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the winter, whereas plants which had only one leaf at that time had much less chance of survival (mortality $<70\%$). The larger and earlier-emerged plants also produced the greatest amount of seed. Surprisingly in spite of the obvious differences in climate there was relatively little difference between the results from the two sites.

Further observation plots are being put down during the current season at these and other sites.

SPREAD OF WILD OATS

It is widely accepted that the explosive increase both in the area of distribution and the density of the wild oat population during the last two to three years, has probably been triggered off by a combination of several factors particularly the increase in intensive cereal production and a decrease in the standards of cleanliness of the seed sown due to economic pressures. The relatively mild winter of 1970–71, as mentioned above, may have further exacerbated the situation in winter crops this last season.

During the last three years wild oats have become established in both Northern Ireland and Scotland and there seems no doubt that the main means of distribution have been seed and straw. The recent joint survey of the amount of wild oat seed in farmers' seed drills at the time of sowing cereals (Elliott & Attwood 1970) carried out by the WRO and ADAS in collaboration with several other organizations, highlighted seed as one important means of distribution. In England and Wales 11% of the samples of seed supplied by merchants and 41% of those from seed originating from the same or another farm were contaminated; in Scotland the figures were 10% and 24% and in Northern Ireland 5% and 2% respectively. However it is encouraging that seed merchants and growers are becoming more conscious of the seriousness of the problem and the threat to those areas which are still relatively wild oat free. The Wilts, Hants & Dorset Seed Growers Associations have recently launched a scheme by which growers, who maintain a high level of wild oat control on their farms and who produce seed free of wild oats, are registered and paid a special premium.

The importance of straw as a whole for disseminating the weed was indicated by Wilson (1970) who, from studies of straw bales originating from crops containing wild oats, concluded that even in relatively late crops where most of the wild oat seed had been shed before harvest, bales were still likely to contain enough seed to provide a source for a new infestation. Up to 20,000 seeds have been counted in a single bale. There is a general movement of straw out of the areas of the country where cereals are grown intensively, such as the Eastern Counties, to areas where cereals are grown less intensively and wild oats are less common. If the straw from fields containing wild oats were to be burned rather than baled, it is likely that the further spread of wild oats could be reduced. Packing straw, feed grain, farm machinery, straw merchants' lorries, used sacks and bags, farmyard manure and birds and vermin are also known carriers for wild oat seeds. All these potential sources of infection need to be watched by the farmer who is attempting to keep his farm wild oat free. In addition it is essential that he should inspect his crops in late June and July for any inflorescences of wild oats. At this time they appear above the crops and if few in number can generally be readily seen and removed.

ROGUING WILD OATS

On many farms, particularly those where crops are grown for seed and which have relatively low populations of wild oats (less than 500/ac), hand-roguing of wild oats is carried out systematically each year. The importance of this as a means of containing or even eradicating the weed cannot be overemphasized. Unfortunately, to prevent the shedding of any viable seed, the whole wild oat plant has to be removed from the crop and destroyed, preferably by burning. This requires labour and time which apart from being expensive are not always available. In any case when the rate of working falls below 1 ac/man-hour it ceases to be economic. However, work by WRO (Holroyd 1972) has shown that the speed of operation can be at least doubled by the use of a herbicide to reduce the viability of the wild oat seed. The problem how to apply the herbicidal solution without contamination of the crop was solved by the development of a 'herbicide application' glove (see p. 8). The solution applied by means of the glove contains additional wetting agent and a marker dye so that treated plants can be easily identified. Over the last three years more than 60 different herbicidal solutions have been tested, and of these a 10% w/v solution of dalapon has proved to be one of the most effective. The viability of seed treated before final ripening has been reduced to less than 1%. This compound also offers little or no hazard to the operator as its mammalian toxicity is low. Another herbicide, which is still in the early stages of development, shows even more promise

A prototype of the herbicide application glove developed at WRO to improve the efficiency of hand-roguing of wild oats. The tubes deliver herbicide from a reservoir to the absorbent pad on the glove palm.

as it kills the whole of the treated plant, thus eliminating any risks of re-tillering.

Many farmers who, each year, have hand-rogued consistently the small numbers of wild oats which have appeared on their farms, have managed to prevent any increase in the populations and have produced clean seed crops. However, even with the glove, it is not possible to deal manually with the high populations which occur on many fields. These populations can only be controlled by using chemical and cultural means.

THE CONTROL OF WILD OATS

The farmer with wild oats in quantity must make a very deliberate decision about his objectives. Should he attempt to eliminate wild oats from his land, or should his aim be to obtain a maximum economic return from his immediate cropping? If the former, then the objective is long-term and requires a programme of treatments extending over several years and cost of control in any one year requires to be viewed against the benefits to be achieved in the long run.

Cultural methods

Cultural methods can help control considerably. Straw on fields with wild oats should advisedly be burned as soon after harvest as possible. The role of stubble cultivations is less clear-cut. Recent investigations at WRO have indicated that when stubble cultivation is delayed the loss from natural causes of newly-shed wild oat seed is very much greater than if the stubble is broken up relatively soon after harvest. However only part of the seed burden in the soil is derived from seed shed during the current season. Where most of the seed is from previous seasons, cultivation should encourage germination and delay may not be advantageous. The presence of couch grasses (*Agropyron repens* or *Agrostis gigantea*) would also make early stubble break-up more advisable.

Changes in the cropping programme can help to reduce either species of wild oat. The winter-germinating *A. ludoviciana* can be controlled by growing a series of spring crops. A vigorous crop of winter wheat will compete very successfully with spring-germinating *A. fatua* and a late-sown crop of spring barley will generally contain relatively few wild oats although at the expense of a reduced yield.

Herbicides

Two herbicides are currently approved for the control of wild oats in cereals, namely tri-allate and barban. Tri-allate is a volatile herbicide which, in the normal liquid formulation, needs to be mixed with the soil immediately it has been applied, either before or after drilling the crop. Unfortunately soil conditions are often not suitable for efficient mixing of the herbicide with the soil, particularly on heavy winter wheat land, and uneven distribution of the herbicide may result in poor weed control and sometimes crop thinning. The development of the granular formation of tri-allate which has been greatly stimulated by work done at the WRO (Holroyd 1968, Holroyd & Bailey 1970, Holroyd & Thornton 1970) has helped to mitigate many of these difficulties. The granular formulation has almost the same level of activity as the liquid but does not need to be mixed with the soil. In addition it can be used either pre- or early post-emergence thus extending considerably the time during which it can be utilized effectively. It does, however, require special application equipment which up to the present has limited its use to those areas where machines are available from merchants or contractors, very few having been bought so far by individual farmers.

Barban is used when both the weed and the crop have emerged. However, timing is critical as the wild oats are most susceptible when they have between 1 and 2.5 leaves and, in seasons when emergence is extended, control may be poor. In addition some varieties of barley, e.g. Proctor, are themselves severely damaged by barban. Barban is, nevertheless, making a major contribution to wild oat control.

New herbicides

Two other 'post-emergence' herbicides, chlorfenprop-methyl and benzoylprop-ethyl, will be available commercially in the UK for the first time in 1972. Both have featured in experimental work at WRO (Holroyd 1968, Holroyd & Bailey 1970). Chlorfenprop-methyl has advantages over barban in that all varieties of wheat and barley appear to be equally resistant and wild oats are susceptible up to the 3-4 leaf stage. One minor draw-back, which applies equally to benzoylprop-ethyl, is that the manufacturers suggest a minimum volume rate of 25 gal/ac for maximum effectiveness. Benzoylprop-ethyl is said to be most effective on wild oats when applied relatively late, at mid-tillering up to jointing. At this late stage some increase in crop yield can be expected, particularly where oat populations are high, but the response is unlikely to be as great as it might have been if the oats had been removed earlier by some other treatment. Recent unpublished work at WRO has shown that wild oats can offer damaging competition to spring cereals soon after they reach the 2-leaf stage of growth. The use of benzoylprop-ethyl is restricted to winter and spring wheat.

Management

For the elimination of wild oats the use of herbicides will need to be followed up by roguing. In the case of severe infestations, unless a farmer is growing for seed, roguing is unlikely to be worth while until the burden of wild oat seed has been considerably reduced in the soil by consistently good control for a period of several years. As the seed burden in the soil is reduced so any introduced seed assumes increasing importance and all possible measures should be taken to keep it out. Herbicide treatment will continue to be needed even in years when the wild oat population is below the level at which a short-term economic return can be expected, but before numbers are reduced to roguable levels. This can present farmers and advisers with a very real dilemma when economic conditions are difficult.

There is the alternative of 'living with wild oats', in which treatments are only used when an immediate economic benefit can be expected. For this approach the post-emergence herbicides have the advantage that the density of the wild oats can be seen before treatments need to be applied. Only levels of wild oats which are expected to interfere with crop yield are treated and although the weed population is temporarily reduced, the effect is only ephemeral and the resurgence of numbers in subsequent seasons is likely to be rapid. Under this regime the presence of the wild oats and the associated trouble and loss of profit become permanent.

Several herbicides effective against blackgrass (*Alopecurus myosuroides*) are active also on a relatively broad spectrum of weeds, both broad-leaved and grasses, but at present their control of wild oats is variable. Multi-purpose herbicides of this type have very obvious advantages, and are likely to be developed further. At WRO we have attempted to increase effectiveness by using mixtures of herbicides but without success so far.

Wild oats are a major and increasing problem but it is to be hoped that a growing awareness of the nature of the problem by the farming community coupled with intensive official and commercial research and better utilisation of existing knowledge, will have an increasing impact on them in the coming years.

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The Persistence of some Horticultural Herbicides in Soil

J. G. DAVISON and D. V. CLAY

INTRODUCTION

The successful use of herbicides which act through the soil necessitate balancing effective weed control with the avoidance of unacceptable injury to the treated and subsequent crops. Since the beginning of the 1960's the use of 'residual' herbicides in commercial horticulture has become widespread. Their acceptance has been encouraged by the increasing cost of labour and the benefits in terms of increased crop yields often consequent on reducing or eliminating cultivations. While chemical weed control programmes using the more persistent of these chemicals were developed first for fruit crops, latterly less persistent soil-acting herbicides have become available and widely used in almost all vegetable crops. In the future, with increasingly intensive methods of growing top fruit being adopted, weed control with residual herbicides will become even more general. From the start of their use, however, there has been an awareness of the need for information on their long-term persistence in the soil and any risks to crops arising from this.

Two possible sources of crop damage were cause for concern. Firstly, would repeated annual applications of herbicide result in a build-up of residues in the soil which might be phytotoxic or reduce crop yield? Secondly, would residues from single or repeated applications be a hazard to following crops?

Most of the research by the Horticulture Section on these problems has been with simazine. This herbicide, which is applied at rates of 1 to 2 lb/ac for the control of annual weeds, is the most widely used residual herbicide in fruit and ornamental crops and amenity areas and one of the most persistent. It was thought that detailed information gained on the behaviour of simazine would also provide a basis for predicting any likely hazards from other residual herbicides. In this work simazine was applied to uncropped plots and herbicide residues in soil samples from the plots were measured by means of a bioassay method based on the reduction in shoot weight of turnips. Using this method the lower limit of measurement varied from ½ oz/ac to 2 oz/ac

A member of the WRO Horticulture Section, assisted by a MAFF colleague, sampling soil in a gooseberry plantation to detect any accumulation of residues of the herbicides used annually to control weeds without cultivation.

in 2 in. depth depending on the organic matter content of the soil. There was generally good agreement between results obtained using biological and chemical methods of residue measurement.

SIMAZINE RESIDUES FROM SINGLE APPLICATIONS

Studies on the rate of disappearance of simazine, applied in summer to an uncropped sandy loam soil at Begbroke, showed that the rate varied considerably from year to year, the time taken for 75% to disappear ranging from 4 to 20 weeks; however, the residue remaining after 12 months was always less than 5% of the amount applied. Soil moisture was shown to have a large effect on persistence. In soil treated in summer with simazine at 2 lb/ac, and kept moist by irrigation, 80% of the simazine was lost in six weeks whereas, in soil kept permanently covered and dry, it took 12 months for the same amount to disappear. When simazine was applied at different times of the year persistence in the four months following spring and summer applications varied appreciably in different years. The evidence pointed to the importance of soil moisture in the two months following treatment. Rate of loss from autumn applications was relatively slow during the winter because of the lower soil temperature. Regardless of application date, however, under field conditions there was never more than 5% remaining after 12 months.

