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AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANIZATION

SEVENTH
REPORT
1976–1977

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Contents

Black-grass (*Alopecurus myosuroides*) is now a very common and competitive weed in cereal growing areas particularly in southern and eastern England but, according to a recent survey, less than 40% of the infested acreage is treated with black-grass herbicides. The volume of research on the biology and control of black-grass at WRO increased significantly in 1976–77.

DIRECTOR'S INTRODUCTION

Two particular events during the period covered by this report deserve special mention here on account of their potential impact on the development and the role of the Weed Research Organization (WRO). The first implied a major threat to the continuing existence of the institute. The second, which only took place after this threat had been removed, was the very welcome decision of the Agricultural Research Council to enlarge the scope of the institute's research capability to include plant physiology and biochemistry at the strategic level.

THE OXFORDSHIRE STRUCTURE PLAN

The threat was revealed by the publication of the First Structure Plan for Oxfordshire in September 1976. In this document two strategies for the future development of the County were described, one proposing an expansion of the County Towns, the other the growth of the City of Oxford and the adjacent towns of Kidlington and Abingdon. It was stated in the report that implementation of this second strategy would be dependent on the allocation for urban development of the whole of the 297-acre Begbroke Hill Farm on which WRO is based. Between publication of the document and the Examination in Public held at the Town Hall in Oxford during May and June 1977 much effort was made to inform those organizations and individuals most closely involved about the role and importance of WRO and the serious consequences of any decision that prevented effective use of the institute's land for research. The local and national press and radio were most co-operative and gave helpful publicity to our cause. Several organizations offered to provide written evidence in support of WRO and many others asked what they could do to help. It was with relief that we learnt at the Examination that there was no longer any support for a plan that would interfere with the work of WRO. It was most encouraging to learn of the widespread recognition that had now become apparent of the important role of the institute in advancing agriculture in the UK and overseas. I should like to take this opportunity to record my grateful thanks to all who supported WRO during this worrying time.

RESEARCH CAPABILITY INCREASED

Once this threat had receded the Agricultural Research Council took the very welcome decision to transfer to WRO three members of the ARC

Unit of Developmental Botany (UDB) at Cambridge and one from the Unit of Systemic Fungicides (USF) at Wye. Both units were due to close on retirement of their directors.

On 1 October 1977 Dr Daphne Osborne, Deputy Director of UDB, Dr J A Sargent and Dr M Wright joined the staff of WRO whilst remaining at the Huntingdon Road Laboratories previously occupied by the Unit. As soon as suitable accommodation is available they will transfer to Begbroke to form the WRO Developmental Botany Group. The experience and expertise of the new group will introduce a new dimension into WRO research and offers exciting possibilities for the development of novel and more efficient methods of weed control through a detailed understanding of the mechanisms determining the behaviour of weed seeds and perennating organs of perennial weeds. Emphasis in the first place is being given to seeds of wild oats and other important grass weeds and to potato groundkeepers. The four projects are listed on p. 105.

On 1 August 1978 Dr H F Taylor of USF, Wye will be joining WRO as a member of the Herbicide Group. He will greatly strengthen the group's programme of research aimed at improving the performance of herbicides. Dr Taylor will be investigating the biochemical and physiological mechanisms responsible for the interaction between certain herbicides when used in mixture or sequentially. Uncertainty about possibilities of crop damage or ineffective weed control when programmes of herbicide treatments are used for a single crop has become a major problem in recent years and is urgently in need of clarification.

Expanded research role recognised

This action by ARC can be seen as an expression of the Council's recognition that strategic research on the physiology and biochemistry of weed behaviour and of herbicide action have an important role to play both in the development of practical weed control measures and in the organization of research at WRO. This a major step forward in the development of the institute which, when these moves have been completed, will have achieved a research capability embracing a well-balanced range of relevant expertise for applied and strategic research.

These developments, together with the welcome transfer in 1977 of D Williams from the Botany Department of Rothamsted Experimental Station to the Botany Group of WRO have made the provision of further laboratory accommodation an urgent necessity. The plan is to have a series of temporary laboratories erected at Begbroke by autumn 1978 to accommodate the new staff and help relieve the worst of the pressures that we have been living with for some time. An extension to the existing range of laboratories is being planned and it is hoped that construction of these will be completed within two or three years.

PLANNING AND CO-ORDINATION OF RESEARCH

The research programme of WRO is divided into 45 main projects of which 31 (68%) are commissioned by the Ministry of Agriculture (MAFF). These account for 56% of the total expenditure of the institute. The remainder are financed by ARC from funds coming from the Department of Education and Science (DES). Much of the research undertaken by the institute is thus under the control of the MAFF operating through the Ministry's Chief Scientist's Group (CSG). Nevertheless, within the agreed programme of research there is a great deal of flexibility concerning what experimentation is actually done. In the more applied fields there is a constant need to review our own work in relation to developments in practical agriculture and as new information becomes available from scientific sources. There is a need also for WRO staff to contribute to the deliberations of the CSG and the Joint Consultative Organization (JCO) to assist these bodies in their reviews of research needs and priorities. To improve the co-ordination and planning of research within WRO and to provide a machinery to link up with the JCO Committees, a Research Strategy Committee (RSC) was established within the institute in 1976 under the chairmanship of the Director. The Committee, whose membership is based on department heads, meets every two months to review in discussion with appropriate colleagues areas of research pertinent to WRO, particularly those of a multidisciplinary nature involving several research groups and/or other organizations. The Committee is supported by a series of tactical planning groups whose purpose is to enhance co-ordination and co-operation between research teams in the institute and to advise RSC on possible changes needed in the programmes as a result of recent developments or recommendations emanating from JCO or elsewhere. The first two years' operation of this scheme have demonstrated its value and we feel that the modest amount of time spent on operating it is well justified.

SCIENTIFIC ADVISORY GROUP

As noted in the last report a group to advise the Director on the institute's programme was set up by the ARC in 1975 with the following membership: Professor A H Bunting, Reading University (Chairman); Prof. J T Braunholtz, ICI Plant Protection Division; Prof. R N Curnow, Reading

University; Prof. R W Edwards, University of Wales, Institute of Science and Technology, Cardiff; Prof. J P Hudson; Mr J G Jenkins; Prof. F T Last, Institute of Terrestial Ecology, Midlothian; Mr J J North, Agricultural Development and Advisory Service; Prof. W D P Stewart, University of Dundee. The group has met formally twice (March 1976 and May 1977) and most of its members in addition have visited the institute individually on a number of occasions to confer with staff members having a common interest. The advice and support given by the group both collectively and individually has been of considerable value and much appreciated by the members of WRO involved.

INTEGRATED CONTROL OF WEEDS

Traditionally weed control has been one of the largest inputs into arable agriculture involving rotation, deep soil cultivation and hoeing. With the advent of herbicides, farmers have been free to adopt novel and much more efficient crop production practices. The combination of these and routine herbicide use has led to new problems of weed control and to an agricultural industry that has become highly dependent on a continuing supply of cost-effective products from manufacturers who are increasingly constrained by regulatory and economic pressures. The cost of developing a single new herbicide is now of the order of £10 million.

