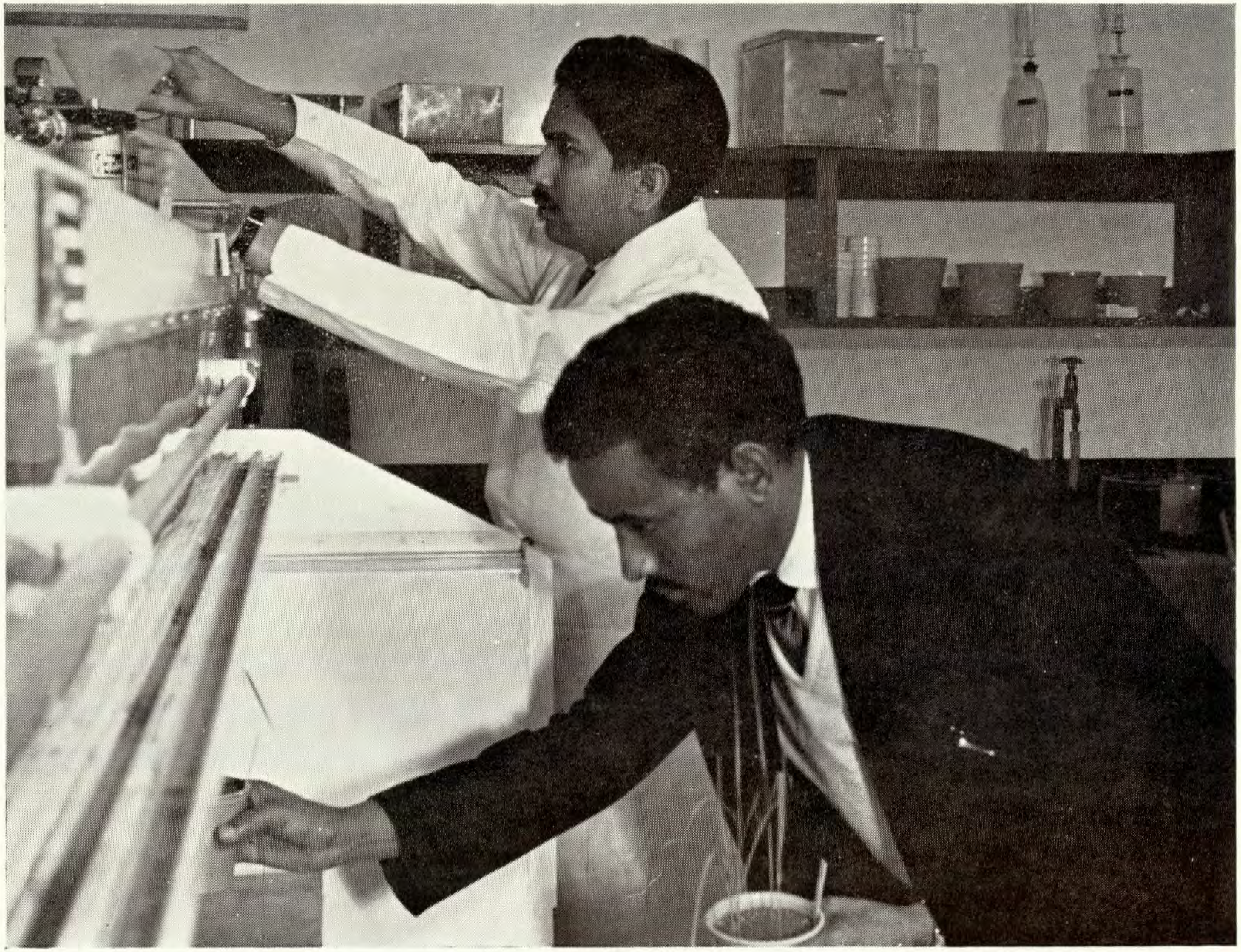
Using diuron as a representative urea herbicide, studies with soil organic matter and a variety of other adsorbents of known structure suggested that under aqueous slurry condition, there is competition for adsorption sites between the herbicide and water. Diuron apparently competes more effectively at organic matter surfaces than at clay surfaces, so that in the presence of water, organic matter is the most important adsorbent. In the absence of water, the picture is changed, as the soil mineral fraction adsorbs more diuron from light petroleum solution than does organic matter.

Investigations designed to assess the rôle of such functional groups of soil organic matter as carboxyl, phenolic hydroxyl and alcoholic hydroxyl seem to indicate that these groups are not involved in the adsorption of ureas except in so far as they affect the hydrophilic/hydrophobic balance of the surface.

Work is currently in progress to study the adsorptive behaviour of other classes of herbicide.

E. K. Woodford, O.B.E., Ph.D., D.I.C.,
Director, 1960 to September 1964

View from forecourt showing house and some of the converted farm buildings



Pot spraying equipment operated by overseas students attached to W.R.O.

Field testing of herbicides with the W.R.O. Logarithmic Sprayer

REPORTS OF SECTIONS

Evaluation Section

Head: K. HOLLY

A primary function of this Section is to investigate the potentialities of new herbicides coming from the agricultural chemical industry. At present this takes the form of an examination of their selectivity, both as foliar-applied and as soil-applied herbicides, on a wide range of species grown in pots. These include annual temperate agricultural and horticultural crops, some perennial crops such as strawberry and blackcurrant (as cuttings), temperate annual and perennial weeds, and a few herbaceous tropical crops and weeds, both annual and perennial. Interesting selectivities are then followed up in more detail in further pot experiments and in small-plot experiments in the field. In addition certain special potential uses of selective herbicides are investigated more intensively in detailed field programmes. Important examples are the selective control of perennial grass weeds without damage to perennial cultivated grasses, the pre- or post-emergence control of broad-leaved weeds in cereals and the control of perennial weeds; special stands of docks (*Rumex* spp.) and couch grass (*Agropyron repens*) are being established in the field for experimentation.

The programme of evaluation of new herbicides is currently being recast to provide more background information regarding their behaviour, so that their performance under various field conditions may be forecast more clearly. Thus it is hoped to ascertain, among other things, the relative importance of root and shoot uptake in relation to herbicidal effect, to learn something of the effect of environmental factors on performance of foliar-applied herbicides, and to determine the liability of soil-acting herbicides to be adsorbed, leached or broken down in soil.

Other research projects undertaken by the Section include studies of inactivation of herbicides in soils as a supplement to the work on adsorption by the Chemistry Section, persistence of herbicides in soils and in plant tissues which may be returned to the soil, and the distribution of herbicides in soil following incorporation by different implements. On the field side the Section is also concerned with the problems of application of herbicides and experimental equipment for this purpose.

Greenhouse Work (S. D. Hocombe)

The W.R.O. greenhouse is divided into six sections, each equipped with supplementary heating and lighting. The installation was not completed until early 1953. Before this a limited amount of work was carried on in the greenhouses at the University Field Station, Wytham, but a great part of the effort of the Section staff was given to supervising the construction work at Begbroke and assembling such ancilliary equipment as greenhouse benching and the lighting system. This interruption of experimental work and the extensive staff changes which followed, led to a considerable accumulation of new herbicides in need of primary evaluation. By the end of 1964 the majority of these herbicides had been tested.

The pot sprayer, which applies herbicides from a moving nozzle to potted plants standing in a closed cabinet, was made to the specification of Dr. K. Holly and was operating by the middle of 1963. Since then it has been used to spray 24 major evaluation experiments, involving over 80 new herbicides. It has also been extensively used by other sections.

Two out of the three students at the W.R.O. studying for higher degrees at Reading University are attached to the Evaluation Section, one working on ioxynil and the other on the selectivity of the triazine herbicides in cereals.

(a) *Standard selectivity tests*

Two standard selectivity tests for new herbicides have been developed. The first of these is a pre-emergence test, in which the new compound is incorporated into the soil in metal boxes, after which crops and weeds are sown. The second is a post-emergence test in which the herbicide is applied as a foliar spray to young crops and weeds growing in pots. After some weeks the effectiveness of the herbicides is gauged by recording plant survival and health, and any interesting selective effects (i.e. differences in reaction between crop and weed species) are noted. Promising herbicides then go on to field trials. At present 24 species, some of them weeds but mostly crops, are used in the pre-emergence test. In the post-emergence test more than 50 species are used. In both tests, the crops and weeds are selected for their importance in agriculture and horticulture and include both temperate and tropical species. Crops such as tobacco and rice are therefore grown, as well as such temperate crops as wheat and sugar beet, and the list includes not only crops and weeds which propagate by seed, but some, such as strawberry, couch grass and nutgrass (*Cyperus rotundus*) which propagate vegetatively.