While the results of these experiments at Begbroke indicated that the persistence of residues from single applications of simazine should not present a hazard to subsequent crops, it was still necessary to determine whether this conclusion would hold for other soil types and climatic areas. Accordingly, in 1968 a series of experiments was begun to test the persistence of single applications of simazine in a number of different soils. The herbicide was applied at 2 lb/ac to uncropped plots at 26 sites in eight areas of the UK. The location of the sites is shown on the map (Fig. 1). Simazine was applied in spring 1968 and the soil was sampled the following autumn. The results from the first application are shown in Fig. 2 in relation to the soil texture at each site. At all but two sites less than 10% of the amount applied in spring remained in the autumn. The treatments were repeated on these plots in spring 1969 and the residues found the following autumn were again generally small, only exceeding 10% of the annual amount applied at three sites. Similar applications were made to other plots in autumn 1968, these being sampled in the following spring and autumn. After 12 months, simazine residues were less than 5% of the amount applied at all but two sites. However, when the amount of simazine remaining in the soil was measured after only six months, the rate of disappearance following autumn treatments was found to vary considerably from site to site. Amounts found ranged from 1 lb/ac at Terrington, Norfolk, to as little as 1 oz/ac at Cheddar, Somerset.

Rainfall and soil temperature data were obtained for each site for the duration of the experiments and soil properties such as pH, organic matter content and moisture holding capacity measured. The variation in persistence in soils of different texture is shown in Fig. 2. However, there seemed to be no direct relationship between persistence at particular sites and any one soil or climatic factor although there was a trend towards greater persistence at drier sites and in more alkaline

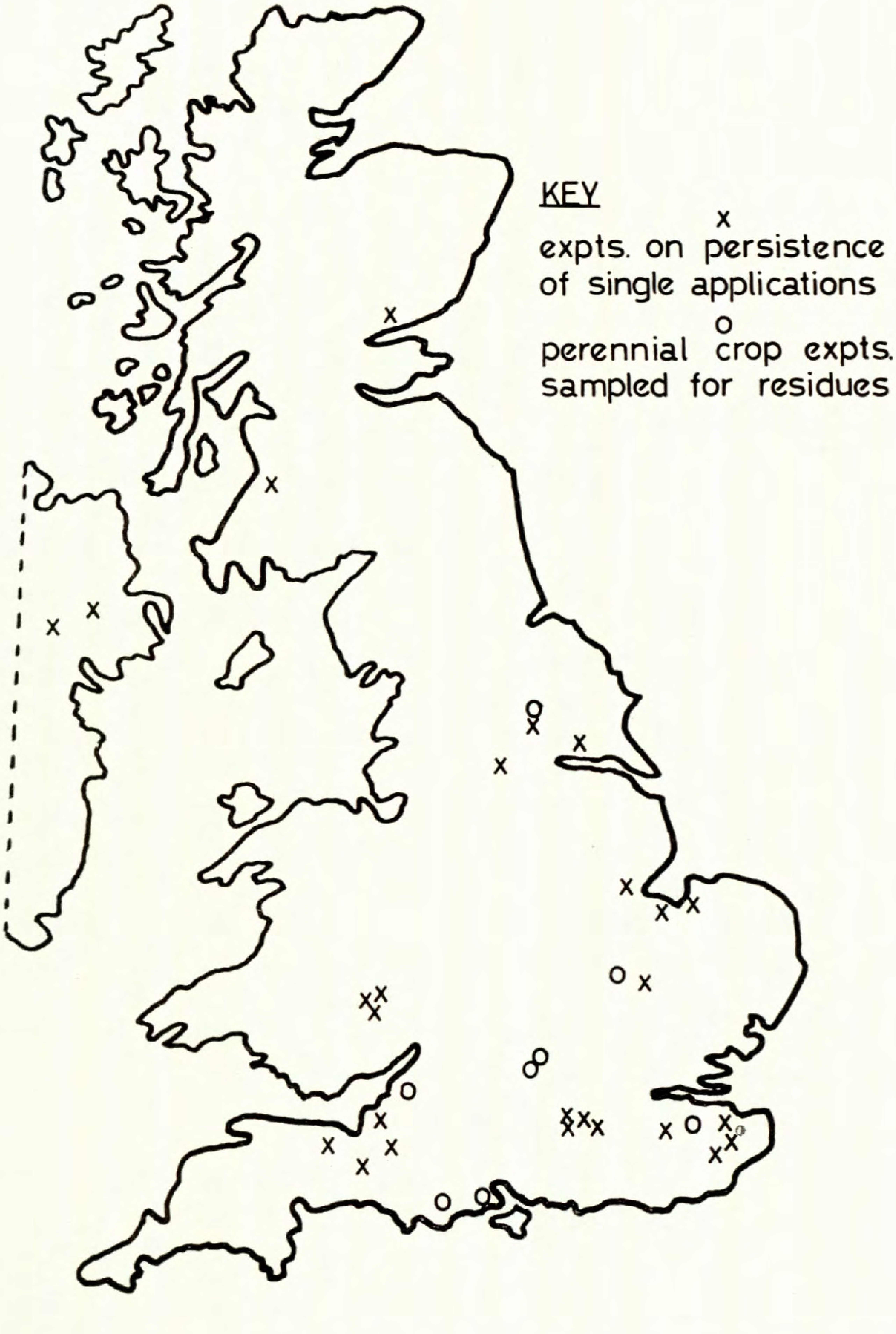

Figure 1. The location of experimental sites used for simazine persistence studies 1968-69.

soils. This series of experiments confirmed that generally there should be no problem with persistent residues from simazine used once or twice on the same site (Clay & Davidson 1970).

SIMAZINE RESIDUES FROM REPEATED APPLICATIONS

The question of the possible build-up of simazine residues under perennial crops receiving repeated annual applications was also examined. In 1969, soil samples were taken from experiments carried out by East Malling Research Station, Long Ashton Research Station, ADAS and the Forestry Commission on the use of simazine in different fruit and ornamental crops. These had been running for a number of years and their location is shown on the map (Fig. 1).

It was found that at most sites no build-up of simazine in the soil had occurred even where applications had continued for up to nine years. At six out of nine sites, where samples were taken more than 8 months after the last treatment, the total residue remaining was less than 10% of the amount applied annually. Where two rates of application were compared the proportion of simazine remaining from the higher rate was greater. Generally there was less simazine remaining in soil under a mulch than in bare soil. The results confirmed those from long term experiments in raspberries and gooseberries at WRO, the Scottish Horticultural Research Institute and Loughgall Horticultural Centre, N. Ireland (Clay & Ivens 1966, Wiseman & Lawson 1970, Allott 1969).

At three sites, however, a much higher proportion of simazine was found than usual, ranging from 20% of the amount applied annually at Efford, Hants, to nearly 50% at Lowick, Northants. The results at Lowick were confirmed by measurement of residues in samples taken from the same plots two years later when similar amounts were found. No explanation for this unusual persistence has yet been found, neither climatic factors nor soil properties being apparently responsible.

RESIDUES OF OTHER HERBICIDES

The possibility of a build-up of residues in fruit plantations of the benzonitrile herbicides chlorthiamid and dichlobenil has also been investigated. These herbicides, formulated as granules, are applied in spring at rates up to 10 lb/ac to control many annual and perennial weeds in bush and cane fruit. Residues in soil have been measured by gas chromatography. Since chlorthiamid breaks down in soil to dichlobenil (the herbicidally active chemical) the residues measured are

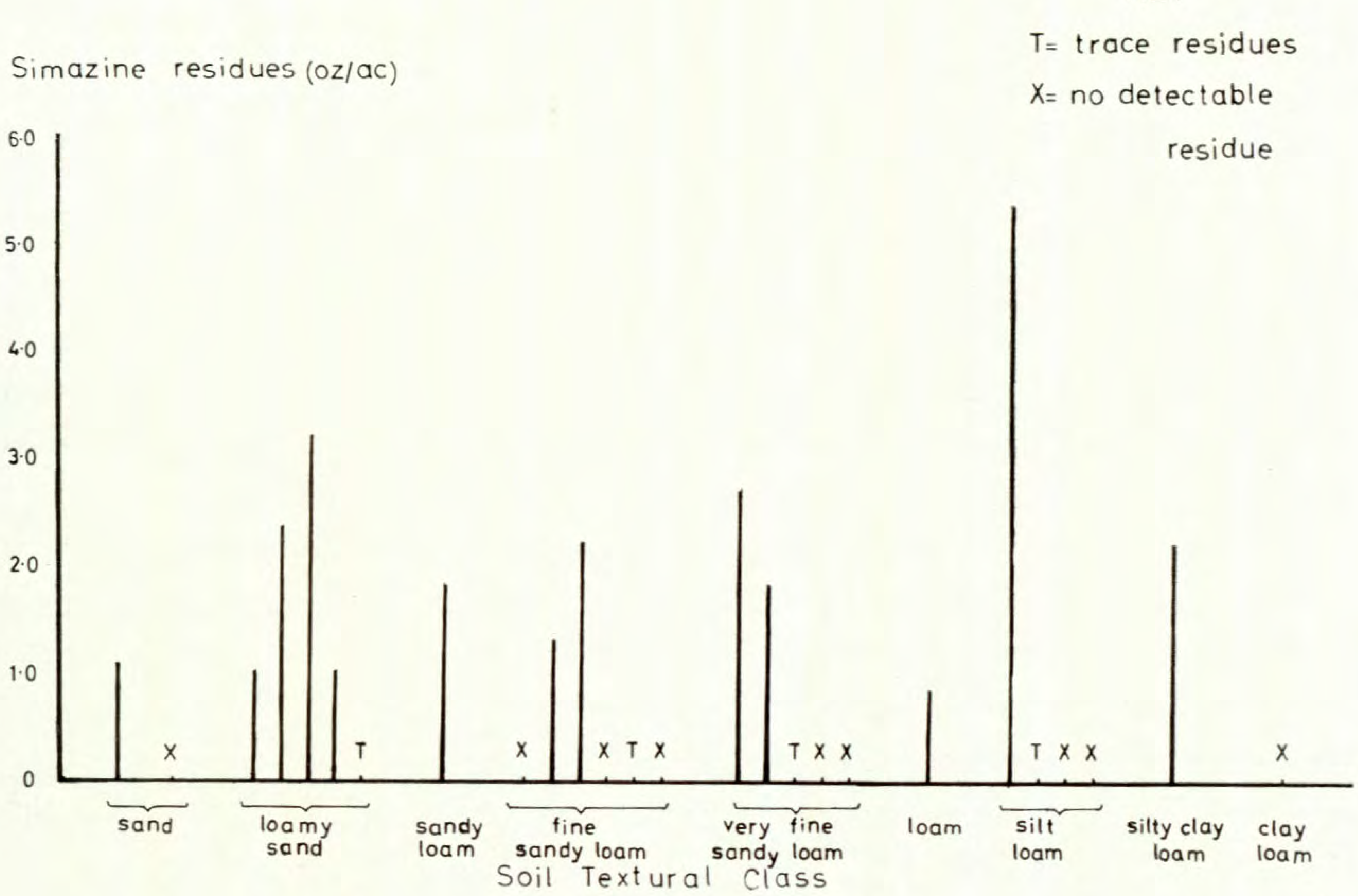

Figure 2. The persistence of simazine in soil in relation to soil texture at 26 sites (simazine applied in spring 1968 at 2 lb/ac; soil sampled in following autumn).

expressed as the total benzonitrile present which includes dichlobenil and any remaining chlorthiamid.

In an experiment in blackcurrants in sandy loam soil at Begbroke rates of 6–24 lb/ac of dichlobenil and up to 48 lb/ac of chlorthiamid have been applied annually from 1967–70. Herbicide residues in spring '71, twelve months after the last application were, irrespective of treatments, not more than 7% of the amount applied annually. Dichlobenil residues were generally about 50% of those remaining from chlorthiamid. Residues were not found below 6 in. except with the highest rate of chlorthiamid (Clay & McKone 1970).