Although many weeds have declined in importance others have been favoured, often requiring more sophisticated and expensive programmes of herbicide usage. A good example is intensive cereal production where wild-oats, black-grass and other grass weeds have largely replaced the traditional dicotyledonous weed flora despite regular use of herbicides specially developed for their control. The cost of a herbicide programme for winter wheat can exceed £40/ha.

The limited effectiveness and great expense of routine herbicide use has been a major stimulus to the WRO programme in recent years. A great deal of progress has been made in demonstrating the value of combining cultural and chemical methods and of adopting long-term, rational systems for the control of such intractable weeds. This approach depends on a detailed knowledge of the behaviour of weeds and of the way they respond to farm practices and environmental conditions; also on a better understanding of how herbicides work. These are both strong features of the present programme. We now have sufficient information about both couch grass and wild-oats in intensive cereal production to be able to formulate integrated control strategies employing optimal and sometimes reduced use of herbicides. This programme has been an all-institute one involving many disciplines and research teams. Extensive collaboration has taken place between WRO, ADAS, the Scottish colleges and the agrochemical industry. The information and experience now available have formed the basis for the very successful National Wild Oat Advisory Programme sponsored by MAFF, ARC, the British Crop Protection Council (BCPC) and industry. A result of this has been that many farmers have begun to reconsider the desirability of routine annual spraying. In its place they are adopting a field by field or an all-farm strategy for long-term wild-oat control based on the detailed information and guidance that we and others have been able to provide.

An important new problem is that wild-oats are now often accompanied by black-grass, a weed that has increased rapidly in recent years. Other grass weeds such as rough meadow-grass, sterile brome and volunteer ryegrass are also coming to the fore in cereals, each demanding intensive study and additions or modifications to existing weed control programmes. We believe that the present emphasis at WRO on an integrated approach to these and other major weed problems offers the best chance of providing farmers with maximum flexibility in cropping practices that are suited to their land and to their managerial and economic policies. One cannot expect such work to be undertaken by the agrochemical industry.

Whilst WRO is concentrating on the development of integrated weed control methods it is becoming increasingly evident that this concept needs to be extended to include crop protection as a whole. With the rapidly expanding use of insecticides, fungicides and herbicides in the same crop, in the same season and sometimes in the same sprayer tank, there is a growing realization that interactions which occur between these chemicals and between weeds, pests and diseases cannot be ignored.

WEED CONTROL IN FORESTRY

Although this topic is outside the formal terms of reference of WRO there have been close links with the Forestry Commission stemming from the early days of the ARC Unit of Experimental Agronomy (the forerunner of WRO) in Oxford. To formalise this liaison and to allow more effective advice to be given by WRO an arrangement was agreed in 1976 between the ARC and the Forestry Commission whereby the latter provides funds for additional research assistance in the Herbicide Group to extend the herbicide evaluation programme to include a range of tree species and forest weeds. This scheme, which was initially for a period of three years, has proved very successful and the Forestry Commission has proposed continuation of such an arrangement for a much longer period.

VISIT OF THE SECRETARY OF STATE FOR EDUCATION AND SCIENCE

It was a pleasure to receive an informal visit to WRO from the Hon Fred Mulley and his wife in August 1976. A tour of the institute was made and Mr Mulley expressed much interest in the work in progress and its relevance to the problems of the amateur gardener.

ACKNOWLEDGEMENTS

It is my pleasure to acknowledge the continuing support and dedication of my colleagues on whom the success of WRO so heavily depends. The breadth of the programme which covers so much of British agriculture, and also has a major role overseas, is such as to dictate a high level of devolution of responsibility from the Director onto department heads and group and team leaders. Without exception all have made a splendid contribution to the institute and to the agricultural industry for whom we work.

That their efforts are only possible when backed by an efficient and helpful administration goes without question. Members of the administration department led by the Secretary have done an outstanding job in coping with the ever increasing amount of paper work whilst maintaining the vitally important and all too rare attitude that 'our job is to help the research to get done'. The same applies to the farm staff whose prime function is to provide land suitable for experimental work but who in reality are expected to operate the farm as a commercially viable unit. Remarkably, they manage to do both jobs very well indeed.

I should like to take this opportunity to express my appreciation for the generous support given to WRO by the Agricultural Research Council and for the interest shown in our activities by many other organizations and people outside the institute with whom we are associated. The range of contacts and the extent of collaborative work are amongst the strengths of WRO and my colleagues and I are deeply grateful for all the help and encouragement we receive.

It is a pleasure also to thank those many members of ARC Headquarters who have helped and guided my colleagues and myself during the past two years. Finally, I should like to thank the many colleagues who have contributed to this report and particularly John Hardcastle, Head of the Information Department at WRO, who has compiled and edited it.

J D FRYER
Director

PROGRESS REPORT

REVIEW OF RESEARCH

ANNUAL GRASS WEEDS

The national survey of wild-oat and other grass weeds conducted in 1976/77 under the aegis of the National Wild Oat Advisory Programme (as described on p. 34) revealed that the percentage of cereal fields in England infested with wild-oats was little changed from the 67% recorded 5 years before, though there is reason to believe that the average level of infestation is now lower than it was. It also revealed the encouraging information that the percentage of infested cereal fields in England sprayed with wild-oat herbicides had trebled to 45% in the same period. This indicates the growing awareness of the seriousness of the wild-oat problem amongst cereal farmers today; it encourages the belief that the proven control options now available will make a more significant impact as they become more widely adopted.

For this reason and because of the extensive information now available on wild-oats, the focus of research at WRO has turned towards another serious weed of cereals—black-grass. However, the experience gained with the wild-oat programme has indicated the most profitable research approaches to the somewhat similar problem posed by black-grass. Many of these have been initiated in the last two years by the Annual Crops Group and pursued jointly or in parallel with continuing research on wild-oats as described here.

Effect of cultivations on black-grass infestations

Experiments have shown that black-grass (*Alopecurus myosuroides*) tends to become a more serious weed of winter wheat when systems of reduced cultivation and direct drilling replace ploughing. One reason for this is that most black-grass seedlings emerge from seed in the top 2.5 cm soil. Thus, seeds shed onto the soil surface prior to direct drilling are ideally placed to give rise to seedlings, whereas ploughing buries seeds to a depth from which emergence is unlikely, although some old viable seed may also be brought up to the surface.

Another possible reason for this problem may be that soil-acting herbicides are sometimes less effective under a reduced cultivation regime. In one experiment, the activity of chlortoluron* and isoproturon

*British Standards Institute common names for herbicides are used throughout this report. The corresponding full chemical name of each compound is given in the glossary at p. 125.

applied pre-emergence to winter wheat varied considerably with both the method of cultivation and straw disposal used. Excellent results were obtained on ploughed land irrespective of how the straw was removed but, after tine-cultivation, poorer control was achieved when the straw was baled than when it was burnt. Poor control was achieved after direct drilling regardless of the system of straw disposal. However, isoproturon applied post-emergence gave excellent control after both traditional and reduced cultivations, and both straw disposal systems.

Straw burning alone can reduce a black-grass infestation by over a half but it is unlikely to prevent a build-up of the weed if no other control measures are taken.