During 1964 eight new herbicides received both pre- and post- emergence tests. Six more were tested pre-emergence only, and eight others only post-emergence. In most cases performance was compared with that of known herbicides used as standards. Attempts are being made to make the recording of experiments more efficient by the use of punched cards for analysis by the Orion computer at Rothamsted.

The 1964 work revealed or confirmed several interesting selectivities. On cereals two new bipyridyl herbicides at present coded PP 407 and PP 745* showed outstanding post-emergence selectivity. Wheat, barley, oat, maize, rice, sorghum and perennial ryegrass all tolerated doses which killed many broad-leaved weeds. The post-emergence selectivity of ioxynil and bromoxynil in these crops was confirmed, and it was found that adding a wetting agent to sprays of ioxynil considerably increased their activity against broad-leaved weeds, with only a slight reduction in crop safety. Several of the new triazine herbicides tested

* See glossary, p. 55.

and also Philips Duphar PH 40-21 were selective in maize when applied pre-emergence.

Among leguminous crops, pea showed a reasonable tolerance of the triazine GS 13529, and its tolerance of foliar sprays of prometryne was confirmed. Dwarf bean and field bean tolerated one triazine herbicide (the composition of which is still confidential), and the substituted urea CIBA 3126 was rather better tolerated than its analogue monolinuron. Lucerne showed a limited tolerance of foliar sprays of ioxynil and bromoxynil, as also did groundnut. Red and white clovers showed no marked tolerance to any of the herbicides tested.

No noteworthy selectivities were found among the brassica crops, sugar beet, tobacco or lettuce. The tolerance of onion to the substituted urea CIBA 3470 was confirmed, as was the selectivity of certain ureas and of prometryne and related triazines in umbelliferous crops.

Monsanto CP 31675 and PH 40-21 both showed some toxicity to couchgrass and nutgrass.

(b) *The future evaluation programme for new herbicides*

The two standard selectivity tests for new herbicides were initiated at a time when the effort allocated by manufacturers to primary evaluation of their new herbicides was smaller than it is now. As the screening facilities of manufacturers have improved, so the W.R.O. selectivity tests have tended increasingly only to confirm selectivities which have already been demonstrated by manufacturers.

It is felt that this element of duplication should be avoided by the W.R.O. The evaluation programme has therefore been revised. The standard pre- and post-emergence tests are being retained, but only for herbicides which from outside information and from a smaller initial test of activity appear to be worth the considerable investment in time and effort involved. The time saved will be devoted to a series of other tests designed to gain basic background information about the factors affecting the activity and performance of new herbicides, with a view to providing a better understanding of their behaviour in subsequent field tests. For instance, a herbicide showing high foliar activity in the initial test might next be subjected to a series of tests examining the influence on its activity of, say, different light intensities, temperatures or humidities, its rain-fastness, the ease with which it is translocated, and so on. Herbicides which are translocated freely in plants will be subjected to a special screening test on perennial weeds. As in the past, soil-acting herbicides will continue to be tested for persistence in the soil; factors such as ability to be leached in the soil, volatility and stability to actinic radiation will also be examined. Many other types of test are planned for the future, several of them depending on the installation of controlled-environment cabinets, on which work will soon begin.

(c) *Screening tests on potatoes*

For several years two screening tests have been carried out annually on potatoes, one a pre-emergence test of soil-acting herbicides involving soil incorporation, and the other a test of foliar-acting herbicides. Several herbicides, all of them soil-acting and most of them ureas and triazines, have shown sufficient promise in these tests to go forward into field trials.

(d) *Residues in plant material*

In 1963 it was suggested that damage seen in glasshouse crops growing on straw bales may have been due to 2, 3, 6-TBA residues which had persisted in the straw following application to the growing cereal crop in the spring. A greenhouse experiment, using dwarf bean as an assay plant, showed that residues of 2, 3, 6-TBA could be carried over in this way. It has since been shown that picloram, dicamba, fenac and Velsicol 59-CS-52 can also persist in or on the straw from treated cereal plants in amounts detectable by bioassay. This work is being extended to examine herbicide residues in lawn mowings and in grasses growing in treated soils.

(e) *Soils project*

The Evaluation Section is concerned with several aspects of the behaviour of herbicides in soils. Using Italian ryegrass as a bioassay plant, the breakdown and leaching of some triazine herbicides in soils in the field has been followed in cereal experiments. It has been shown that crop damage can be related to movement of herbicide into the lower soil layers, where the majority of cereal roots are found. Where little movement into the lower soil layers was detected, little or no crop damage was seen. This is the so-called depth-protection phenomenon. The breakdown and movement under field conditions of several other herbicides has also been followed, using bioassays.

The degree to which a number of substituted ureas are adsorbed onto soils of various types has been studied by the Chemistry Section using chemical detection techniques. A series of pot experiments recently initiated by the Evaluation Section has the aim of relating these chemical data on adsorption to phytotoxicity measurements. Preliminary indications are that, for a particular herbicide, differences in the degree of adsorption between one soil and another closely parallel differences in phytotoxicity.

(f) *Swamp rice*

A technique has been evolved for growing swamp rice in pots, and has been used to compare the phytotoxicity of several potential molluscicides to this crop.

Field Work (J. HOLROYD)

Field work in the Evaluation Section is concerned with the testing of herbicides which have either shown promise in the initial evaluation tests in the greenhouse or need evaluating on crops or weeds which cannot be grown satisfactorily under greenhouse conditions. In addition, more promising herbicides are subjected to a detailed investigation in respect of particular weed control problems.

The main crops and weeds under investigation at present are cereals, potatoes, kale, forage grasses and clover, most of the annual broad-leaf weeds, particularly those which are more resistant to the ordinary growth-regulator type of herbicide such as corn marigold (*Chrysanthemum segetum*) and the mayweeds (*Matricaria* spp.), creeping thistle (*Cirsium arvense*), broad-leaved dock (*Rumex obtusifolius*), wild oats (*Avena* spp.) and *Poa annua*, *Agropyron repens*, *Holcus lanatus*, *Poa trivialis*, *Festuca rubra*, *Festuca ovina* and *Agrostis tenuis*. Each year an increasing number of herbicides have come forward for primary evaluation. Thus in 1961 23 herbicides were tested in the field and in 1964 53. A number of herbicides have proved sufficiently promising to be worth following up in more detailed investigations. Some of these are summarised below.

(a) *The control of wild oats in cereals*

The two wild oat herbicides barban and di-allate became available in 1959–60 and during the period up to and including 1963, an extensive programme was carried out to investigate their potentialities in cereals. The results of this work emphasised the importance of applying barban to the wild oats at the susceptible 1 to 2½-leaf stage, the antagonism between barban and other growth regulators (particularly 2, 3, 6-TBA and MCPA) if applied together, the importance of crop competition, and the increased susceptibility of winter wheat to treatment at the 4–5 leaf stage in March. This work also demonstrated the relationship between the distribution of di-allate and tri-allate in the soil when incorporated and their selectivity against *Avena* spp. growing in spring barley or wheat. Selectivity was governed by the depth and efficiency of incorporation, the depth from which the *Avena* plants were growing and the depth the crop was sown. A further small-scale investigation in 1964 indicated that most *Avena* plants (80%) arise from seed in the top 3 in. of the soil. Some emerged from depths of 7–8 in., but the most vigorous plants appeared to arise from 1–2 in. below the depth of the final seedbed cultivations.

(b) *The distribution of herbicides in the soil after incorporation by farm implements*

The previous project emphasised the need for knowledge of the distribution of surface-applied herbicides in the soil after incorporation by farm implements. During 1961 and 1963, this problem was investigated using both fluorescent and radio-active tracers—the latter in collaboration with the A.R.C. Radiobiological Laboratory at Letcombe Regis. The implements tested included rotary cultivators, spring-tine harrows and chain harrows, but only one soil type was used. The results illustrated the relative inefficiency of farm implements as incorporation tools. Rotary cultivators were the most efficient, but after a single pass with the implement working to 4–5 in., more than 70% of the tracer still remained in the top 2 in. of soil. Similarly, lateral distribution varied greatly and the coefficients of variation for the sample counts ranged from 28% for a rotary cultivator to 84% for a tined weeder.