Residues of 2,6-dichlorobenzamide in the soil have also been measured. This is a product of chlorthiamid and dichlobenil breakdown in the soil which can cause marginal chlorosis of crop leaves but which is only slightly phytotoxic. The amount in the 0–6 in. layer of soil in all plots was small, usually less than 5% of the amount of benzonitrile applied; however, higher concentrations were found in the 6–8 in. soil layer.

Residues of these same chemicals in the soil were also measured in four experiments in gooseberries in the West Midlands and Yorkshire. Chlorthiamid or dichlobenil were applied in either early or late spring at rates up to 30 lb/ac. Total benzonitrile and 2,6-dichlorobenzamide content was measured in soil samples taken in the autumn after one or two years of treatment. Residues of total benzonitrile and 2,6-dichlorobenzamide each varied between 5 and 20% of the amount of chlorthiamid applied annually and between 5 and 10% for dichlobenil. A smaller proportion persisted from rates of 20 lb/ac and more than did from lower rates. Residues from late spring applications were from one and a half to three times as large as those from early spring treatments. The amount of 2,6-dichlorobenzamide found in the top 6 in. of soil varied from a half to three times the quantity of the total benzonitrile residue.

IN CONCLUSION

The results from the analyses of soils receiving repeated applications of residual herbicides have been reassuring in that generally no build-up of residues has occurred. There thus appears to be no danger to treated crops from repeated applications of these herbicides, or to crops planted after such crops have been grubbed, providing application was accurately carried out in the first place. Further reassuring evidence on soil residue levels has also come from long term studies at Begbroke where the repeated annual use of simazine, linuron, MCPA and tri-allate on annual crops growing on the same plots has not led to crop reduction or to the build-up of herbicide residues in the soil after six years of use (Fryer & Kirkland 1970). Problems from residues may arise, however, where overdosing with soil-acting herbicides has occurred (Clay & Stott 1972) and are also more likely following the use of the more recently introduced herbicides bromacil and terbacil (Wiseman & Lawson 1970). Where the presence of large amounts of herbicide residue is suspected, for example where no annual weeds develop during autumn or winter, the precaution of omitting the residual herbicide treatment in the final seasons of cropping and following with a crop tolerant to the herbicide can minimise any risk of crop losses.

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Grassland Improvement with Herbicides

A. M. BLAIR and A. K. OSWALD

There are some eleven million acres of permanent grass in Great Britain (excluding rough grazing) and a further five million acres of temporary grassland, much of which has been sown since 1964. In this large area of land modern methods of weed control based on herbicides are seldom used.

Most of the early work on the use of herbicides in grassland centred around the control of broad-leaved weeds; MCPA and 2,4-D have now been available for some twenty-five years while, latterly, herbicides such as asulam, mecoprop and dicamba have opened up new possibilities in, for example, the control of docks (*Rumex* spp.). Until recently little attempt has been made to investigate the role of herbicides in altering the balance between different grass species in swards. Allen (1968) reviewed and included an account of the work at WRO up to that time. This article is intended to bring the reader up to date with developments since then.

One aim of the grassland programme of WRO has been to produce systems for improving old pasture without the need of the expensive and time-consuming operation of ploughing and reseeding. Another has been to keep new leys, however established, free from the rapid ingress of the less productive weed grasses.

In the past three years the research has ranged from an attempt to understand the nature and degree of competition between crop and weed grasses at the initial stages of establishment to a large field experiment to measure, in terms of animal output, the production of swards improved by dalapon.

COMPETITION BETWEEN CROP AND WEED GRASSES

It is well established that bent (*Agrostis* spp.), rough-stalked meadow grass (*Poa trivialis*), and Yorkshire fog (*Holcus lanatus*) are widespread species in British grassland. Owing to their low production of dry matter, which is unevenly distributed over the growing season, and to the poor nutritive quality of their herbage, they are regarded as weeds by comparison with perennial ryegrass which is widely held to possess many of the desirable characteristics of a good pasture grass in Britain including sustained and abundant dry matter production, leafy growth and high nutritive value to the grazing animal. However, there is a lack of reliable information on the extent to which weed grasses reduce sward production. Little is known about the role of the various indigenous grasses that occur in British grassland, the factors which govern the competition among them, and the effects they have upon one another in the sward. Current experiments at WRO are concerned with the competition between perennial ryegrass and rough-stalked meadow grass and involve the measurement of yield from planted mixtures of the two species at various densities. Later, observations will be carried out on similar planted mixtures at different levels of nitrogen and soil moisture. The object of this work is to extend our knowledge of the behaviour of crop and weed grasses growing together in a sward so as to provide a basis for the techniques of chemical control being developed, and enable farmers to use selective herbicides more effectively as management tools.

THE SELECTIVE CONTROL OF WEED GRASSES IN ESTABLISHED GRASSLAND

As reported by Elliott and Allen (1964), successful improvement of established swards infested with weed grasses but still containing perennial ryegrass is possible using dalapon. It was found that, when applied at 2.5 lb in 20-30 gal/ac of spray solution containing 0.1 per cent 'Agral 90' surfactant, dalapon suppressed unwanted grasses such as rough-stalked meadow grass, creeping bent and Yorkshire fog leaving the perennial ryegrass only temporarily checked. A complementary fertilizer dressing at the time of spraying assisted the recovery of the treated sward. A series of experiments has since confirmed that young perennial ryegrass is sufficiently resistant to allow use of the dalapon + fertilizer technique. Yield assessments at ten sites from autumn 1969 to summer 1970 gave the following mean results:

	Mean d.m. yield/ac	*% Perennial ryegrass*
On untreated area	19,500 lb	65
On area treated with dalapon + fertilizer technique	23,800 lb	85

Although the results had repeatedly indicated that the technique could be of value to the British grassland farmer little enthusiasm was shown by advisers and farmers until late in 1970 when a field demonstration in Dorset obtained wide publicity. Further demonstrations are now being carried out by ADAS and interest is steadily growing.

An experiment has begun at Begbroke Hill to evaluate the dalapon technique in terms of live weight gain in beef cattle which, it is hoped, will assist an appraisal of the economic consequences of the treatment.

RECENT DEVELOPMENTS IN SELECTIVE GRASS KILLERS

It has been noticed that, following the treatment of established swards with dalapon, rough-stalked meadow grass and other weed grasses are liable to invade bare patches. Therefore, in screening new herbicides from industry, attention has been given to controlling such weed grasses during the establishment phase of new ryegrass swards, either pre-emergence or early post-emergence. Following a lead from this programme, methabenzthiazuron has been shown to be efficient in controlling rough-stalked meadow grass in establishing ryegrass. This herbicide can be used either pre- or early post-emergence which increases its flexibility. Although undersown ryegrass crops can be treated, a barley 'nurse-crop' is liable to damage from post-emergence applications. An application of methabenzthiazuron which is causing interest is in the control of rough-stalked meadow grass in ryegrass seed crops; much work with this herbicide has been carried out by the National Institute of Agricultural Botany. Fluorodifen has shown similar activity but is not so flexible in its time of application. Red fescue (*Festuca rubra*) is a weed grass which has proved difficult to control but in the last year a new herbicide (NC8438) has selectively controlled this species without harming ryegrass when applied before the emergence of a young ley.

The combined effect of all these herbicide developments is significant and it is now possible to limit the ingress of many of the more important weed grasses into a newly sown or established ryegrass sward. They should make a useful addition to other pasture maintenance techniques, or to sward destruction and reseeding but there is much work to do before their economic role in grassland management can be appraised.

CHEMICAL SWARD DESTRUCTION

The technique of chemical sward destruction prior to direct reseeding is well known and commercial recommendations based on paraquat

Complete selective control of rough-stalked meadow-grass (*Poa trivialis*) by methabenzthiazuron. This herbicide was applied to all the labelled plots; note the undamaged plot of perennial rye-grass in the foreground.

and aimed at ensuring its success are widely accepted. However, there may still be room for improvement in sward destruction techniques in regard to such factors as doses and volume rate required to completely kill a sward, the best preparation to give a sward before treatment and the most effective way of getting the spray onto the herbage. Consequently for the past two years experiments have been carried out with the aim of improving the efficiency of herbicides for sward destruction.

In work carried out under purely experimental conditions at Begbroke, a densely-tillered prostrate sward was more susceptible to paraquat than more erect swards of lower tiller density or swards with a heavy canopy; spraying immediately after the preparatory cutting of the sward enhanced the overall kill. The programme is currently being extended to cover a wider range of situations.

Similar basic experiments are also being carried out involving the use of various pressure/volume rate combinations. Interim results indicate that a better sward kill can be achieved using a volume rate of 40–50 gal/ac compared with lower rates.

Herbicides other than paraquat are also of interest in sward destruction work and some attention is being paid to dalapon and aminotriazole. For all three herbicides it is important that the reaction of individual constituents of the sward is known and a detailed study is now under way, the results of which will be useful for both selective and non-selective applications.

CONTROL OF DOCKS

Following the discovery by WRO that asulam showed promising activity against docks (*Rumex* spp.), this herbicide has been widely used on a commercial scale for this purpose. It has, however, caused damage to some grasses. Recent work at WRO has largely involved a study of the effects of autumn applications on both the level of dock control and grass production. The current recommended dose of 1 lb/ac has given dock control lasting through the following summer with an increase in perennial ryegrass yield. A higher dose of asulam (2 lb/ac), although causing marked initial reduction in ryegrass yield, gave better control of docks; after eight months ryegrass yields were comparable with those at the lower dose. Whilst asulam, dicamba and mecoprop can give good control of docks WRO is still looking for new herbicides giving improved dock control.

IN CONCLUSION

It can be seen that the list of herbicides for weed control in grassland is already quite extensive. However, a better understanding of the factors involved in the competition between crop and weed grasses, and of the reasons for herbicide selectivity between grasses and variability in performance, is still required. As in all grassland work, an economic assessment of new technical developments such as those outlined above under specific systems of pasture management is vital.

With current research pinpointing the need for weed control in intensively managed pasture, and with the present increase in economic incentives for the grassland farmer, it is apparent that the use of herbicides for increasing grassland productivity is likely to expand.

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Do Herbicides affect the Micro-Organisms of the Soil?

E. GROSSBARD

INTRODUCTION

The importance of soil micro-organisms

The microbial population of the soil consists of very large numbers of algae, actinomycetes, bacteria and moulds whose highly efficient enzyme systems enable them to decompose plant and animal residues in the soil. In breaking down complex organic material into simpler products, that is by the 'mineralization' of organic to inorganic forms of nitrogen, phosphorus and sulphur, these micro-organisms not only provide the source of their own energy and growth but supply the nutrients that can be assimilated by growing plants. Additionally, some can 'fix' atmospheric nitrogen.

The extent to which the existence of man is dependent on the activity of soil micro-organisms is not always appreciated. This is especially true with respect to soil fertility. The successful cultivation of crops is determined to a large extent by the recycling of nutrients. Micro-organisms also contribute to the crumb structure of the soil by their cementing action.

Soil micro-organisms and herbicides: the point of contact

Of the large amounts of herbicides applied annually, either to the foliage of crops or directly to the soil, a major proportion reaches the soil surface. Because they do not readily dissolve in the soil water or may quickly become fixed to particles of clay or organic matter, many herbicides do not penetrate the soil to a depth of more than a few centimetres—unless they are mixed in by cultivation. Moreover because of the better aeration and the supply of nutrients from plant roots, the largest numbers of micro-organisms are also to be found in the surface layers of the soil. It is here, therefore, that contact between herbicides and micro-organisms is most likely to occur. Another important area of contact is the immediate vicinity of roots, the rhizosphere. High levels of micro-organisms are found here which may be exposed to certain foliar herbicides following excretion by the roots.

The reasons for concern

Many, though not all, herbicides can at appropriate dose levels be toxic not only to weeds but to soil micro-organisms as well. This has been demonstrated in laboratory experiments when single species have been subjected to treatment with concentrations of herbicide well above those likely to result in the soil from agricultural practice. However, not all micro-organisms examined in this way have been adversely affected.