There will always be complex interactions between the control measures taken and subsequent cultivations. This is because the herbicide used in any one year only affects one generation of seeds. Older seeds may be present throughout the soil profile depending on the past history of the land. Mould-board ploughing redistributes these seeds, albeit slowly. Minimum tillage and especially direct drilling leave the lower soil layers undisturbed so that buried seed may possibly survive to create a problem if the land is eventually ploughed. Currently, therefore, we are trying to determine what factors are involved in the survival of black-grass seeds in the soil under different cultivation systems.

Control of mixed infestations of black-grass and wild-oats

In recent years there has been an increase in the acreage of winter wheat infested with both black-grass and wild-oats. The advantage of early control of these mixed infestations has been demonstrated, even in winter wheat crops which were well established before the winter. Control of both species in the autumn gave the largest increases in yield, larger than when only one species was controlled. Delaying control measures until April or May reduced the yield response by one third to one half, but still gave large increases over the unsprayed crop. There were indications that black-grass mostly affected tiller production in the early stages of crop growth, while competition from wild-oats was, in a wet summer, sustained over a longer period, affecting tillering, number of grains per ear, and individual grain weight.

The importance of crop competition in minimizing the effects of these two weeds was demonstrated when greater tillering of the weeds and larger yield responses to their control occurred in a late sown, thinner crop (210 seedlings/m^2) than in an early sown, vigorous crop (350 seedlings/m^2).

Tank-mixtures of black-grass and wild-oat herbicides

Although there is an increasing occurrence of mixed infestations of black-grass and wild-oats in winter cereals, few of the currently available herbicides give reliable control of both weeds. An experimental programme was therefore started at WRO in 1976 to assess the performance of 'tank-mixtures' of wild-oat and black-grass herbicides. This showed that the activity of the commercial formulation of the black-grass herbicide isoproturon against wild-oats could be improved if it was applied as a mixture with the commercial formulation of either difenzoquat or diclofop-methyl. Excellent control of both weeds was obtained when 2.0 kg/ha isoproturon was mixed with 0.5 kg/ha difenzoquat. Mixtures of proprietary products containing diclofop-methyl and clofop-isopropyl also gave acceptable levels of control of both weeds. This work led to the development of the current commercial recommendation for the 'tank-mix' of difenzoquat with one of the proprietary formulations of isoproturon.

Yield response to sequential use of wild-oat herbicides

Control of wild-oats early in the life of winter cereals has already been shown to give the largest yield response because it is those wild-oats which emerge with or soon after the crop which are subsequently the most competitive. However, after treatment, wild-oats may continue to emerge during the late winter and spring, so that early control, necessary to safeguard yields, may not be accompanied by an effective reduction in the numbers of wild-oats. Sequences of two treatments, with the object of combining the yield advantage from early removal with the reduction in wild-oat population achieved by a follow-up treatment in the spring, have been investigated.

A promising sequence has been found to be barban in the autumn followed by benzoylprop-ethyl in the spring. Applied in sequence, half the recommended dose of each herbicide gave better wild-oat control and crop yield response than either applied alone at the full dose. Difenzoquat applied in two half-doses in sequence has also generally given improved wild-oat control and crop yields compared with a single application at the recommended dose. The advantage of a sequential treatment was less apparent in a very dry summer like 1976 when late seedlings suffered from competition for moisture and were severely suppressed by the crop.

Cultivations and the decline of wild-oat populations

In the autumn of 1974 wild-oat seeds were sown on land at WRO free from this weed. The land has since been cropped annually with spring barley, no further seeding has been allowed, and the annual decline in the population of wild-oats has been monitored.

Depth of seed burial has had a marked effect on seedling populations. Although similar numbers of seeds were originally present in the soil, tine cultivation in the winter of 1974 resulted in more than four times as many seedlings the following spring as did ploughing. But, re-ploughing a year later brought up many dormant seeds and resulted in more seedlings in 1976 than did tine cultivation.

The effect of direct drilling was shown to depend on the initial distribution of seeds in the soil. Seedling populations were similar to those occurring after tine cultivation where seeds had originally been incorporated to shallow depth, but remained very low where seeds had been buried deeply by ploughing in 1974. This suggests that, once seeds have been depleted from the surface soil, annual direct drilling can maintain low populations, even though a large reserve of seeds remains buried at depth.

During 1977, the populations of seeds in the soil continued to decline, including those originally buried deeply by ploughing and subsequently undisturbed by direct drilling. The initial population of 978 viable seeds/m^2 in 1974 had, by August 1977, declined to 0.5/m^2 with annual tine cultivation, 12/m^2 with ploughing, and with direct drilling 2/m^2 and 17/m^2 respectively where the seeds were initially placed shallow and deep.

PERENNIAL GRASS WEEDS IN CEREALS

Onion couch

Previous work at WRO on the growth of onion couch (*Arrhenatherum elatius* var. *bulbosum*) has shown that the proliferation of this perennial grass weed of arable land is favoured by minimum tillage and, in particular, by direct drilling. In these circumstances, control of onion couch may be wholly dependent on the use of foliage-applied herbicides and, since ADAS colleagues had suggested that control achieved was sometimes poor, we examined the response of this weed to a number of these herbicides. Glyphosate, dalapon and aminotriazole were applied to autumn regrowth of onion couch in cereal stubble, after the straw of the previous crop had been removed either by baling or burning. Control with glyphosate was excellent and the burning of the straw did not appear to affect this herbicide's performance. Both dalapon and amino-triazole were less effective than glyphosate, particularly when applied after the straw had been burnt. However, onion couch is slower than common couch to regrow after cereal harvest and it appears likely that, in a mixed population, poor control could occur if the timing of the glyphosate application was based only on the degree of regrowth of common couch.

BROADLEAVED WEEDS IN CEREALS

The identification and development of a simple and reliable indicator which any farmer can use to determine the correct time to apply broad-leaved weed herbicides in winter wheat, is described in the article on p. 44. This research programme occupied one scientist and his assistant in the Annual Crops Group four years. An even longer Botany Group programme, which to date has lasted 15 years, is now revealing how cropping practices and chemical control measures may affect the components of a typical arable weed flora.

Long term studies of changes in weed populations

Since 1960, when the WRO was established at Begbroke Hill Farm, the weeds in the arable fields have been systematically assessed by the Botany Group for experimental and management purposes. The data, which now go back over some fifteen years, not only show how the composition and density of the weed flora have changed with changes in management, but also reveal some of the behavioural characteristics of the species present.