(c) *Pre-emergence herbicides for cereals*

Post-emergence herbicides or herbicide mixtures at present available will control most of the annual broad-leaf weeds present in cereals and suppress the aerial shoots of many perennials. The farmer may not, however, be receiving the full yield increase from the removal of these weeds, for it is known that weed competition can exert its maximum effect relatively early in the life of the crop. Only by growing the crop under weed-free conditions for the whole of its life is it likely that its full yield potential will be realised. Soil-acting herbicides applied before emergence can achieve these conditions, but must be selective and reliable. Unfortunately their effectiveness can be influenced by such factors as soil, depth of sowing and weather at the time of application and also perhaps for several weeks afterwards. However, in trials at Begbroke and elsewhere during 1962 and 1963, one herbicide was selective enough to demonstrate that under experimental conditions yields can be increased more by removing the weeds immediately they emerge than later in the life of the crop. In 1964, pre-emergence treatments were further tested by the N.A.A.S. with promising results. A more reliable herbicide for this purpose is however still required.

(d) *The selective control of grass weeds in grassland*

Studies on herbicides for the selective control of different grasses have been in progress for several years. Since 1961, over 40 herbicides or herbicidal formulations have been evaluated at Begbroke on crop and weed grasses grown as pure stands in rows or as swards. The crop grasses used have been mainly pasture strains of *Lolium perenne*, *Dactylis glomerata*, *Phleum pratense*, *Festuca pratensis* and occasionally *Lolium multiflorum*. The weed grasses *Holcus lanatus*, *Festuca rubra*, *Festuca ovina*, *Poa trivialis* and *Agrostis tenuis* have been used regularly, and *Poa annua*, *Festuca tenuifolia* and *Deschampsia flexuosa* occasionally. Mixed swards of two species were established in 1964 to introduce the added factor of competition.

Initially, work was confined to the herbicides with known activity, such as diquat, paraquat, dalapon and amitrole. Such aspects as the susceptibility of the various species, the importance of the time of application and the interaction between weather and with selectivity were studied. Most grasses were more susceptible in autumn than in early summer. Adding a wetter generally increased herbicidal retention and hence effectiveness, but the amount of the increase varied between species. Both dalapon and paraquat showed useful selectivities. Dalapon suppressed both *Poa trivialis* and *Agrostis tenuis* more than *Lolium perenne* or *Festuca pratensis* but differences in susceptibility were not great. Paraquat was particularly effective against certain weed grasses, e.g. *Holcus lanatus*, in the autumn, but the initial scorch it causes in all species detracts from its possible use for selective grass control in pastures.

The most promising herbicides at the present are the new sulphonyl carbamates and some substituted ureas. The former are more active on *Holcus*, *Poa* spp. and

Agrostis spp. than the other species in July, whereas of the latter, linuron and monolinuron, are more active against *Holcus* than the other species under winter conditions. Some of the new uracil herbicides have selectively reduced *Festuca* spp. when applied in July.

In 1965 some of the more important factors influencing selectivity, such as differences between species in foliar retention of herbicide and sites of herbicide entry, will be investigated.

Because of the possible importance of these studies for the control of grass weeds in herbage seed crops any promising results will be passed on to the National Institute of Agricultural Botany at Cambridge for further evaluation.

(e) *Herbicides for the control of broad-leaf dock* (Rumex obtusifolius)

In 1963 a half-acre plot was planted with this troublesome weed. In tests of various herbicides, the following appear to be the most effective: (I) picloram either alone at 2 to 4 oz a.i. per acre or as a mixture with MCPA or 2, 4-D, (II) dicamba at 1 lb per acre or at lower doses, as a mixture with 2, 4-D, (III) a sulphonyl carbamate at 2–4 lb a.i. per acre. Docks appear to be most susceptible to treatment in September or early October, but a reliable assessment cannot be obtained until 18 months after treatment, owing to the possibility of regeneration from roots.

Herbicide evaluation on perennial weeds is being extended to include *Agropyron repens* and *Cirsium arvense*. The initial work will be restricted to single clones established under field conditions.

Agronomy Section

Head: J. G. Elliott

The main function of the Section is to carry out practical field research either on weed problems of immediate concern to farmers or on new methods of weed control made possible by the development of herbicides. The Section has two research teams dealing respectively with grassland and arable weed problems. Each team does active research on two projects. In addition, work is in progress on a technique of sowing seeds suspended in fluids. More recently, the Section has become responsible for a new project on the use of herbicides in minimum cultivation husbandry. There are thus six projects in hand at the present time. Brief details of these are outlined below.

Apart from its research activities, the Section keeps in close touch with farmers and their weed problems in order to provide a link between the research work of W.R.O. and the requirements of the farming community. By this means, the results of research can be realistically conveyed to the user, and at the same time a watch can be kept on the changing priorities among the weed problems awaiting research. This function is developed in conjunction with the N.A.A.S. Liaison

Officer. During 1964, the work of the Section involved some 15,000 miles of travel. Talks or demonstrations were provided for members of the agricultural community on 24 occasions.

Grassland (*Team Leader:* G. P. ALLEN)

The selective control of Agrostis *and* Poa *spp. in permanent pasture*

In England and Wales, there are at least 2 million acres of permanent pasture that contain some ryegrass, but are also infested with *Agrostis* and *Poa* species. In an experiment carried out in 1963, it was observed that dalapon at 5 lb/ac applied in July had selectively reduced the two weed grasses, allowing perennial ryegrass to achieve dominance over the sward. This finding is now being followed up in two new experiments involving a range of dalapon doses applied in conjunction with fertilisers. The results so far are encouraging. The aim of the project is to develop an entirely novel method of improving this type of grassland, based on the selective suppression of grasses by herbicides as a management tool.

Sward destruction prior to surface reseeding

The object is to develop herbicides which will kill established grass swards and to study methods of reseeding which do not involve deep or power-consuming cultivation. Dalapon, paraquat and amitrole-T have been applied at Begbroke in many different ways to determine the best way of killing the *Agrostis/Festuca* swards available. It is clear that these herbicides perform best when the main application is made in autumn and when followed up with a very low dose of paraquat in the spring. By this means the growth of the old sward can be prevented between October and May so as to allow the establishment of an arable or grass crop in the autumn or spring. Soil-acting herbicides are now being tested for their ability to control germinating weeds selectively.

This project has been co-ordinated with similar work at the Grassland Research Institute. The co-operation of the Entomology Department of the National Agricultural Advisory Service at Reading has been obtained in examining the behaviour of slugs in killed swards.

Arable Crops (*Team Leader:* T. I. COX)

Weed control in kale

The weed problem in this crop has always been a serious one and no comprehensive remedy, apart from expensive hand-hoeing, has been available to farmers. At the start of the project in 1961, information obtained through N.A.A.S. Regional Officers showed that fathen (*Chenopodium album*), the brassica and polygonaceous weeds were very widespread and troublesome. The importance of weed control was demonstrated in 1961 and 1962 in experiments which made it clear that the yield of kale can be much reduced by the competition from these weeds. Early in the chemical evaluation programme it was discovered that desmetryne (then named G.34360) was capable of selectively controlling fathen in kale. After further development in co-operation with the firm holding the development rights for desmetryne and with the N.A.A.S., this herbicide was made commercially available to farmers in 1963.

Further evaluation of chemicals has reduced to four the number which are of current interest. These are desmetryne for the control of fathen and young redshank (*Polygonum persicaria*), SMA for the control of young brassica weeds and redshank, and dicamba and picloram for the control of annual polygonaceous weeds and others. In 1964 various mixtures of these chemicals were tested with fair success on mixed weed populations, and further experience will be obtained in 1965. The kale project has involved co-operation with the Fodder Crops Branch of the National Institute of Agricultural Botany and the Institute of Rural Science of the University College of Wales, Aberystwyth.