Some micro-organisms are very important agents in the biological decomposition and de-toxification of pesticides including herbicides in the soil. One of the most fascinating aspects of the herbicide-soil microflora relationship is that while certain micro-organisms may detoxify a particular herbicide, related micro-organisms may be killed or inhibited by the very same chemical.

It is one of the great virtues of herbicides that they are effective in very small amounts, often only one pound or so per acre. As a result, the mean concentration reached in soil may well be much lower than that required to reduce significantly the growth of soil micro-organisms under laboratory conditions. However, in the presence of millions of other micro-organisms competing for space and food in the soil, the response of any one kind of micro-organism may not necessarily be the same as that observed in an artificial situation. Moreover, herbicides are not uniformly distributed in the soil and can become concentrated in certain components, particularly in organic matter, where micro-organisms are prevalent. For some years now scientists have been concerned about the repeated application of persistent herbicides to the same land and the possibility of their accumulation in the surface layers of the soil. They have sought, at WRO and elsewhere, to discover whether their use may be significant in adversely affecting the activity of soil micro-organisms and consequently soil fertility.

RESEARCH AT WRO

The general approach

Possible effects on the soil microflora of both established and new herbicides are examined in the course of the overall herbicide evaluation programme at Begbroke. Treated soils from both field and laboratory experiments are tested. Since it is not possible to examine effects on all the numerous kinds of micro-organisms that populate the soil or all their activities, a selection has to be made on the basis of their probable importance to agriculture and on the availability of suitable techniques. This, however, is by no means easy since few clear-cut correlations have been established between microbial activities and factors affecting properties of the soil which contribute towards structure, freedom from disease and good crop yields. Micro-organisms may go through long periods of inactivity; nevertheless it is generally assumed that the greater the overall microbial activity the better the crop growth. As a measure of overall activity, the respiration of the soil provides a basic criterion by which to judge the effect of applied chemicals. Expressed as the evolution of carbon dioxide, this also serves as an approximate measure of the decomposition of organic matter. Another part of this very important process is the mineralization of organic nitrogen culminating in nitrification: the conversion of ammonia to nitrate. The examination of herbicides for their effect on these activities is therefore routine.

If a herbicide were to have a lethal effect on all micro-organisms in the soil the evolution of carbon dioxide would cease and so equally would the uptake of oxygen. If no effects are found on carbon dioxide evolution it cannot, however, be concluded that the chemical has had no important effect. It is feasible that certain groups of micro-organisms have been eliminated while the survivors have multiplied profusely producing in the end the same quantity of carbon dioxide as before. Therefore, changes in the composition of the soil microflora and in specific microbial activities of agricultural interest, such as the fixing of atmospheric nitrogen or the decomposition of cellulose and other materials, are also investigated at Begbroke (Grossbard 1970b) (Fig. 1).

Field experiments

Soils from a series of field plots treated annually for 8 years with four herbicides (MCPA, tri-allate, simazine and linuron—see p. 28) have been examined periodically (Grossbard 1971). Carbon dioxide evolution, mineralization of nitrogen and, in a few instances, oxygen uptake were measured in soil from bare plots to which 3-4 times the recommended amount had been applied each year. MCPA and tri-allate showed no significant effects but simazine and linuron resulted in carbon dioxide output being reduced by 20-30% compared with soil from weeded control plots. Mineralization of nitrogen was adversely affected in only a few of the many assessments made. The lower output of carbon dioxide from simazine- and linuron-treated soils was inves-

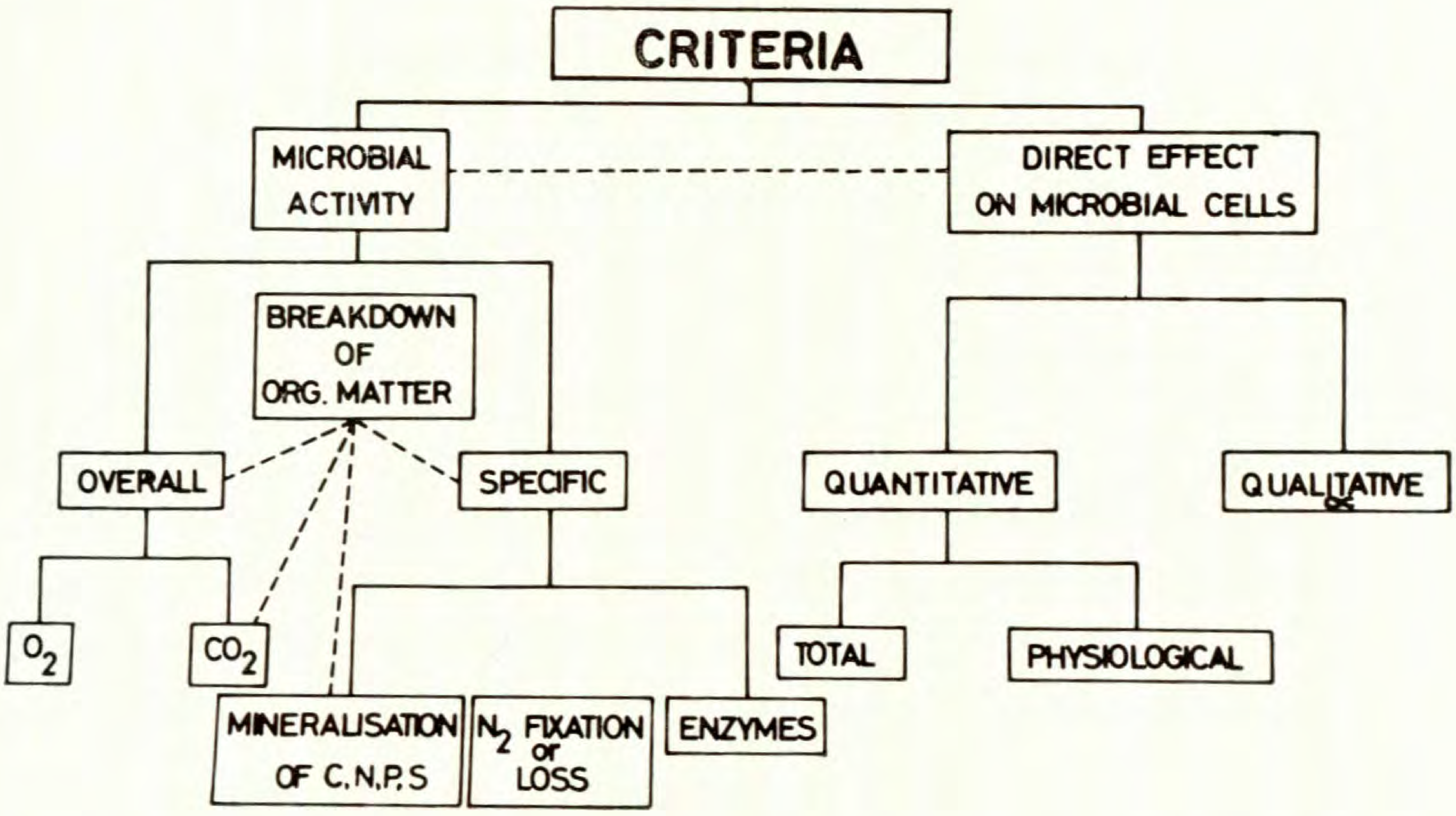

Figure 1. Diagrammatic representation of the criteria by which the effect of herbicides on the soil microflora is measured. It is necessary to distinguish between effects on microbial activities and effects on the micro-organisms themselves.

tigated in detail and found probably not to be due to direct anti-microbial action. Rather, it could be attributable to the difference in the content of easily digestible organic matter between the control and treated plots resulting from the early eradication of all weed growth by these two herbicides and the presence of some plant material in the soil of the control plots. MCPA and tri-allate, in contrast, are only effective on certain weed species, allowing a comparable seedling weed population to develop on treated as well as control plots prior to weeding. This explanation is supported by laboratory experiments, in which simazine at a concentration of 500 ppm (over 100 times that likely to be obtained in the field) had no adverse effects upon microbial activity. At such high concentrations linuron inhibited respiration by up to 30% in the laboratory but had no effect at concentrations comparable to field applications (Grossbard & Marsh 1971).

Soil taken from cropped plots treated with simazine and linuron at recommended doses over several years behaved in a similar way to soil from weeded control plots. Such reductions in microbial activities as occasionally occurred were minor and inconsistent. Similarly in an experiment with raspberries in which simazine was applied over a period of years to mulched plots no significant adverse effects of the herbicide were recorded.

Laboratory experiments: overall activities

In the present programme soils have been treated with over 30 different herbicides at 500 ppm. During subsequent incubation, samples have been examined for changes in some of the principal microbial activities. If a chemical has not shown any adverse effects even at this high concentration it has been assumed it would be equally innocuous at the much lower concentrations arising from normal usage and could then be excluded from further tests. In fact, it was found there were very few herbicides that were without adverse effects at high concentrations. Herbicides affected each microbial activity in a different manner. For instance, picloram had no adverse effect on mineralization of nitrogen, but markedly inhibited the production of carbon dioxide by up to 35%. On the other hand formulated aminotriazole and metoxuron reduced carbon dioxide output by up to 35% as well as mineralization of nitrogen (Fig. 2). In contrast simazine in our experiments did not affect either of the two activities. To obtain a better understanding of the toxicity/concentration relationship selected herbicides were tested at a range of concentrations against several microbial activities and populations. Generally, inhibitory effects on respiration did not occur at 5 ppm but were recorded at 50 ppm with, for instance, asulam and linuron. Though the mineralization of nitrogen is a microbial activity very susceptible to herbicides, of the chemicals examined barban alone, and in one exceptional case asulam, showed an inhibitory effect at 50 ppm.

Although a herbicide itself may not cause inhibitory effects, there is still the possibility that metabolites found in the course of breakdown in soil may be toxic to the microflora. Thus the curious situation might arise in which degradation of the herbicide rendered it harmless to weeds and crops but produced by-products more toxic to micro-organisms. Research into this possibility is just beginning and some interesting results have been obtained (see p. 30).

Also it is possible that effects on micro-organisms may be exerted by the constituents of the formulation as opposed to the active ingredient itself. In the case of a commercial formulation of barban the solvent complex stimulated respiration and increased the number of