Details of the weed changes consequent upon several years' herbicide use in two adjacent fields were published in 1976. These fields, Wrenches and Upper Begbroke Ground, were very similar in the original composition of their weed floras and although they have frequently differed in their cropping since 1960 (see Tables 1 and 2) the changes in the weed populations have on the whole been quite similar. The most frequent weed in both fields in 1960 was corn marigold (*Chrysanthemum segetum*), which, as a result of a succession of herbicide treatments (Tables 1 and 2), was reduced in Wrenches field from 140 seedlings/m^2 to 1/m^2 over eleven years. In Upper Begbroke Ground the reduction was from 186/m^2 to only 1/10m^2 over fifteen years. Reductions of wild radish (*Raphanus raphanistrum*) closely paralleled this result with a 93% reduction in

Table 1 Details of field management in Wrenches

Crop	Planting date	Herbicides used
Spring barley under sown with grass	March 1962	dinoseb
Grass	March 1963	
Fallowed to control *Agropyron repens*	March 1964	
Winter wheat	Oct 1964	
Expts drilled round with spring barley	March 1966	
Spring barley	March 1967	mecoprop
Expts drilled round with spring barley	March 1968	dinoseb
Spring barley	March 1969	dinoseb/MCPA
Spring barley	March 1970	dinoseb/MCPA/mecoprop
Winter oats	Sept. 1970	mecoprop
Potatoes	April 1972	paraquat/linuron
Fallowed to control potatoes	April 1973	

Table 2 Details of field management in Upper Begbroke Ground

Crop	Planting date	Herbicides used
Spring barley under-sown with grass	March 1961	dinoseb
Grass	March 1962	
Grass	March 1963	
Winter wheat	Autumn 1963	mecoprop
Expts drilled round with oats and vetches for silage	March 1965	
Spring barley	March 1966	dinoseb & MCPA
Spring barley	March 1967	dinoseb & mecoprop
Spring barley	April 1968	mecoprop
Spring barley	April 1969	mecoprop
Winter oats	Oct. 1969	mecoprop
Potatoes	April 1971	paraquat
Winter wheat	Nov. 1971	
Expts drilled round with spring barley	March 1973	dicamba, mecoprop & MCPA
Spring barley	March 1974	bromoxynil, ioxynil & dichlorprop
Expts drilled round with spring barley	April 1975	bromoxynil, ioxynil & dichlorprop
Spring barley	Feb. 1976	

Wrenches and a 99.7% reduction in Upper Begbroke Ground. Other species that were reduced in both fields were chickweed (*Stellaria media*), black-bindweed (*Polygonum convolvulus*) and field pansy (*Viola arvensis*). The overall reduction in weed density in Upper Begbroke Ground was from 404 to 215 seedlings/m², a 47% reduction, and in Wrenches from 279 to 137/m², a reduction of 51%.

However, not all weeds were reduced. Fool's parsley (*Aethusa cynapium*) and henbit dead-nettle (*Lamium amplexicaule*) maintained their densities in both fields over the eleven or fifteen year period, although there was some fluctuation up or down during the intermediate years.

A few species managed to increase in numbers despite the frequent use of herbicides. In both fields the main increases were by knotgrass (*Polygonum aviculare*), shepherd's purse (*Capsella bursa-pastoris*) and annual meadow-grass (*Poa annua*). Knotgrass increased in Upper Begbroke Ground from 8/m² to 143/m² over fifteen years and in Wrenches from 5/m² to 15/m² in eleven years. It is suggested that these increases, in Upper Begbroke Ground at least, are due in part to the preponderance of spring cereals, which would have encouraged this weed which germinates only in spring. Furthermore, its early emergence would have allowed it to become resistant to dinoseb by the time that that herbicide was applied (Tables 1 and 2). It is resistant at all stages to mecoprop, another herbicide frequently applied during the period. Consequently it was able to increase in density. However, shepherd's purse is not resistant to these herbicides. The only explanations for its increase in both fields are, either that it germinates and seeds in late summer and autumn after the crop has been harvested, or that it has been re-introduced as a contaminant of crop seed.

The study of changes in weed populations can thus provide guidance on what weed problems are likely to arise or diminish as a result of changes in herbicide usage or other aspects of management. The results obtained so far certainly illustrate the need to practise the rotation of herbicides, particularly if crop rotation itself is not possible.

REDUCED CULTIVATION AND CEREALS

The last in the present series of annual progress reports on the WRO/Letcombe Joint Tillage Project, published alternately in the reports of the two institutes, appears on p. 55. The experience gained by the Annual Crops Group in 10 years research into the application of minimum tillage to cereal production has led to a serious questioning of the agricultural engineers' current approach to crop production. An alternative strategy, based on low power, light weight vehicles, is discussed in the article on p. 57.

The burning of straw to leave a clean surface for direct drilling, particularly of winter cereals, is a practice which, in careless hands, can earn criticism for aerial pollution if not condemnation as a fire hazard. The alternatives to burning straw have therefore been investigated at WRO for three years and the conclusions are summarised here.

Straw and direct drilling

Straw residues can have a deleterious effect on the establishment of a subsequent direct drilled winter wheat crop. Experiments to examine some of the causes of this have shown that the mechanical problems of inserting seed into the soil may be responsible for many of the crop failures which occur. When triple-disc drilling took place through spread straw, seed was not always planted properly. Apart from blockages of the whole drill or of individual coulters which caused uneven seed distribution, soil penetration was very variable and seeds were not planted at a consistent depth, occasionally even being left on the surface. Frequently, seed was found to be planted in a 'cradle' of straw and was not in contact with the mineral soil. Reductions in grain yield of up to 59% occurred after drilling through spread straw when compared to drilling into burnt stubbles. However, when the straw was removed by raking prior to the drilling operation and then replaced afterwards, no loss of yield occurred.

Observations on the decay of straw over three winter periods indicated that, by the time for planting spring barley, a large proportion of the original dry matter had decomposed and much of the remainder had disintegrated. Crops direct drilled through these decomposed residues suffered no deleterious effects and yielded well provided the straw was distributed uniformly after harvest.

WEED CONTROL IN GRASSLAND

The biology and selective control of problem weeds—or alleged weeds—of sown and permanent grassland, and new methods of renovating old pasture and maintaining it with the aid of herbicides continue to claim equal attention from the Grass and Fodder Crops Group.

Establishing weed-free leys

Research is showing that one key to establishing a productive and lasting improved sward is the control of weeds during the first few weeks after sowing. Tillering of young rye-grass plants is reduced by the major invading species, annual meadow-grass (*Poa annua*) and chickweed (*Stellaria media*). For example, in a competition experiment, meadow-grass seedlings germinating at the same time as rye-grass and left unweeded for six weeks reduced the tillering of the sown grass by up to 30%. Also, the effects of the age and size of the weed grass were cumulative so that plants that were already six weeks old when the rye-grass was sown caused an 80% reduction in tillering when allowed to compete with the rye-grass for six weeks after sowing.

Fortunately, these contaminants can now be controlled by two selective herbicides, ethofumesate and methabenzthiazuron. Research has shown that a single dose of either of these two herbicides at 1.6 kg/ha can virtually eliminate chickweed while, at the same time, reducing the number of tillers of meadow-grass by about 80%.

Improvement of grass weed control in rye-grass seed crops

Grass weeds pose a threat to herbage seed production, because of seed losses resulting from competition in the field, seed cleaning and failure to achieve a certifiable standard of purity. In collaboration with ADAS and seed growers, WRO has been looking at methods of improving the control of the major weeds including rough meadow-grass (*Poa trivialis*), black-grass (*Alopecurus myosuroides*), and volunteer cereals in rye-grass.

For the control of rough meadow-grass, dalapon applied at low doses in April has proved effective although results have been variable, particularly with respect to crop tolerance. Further investigations are required on the influence of soil type, climate and varietal susceptibility before any firm recommendations can be made.

Ethofumesate has given the most dependable control of black-grass as well as certain other grass weeds, although a reduction in its effectiveness during adverse weather conditions also suggests further work is necessary.

Excellent control of volunteer cereals has been achieved in WRO and ADAS experiments by the application of TCA at doses up to 10 kg/ha. There are indications that some control of black-grass may also be possible with TCA.