Weed control in potatoes

A very full project concerned with the development of chemical weed control in potatoes has taken about half the time of the arable crop team since 1961. The project has involved chemical evaluation and field trials to compare chemical with cultural weed control. A full description of the Section's activities may be seen on page 10.

The growing of cereals in cultural systems involving minimal soil disturbance

One result of the development of herbicides is the successful attempts now being made to grow cereals with little or no soil cultivation. Both commercial research establishments and the Ministry of Agriculture's Experimental Husbandry Farms have begun long-term experiments on the subject. Activity at the W.R.O. has been limited to exploratory field trials to gain experience of the suitability of existing cereal drilling equipment for operating under minimum-tillage conditions.

While the responsibility of the W.R.O. is perhaps technically limited to observation of, and advice concerning, the weed problems encountered in this new system of growing cereals, there is a clear need for collaboration between all concerned with this project. It is hoped that it will be possible to start active experimentation as soon as the staff of the Section has been strengthened.

Fluid Drill Project (*Research Worker:* J. D. PARKER)

Progress in using herbicides to kill grass swards as a first step to reseeding without cultivation, has indicated the need for new methods of sowing small-seeded crops into the littered surface that is left after herbicide treatment. The National Research Development Corporation is currently financing a two-year programme to investigate the possibilities of a novel method involving seed suspended in an aqueous gel which can be pumped into slits cut into the ground.

In addition to providing a carrier for the seed, the gel provides water for germination and also allows nutrients and crop protection chemicals to be added. This project is in co-operation with the National Institute of Agricultural Engineering by whom the equipment is constructed. Biological aspects are investigated at Begbroke.

Other Activities

It is a common misapprehension amongst laymen that research involves a series of individuals testing the results of their theories and deciding from day to day what they will do. Modern technological research involves the careful execution of detailed plans thought out well in advance and co-ordinated with the activities of others' team research. During the past five years, which have covered the period of setting up the Weed Research Organisation, a great deal of time has been taken up in planning and co-ordinating the experimental work and facilities. Each year about 100 field experiments are carried out on the Station. These are administered by the Field Experiments Committee, of which the Head of Section is now Chairman.

As chemical weed control has ramified throughout crop husbandry there has been increasing interest in research on many different aspects on the part of universities and other institutes. The Section is encountering an increasing number of requests for advice on the use of herbicides in experimental work done by others.

Horticultural Section

Head: G. W. IVENS

The primary functions of the horticulture section are to develop new techniques for the control of weeds in horticultural crops, and to investigate any special problems that arise in the use of herbicides in horticulture. Since 1960 advisory work in the form of answering N.A.A.S. and growers' queries, advising on experiments at N.A.A.S. Experimental Horticulture Stations and talking at growers' meetings has been an additional function, but the appointment of a N.A.A.S. horticultural liaison officer at Begbroke in 1964 is expected to diminish the amount of this work.

The experimental work is mainly concerned with fruit and ornamental crops and has been divided into three main projects.

Evaluation of new chemicals

Tests on the effects of herbicides applied to the foliage have been conducted in the glasshouse in conjunction with the Evaluation Section. The effects of soil-applied chemicals have been tested in the field on a range of crops, including apple rootstocks, blackcurrants, raspberries, strawberries, rose rootstocks and dahlias. No outstanding foliar selectivity has appeared in these trials, but a number of soil-applied materials appear to be worth further test. 3-Cyclohexyl-5, 6-trimethylene uracil (Du Pont 634), for example, shows promising selectivity in strawberries and other fruit crops, bromacil and buturon (HS 95) have possibilities in raspberries, buturon in blackcurrants and bromacil, buturon and monolinuron in apples.

Chemicals showing promise in the initial tests are further evaluated at Begbroke for specific crops by means of larger trials in which effects on yield are assessed. The extension of such trials to crops growing on different soil types and under different climatic conditions has been achieved by sponsoring experiments at N.A.A.S. Experimental Horticulture Stations and, in the past few years, trials on fruit crops have been undertaken by the Stations at Luddington (Warwickshire), Efford (Hampshire) and Stockbridge House (Yorkshire). Most of these trials have been conducted on strawberries and extensive experimental work on this crop has been done with simazine and chloroxuron, both of which are now in common use. Possible alternatives such as diphenamid, 3-cyclohexyl-5, 6-trimethylene uracil, bromacil, trietazine and 4, 5, 7-trichlorobenzthiadiazole (Philips 40-21) are currently being investigated.

The most promising chemicals are also included in variety trials to determine whether varieties differ materially in sensitivity. Appreciable differences have been found between strawberry varieties, especially in their reaction to simazine, but the position is complicated by the fact that relative susceptibility appears to be influenced by time of application and growing conditions.

Experiments on the use of herbicides (especially simazine) in woody and herbaceous nursery stock have been conducted at several commercial nurseries and simazine has been shown to be a practical treatment on a wide range of subjects. Information from these trials has been summarised, together with information obtained from the practical experience of growers and from published work elsewhere, in the form of a W.R.O. Technical Report. This has been made available to growers and advisory officers and a heavy demand has developed.

A series of field trials has been done at Begbroke on dahlias and it has been shown that simazine can be used in this crop also. The margin of safety, however, is not large and some varieties appear to be distinctly more susceptible than others.

Non-cultivation trials

In certain fruit crops, herbicides are now effective enough for there to be no further need of cultivation to control annual weeds. As these crops are perennials which occupy the land for a number of years, herbicides are liable to be applied repeatedly to the same piece of land. Two important problems arise in consequence:—

(a) *Is repeated herbicide application likely to result in a gradual build-up of residues?*

In the non-cultivation experiments at Begbroke on raspberries and strawberries, in which weeds are controlled with appropriate chemicals such as simazine, chloroxuron and paraquat, soil samples are taken at intervals and the herbicide residues at different depths determined by bioassay. Persistence has been shown to be closely connected with climatic factors, being longer in dry or cold periods than under warm, moist conditions. Over the last four years, however, the average persistence of simazine applied at 1 lb/acre (active material) has not exceeded 6 months and on this soil type it appears to be possible to apply 2 lb/acre annually without a build-up occurring.

Special trials are also being conducted on uncropped land to obtain further information on the effect of such factors as timing of rainfall in relation to time of application, levels of organic and inorganic fertiliser and soil disturbance on the penetration and persistence of simazine.

Existing plant bioassay methods for detecting such herbicides as simazine take 2 to 3 weeks. Attempts are being made to develop improved techniques and much promise has been shown by a novel method* for detecting herbicides such as the ureas and triazines which inhibit the light reaction of photosynthesis and whose effects are very slow to become visible.

The method involves the use of paraquat, a herbicide whose effects are dependent on activation by this light reaction. Healthy plants are rapidly damaged by spraying with paraquat, whereas those in which the light reaction has been inhibited by prior treatment with herbicides such as the ureas or triazines are relatively unaffected. Assessments can be made in 2 to 3 days with this technique.

(b) *What functions does cultivation fulfil when it is not needed to control weeds?*

In addition to comparing the effects on the crop of non-cultivation regimes and traditional cultivation, various aspects of the soil are under investigation. Effects on soil fauna are being studied in collaboration with the Nature Conservancy and results to date have failed to indicate any marked effect on soil arthropods.

The selective action of soil-applied herbicides

With many of the herbicides in current use in fruit and ornamental crops, selectivity is thought to depend to some extent on 'depth-protection', i.e. the roots of the crop being at greater depths than those reached by the chemical. However, under conditions favouring penetration of the chemical such as light

* Parker, C. P. (1965) *Weed Res.* (In press)

soil or heavy rainfall, depth-protection can fail and the crop suffer damage. In order to assess the safety of treatments with soil-applied herbicides, it is thus important to know the sensitivity of the crop plants when their roots are known to be in contact with the chemical. A series of pot trials is therefore being conducted in the glasshouse with various fruit and ornamental species planted in soil with which various doses of herbicide have been mixed. Some of the findings are as follows:—

(a) Apple and rose rootstocks (*Rosa canina* and *R. laxa*) show considerable resistance to simazine, raspberries and strawberries moderate resistance and anemone corms very little. Thus the order of susceptibility is very much the same as that shown in the field. The size of plant used in pot trials, however, has a considerable influence on its sensitivity'

(b) Strawberries are inherently less resistant to atrazine than simazine, but show considerable resistance to chloroxuron, diphenamid and trietazine.