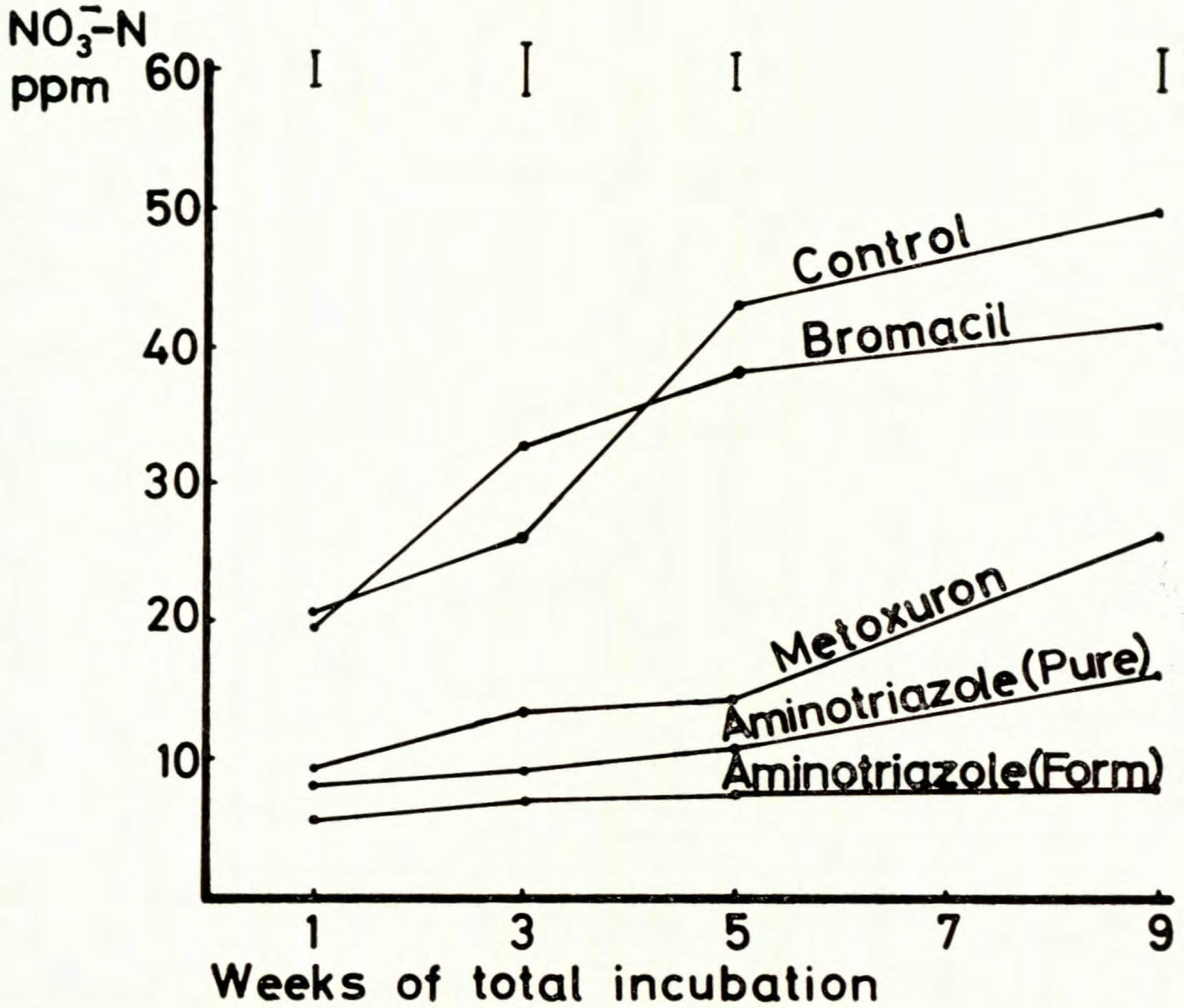

Figure 2. The effect of the herbicides bromacil, metoxuron and pure and formulated aminotriazole on the mineralization of nitrogen. (All concentrations 500 ppm active ingredient.)

micro-organisms, perhaps through utilization as a food source. When pure and formulated aminotriazole were compared the formulated product had a more adverse effect than did the pure compound on soil respiration and especially on mineralization of nitrogen (Fig. 2). This work emphasises the need to study complete proprietary products rather than confine attention to the pure active compound.

Laboratory experiments: specific activities

Nitrogen fixation. The bacterium *Rhizobium* found in the nodules of legume plants fixes atmospheric nitrogen and converts it into a form that can be used by the plant. This symbiosis could be disrupted by herbicides applied directly to a leguminous crop or to the soil. It has, for example, been reported that as little as 5 ppm MCPA drastically reduced the growth of clover (Fletcher *et al.* 1957). Herbicidal action on the bacterium must be distinguished from that on the legume. There is also the possibility that a herbicide may affect the free-living bacteria in the soil when applied in the course of rotation to a crop other than a legume.

Laboratory work at WRO with atrazine and pyrazone has indicated that the bacterium is far less sensitive than is white clover. The small reduction in numbers of bacterial propagules observed would be unlikely to be important in field situations since enough cells would survive to initiate nodule formation. Activities, such as respiration (Fig. 3) and nitrogen fixation by the bacteria have been rarely inhibited (Grossbard 1970a). However, clover seedlings have been injured when inoculated with cultures of bacteria pretreated with the herbicide. This was shown to be due to a trace of herbicide transferred in the bacterial suspension (Fig. 4). When this trace was removed normal plants developed. Thus when a reduction in nitrogen fixation is observed it is probably because the legume is affected rather than the bacterium.

Cellulose decomposition. This microbial activity is of even greater importance than is nitrification or nitrogen fixation because it is part of the scavenging function of the soil microflora. At WRO the effect of linuron on cellulose activity has been studied in detail by burying cellulose in the form of calico strips or cotton wool in soil treated with linuron at 50 and 500 ppm. Decay of the two types of cellulose has been markedly slowed down only in soil treated with 500 ppm. This effect, over a 6-month period, has been correlated with the concentration of linuron remaining at a very high level. Another aspect of decomposition of cellulose including also that of plant proteins, lignin, etc., is the study of the effect of herbicides on the decay of vegetation on the surface that has been described elsewhere (p. 19).

Microbial cells and populations

The same selectivity as is observed among higher plants operates with respect to micro-organisms. Some are quite resistant while others are more susceptible. Though inhibitory effects occur mostly at high concentrations, some micro-organisms, especially some of the fungi causing plant diseases, are affected by herbicides at the recommended

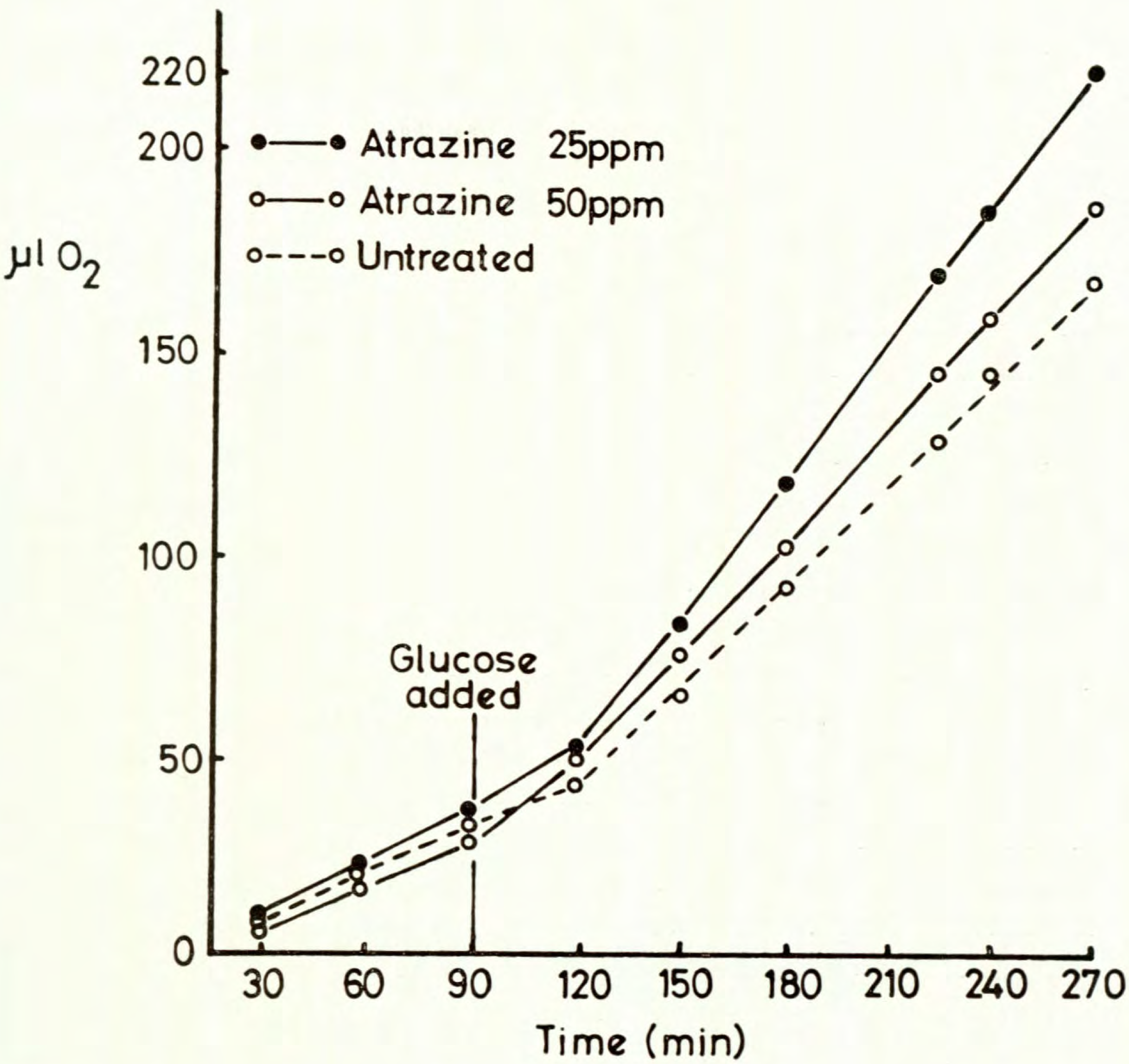

Figure 3. The effect of atrazine on oxygen uptake by the nitrogen-fixing bacterium *Rhizobium trifolii* (by permission of the editors, *Proc. White Clover Res. Symp.* 1969).

doses. The composition of the microbial populations in the soil may be changed; for instance the number of fungal propagules has been drastically reduced by formulated barban (at 200 ppm) (Quilt *et al.* 1971), by bromacil and by linuron (at 50 or 500 ppm) (Grossbard & Marsh 1971), while the bacteria grew profusely since the competition for food and space was lessened. Micro-organisms that have the ability to detoxify herbicides may use the breakdown products for food, thus giving rise to increased populations. This has been shown to occur in laboratory experiments when relatively large concentrations of herbicide have been used. Whether this also happens in the soil where only small amounts of the chemicals are available has yet to be proved conclusively.

CONCLUSIONS FROM WRO RESEARCH

From the above examples it is clear that some herbicides do indeed exert an influence on the micro-organisms of the soil at Begbroke though adverse effects occur mainly at high concentrations compared with those required to kill higher plants through root uptake. This encouraging result must not impart a false sense of security. Although concentrations equivalent to field rates have rarely resulted in severe depressions of microbial activities, workers elsewhere have demonstrated such effects (reviewed by Audus, 1970). Further research is necessary to elucidate this variation in effect and to ascertain whether it arises from differences in soil type and conditions or, in part at least, from experimental techniques. There will also be a continuing need for new herbicides, as they are developed, to be investigated for their capability to affect adversely soil micro-organisms.

Some care is needed in interpreting levels of concentration of herbicide. In laboratory experiments the concentration in soil is generally expressed as ppm of dry soil. However, it is the concentration in the soil solution that is probably most relevant to effects on micro-organisms. This concentration will usually be much lower because of adsorption on clay or organic matter and the limitation imposed by water solubility. Raising the total concentration in the soil does not necessarily lead to a proportionate increase in concentration in the soil solution. In laboratory experiments conducted in the absence of soil, toxicity is to be expected at much lower concentrations in the medium than when soil is present and concentration is expressed relative to weight of soil. The situation is further complicated in the field where a measured dose is applied to the soil surface but concentration in terms of soil or soil solution is generally not known. Moreover, redistribution is uneven with greater amounts held on plant residues, in roots, and on other organic particles (Grossbard 1970c). These are sites where the population of active soil micro-organisms is particularly dense. Hence concentrations of herbicide in contact with micro-organisms may be higher or lower than is apparent at first sight.