Development of one-pass seeding

Rapid progress has been made with the development of the WRO one-pass seeding technique since it was described in the WRO Sixth Report. Using the WRO prototype drill, rye-grasses and clovers have been successfully introduced into a wide variety of permanent sward types varying from hill pastures through downland swards to lowland meadows, all with minimal interruption to grazing management or damage to the

An area of Somerset hill pasture soon after renovation with a one-pass seeder based upon the original WRO design. The technique has been extensively tested in the last two years.

original sward. Italian rye-grass introduced in September 1976 into a permanent grass sward at Begbroke gave a yield increase of 20% in total grass growth the following year, measured under grazing conditions—with most of the increase occurring in the early spring.

In 1977 Messrs Gibbs of Bedfont produced seven prototype one-pass seeding drills which were widely tested by WRO, ADAS and contractors. Results were mixed but encouraging; the bandspray always gave good suppression of the old sward, but the coulter system did not always cut out the slot cleanly. Where there was a good slot there was usually good establishment. In 1978 a further six prototype machines produced by Gibbs to an improved specification are expected to be tested; four of these prototypes have been commissioned by Monsanto (UK) Ltd.

The productivity of indigenous grasses

A three-year study on the agro-ecology of Yorkshire fog (*Holcus lanatus*) demonstrated how this species, commonly assumed to be a weed, can be controlled when it occurs in perennial rye-grass swards. Factors which selectively discourage Yorkshire fog in swards include treading by cattle, close cutting in early June and the use of herbicides like asulam and linuron. But the major question raised by this study is: in what situations should this highly productive species be controlled and when should it be regarded as a desirable plant?

The productivity of an indigenous grass sward has also been studied at Begbroke Hill. The results of a 9-year grazing experiment, involving 416 beef animals, showed that animal output from this well managed and fertilized permanent pasture was as good as that achieved by the top one-third of beef producers from leys, as recorded by the Meat and Livestock Commission. Indeed, the outputs from this sward which consisted of red fescue, bent grass, rough meadow-grass and Yorkshire fog agreed closely with the outputs expected from perennial rye-grass at the nitrogen levels used (150–200 kg/ha p.a.).

Thus, it seems that the large area of permanent pasture in Britain, much neglected by research workers to date, might merit more attention from farmers.

WEEDS IN PERENNIAL CROPS

Soil-applied herbicides have been widely used in fruit crops for many years. At one time fears were expressed that residues would accumulate and cause damage to crops. This has not happened in practice and further re-assuring evidence is presented in the review article on page 70. More effective herbicides are still needed for perennial crops, particularly for strawberries, but development is being inhibited by shortcomings in existing techniques of field testing. Improved methods are under investigation at WRO. Many nurserymen are reluctant to use herbicides in young trees and shrubs for fear of damaging them. Recent experiments at WRO have shown the importance of controlling weeds early in the life of these crops.

New herbicides for strawberries

Cheaper and more effective weed control in this crop is now possible with the soil-applied mixture of trietazine and simazine and the foliage-applied phenmedipham. Experiments by WRO, in collaboration with other ARC organizations and research centres in Ireland, have helped to define the circumstances in which these herbicides can be used safely.

Ethofumesate, metamitron, propachlor, oxadiazon and pendimethalin can also solve many of the outstanding problems in strawberry weed control. The first four are already marketed for other crops, and the fifth will probably be marketed for cereals. None of them has yet been cleared by the Pesticides Safety Precaution Scheme for use in strawberries but we have collaborated with the agrochemical industry by providing samples of fruit for residue analysis, with a view to obtaining their clearance.

Pendimethalin is the most promising. It gives residual control of annual weeds under dry conditions without incorporation, a practical advantage not shared by trifluralin, an otherwise similar herbicide. It is envisaged that pendimethalin will be used in mixtures with propachlor, already widely used in conjunction with trifluralin for weed control in vegetables. Propachlor could also be used with lenacil to control otherwise resistant weeds.

Metamitron and ethofumesate are two sugar beet herbicides giving pre- and post-emergence control of annual weeds. The latter has proved particularly promising for strawberries because the mixture with phenmedipham controls all the most important annual weeds including annual meadow-grass, cleavers and mayweeds. Oxadiazon is of interest because it can be used for the pre-emergence control of field bindweed. Even though it has reduced the yield of fruit it is still worth pursuing as a 'spot treatment' because there is no safer alternative.

These herbicides were originally selected for field testing after their safety to strawberries had been demonstrated in pot tests, using the sand-culture technique outlined in the Fifth Report. It is hoped that, with further experience, it will prove possible to reduce the amount of field testing needed to establish the tolerance of soil-applied herbicides by strawberries and other perennial crops. This should benefit growers because, if a simple and cheap test of crop tolerance of new herbicides is available, the agrochemical industry itself is more likely to develop treatments for these small acreage crops.

Weed control in trees and shrubs

Many nurserymen are reluctant to use herbicides in young trees and shrubs because of reported damage. But it is difficult to maintain a high standard of weed control without them. This dilemma prompted an investigation into the effect of weeds on the growth, and hence market value, of nursery stock. This information has been used to define the requirements for herbicides in these crops.

Crops that should be worth £10,000 to £25,000 per hectare after two years in the nursery were reduced in value by as much as 85% when weeds were not controlled in the year of planting. Five species were chosen for trial on the basis of a diverse habit of growth. The value of four, *Acer platanoides* (Norway maple), *Chamaecyparis lawsoniana* (Lawsons cypress), *Philadelphus virginalis* (mock orange) and *Potentilla fruticosa* 'Primrose Beauty' (shrubby cinquefoil) was reduced by 30 to 50%. *Prunus laurocerasus* 'Zabeliana' (laurel) was much more sensitive, being reduced by 85%. These are, of course, extreme results because there is usually some weed control in the year of planting, but they do emphasise the importance of weed control.