(c) Anemones show greater resistance to chlorpropham, linuron, chloramben and chloroxuron than to simazine or fenuron.

(d) Rose rootstocks show considerable resistance to linuron and prometryne.

(e) With dahlias, simazine applied to the soil has a very much greater effect than applied to the foliage. When high doses are sprayed onto young, rapidly expanding leaves, however, sufficient foliar uptake can take place for some injury to result and the varieties susceptible to simazine taken up through the leaves appear to be the same as those susceptible to root uptake in the field.

Another aspect of herbicide selectivity is being studied in an investigation of the rooting characteristics of certain perennial crops. Observations have been made on the distribution of the roots of strawberry plants grown under field conditions and attempts are being made to obtain information on which parts of the root system are most important as regards herbicide uptake and whether seasonal variations occur.

Chemistry Section

Head: R. J. Hance

The Chemistry Section has two functions: (a) to provide an analytical service to the rest of the Organisation, and (b) to carry out research on chemical problems associated with weed control.

Service Activities

Much of the early activity of the Section, which began operations in December, 1962, was concerned with exploratory work on those methods of herbicide analysis which were likely to be needed in the future research programme of the

Organisation. Services to other Sections have so far usually been of a miscellaneous nature, but analyses of linuron residues from the W.R.O. long-term experiment are now being carried out on routine basis. It is hoped that the acquisition of gas chromatography equipment in the near future will increase the range of analytical services offered by the Section.

Research Activities

Studies have been made of some of the factors involved in the adsorption of herbicides by soils. Investigations so far have been concentrated on the urea derivatives.

Relation of chemical structure to extent of adsorption. Relationships between the structure of substituted ureas and adsorption have been noted, but it has not so far been possible to explain these relationships in physical-chemical terms.

Effect of soil properties on adsorption. Studies with a number of soil types from Britain and East Africa showed that under aqueous slurry conditions, organic matter content was the only soil characteristic that could be statistically correlated with the adsorption of substituted ureas. The soil mineral fraction appeared to have a low adsorptive capacity for these compounds.

The role of soil organic matter in adsorption. Evidence has been obtained which suggests that there is competition between water and herbicides for adsorption sites and that the substituted ureas compete more efficiently at soil organic surfaces than at soil mineral surfaces. The functional groups of organic matter appear to take no part in adsorption other than to influence the hydrophilic/hydrophobic balance of the surface.

Current Investigations. These include:

(a) A comparison of the adsorptive behaviour of other classes of herbicide with that of the substituted ureas.

(b) An assessment of the practical importance, if any, of the competition between the substituted ureas and water for adsorption sites.

(c) A study of seasonal changes that may occur in the adsorption characteristics of soil.

(d) A comparison of the adsorptive capacities of soil organic matter fractions.

(e) An assessment of the effect of adsorption on the susceptibility of herbicides to microbiological attack.

(f) A collaborative study with Dr. M. Horowitz on the effect of water content and soil type on the uptake of thiolcarbamate vapours by soil.

Information on several aspects of the above programme is given in the article on page 20.

Botany Section

Head: R. J. CHANCELLOR

The Botany Section was established in 1962 to investigate various aspects of the behaviour and biology of weeds in order to understand the factors that contribute to their success and to find weak points that might be exploited for their control.

The weed survey

The programme was initially concentrated upon annual weeds. Soon after Begbroke Hill Farm was taken over, a weed survey was made of the arable fields, using a system of quadrats at 20-yard spacing throughout the fields. In the first year's survey, over 50,000 weed seedlings, representing 108 species, were counted, identified and mapped. The survey also included assessments of the distribution and frequency of the weeds in fields under grass. Since that time, every field has been re-assessed whenever cultivations or cropping have allowed, so that a continuous record is being built up of changes in the weed flora.

Periods of weed emergence

Three experiments were started in different fields in 1962 to investigate the periods of emergence of annual weeds under various frequencies of cultivation. The behaviour over several years of the 33 weed species studied in these experiments is now known and the results are discussed elsewhere in this report. In addition monthly testing of the seeds of twenty weed species has been carried out in the laboratory over a period of nine months to investigate the duration of dormancy and methods of breaking it.

Other annual weed studies

Other aspects of annual weeds that have been or are being investigated include: the depth from which weed seedlings emerge in the field under various conditions; the survival of weed seeds under recently established grassland, and under old permanent pasture; the life-history of spaced individuals of a number of weed species, and the development, mortality and seed production of dense weed stands.

Study of rhizomatous perennials

In 1964 the main programme of work was directed to investigating the regenerative ability of the creeping underground stems of *Polygonum amphibium*, a perennial weed of arable land which occurs frequently in fields at Begbroke Hill and is a very suitable test plant.

The experimental work included testing the regenerative ability of two-node sections cut from long lengths of rhizome at various times of the year. This series of tests showed that all sections were capable of regenerating at any period of the year. The effect of different depths of water table on regenerative capacity was also investigated. It was found that the highest water tables apparently retarded regrowth, which is surprising because the plant often occurs as a water weed. Experiments on the depths from which rhizome fragments could emerge showed that even one-node fragments planted 15 in. deep were able to regenerate to produce a vigorous plant in less than five weeks. Studies on the regenerative capacity of rhizomes of different ages showed that the rhizome life-span in undisturbed conditions is probably between 3 and 5 years.

The minimum length of rhizome with one bud that could produce a new plant was found to be about 0·25 cm, at which size half of the fragments planted produced healthy shoots. The length of fragments occurring naturally in arable fields was also investigated. The majority were found to be very long indeed and well able to produce new plants. These investigations will be continued in 1965, together with studies on couch grass (*Agropyron repens*) and ground elder (*Aegopodium podagraria*).

Other activities

The Botany Section also specialises in the identification of weeds, especially in the earliest stages of growth, and a technical bulletin has recently been written for the Ministry of Agriculture on the identification of water weeds. In addition, the Section maintains a weed garden, an herbarium and a seed collection.

Information Section

Head: P. J. Boyle

The main functions of the Information Section are: (a) to provide library and information facilities to the W.R.O., and (b) to prepare *Weed Abstracts** for publication by the Commonwealth Agricultural Bureaux (C.A.B.).

The Library

Together with the rest of the Section, the library was transferred to Begbroke from the University Department of Agriculture, Oxford, in July 1962 and at the same time the holdings of serial publications and basic textbooks were greatly enlarged.

The W.R.O. library now constitutes the main official repository of weed control literature in the U.K. At present, some 220 serial publications are taken and a very complete collection of weed control conference proceedings is held. There is also an extensive collection of reprints of papers published in journals not taken by the library, together with technical reports, bulletins, circulars and similar material, as well as literature issued by commercial firms.

* Obtainable on subscription from the Commonwealth Agricultural Bureaux, Farnham Royal, Bucks.

Weed Abstracts

From 1956, when it first made available to the public and until 1961, *Weed Abstracts* was produced in mimeographed form and distributed by the Section. The British Weed Control Council administered its sales and subscriptions. By an agreement reached in 1961, responsibility for sales and distribution was taken over by the C.A.B., while the W.R.O. continued to be responsible for its preparation. As from Volume 11 (1962), the further important step of printing *Weed Abstracts* by letterpress was also taken.

As one of the series of C.A.B. abstract journals covering the various branches of agricultural science, *Weed Abstracts* now serves a wide international readership as the only journal in its field. Its total circulation for Vol. 13 (1964) was 900, compared with 822 for Vol. 12, 768 for Vol. 11 and 586 for Vol. 10.

Shortages of staff have made it difficult to keep pace with the growing volume of world literature to be abstracted; furthermore, it has not been possible to provide adequate cover of the increasing important literature in the Slavonic languages. It is hoped that arrangements to place the Section on a more satisfactory basis will be made so that these deficiencies can be remedied.

The Index

An important facility maintained by the Section is the index. This is compiled from entries prepared from the abstracts published in *Weed Abstracts*, to which it provides a comprehensive and cumulative key. The index is based on a visual card system and is particularly well suited to dealing with weed control literature. Entries for the current numbers of *Weed Abstracts* are included as the year proceeds. At the end of the year, these entries are extracted and used to compile the indexes to *Weed Abstracts*, which are published annually.