Effects of herbicides on the soil microflora may not always be harm-

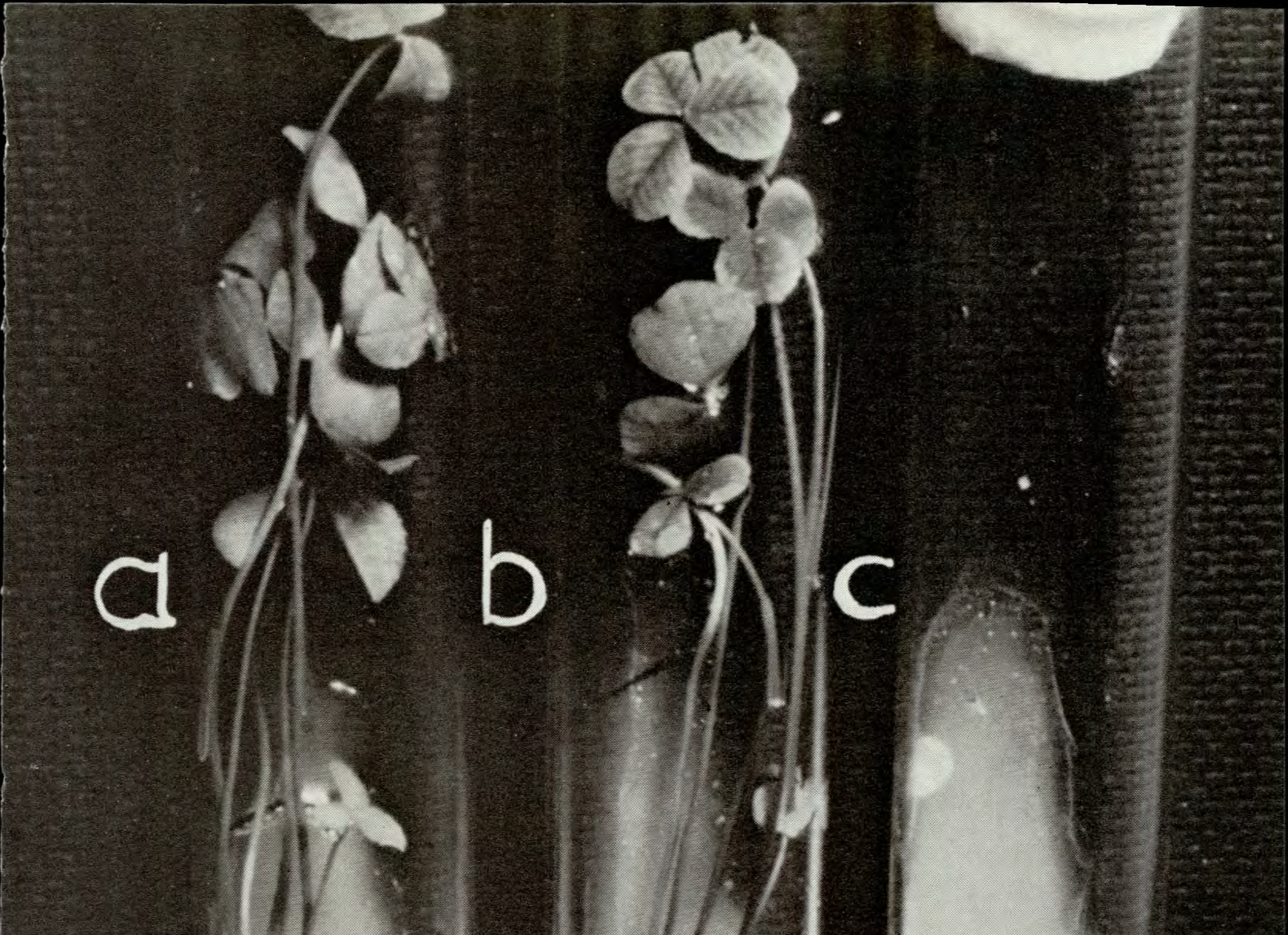

Figure 4. The effect of *Rhizobium trifolii*—grown in the presence of 25 ppm atrazine for 6 weeks—on the growth of white clover. Sterile clover seedlings (a) inoculated with a suspension of untreated bacteria; (b) inoculated with pre-treated bacteria from which the traces of herbicides were removed; (c) inoculated with pre-treated bacteria with traces of herbicide remaining in bacterial suspension.

ful. Thus the inhibition of nitrification may be advantageous in some circumstances through curtailing loss by leaching of nitrogenous compounds in the form of nitrate.

Interpretation of antimicrobial effects in relation to soil fertility is difficult. In the long-term field experiments at WRO reduction in soil respiration has occasionally occurred but has not been reflected in a lowering of crop yield. In experiments at the Grassland Research Institute comparing aminotriazole treatments at recommended doses with conventional ploughing, the former resulted in lower figures for mineral nitrogen but the wheat yields were unaffected (Arnott & Clement 1966). Yet work at the same Institute, comparing two types of ley management (Clement 1958), demonstrated considerable treatment differences in carbon dioxide output of soil and numbers of propagules of certain bacterial populations (Hall & Grossbard, in press). Here, lower microbial activities coincided with lower yields of wheat (Clement, personal communication). It cannot be said yet whether high overall microbial activity creates the conditions that improve crop yield or whether it acts merely as an indicator of environmental conditions that are favourable both to overall microbial activity and successful growth of the crop. If we wish to learn more about the way herbicides affect soil fertility more research is required on the complex interdependence of soil micro-organisms and crop production. There is need for more co-ordinated integration of research between soil microbiology, plant pathology, entomology and crop husbandry.

Microbial activities are of paramount importance for human existence far beyond the field of soil fertility. Thus safeguarding the unimpeded functions of the soil microflora, under all conditions, is an essential objective for future research.

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Begbroke Hill Farm

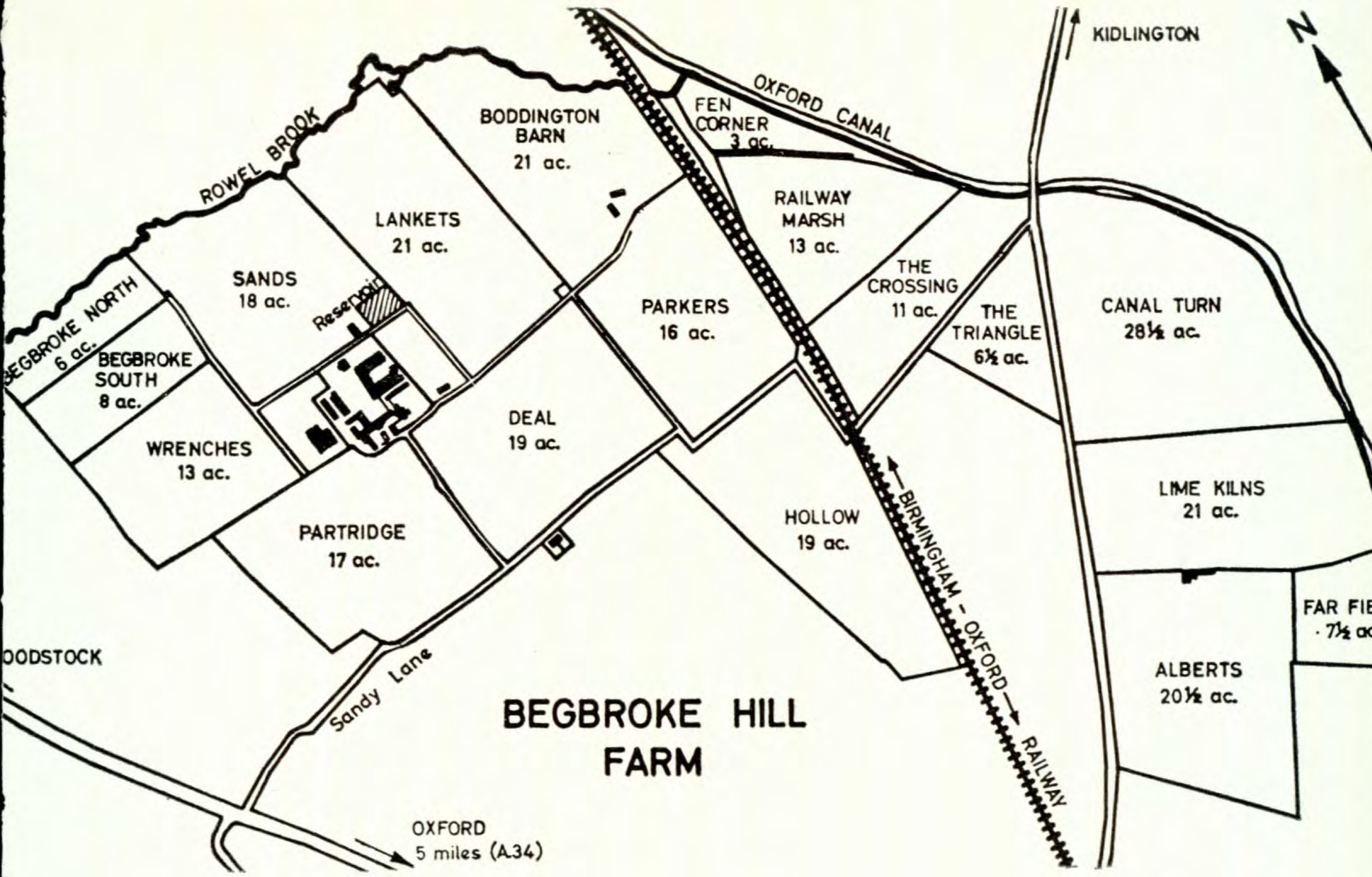
Begbroke Hill Farm lies five miles north-west of Oxford, near the road to Woodstock. Its 286 acres fall naturally into two parts, separated by the Oxford-Birmingham railway. The part west of the line on which are the main buildings consists of 176 acres of deep, sandy loam topsoil overlying gravel, most of which is used for arable experimentation and cropping. The area east of the line consists of 110 acres of low lying, rather wet, alluvial soil, mostly under permanent pasture. The farm thus caters for experimentation on arable and horticultural crops and grassland. The holding is equipped with the basic facilities that go to make both an efficient experimental station and a modern farm. They include all-weather roads, buildings and equipment for the handling and storage of 200 tons of cereals, 200 tons of potatoes and 90 beef cattle. Irrigation is available on the arable land.

ORGANIZATION

Priority is given to the use of the land for experiments which involve three main types of requirement. For short term experiments lasting 1-3 years, two fields on the arable farm become available in rotation each year. For long term experiments lasting three years or more, one field is permanently set aside and farm crops are grown only to fill in the land not taken up by experiments. In the grassland it has been necessary to apply a more piecemeal approach. Twenty acres are reseeded systematically so as to provide young and established sown swards. Twenty-seven acres remain in permanent pasture farmed at a high level of fertility, while the remainder is deliberately kept in a low state of fertility as a reservoir of typical grassland weeds. The average number of field experiments carried out each year on the farm is about 130. The grassland is well able to meet the requirements of experiments but there is increasing pressure on the arable land.

FARM ENTERPRISES

The land not in experiments is farmed to a high commercial standard. The cereal crops are winter wheat, winter oats and spring barley and are in rotation with King Edward potatoes. The livestock policy is based on a 500 lb cross-bred steer aged 6 months when purchased in the autumn; the animals are yarded on a modest ration during the



winter and are finished off on grass the following summer and autumn. About 90 such animals are carried each year. In addition, about 40 heifers are reared on summer grazing for the Grassland Research Institute.

DEVELOPMENT WORK

Apart from the activities that have been described, the farm plays an active part in fostering the development of techniques coming out of research. Earlier reports have described the way in which the use of herbicides for potatoes was developed on the farm and integrated into a husbandry system. This activity has continued with studies on the interacting managerial requirements of weed control, irrigation and blight control. The important development during the past three years has been the evolution of a system of cereal land management after harvest which combines the control of perennial grass weeds with minimum cultivation in preparation for the sowing of the next crop. The system which has been published (Barnes & Elliott 1970) depends on the use of tine and disc cultivators backed up by herbicides. Substantial economies in soil cultivation have been obtained.

WRO receives a very large number of visitors each year who come to see and discuss the research. However, a proportion of these visitors, particularly farmers, come primarily to see the farm activities. Particularly has this been so in respect of the cultivation system and the production of beef from permanent pasture.

LIST OF RESEARCH PROJECTS

DEPARTMENT OF WEED SCIENCE

Head of Department: K. Holly

HERBICIDE EVALUATION SECTION (Joint Section Heads: K. Holly, J. Holroyd)

1. Preliminary appraisal of the activity, selectivity and persistence in soil of new herbicides: W. G. Richardson.
2. Evaluation of herbicides for control of *Avena* species (wild oats) and *Alopecurus myosuroides* (black grass): J. Holroyd, M. E. Thornton.
3. Development of techniques for the chemical roguing of *Avena* species (wild oats): J. Holroyd, M. J. May.
4. Evaluation of herbicides for control of *Agropyron repens* and *Agrostis gigantea* (couch grasses): J. Holroyd, A. M. Blair.
5. Selective control of indigenous weed grasses in sown forage grasses: J. Holroyd, A. M. Blair.
6. Evaluation of new herbicides for the control of *Pteridium aquilinum* (bracken): J. Holroyd, M. E. Thornton.
7. Weed control by herbicides on fen soils: J. Holroyd, M. J. May.
8. The influence of environment on the activity of herbicides: J. Caseley.
9. Influence of application techniques on the effectiveness of herbicides: W. A. Taylor. (Joint project with National Institute of Agricultural Engineering.)
10. The use of chemicals for the control of woody plants: D. J. Turner, M. P. C. Loader.