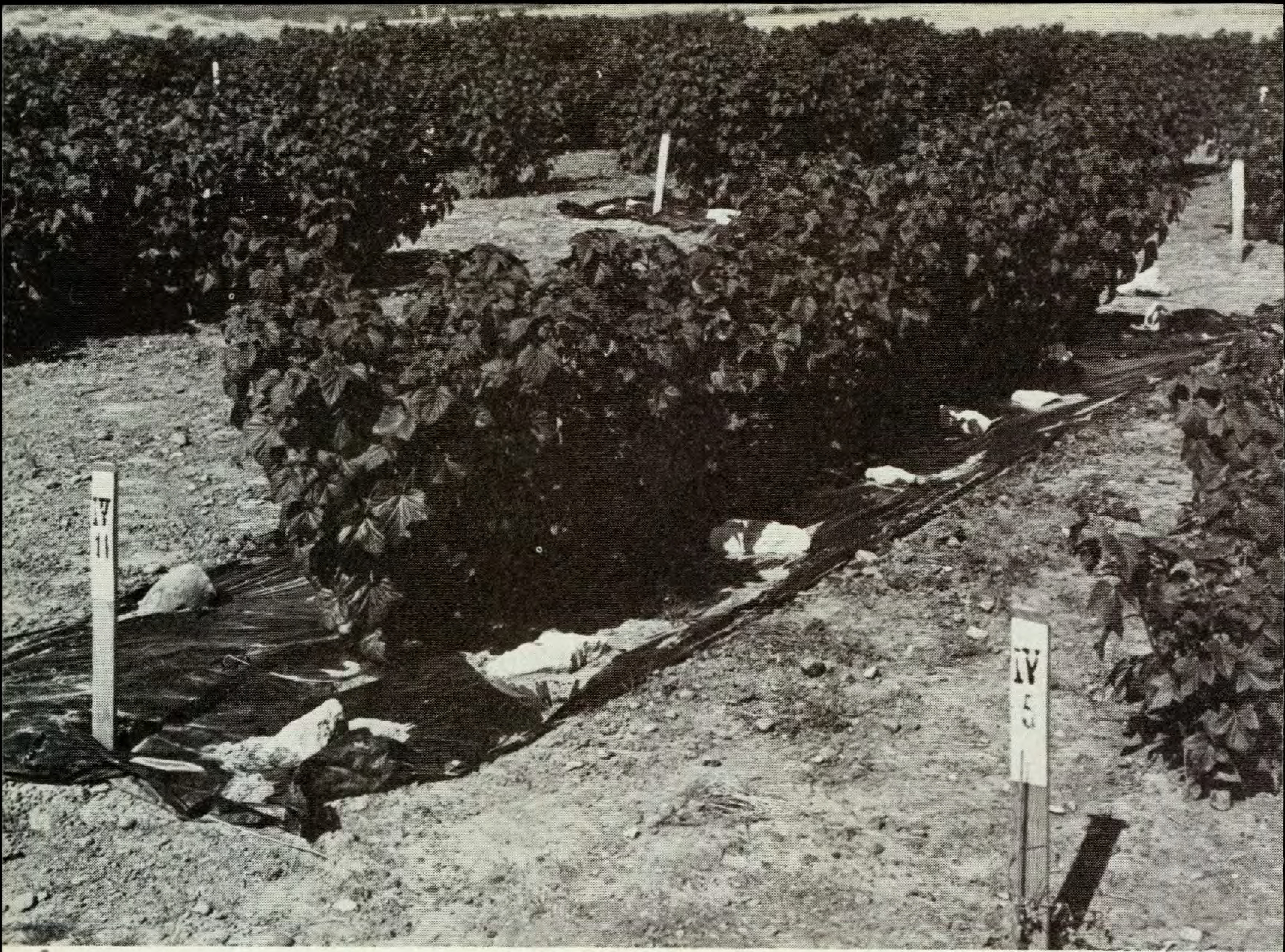
Weeds in May and June had the most serious effect on crop growth, but weeds at other times were also important. For instance, seedling weeds that were allowed to grow unchecked until mid-May in the year of planting had relatively little effect on growth as recorded at the end of the first season, but there was a reduction in value of between £1,200 and £5,200 per hectare when the crops were graded for selling at the end of the second season during which complete weed control was practised.

If annual weeds can be controlled for six to ten weeks after planting this may be long enough to overcome their main competitive effect in the first season. This could be achieved using some of the less persistent, soil-applied herbicides such as chloroxuron, lenacil and propachlor; these are generally safer on perennial crops than simazine which gives longer weed control.

Black polythene can be used as alternative to herbicides. In experiments at WRO the above species were worth up to £3,700 per hectare more when they were mulched with polythene sheet than when they were carefully hand-weeded. Black polythene has also given promising results in blackcurrants at WRO, and in apples in a series of trials on different soils in the main apple growing areas. The existing equipment for laying polythene is only suitable for hardwood cuttings and crops that are cut to ground level after planting. A new design of equipment would enable the technique to be extended to rooted cuttings and trees.

HERBICIDE RESEARCH

The recent change in emphasis in the Herbicide Group's programme, away from herbicide evaluation *per se* and towards research aimed at improving the performance and safe use of herbicides, was reflected in



Mulching blackcurrants with black polythene sheeting gave substantial increases in growth when compared with hand weeded plots.

the two years' achievements. The continued research on, and development of, controlled drop application in collaboration with the Annual Crops Group, ADAS, and industry is described in the article on p. 49, while research into the effects of climatic factors on herbicide performance is reported here.

Despite the reduction in the number of new chemicals reaching the market, which contributed to the change in emphasis mentioned above, the application of WRO expertise in the evaluation of herbicides still plays a vital role in the research programme. The activities of the Herbicide Group in promoting the maximum exploitation of new compounds, in evaluating the effect on selectivity of mixing herbicides, and in improving our understanding of the mechanisms of selectivity of soil-acting herbicides are described below. A full account of the rewarding re-evaluation of old and new chemicals for their potential use in forestry is described in the article on p. 77.

The Chemistry Group's continued pursuit of a clearer understanding of the inter-relating factors determining herbicide movement, persistence and degradation in the soil is reported here; it is matched by the concern of the Microbiology Group, elaborated on p. 95, that too simplistic a view of herbicide effects on microbial activities may be adopted by the regulatory authorities in Europe and North America.

The effect of environment on herbicide performance

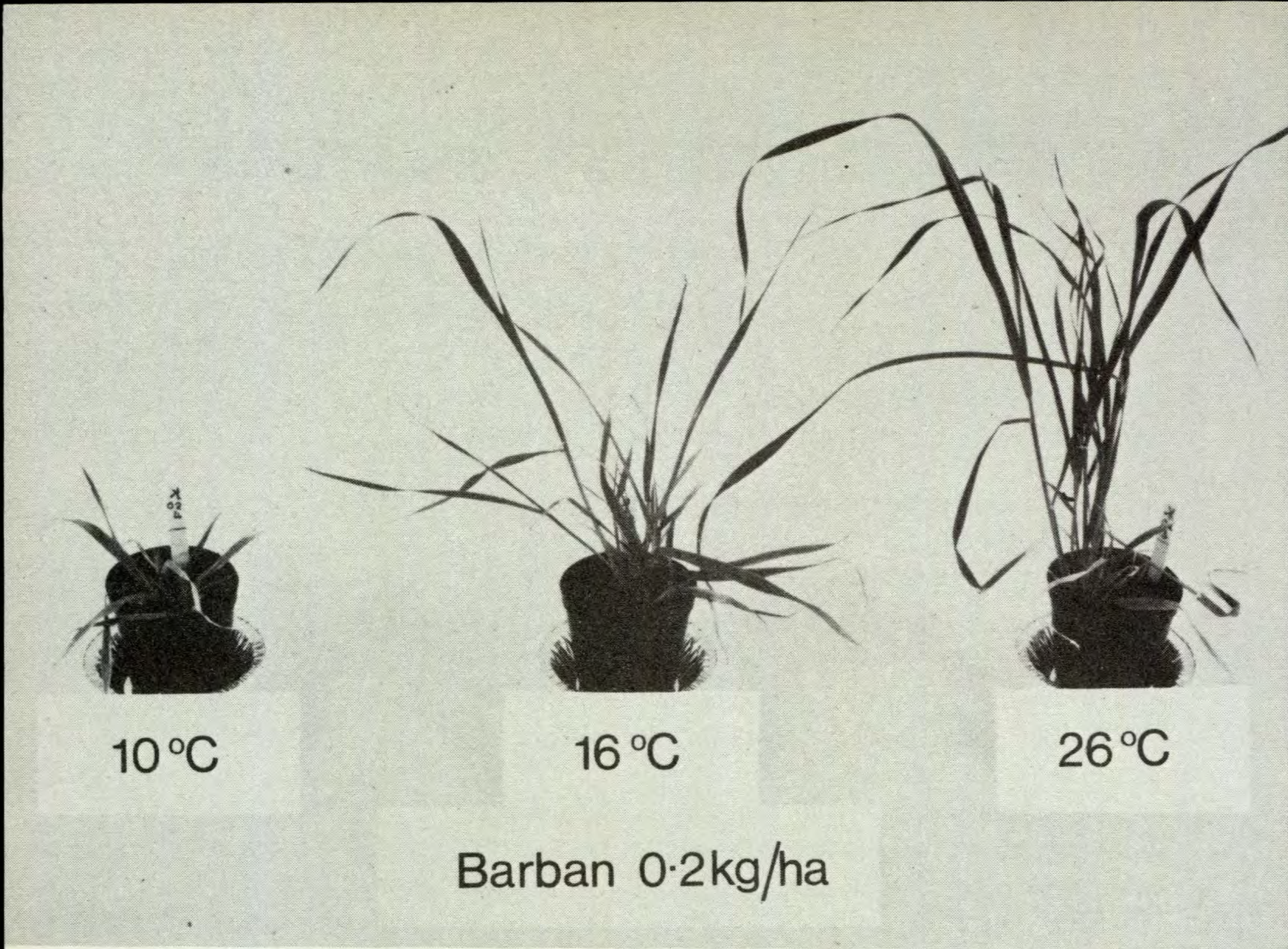
The bringing into use of three new controlled environment rooms during the past two years has greatly improved facilities for investigating the effect of temperature, light and humidity on herbicide performance. The research has concentrated on the herbicides benzoylprop-ethyl, difenzoquat and barban used for the control of wild-oat (*Avena fatua*) and on the non-selective herbicide glyphosate in respect of its effectiveness on common couch (*Agropyron repens*).