Much use is made of this index by W.R.O. staff and in answering the increasing number of technical enquiries received by the Section from the U.K. and overseas.

Overseas Section

Head: E. C. S. LITTLE

Throughout the world there is an increasing realisation that traditional methods of weed control are, or soon will be, inadequate to cope with the demands of more intensive agriculture. As yet, many countries are not sufficiently advanced to provide the research staff needed to carry out the research necessary to keep pace with the rapid expansion of herbicide chemicals and the complexities of their use. Recognising the possibilities of giving useful aid in this direction, the Ministry of Overseas Development (O.D.M.) have financed the appointment of an Overseas Officer and assistant at W.R.O. to form the Overseas Section. The formation of this Section in 1963 has enabled progress to be made in expanding the contacts with overseas workers which already existed through the travel and experience of several of the W.R.O. staff.

Among the most useful overseas contacts are the Weed Research Section of the Tropical Pesticides Research Unit at Arusha in Tanzania and the Weed Research Unit of the University of West Indies in Trinidad. The officers working in these stations are kept informed of the results of screening work at W.R.O. on tropical weeds and crops.

During the course of a tour of Africa in 1964 by the Head of Section, personal contact was made with the T.P.R.I. at Arusha. A visit to Trinidad is planned to take place in 1965. The tour of Africa also enabled many fresh contacts in thirteen countries to be made with field and laboratory workers interested in the development of weed control research. It is clear that W.R.O. can make an important contribution to this aspect of agricultural development in many countries, especially if facilities at W.R.O. are expanded and officers provided who are trained in the special techniques of weed research and who are willing to spend short periods abroad.

By correspondence and from enquiries arising as a result of travel by other officers of the O.D.M., contact has been made with workers in India, Pakistan and Ceylon. In addition, various enquiries have come in from a number of other countries. These queries have included, for example, weed control in rice, soya beans, groundnuts and vegetables and the control of problem weeds like nutgrass and dodder, and these we have been able to answer by reference both to the extensive resources of the Information Section of W.R.O. and by drawing on the knowledge and experience of overseas problems of many of the senior officers at W.R.O.

Contact has also been maintained with the United Nations agencies concerned with agriculture, especially F.A.O. and U.N.E.S.C.O. Many overseas visitors call at W.R.O., which leads to valuable exchanges of ideas and information.

The comparatively short time the Overseas Section has been operating has been sufficient to show that there is great scope for practical aid to many countries needing it and at the same time to bring in useful knowledge and ideas which are directly helpful to the research work undertaken at Begbroke. As an indication of the range of contacts being made, nearly 300 letters were sent overseas in 1964 to 40 countries.

Special Activities and Projects

Pest Articles, Section C (*Editor:* B. STEELE)

Among the contributions made by the W.R.O. in promoting weed research in tropical countries is the production of Pest Articles, Section C, more familiarly known as PANS(C).

The journal, a companion to Sections A and B which deal respectively with insects and fungi, is issued quarterly and contains original research papers, reviews, news, notes and abstracts. It serves research and extension workers in the tropics, as well as progressive growers and others, by providing them with a means of keeping abreast of current developments in the science and practice of weed control. Workers in tropical countries often find it difficult to maintain a satisfactory degree of awareness of the progress and activities of their fellow workers in other countries. PANS(C) offers such a link, as well as providing a medium in which they can publish original research papers.

PANS(C) is administered by the Ministry of Overseas Development (O.D.M.) through its Tropical Pesticides Research Committee. Because of the research and information facilities available there, the journal was prepared at the Unit of Experimental Agronomy, Oxford, up to 1962. Since that time, it has been prepared at the W.R.O., Begbroke. From 1960 until October 1963, PANS(C) was edited jointly by J. D. Fryer and P. J. Boyle. As from October 1963, the Editorship was taken over by an Officer (Dr. C. H. Tinker) appointed by the O.D.M., and stationed at Begbroke. Dr. Tinker resigned in April 1964 and the Editorship was resumed by P. J. Boyle. A new Officer (Dr. B. Steele) has been appointed by O.D.M. and will take over the Editorship from April, 1965.

PANS(C) is now in its eleventh year. At present, more than 800 copies are distributed in over 50 countries. The circulation includes organisations in the U.K. and other temperate countries which have interests in the tropics. Distribution is normally free to persons in State institutes and research establishments working in or on behalf of the developing countries.

Aquatic Weed Project (T. O. ROBSON)

Aquatic plants have to be cut and removed annually from many hundreds of miles of drainage channels and rivers as a flood-preventative measure. Many more miles of ditches have to be cleared to maintain good sub-surface land drainage and to prevent waterlogging of the soil. In some places water weeds have to be controlled to facilitate navigation or to provide other amenities. Traditionally this is done by hand methods of cutting and raking, but in recent years the authorities concerned have experienced increasing difficulty in obtaining the labour necessary for this work. As a result the A.R.C. decided to investigate the problem and to assess the need for research to assist the development of new methods. In the autumn of 1963 the W.R.O. was allotted the task of surveying the problem.

The survey has been planned to examine all methods of control at present in use, with particular reference to the ecological aspects of the problem. Information has been collected from all River Boards, whether they have serious weed problems or not, and from certain Internal Drainage Boards known to be interested in developing new techniques.

This has provided details of the methods used and it was possible during the summer of 1964 to see almost all of them in action and to observe their effect on the vegetation.

Much of the work is still done by hand, but many River Board and Drainage engineers have had to make attempts to mechanise the cutting operations. A few weed-cutting launches are available commercially for sub-surface cutting, but they are restricted to the larger channels and satisfactory solutions to the problem of smaller ditches and the banks are needed. Suitable machines for removing the cut material from the water to replace hand-raking have also to be developed.

Particular attention is being paid in the survey to herbicide use and many experiments laid down by commercial firms and other organisations have been visited. The possible control of aquatic weeds by means of chemicals has many attractions, but also raises the problem of how to assess and control side effects and the possible hazards to other interests. One chemical which has proved to be a safe and very useful new tool is dalapon. When used at the recommended rate on emergent weeds, ditches have been kept clear for two to three summers without further treatment. It is now used quite extensively for this purpose and no adverse side effects have been reported.

Because of the numerous ditches and cross-ditches, difficulty of access often makes the application of dalapon or other herbicides by conventional ground spraying methods slow and tedious. A project to develop a method of accurate, drift-free application from a helicopter was initiated and, with the co-operation of the Tropical Pesticides Research Unit at Porton, the first trials were carried out successfully in the summer of 1964.

Enquiries into the use of biological methods have produced only one example of this approach being used in practice. A large fen drainage channel has been fenced and sheep are grazed on the banks for the express purpose of keeping the grass and reeds in check. In the Romney Marsh area, the effect of sheep on reeds is very marked in ditches bordering pastures. Control is, however, only temporary and as soon as the sheep are removed the reeds grow away again. Wider use of this system is prevented by the steepness of the banks of most channels and difficulty of access in the intensively cropped areas of the fens. Recently, interest has arisen in the possibility of using the herbivorous Chinese grass carp to suppress submerged weed growth and experiments to test this idea are planned to start in 1965.

The second stage in the survey, which is a more detailed appraisal of the problem and the need for research, is expected to be completed in 1965.

Long-term Herbicide Project (J. D. FRYER AND K. KIRKLAND)

This project, which started in 1963, is an attempt to investigate whether certain herbicides have any long-term effects on the soil. The main project is based on a series of paired field plots, the only difference between the individual plots of each pair being that one receives applications of the chosen herbicide, whereas the other does not. As far as possible all other factors are the same for both plots. The herbicides under long-term investigation are MCPA, simazine, tri-allate and linuron, representatives of contrasting chemical types. Each chemical is applied (a) to a crop in which it can be used selectively at the normal time and dose, and (b) to plots kept free of vegetation by means of cultivation and on which higher and more frequent doses are given to the treated plots, so as to favour exaggerated and more rapid changes. Each plot receives the same treatment year by year.

Routine assessments carried out at Begbroke include crop vigour and yield and a study using bioassay and chemical assay methods of the rate of disappearance of herbicide residues in the soil throughout the year. Some chemical assays of residues are also undertaken by co-operating firms who have supplied the herbicides. Assessment of the microfaunal populations in samples from the plots are made by the Entomology Department at Rothamstead. Studies on the soil bacteria in the plots are undertaken by the N.A.A.S. Regional Bacteriologist, Coley Park, Reading. Chemical and physical measurements of soil properties are carried out by the N.A.A.S. Soil Chemistry Department at Coley Park.