CHEMISTRY SECTION (Section Head: R. J. Hance)

1. Development of analytical methods for herbicides and analysis of herbicide residues in soils, plants and water: R. J. Hance, C. E. McKone, T. H. Byast.
2. Interactions of herbicides with the soil: R. J. Hance.

BOTANY SECTION (Section Head: R. J. Chancellor)

1. Growth patterns of shoots arising from fragmented rhizomes of *Agropyron repens* and the effect of synthetic growth regulators thereon: R. J. Chancellor, R. R. B. Leakey.
2. Investigation of competition between *Avena fatua* and cereal crops: R. J. Chancellor, N. C. B. Peters. (Joint project with Rothamsted Experimental Station.)
3. Control of dormancy in seeds: R. J. Chancellor.
4. Monitoring changes in weed populations in the British Isles: R. J. Chancellor.

MICROBIOLOGY SECTION (Section Head: E. Grossbard)

1. Evaluation of the effect of herbicides on microbial activities in the soil: E. Grossbard, J. A. P. Marsh.
2. Effect of herbicides on total populations, physiological groups, and species of soil micro-organisms: E. Grossbard, G. I. Wingfield.
3. Effect of herbicides on *Rhizobium* and on nitrogen fixation: E. Grossbard.
4. Decomposition of cereal stubble exposed to herbicide treatment: E. Grossbard, J. A. P. Marsh.
5. A detailed study of the effect of barban on the activities of soil micro-organisms: P. Quilt (Ph.D. project).

DEPARTMENT OF WEED CONTROL

Head of Department: J. G. Elliott

AGRONOMY SECTION (Section Head: J. G. Elliott)

1. Growth and control of couch (*Agropyron repens* and *Agrostis gigantea*) in cereal cropping systems: G. W. Cussans.
2. Growth and control of weeds in cropping systems using reduced tillage: G. W. Cussans. (Part of joint project with the ARC Letcombe Laboratory and ADAS.)

3. Agronomic aspects of the wild oat (*Avena* spp.) problem: G. W. Cussans, B. J. Wilson.
4. Production of cereals by reduced cultivation: J. G. Elliott, F. Pollard. (Joint project with the ARC Letcombe Laboratory.)
5. Retrieval of information about weeds and weed control in agriculture: J. G. Elliott, A. Phillipson.
6. Selective control of mono- and dicotyledonous weeds in pasture: R. J. Haggar, A. K. Oswald.
7. Development of herbicides for the destruction of swards prior to surface re-seeding: R. J. Haggar, A. K. Oswald.
8. Establishment of grass and fodder crops by reduced cultivation: J. G. Elliott, N. S. Squires.
9. Competition between cultivated grasses and weed grasses: R. J. Haggar.
10. Tolerance of cereals to herbicides: J. G. Elliott, D. R. Tottman.

HORTICULTURE SECTION (Section Head: J. G. Davison)

1. The development of new methods of controlling specific weeds: J. G. Davison.
2. The tolerance of crops to herbicides.
   (a) Evaluation of inherent tolerance in sand cultures: D. V. Clay.
   (b) The field evaluation of treatments that show promise in sand cultures: J. G. Davison.
3. The persistence in the soil of simazine and other herbicides being developed in 1 and 2 above: D. V. Clay, J. G. Davison.

AQUATIC WEED SECTION (Section Head: T. O. Robson)

1. Effect of time of application of dalapon and cutting on the control of some common aquatic plants: P. R. F. Barrett, T. O. Robson.
2. Assessment of characteristics and potentialities of promising new herbicides and growth retardants on vascular aquatic plants: T. O. Robson, P. R. F. Barrett.
3. Development of methods for controlling *Cladophora* and other filamentous algae: T. O. Robson.
4. Exploratory experiment to determine the range of persistence of diuron residues in water from various sources: T. O. Robson.
5. Assessment of the potential of grass carp (*Ctenopharyngodon idella*) for the control of aquatic weeds: T. O. Robson. (Joint project with Freshwater Fisheries laboratory MAFF.)

LONG-TERM HERBICIDE PROJECT (J. D. Fryer) J. W. Ludwig

1. Influence of repeated applications of MCPA, tri-allate, simazine and linuron on 'fertility' of soil at Begbroke Hill.
2. Persistence in Begbroke Hill soil of paraquat applied repeatedly to (a) vegetation cover, (b) bare soil.
3. Persistence in Begbroke Hill soil of picloram applied annually (due to finish in 1972).

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16. Selected references on linuron residues in carrots, 1965-1967 (5 references), price £0.25.
17. Selected references on *Striga hermontheca*, 1930-1968 (43 references), price £0.45.
18. Selected references on aerial application of herbicides, 1963-1967 (42 references), price £0.60.
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23. Selected references on broomrape (*Orobanche* spp.), 1964-1970 (114 references) price £0.75.
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* Obtainable, together with complete list, from WRO Information Section.

25. Selected references to the persistence of paraquat residues in the soil: a supplement to Annotated Bibliography No. 3, 1964-1970 (66 references), price £0.25.
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32. Selected references to the biology and control of *Cuscuta* spp., 1923-1970 (115 references), price UK and overseas surface mail £1.15, overseas air mail £1.40.
33. Selected references to the control of *Scirpus* spp. 1963-1970 (18 references) price UK and overseas surface mail £0.30, overseas air mail £0.50.
34. Selected references to *Mikania* spp., 1960-1971 (33 references), price UK and overseas surface mail £0.55, overseas air mail £0.80.
35. Selected references to biology and control of *Equisetum* spp., 1959-1971 (132 references), price UK and overseas surface mail £1.65, overseas air mail £1.90.
36. Selected references to the bioassay of picloram, 1964-1971 (17 references), price UK and overseas surface mail £0.35, overseas air mail £0.55.
37. Selected references to the biology and control of *Cyperus rotundus* and *Cyperus esculentus*, 1968-1970 (150 references), price UK and overseas surface mail £1.50, overseas air mail £1.70.
38. Selected references to the biology and control of *Sorghum halepense*, 1939-1971 (267 references), price UK and overseas surface mail £2.75, overseas air mail £3.00.
39. Selected references to the biology and control of *Oxalis latifolia*, 1958-1970 (29 references), price UK and overseas surface mail £0.45, overseas air mail £0.65.
40. Selected references to the biology and control of *Convolvulus arvensis*, 1931-1970 (166 references), price UK and overseas surface mail £1.75, overseas air mail £1.95.

STAFF OF THE ARC WEED RESEARCH ORGANIZATION

As at 31st December 1971

Director
J. D. Fryer, M.A.

Secretary
B. A. Wright

DEPARTMENT OF WEED SCIENCE

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

HERBICIDE EVALUATION SECTION

Joint Heads: K. Holly, B.Sc., Ph.D.; J. Holroyd, B.Sc.

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J. A. Slater
D. J. Turner, B.Sc., Ph.D.
J. C. Caseley, B.Sc., Ph.D.
W. G. Richardson, B.Sc.
W. A. Taylor
M. P. C. Loader, B.Sc.
R. C. Simmons, B.Sc.
M. E. Thornton
R. H. Webster

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Miss J. G. Sargeant
D. J. Cambray
Miss J. R. Hilton
C. R. Merritt
E. S. Peck*
A. Douglas
Miss P. Jones
M. R. Nowakowski
R. Porteous

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Scientific Staff

T. H. Byast
C. E. McKone

Assistants

E. G. Cotterill
S. J. Embling

BOTANY SECTION

Head: R. J. Chancellor, M.A.

Scientific Staff

N. C. B. Peters, B.Sc.

Assistants

Mrs. A. P. Martin
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MICROBIOLOGY SECTION

Head: Miss E. Grossbard, B.Sc., Ph.D., D.I.C.

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J. A. P. Marsh
G. I. Wingfield, B.Sc., M.Sc.

Assistants

Miss S. L. Giles
Miss C. Standall

Student

Miss B. Martin

EXPERIMENTAL RECORDS

Vacancy

**Part-time staff*

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AGRONOMY SECTION

Head: J. G. Elliott, M.A.

Scientific Staff

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A. Phillipson | F. Pollard, B.Sc. | P. D. Smith
N. R. W. Squires, B.Sc. | D. R. Tottman, B.Sc. | B. J. Wilson, B.Sc.

Assistants

P. Ayres | N. J. Eagling | C. M. Ellis | A. J. H. Everett
S. J. Godding | F. W. Kirkham | R. Robinson | Mrs. J. A. McDonnell*

HORTICULTURE SECTION

Head: J. G. Davison, B.Sc., Ph.D.

Scientific Staff

D. V. Clay, B.Sc.

Assistants

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Miss P. A. Prior | Mrs. G. Young*

AQUATIC WEED SECTION

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

Scientific Staff

P. R. F. Barrett, B.Sc.

Assistants

Miss S. A. D. Ball | Miss M. C. Fowler

LONG TERM HERBICIDE PROJECT

Scientific Staff

J. W. Ludwig, Ll.M., M.A., B.Sc.

Assistant

D. B. Loach

EXPERIMENTAL RECORDS

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Farm Manager: F. Barnes

C. B. Miller | T. A. Penfold | B. C. Viles | C. G. Woodhams

INFORMATION SECTION

Head: J. E. Y. Hardcastle, O.B.E., B.Sc.

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

Information Staff

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Miss E. M. Watson, B.Sc. | Mrs. E. M. Young, M.A.*

Librarian

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

Indexer

Miss C. R. Deans, B.Sc.

* *Part-time staff*

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Scientific Staff

M. L. Dean, B.Sc.
G. W. Ivens, B.Sc., M.A., D.Phil. (Home Based Post)
L. Kasasian, B.Sc. (ODA Research Scheme)
P. J. Terry, B.Sc. (Home Based Post)

Assistant

Miss A. M. Hitchcock

POST GRADUATE RESEARCH STUDENTS

R. Leakey, N.D.A., B.Sc. (MAFF Scholar)
Miss L. M. Boize, B.Sc. (S.R.C. Scholar)
G. Wells, B.Sc. (Melbourne), M.Agr.Sci.

ADMINISTRATION

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Mrs. P. L. Stark: *Secretary to Director*

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G. D. Champken

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H. Peacock	P. Reece	P. A. Savin	P. Wickson

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H. A. Wilkinson

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Mrs. M. Birt*
Mrs. C. Jackson*

ATTACHED STAFF

MINISTRY OF AGRICULTURE, FISHERIES & FOOD

Agricultural Development and Advisory Service Liaison

P. J. Attwood, B.Sc. (Agriculture)
J. W. Hancock, C.D.H. (Horticulture)

Agricultural Chemicals Approval Scheme Liaison

R. J. Makepeace, B.Sc.

SOIL SURVEY OF GREAT BRITAIN

R. Webster, B.Sc., D.Phil.
M. Jarvis, B.A.
J. Hazleden, B.A.

* *Part-time staff*

CHANGES IN SCIENTIFIC AND INFORMATION STAFF

NEW APPOINTMENTS

M. J. May	SO	Evaluation	1. 1.71
M. P. C. Loader	SO	Evaluation	1. 7.69
R. C. Simmons	SO	Evaluation	1. 9.70
G. I. Wingfield	HSO	Microbiology	6. 9.71
Mrs. H. A. Davies	SO	Microbiology	1. 3.71
R. J. Haggar	SSO	Agronomy	1. 6.70
A. Phillipson	HSO	Agronomy	21. 9.70
F. Pollard	HSO	Agronomy	1. 1.70
D. R. Tottman	SO	Agronomy	1. 7.71
J. W. Ludwig	SSO	Long Term Project	1. 2.69
J. E. Y. Hardcastle	PSO	Information	22.10.69
M. J. Latham	SO	Information	20. 4.71
Miss E. M. Watson	SO	Information	11.10.71
Miss C. R. Deans	Ind.	Information	16. 8.71
P. J. Terry	SO	Overseas	2. 8.71
M. L. Dean	SO	Overseas	7. 9.70

RESIGNATIONS

E. Ramand	EO	Evaluation	7.11.69
G. P. Allen	SSO	Agronomy	28.11.69
T. W. Cox	SEO	Agronomy	31. 8.70
D. O'D. Bourke	PSO	Information	30. 6.69
Miss C. N. Hasnip	EO	Information	31.12.69

STAFF VISITS OVERSEAS

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

to June 1970	G. W. Ivens	Kenya for bush control research while on 4 year secondment to FAO.
March 1969	J. G. Elliott	Holland to present paper to Dutch Weed Control Conference. Sponsored by IBS Wageningen.
April/May 1969	C. Parker	Ghana to advise on weed problems on behalf of ODA.
May 1969	K. Holly	Belgium and Holland to attend meeting of Scientific Organizing Committee of 3rd EWRC Symposium on New Herbicides, 21st International Symposium on Crop Protection and to visit IBS Wageningen on behalf of EWRC.
June 1969	J. D. Fryer	Germany to see herbicide work at the biological Institute of Bayer AG. Sponsored by Baywood Chemicals Ltd.
June 1969	E. Grossbard	Denmark to visit Plant Protection Institute.
July 1969	K. Holly	Norway to see weed control programme at Agricultural College of Norway at own expense.
September/ October 1969	C. Parker	Ethiopia and Sudan for liaison and to advise on Ethiopian weed problems on behalf of ODA.
October 1969	J. D. Fryer K. Holly	Switzerland to see herbicide research of Ciba and Geigy SA at Basle. Sponsored by Ciba Ltd.
November 1969	K. Holly	Belgium to attend meeting of Scientific Organizing Committee for 3rd EWRC Symposium on New Herbicides on behalf of EWRC.
December 1969	R. J. Chancellor	France to present paper at 3rd Colloquium on Weed Biology at Grignon.