The imposition of a cool humid atmosphere for some weeks prior to spraying substantially reduced the activity of benzoylprop-ethyl. Difenzoquat performance was similar in both cool, humid and warm, dry environments. Subjection to high temperatures in the period after spraying difenzoquat gave a more rapid development of phytotoxic effects on wild-oats but the ultimate control achieved was equally good at both high and low temperatures. The difenzoquat-susceptible wheat cultivars, Sicco and Sportsman, also suffered most damage at high temperatures. In contrast, barban was most effective at low temperatures, with greater recovery of wild-oats under a warm regime.

Glyphosate was most effective against common couch when the post-spraying environment was kept cool for several weeks. Performance decreased when temperature was high.

The influence of rainfall is also under investigation. Simulated slight rain, less than 0.5 mm/h, immediately following spray application of the recommended dose of difenzoquat removed 50% of the herbicide from the foliage of wild-oats but did not reduce the performance of the chemical. Retention studies indicated that most loss of spray deposit occurred from the leaf lamina. Loss from the more critical ligule and leaf sheath areas was less.

Enhancement of the activity of glyphosate for the control of *Agropyron repens* has been the subject of continuing study. The advantage of ammonium sulphate for this purpose has been most evident under conditions



The wild oat herbicide barban is most effective when a period of low temperature occurs immediately after spraying; at higher temperatures there is a greater recovery of the wild oats.

conducive to glyphosate phytotoxicity. Thus, a greater increase in effect was obtained under cool environmental conditions than at high temperatures. There is also a complex interrelationship with the type of surface-active agent which may be added.

Selectivity of herbicides

The agrochemical industry worldwide continues to develop new herbicides in spite of the high costs involved. The Herbicide Group has maintained its traditional role in investigating the selectivity of such new herbicides by applying them in a number of ways to a wide variety of weeds and crops grown in pots. In this way the information on selectivity from the manufacturer is broadened and other possible uses found, additional to those on which the initial development is being based. New species are included as new needs arise; thus, information was acquired on the response of barren brome (*Bromus sterilis*) to a range of herbicides because of an upsurge of interest in the occurrence of this grass as a weed.

The increasing interest in joint application of more than one herbicide to a crop raises many questions regarding the maintenance of selectivity which require investigation. For example, possible mixtures of a number of herbicides effective for the control of wild-oat (*Avena fatua*) in wheat with others capable of killing black-grass (*Alopecurus myosuroides*) have been studied in pot experiments. Whilst such mixtures often gave good results for control of a mixed population of these grass weeds, there was a clear indication that the risk of a reduction in crop tolerance existed and would need more detailed assessment under field conditions.

An understanding of the underlying mechanisms of selectivity can assist reliable exploitation of herbicides. One detailed study is in progress on the selectivity of urea herbicides such as chlortoluron, isoproturon and metoxuron between annual grass weeds and wheat. This is revealing the importance of such factors as the distribution of the herbicide in the soil, in particular whether it moves below the level of the seed, and the speed of development of secondary roots in the surface regions of the soil.

Movement of herbicides in the soil

There is a good deal of evidence that herbicides are much less mobile in the field than one would expect from the results of laboratory experiments. A particularly striking example occurred in Deal field at WRO where there are plots that have received massive doses of linuron and simazine, sufficient to persist for several years, adjacent to plots that receive annual applications of paraquat. Paraquat is completely adsorbed so should not move from the surface, but in fact about 30% of the residue was found below 5 cm. The vertical distribution of linuron and simazine was very similar. Since the paraquat can only have moved together with the soil particles to which it is attached, through cracks and channels in the soil, is this also a significant process for the movement of linuron and simazine?

In a joint experiment, colleagues from the Letcombe Laboratory monitored soil particle movement using radioactive ^{144}Ce as a tracer, while herbicide movement was assessed by the WRO Chemistry Group. In addition, Professor J M Davidson of the University of Florida processed the herbicide movement data using a mathematical model.

The observed distribution of linuron and simazine extended farther down the soil profile than that of the radioactive soil particles but was very much less than that predicted by the theoretical model. Hence, an adequate explanation of herbicide movement in the soil does not yet seem possible. More elaborate experiments in collaboration with other institutes are in progress as a proper understanding of the issue is vital to improve both the performance of soil-applied pesticides and the prediction of their environmental fate.

Soil pH can change rate of herbicide degradation

It is often convenient to classify herbicides in broad classes according to their persistence in the soil, and to compare new compounds with a well established reference compound. That this approach has its limitations was illustrated by observations on the rate of herbicide decomposition in soils from two fields at WRO. In laboratory incubation experiments, soil from Boddington Barn field (pH about 7) decomposed linuron nearly four times faster than atrazine, whereas in soil from the Triangle field (pH about 5) atrazine disappeared more than twice as fast as linuron. To determine how far this difference was due to pH, samples of these soils were amended with acid or lime to give a range of pH. Linuron disappeared faster at higher pH in both soils but, although atrazine degraded faster in the Boddington Barn soil at high pH than at low pH, the reverse obtained in the Triangle soil.

In other experiments, atrazine and linuron decomposition rates in the two soils responded differently to added fertilizer materials. Combining the results of the two sets of experiments it is possible to choose conditions in which the ratios of the breakdown rates of linuron and atrazine can change from 3.5:1 to 1:4.4. Hence the concept of relative persistence must be used with discretion.