Finally, an investigation on the growth of *Ophiobolus graminis* (take-all) and other soil fungi in soil from the long-term plots by a research student at the University Department of Agriculture in Oxford is in progress.

Reports on the results of this project will be issued from time to time.

Students at W.R.O.

Three post-graduate students are working at W.R.O. for higher degrees of Reading University. They are:

(1) Mr. D. T. Wettasinghe of the Tea Research Institute, Talawakelle, Ceylon, working on the general selectivity of some triazine herbicides.

(2) Mr. A. M. Hamdoun of the Ministry of Agriculture Research Division, Kenana Research Station, Abu Naama, Sudan, working on the biology of creeping thistle (*Cirsium arvense*) and field bindweed (*Convolvulus arvensis*).

(3) Mr. P. J. Davies of the United Kingdom, working on the phytotoxicity of ioxynil.

National Agricultural Advisory Service Liaison

S. A. EVANS (Agriculture)
R. F. CLEMENTS (Horticulture)

Two officers of the N.A.A.S. specialising respectively in weed control in agricultural and horticultural crops are attached to the W.R.O. They act as channels through which N.A.A.S. Advisory Officers can have access to the specialist information and advice on weed control available at the W.R.O. Each year between 300 and 400 individual technical queries from the N.A.A.S. have been dealt with. In turn, they help in keeping the W.R.O. informed of weed problems of importance to British agriculture and horticulture.

The officers also organise series of national trials on behalf of the N.A.A.S. at regional centres. The trials are planned mainly to extend or supplement the work of W.R.O. For example, in 1964 five trials on the use of pre-emergence herbicides in spring-sown cereals were organised to extend recent work undertaken by the Evaluation Section of the W.R.O. The trials showed that an effective pre-emergence treatment could give better crop yields than a post-emergence spray, although yield responses to herbicides at all sites was small. In recent years the N.A.A.S. has done more than 60 trials on potatoes, utilising information gained from W.R.O. work to determine the treatments. These trials have shown the weed control that might be expected from various herbicides and indicated some of their limitations, thus enabling the N.A.A.S. adviser to speak with some experience on the subject. The work with mixtures of herbicides on kale at the W.R.O. has been extended to some 30 N.A.A.S. trials in the last three years in various parts of the country and have confirmed the usefulness of mixtures of desmetryne, dicamba and SMA in controlling most of the important weeds of kale. New herbicides such as pyrazon for sugar beet and ioxynil for cereal crops were tested in 1964, the season before their introduction to British farmers. The N.A.A.S. have been studying the use of herbicides for sward destruction prior to reseeding for the past ten years. In 1964 a series of 19 trials was carried out to assess the value of paraquat and dalapon in a scheme of reseeding lowland pastures. These showed that the crux of the technique lies in getting a good establishment of the sown seed and that to achieve this with conventional seed drills, the more thorough the pre-sowing cultivations the better. The greater the intensity of cultivation, however, the less was the need for a preliminary herbicide treatment. Work by the N.A.A.S. in horticultural crops has been collated by the N.A.A.S. Liaison Officers and has covered such herbicides and crops as amitrole, paraquat, chloroxuron, simazine and 2,6-dichlorothiobenzamide in tree and bush fruit; chlorpropham on lettuce, beet, celery and brassicas; linuron and prometryne on umbelliferous crops; and desmetryne on brassicas.

The W.R.O. is responsible through the Liaison Officers for advising the N.A.A.S. on experimental work (other than the National Trials) on weed control, undertaken by Advisory Officers. The liaison officers help the W.R.O. in finding sites for its own experiments on private farms and market gardens and assist in arranging certain N.A.A.S. trials which are carried out in collaboration with the W.R.O.

The Liaison Officers write much of the advisory literature on weed control published by the N.A.A.S. and act as editorial advisers for similar publications not written by themselves. Press articles and review papers for scientific journals are prepared. Extensive lecture work is also done. The Liaison Officers act as the N.A.A.S. representatives on the British Weed Control Council and the Liaison Officer (Agriculture) is secretary of the Council's Recommendations Committee and joint editor of the Council's Weed Control Handbook.

The Agricultural Chemicals Approval Scheme—Herbicides Liaison

J. G. DAVISON

The Ministry of Agriculture, Fisheries and Food operates a voluntary Scheme under which proprietary brands of crop protection chemicals can be officially approved. The Scheme is supported by the Association of British Manufacturers of Agricultural Chemicals, the National Association of Corn and Agricultural Merchants and the National Associations and Unions of farmers and growers in the United Kingdom. Labels of approved products bear an Approval Mark, an 'A' surmounted by a crown, which indicates that the Organisation which operates the Scheme is satisfied that the claims and recommendations made by the manufacturers are reasonable and reliable within the limits of normal use. The Approval Organisation maintains a liaison officer at the Weed Research Organisation to ensure close contact with the work done there and to make use of other facilities, such as the library and Information Section. As the centre for official research and development in weed control in the United Kingdom, the W.R.O. also attracts many visitors, contact with whom is important for the close liaison which must exist between the Approval Organisation, independent workers and industry.

Manufacturers of herbicides are encouraged to inform the Approval Organisation of new products as soon as they reach the stage of field testing, and it is the responsibility of the Herbicides Liaison Officer to be familiar with the development work done by both commercial and non-commercial organisations. Although the Organisation does not itself conduct field trials, it can arrange for the National Agricultural Advisory Service to undertake such work where it feels there is a need. In this way, evidence is collected on which to make an overall assessment of the potentialities of a product.

As the Scheme is voluntary, manufacturers are under no obligation to get approval for their products before marketing them. In practice, however, most of the products now on the market in the U.K. are approved. Precise figures are not available, but so far as herbicides are concerned, it is estimated that about 90% of the products at present available are approved and these account for more than 90% of the acreage sprayed.

Each year, the Approval Organisation publishes a List of Approved Products. The current list for 1965 includes about 700 products in all, of which more than 260 are herbicides. Between them, the herbicidal products represent a total of 38 different active ingredients. Of these, 30 are available as products containing one active ingredient only and the remaining 8 as mixtures of in most cases two, but in some cases of three or even four. From these figures, it will be apparent that there are virtually no herbicidal chemicals recommended for use in the U.K. for which an approved product cannot be found in the list.

In the last few years, the numbers of approved products have increased at a rate of approximately 30 per year, of which approximately 12 contained more than one active ingredient. This trend looks like continuing. Through the Approval Scheme it is hoped that advisers can recommend and users select an appropriate and efficient product, confident in the knowledge that the recommendations have been agreed by an independent Organisation. This is especially true in the early commercial life of a product when farmers and growers have no practical experience. Early approval of products containing such recently introduced chemicals as chloroxuron, desmetryne, ioxynil, linuron, paraquat and prometryne has encouraged farmers and growers to take advantage of the most recent additions to the list of chemicals available for the continuous fight against weeds.

The Farm

Farm Director: J. G. Elliott
Farm Manager: H. J. Cunnington

Begbroke Hill Farm lies five miles north west of Oxford, near the Woodstock road. Its 286 acres fall naturally into two parts, separated by the Oxford-Birmingham railway line and connected by a level crossing.

The part west of the line includes the main buildings and consists of 176 acres of deep, sandy loam topsoil overlying gravel, most of which is used for arable cropping. The area east of the line, known as 'The Marshes', consists of 110 acres of low-lying, rather wet, alluvial soil, all under low-grade permanent pasture.

The farm thus caters for experimentation on arable and horticultural crops and grassland. During the past five years the holding has progressively been equipped with the basic facilities that go to make both an efficient experimental station and a modern farm. The list of capital works undertaken includes a new house for the farm manager and two new cottages for farm workers, the renovation of two existing cottages, and the provision of all-weather roads, buildings and equipment for the handling and storage of 160 tons of cereals, 200 tons of potatoes and 60 beef cattle. Irrigation has been made available on the arable land by tapping the water from a spring and piping it into a 600,000 gallon P.V.C.-lined reservoir. Many additional minor facilities have also been provided.