December 1969	J. D. Fryer	France to attend meeting of European Weed Research Council and EWRC 3rd Symposium on New Herbicides. Sponsored in part by British Crop Protection Council.
December 1969	K. Holly	France to present paper at 3rd EWRC Symposium on New Herbicides and to attend COLUMA meeting.
February 1970	J. G. Elliott	Canada and United States to present paper to Weed Society of America. Sponsored by WSSA and Canadian Department of Agriculture.
February/ March 1970	C. Parker	Saudi Arabia, Lebanon and Malta for liaison and to advise on weed problems in oasis agriculture in Saudi Arabia on behalf of ODA.
May 1970	E. Grossbard	Belgium to present papers at the International Colloquium on Soil Microbiology at Ghent.
May 1970	J. D. Fryer	Germany to see herbicide research at BASF AG Agricultural Research Station, Limburgerhof. Sponsored by BASF.
May/July 1970	G. E. McKone	USA and Canada to study methods of herbicide residue analysis sponsored by the Winston Churchill Memorial Fund.
June/July 1970	J. D. Fryer C. Parker	USA to attend first FAO International Weed Control Conference at Davis, California and to visit other institutions on behalf of ODA.
August/ September 1970	C. Parker	Ethiopia, Kenya, Uganda, Tanzania and Nigeria to attend 4th East African Herbicide Conference at Arusha and to study a request for assistance with a weed research project at Ibadan University, Nigeria. Also to reinforce contacts with workers in East Africa and Nigeria on behalf of ODA.
August/ September 1970	J. D. Fryer	Ethiopia, Kenya and Tanzania to serve as Chairman of the 4th East African Herbicide Conference; also to visit Ministry of Agriculture, Addis Ababa, the Tropical Pesticide Research Institute and to advise Kenya Ministry of Agriculture on behalf of ODA.
September 1970	E. Grossbard	France to study soil microbiological techniques at Pasteur Institute, Paris.
October 1970	C. Parker	Netherlands to attend a meeting of the Dutch Working Group on Tropical Weed Control on behalf of ODA.
January 1971	J. Holroyd	Canada and USA to give review of work with tri-allate granules at 'Small Grain Symposium' in Winnipeg and to see herbicide developments. Sponsored by Monsanto Chemical Company.
January/ February 1971	J. D. Fryer	Indonesia to advise the SEAMEC Regional Centre for Tropical Biology (Biotrop) on their weed biology project, to attend 1st Indonesian Weed Conference and to undertake a lecture programme. Sponsored by the British Council.
June 1971	G. W. Ivens	Malaysia, Indonesia and Ceylon to attend 3rd Asian Pacific Weed Conference and to tour research stations on behalf of ODA.
June 1971	E. Grossbard K. Holly C. Parker T. O. Robson	Netherlands to present papers at an International Course on Weed Control at Wageningen. Sponsored by Dutch International Agriculture Centre.
July 1971	D. V. Clay	Netherlands, Germany and Switzerland to study methods of herbicide evaluation in fruit crops and techniques for growing perennial plants in containers.

August 1971	J. D. Fryer	USA for work for the US National Academy of Sciences.
September 1971	R. J. Haggar	Netherlands to study latest developments in plant competition research and mathematical model procedures at IBS, Wageningen.
September/ October 1971	J. D. Fryer	Thailand and Vietnam on behalf of US National Academy of Sciences.
September/ October 1971	L. Kasasian	Malta and Italy for field trials on control of *Orobanche* in broad beans and to attend 2nd International Symposium on Biological Weed Control, on behalf of ODA.
October 1971	J. G. Elliott	France to see tillage research. Sponsored by Howard Rotavators Ltd.
November 1971	J. D. Fryer	Netherlands to attend meeting of the European Weed Research Council.
November 1971	J. D. Fryer	Puerto Rico and Mexico for the US National Academy of Sciences and to attend the 1st Latin American Weed Society (ALAM) Conference at Mexico City. Sponsored by NAS and Plant Protection Ltd.
November 1971	G. W. Ivens	To Nigeria for two years to conduct a weed control project on behalf of ODA.
December 1971	P. J. Terry	To Tanzania for three years to conduct a herbicide research project at Tropical Pesticides Research Institute on behalf of ODA.

STAFF COMMITTEE SERVICE

Members of WRO have served on the following committees:

ADAS Experimental Husbandry Committee—Cereals Experiments: Minimum Cultivations Working Party
ADAS/WRO Liaison Group
Agricultural Chemical Approval Scheme Science Advisory Committee
ARC Technical Committee on Aquatic Weeds
ARC Technical Committee on Potato Problems
ARC Working Group on Tillage
British Crop Protection Council (BCPC)
- 6th, 7th and 8th Annual Review of Herbicide Usage
- Conference Organizing Committee
- Pesticides Application Committee
- Programme Committee (Weeds)
- Programme Policy Committee
- Recommendations Committee (Weeds)
- Sub-committee on Road Verges Symposium

British Standards Institution Technical Committee PCC/1
Consultative committee on weed science assisting FAO in compilation of manual on crop losses due to weeds
European Weed Research Council (EWRC)
- Evaluation Committee
- Education Committee
- Finance Committee
- Research Group on Annual Grass Weeds
- Research Group on Aquatic Weeds
- Symposium Programme Committee

Ministry of Agriculture, Fisheries & Food
- Pesticides Analysis Advisory Committee: GLC Panel
- Pesticides Analysis Advisory Committee: Compatibility Panel
- Research Group on Pesticides in the Aquatic Environment

Overseas Development Administration (ODA) PANS Policy Committee
Oxford Farming Conference Committee
Oxfordshire Youth Employment Committee
Rothamsted Statistics Department: Remote Access Users' Committee

JOINT RESEARCH PROJECTS OF THE ARC LETCOMBE LABORATORY AND THE WEED RESEARCH ORGANIZATION

To facilitate liaison on joint projects between the two institutes, other institutes and ADAS, responsibility for planning each project is vested in a Co-ordinating Committee while a Project Group is responsible for the execution of research.

JOINT CEREALS TILLAGE PROJECT

Co-ordinating Committee

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

Project Group

Leaders:	J. G. Elliott (*convenor*)	(WRO)
	R. A. Cannell	(Letcombe)
Members:	F. B. Ellis	(Letcombe)
	F. Pollard	(WRO)

JOINT HERBICIDE PROJECT

Co-ordinating Committee

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

Project Group

Leaders:	K. Holly (*convenor*)	(WRO)
	E. R. Mercer	(Letcombe)
Members:	J. Caseley	(WRO)
	R. J. Hance	(WRO)
	J. Holroyd	(WRO)
	M. G. T. Shone	(Letcombe)

Glossary of Herbicides Mentioned in this Report

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

aminotriazole*	3-amino-1,2,4-triazole
asulam*	*N*-(4-aminobenzenesulphonyl)methylcarbamate
atrazine*	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
barban*	4-chlorobut-2-ynyl *N*-(3-chlorophenyl)carbamate
benzoylprop-ethyl	ethyl 2-(*N*-benzoyl-3,4-dichloroanilino)propionate
bromacil*	5-bromo-6-methyl-3-(1-methyl-n-propyl)uracil
chlorfenprop-methyl*	methyl 2-chloro-3-(4-chlorophenyl)propionate
chlorflurecol*	2-chloro-9-hydroxyfluorene-9-carboxylic acid
chlorthiamid*	2,6-dichlorothiobenzamide
2,4-D*	2,4-dichlorophenoxyacetic acid
dalapon*	2,2-dichloropropionic acid
dicamba*	3,6-dichloro-2-methoxybenzoic acid
dichlobenil*	2,6-dichlorobenzonitrile
dichlorprop*	(±) 2-(2,4-dichlorophenoxy)propionic acid
diquat*	9,10-dihydro-8a, 10a-diazoniaphenanthrene-2*A*
diuron*	*N*'-(3,4-dichlorophenyl)-*NN*-dimethylurea
'Ethrel'	2-chloroethylphosphonic acid
fluorodifen*	4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether
lenacil*	3-cyclohexyl-6,7-dihydro-1*H*-cyclopentapyrimidine-2,4-(3*H*,5*H*)dione
linuron*	*N*'-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea
maleic hydrazide	
MCPA*	4-chloro-2-methylphenoxyacetic acid
MCPB*	4-(4-chloro-2-methylphenoxy)butyric acid
mecoprop*	(±) 2-(4-chloro-2-methylphenoxy)propionic acid
methabenzthiazuron*	*N*-(benzothiazol-2-yl)-*NN*'-dimethylurea
metoxuron	*N*'-(3-chloro-4-methoxyphenyl)-*NN*-dimethylurea
NC 8438	2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methylsulphonate
Orga 3045	sodium 2,2,3,3-tetrafluoro propionate
paraquat*	1,1'-dimethyl-4,4'-bipyridylium-2*A*
picloram*	4-amino-3,5,6-trichloropicolinic acid
pyrazone*	5-amino-4-chloro-2-phenylpyridazin-3(2*H*)-one
simazine*	2-chloro-4,6-bisethylamino-1,3,5-triazine
2,4,5-T*	2,4,5-trichlorophenoxyacetic acid
TCA	trichloroacetic acid
terbacil	5-chloro-6-methyl-3-t-butyluracil
tri-allate*	*S*-2,3,3-trichloroallyl *NN*-di-isopropyl(thiocarbamate)

PRINCIPLES GOVERNING ACCEPTANCE OF NEW HERBICIDES FOR EVALUATION BY THE WEED RESEARCH ORGANIZATION

The Weed Research Organization welcomes offers of new herbicides and growth regulators under development by the agricultural chemical industry for possible inclusion in its own research programmes. WRO is not, however, under any obligation to accept chemicals from other organizations or commercial firms for evaluation purposes.

Chemicals will only be accepted if the following conditions are agreed to (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 suppliers 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 suppliers must have carried out adequate preliminary tests that indicate the chemical has herbicidal or growth regulatory properties.

(d) There must be a reasonable prospect of the herbicide being developed commercially if promising uses are found.

(e) The suppliers must agree to comply with the terms of the British Pesticides Safety Precautions Scheme and to keep WRO fully informed of their action, where relevant.

(f) The suppliers must be agreeable to a two-way interchange of information between themselves and WRO during the period of development of the herbicide and to giving prior information concerning the nature of their future development programme.

Acceptance of a herbicide by WRO does not imply any obligation on the part of the Organization to carry out work on the herbicide or to report the results of any work that may be carried out.

WRO retains the right to publish the results of its work on publicly disclosed compounds without consulting the suppliers. 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 WRO will always try to be co-operative in relation to specific patent situations.

Any information given by WRO to the suppliers must not be reproduced in published documents without specific permission and in no circumstances must it be used in advertising.