In planning the use of the land, priority is given to the requirements of the field experiments which now number about 100 yearly, but attention is given to farming the remainder of the land efficiently. It is considered important that the farm should run on sound commercial lines, so that new techniques developed by experimentation can be tested on a whole-field scale. A rotational system has therefore been evolved on the arable part of the farm within which it is possible to meet the requirements of the experimental work and at the same time run the farm as a normal commercial enterprise.

When the Organisation was set up in 1960, only the arable part of the farm was taken in hand. On it, eight fields were put into a rotation involving two years of experiments and six years of cereals, potatoes and ley. The discard areas around the experiments were filled partly with maize and partly with barley.

When the permanent pasture was taken in hand in 1963, it became possible to readjust the rotation on the arable part so as to increase the scale of experimentation on cereals and potatoes. One 18-acre field (Deal) has been set aside for long-term experiments and is therefore not included in the rotation. Because of these changes, the cropping programme is only now beginning to settle down.

The farm has already shown its worth as an adjunct to research in a variety of ways. Following the results achieved in chemical weed control experiments in potatoes, it was decided to treat the entire farm crop in 1964 and thereby eliminate cultivations after planting. This practice will continue in association with a critical scrutiny of crop performance.

Couch grass (*Agropyron repens*) is widespread on the arable part of the farm, so there is ample opportunity to study its increase or decrease throughout the rotation. Conventional spraying with amitrole-T is being tried at one point in the rotation with mixed results. A full-scale fallow by rotary cultivation has been studied. This operation proved successful, but expensive.

The grassland area is just beginning to come into full use as land for experimental work. On much of it, no fertilisers or modern grazing techniques are used with the deliberate aim of preserving its status as a typical, poor quality pasture containing a wide variety of species and thus providing a reservoir of this type of land for future research.

Cross-bred beef cattle are brought in as yearlings in spring, and spend the summer on pasture. In autumn they are put in yards and are fed on hay, silage and residues from the arable crops and experiments, so as to be fit for slaughter at about two years old. During 1964 some 80 cattle were carried.

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Glossary of Herbicides mentioned in this Report

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

Amitrole	3-Amino-1, 2, 4-triazole
Amitrole-T	3-Amino-1, 2, 4-triazole + NH_4SCN
Atrazine*	2-Chloro-4-ethylamino-6-isopropylamino-1, 3, 5-triazine
Barban*	4-Chlorobut-2-ynyl *N*-(3-chlorophenyl) carbamate
Bromacil*	5-Bromo-3-*s*-butyl-6-methyluracil
Bromoxynil*	3, 5-Dibromo-4-hydroxybenzonitrile
Buturon*	*N'*-(4-Chlorophenyl)-*N*-isobutinyl-*N*-methylurea
Chloroxuron*	*N'*-4-(4-Chlorophenoxy) phenyl-*NN*-dimethylurea
CIBA 3126	*N'*-(4-Bromophenyl)-*N*-methyl-*N*-methoxyurea
CIBA 3470	*N'*-(4-Methoxyphenoxy)-phenyl-*NN*-dimethylurea
CP 31675	6-tert-Butyl-2-chloro-methylacetanilide
2, 4-D*	2, 4-Dichlorophenoxyacetic acid
Dalapon*	2, 2-Dichloropropionic acid
2, 4-DES*	2-(2, 4-Dichlorophenoxy) ethyl hydrogen sulphate
Desmetryne*	4-Isopropylamino-6-methylamino-2-methylthio-1, 3, 5-triazine
Di-allate*	*S*-2, 3-Dichloroallyl *NN*-di-isopropylthiolcarbamate
Dicamba*	3, 6-Dichloro-2-methoxybenzoic acid
Dinoseb*	2-(1-Methylpropyl)-4, 6-dinitrophenol
Diphenamid	*NN*-Dimethyl-αα-diphenylacetamide
Diquat*	9, 10-Dihydro-8a, 10a-diazoniaphenanthrene-2*A*
Diuron*	*N'*-(3, 4-Dichlorophenyl) *NN*-dimethylurea
EPTC	*S*-Ethyl-*NN*-dipropylthiolcarbamate
Fenac	2, 3, 6-Trichlorophenylacetic acid
Fenuron*	*NN*-Dimethyl-*N'*-phenylurea
Loxynil*	4-Hydroxy-3, 5-di-iodobenzonitrile
Linuron*	*N'*-(3, 4-Dichlorophenyl)-*N*-methoxy-*N*-methylurea
MCPA*	4-Chloro-2-methylphenoxyacetic acid
Monolinuron*	*N'*-(4-chlorophenyl)-*N*-methoxy-*N*-methylurea
Monuron*	*N'*-(4-Chlorophenyl)-*NN*-dimethylurea
Neburon*	*N*-Butyl-*N'*-(3, 4-dichlorophenyl)-*N*-methylurea
Paraquat*	1, 1'-Dimethyl-4, 4'-bipyridylium-2*A*
Philips Duphar PH 40-21	4, 5, 7-Trichlorobenzthiadiazole
Picloram*	4-Amino-3, 5, 6-trichloropicolinic acid
PP 407	1, 1'-Di (pentamethylenecarbamoylmethyl)-4, 4'-bipyridylium dichloride
PP 745	1, 1'-Bis (3, 5-dimethylmorpholinocarbonylmethyl)-4, 4'-bipyridylium dichloride
Prometryne*	4, 6-Bisisopropylamino-2-methylthio-1, 3, 5- triazine
Pyrazon*	5-Amino-4-chloro-2-phenyl-3-pyridazinone
Simazine*	2-Chloro-4, 6-bisethylamino- 1, 3, 5-triazine
SMA	Sodium monochloroacetate
2, 3, 6-TBA	2, 3, 6-Trichlorobenzoic acid
Tri-allate*	*S*-2, 3, 3-Trichloroallyl-*NN*-di-isopropylthiolcarbamate
Trietazine*	2-Chloro-4-diethylamino-6-ethylamino-1, 3, 5-triazine
Velsicol 59-CS-52	2-Methoxy-3, 6-dichlorophenylacetic acid

Principles Governing Acceptance of New Herbicides for Evaluation by the Weed Research Organisation

The Weed Research Organisation is faced with an ever-increasing number of new herbicides under development by the agricultural chemical industry, which need to be considered for possible inclusion in its own research programmes. The Organisation has, therefore, found it necessary to formulate certain principles regarding the acceptance or otherwise of such compounds for investigation in its programme of new herbicide evaluation and development. These are as follows:

1. The W.R.O. is not under obligation to accept chemicals from other organisations or commercial firms for evaluation purposes.

2. Chemicals will only be accepted if the following conditions are agreed (information to be provided, if necessary, in confidence):
   (a) Composition of chemical and details of concentration and type of formulation must be stated.
   (b) The supplier must agree to provide the information, as far as it is available, asked for in a standard questionnaire covering physical and chemical properties, toxicology and phytotoxic properties.
   (c) The supplier must have carried out adequate preliminary tests that indicate the chemical has herbicidal properties.
   (d) There must be a reasonable prospect of the herbicide being developed commercially if promising uses are found, and the suppliers must have arranged to give priority to the chemical in their evaluation and development programmes.
   (e) The supplier must agree to comply with the terms of the Pesticides Safety Precautions Scheme and to keep the W.R.O. fully informed of their action, where relevant.
   (f) The supplier must be agreeable to a two-way interchange of information between themselves and the W.R.O. during the period of development of the herbicide and to giving prior information concerning the nature of their future development programme.

3. Acceptance of a herbicide by the W.R.O. does not imply any obligation on the part of the Organisation to carry out work on the herbicide or to report the results of any work that may be carried out.

4. The W.R.O. retains the right to publish the results of their work on publicly disclosed compounds without consulting the supplier. In the case of herbicides disclosed confidentially, some indication of the period for which confidential status is requested must be given. Material cannot be withheld from publication indefinitely, though W.R.O. will always try to be co-operative in relation to specific patent situations.

5. Any information given by the W.R.O. to the supplier must not be reproduced in published documents without specific permission and in no circumstances must it be used in advertising.

6. If there is an agreed programme between the firm and W.R.O. involving application to field plots of an edible crop, the firm must agree to accept financial liability in the event of the produce not being allowed to go forward for human consumption.