Soil fertility unimpaired by repeated herbicide application

As mentioned in the article on p. 90, the plots of the experiment on the long term effects of repeated herbicide application have been reduced in size. This has provided an opportunity to re-assess the fertility of these plots and their ability to decompose herbicide after 14 years of repeated herbicide application.

One area was used for a fertility test in which barley, dwarf bean, turnip and lettuce were grown. The yields of each crop were similar on all plots, irrespective of the treatment received during the previous 14

These healthy test crops demonstrated that 14 years' repeated application of the recommended dose of four herbicides had in no way impaired the soil fertility of the WRO long-term experimental area.

years, so the conclusion is that repeated herbicide use has not affected soil fertility.

In another area the decomposition of freshly-applied linuron, simazine and tri-allate in the plots that had received annual applications of these herbicides for 14 years was compared with that in the previously untreated control plots, both in the presence and absence of crops. The persistence of each compound proved to be independent of the history of the plot. This contrasts with MCPA where the treated plots have shown an enhanced ability to degrade the herbicide since at least 1966. The effect of crop cover was small, with a tendency for faster disappearance from the uncropped areas, probably because soil moisture was higher there.

AQUATIC WEED CONTROL

Of all the means of controlling aquatic vegetation that the Aquatic Weed and Uncropped Land Group (to give it its full title) have investigated, the herbivorous Chinese grass carp has attracted the most public interest. Many who have heard of it generally assume that the use of this fish will be accompanied by fewer undesirable side effects upon the aquatic environment than the use of chemicals. Whether this is true in practice may be judged from the account of our recent investigations given on p. 85. Any method of controlling water weeds must be acceptable to all users of the stretch of water concerned; hence our constant concern, exemplified by the other investigations described here, that the use of herbicides is attended by a minimum of undesirable environmental effects.

Successful control of blanket weeds with terbutryne

Two years ago we gave a preliminary account of the WRO contribution to the development of terbutryne for the control of filamentous algae in lakes and drainage channels. We have now investigated the effects of three repeated biennial applications of terbutryne to maintain the control of blanket weed (principally *Rhizoclonium hieroglyphicum*) originally achieved. Monthly or more frequent observations have been made on the zooplankton, phytoplankton, dissolved oxygen and herbicide residues as well as on the reaction of the weed algae. No adverse effects have been revealed, fish have thrived and the beauty of the trial lake has been restored. The experiment will continue for one more year to confirm the promising results to date.

Viscous herbicide formulation proves promising

In 1976 work started on developing a novel method of placing herbicides on to weeds in water. The technique employs a viscous sodium alginate sol as the herbicide carrier. Following satisfactory laboratory tests the new formulation was used successfully to clear a selected portion of a weed bed in a swiftly flowing river. Because it was possible to place the herbicide accurately on the weed very little herbicide was needed, any risk of pollution was removed and the cost was much reduced. An intensive programme is planned for 1978 to test this formulation more thoroughly under different river conditions and also for limited weed removal in lakes and channels.

BIOMETRICS

The staff of the ARC Letcombe Laboratory/WRO Joint Biometrics Group have given more emphasis in the past two years to training and encouraging WRO staff to use the computer for themselves. This became necessary as a result of the loss of Biometrics Group posts during the standstill on the filling of vacancies in 1974–5; there are also advantages in having staff who are fully familiar with the data closely involved in its analysis on the computer. WRO staff now punch most of their own data onto paper tape and, wherever possible, undertake the analysis with help and advice from members of the Group.

During the period, considerable effort has been devoted to analysing the results of experimental work on the competition of wild-oats with cereal crops and on the dormancy and germination of wild-oat seed. Particular assistance has been provided with programme writing and statistical analysis for data on the effects of environment on the activity of herbicides. The Rothamsted MLP (maximum liklihood programme) has proved increasingly useful in analysing the results of bioassays and other similar data.

OVERSEAS ACTIVITIES

ODM TROPICAL WEEDS GROUP

A modest programme of herbicide evaluation has continued on tropical weed problems. Four outstanding new grass-killing herbicides have been shown to have potential for selective use in most broad-leaved annual and perennial crops. Several important tropical perennial weeds including *Cynodon dactylon* and *Paspalum distichum*, were found to be exceptionally susceptible to the new compound trifop-methyl, while the potential uses of asulam were further expanded by evidence of good control of *P. distichum, Oryza longistaminata* and *Mikania micrantha*.

The research responsibilities of the group have now been increased to include a special project on the parasitic weed, *Striga*, requested by ICRISAT (*International Crops Research Institute for the Semi-arid Tropics*) and financed by ODM.

There has been a continued demand for advice and information from overseas correspondents and visitors and in response to such requests a further 16 annotated bibliographies have been prepared on tropical weed control topics.

The main feature of the period has been the increased number of requests from developing countries for short advisory visits by the Group Leader.

A plant of *Striga hermonthica* growing characteristically close to the base of the sorghum plant it is parasitizing. Several parasitic species of this genus cause significant yield reductions in cereals, sugar cane and cow peas in many developing countries.

Advisory visits to developing countries

In general, developing countries have been slow to recognise the advantages to be gained from increased weed research and the use of herbicides. In recent years, however, there has been increased interest, generated in part by the international agricultural research institutes, and this has led in turn to a greater demand for advice on weed research programmes and priorities. During the period two of the international institutes themselves asked for help in re-appraising their weed work. Other institutions seeking similar advice were the Tea Research Association in India and the University of Jordan while the government of The Gambia requested a general survey of their weed problems.

Other countries have called for help with more specific problems such as *Striga* in sugar cane in Sudan, *Striga* in rice in Sumatra, various weeds in rice in Swaziland, and weeds of experiment stations in Egypt. The problem in Egypt was mainly from *Cynodon dactylon* and had reached such an acute state on several stations, that all agronomic research was being severely affected.

An extensive tour of West Africa was made in connection with the new *Striga* research project, to study the problem and to collect seed for use in the experiments at WRO.

These visits were variously financed by ODM, British Council, FAO, CDC, etc., and were mostly carried out by the leader of the Tropical Weeds Group (as ODM Liaison Officer). The Gambian study, however, was made by P J Terry, the ODM 'home-based officer', who was truly home-based for the 18 month period during which another WRO staff member, T O Robson of the Aquatic Weeds Group, was released for secondment to BIOTROP, the *Regional Centre for Tropical Biology* in Indonesia. The purpose of this assignment was to help in directing the research programme and in supervising staff and research scholars in a range of topics, several of which involved aquatic weed studies. He also assisted with a number of BIOTROP short courses held in Indonesia, Malaysia and Thailand. The leader of the WRO Chemistry Group (R J Hance) assisted with the course in Thailand and went on to Indonesia to advise on the more chemical aspects of BIOTROP's research. Robson assisted in the development of BIOTROP plans for the next five years and it is anticipated that WRO will continue its collaboration with this institute which is playing a key role in the training of weed research workers in S E Asia and in the development of sound principles of weed management for the region.

Other liaison activities

Apart from the personal visits overseas, the Tropical Weeds Group maintained contact with a large number of workers and institutions concerned with weed control in developing countries. In addition to the BIOTROP project, regular correspondence was maintained with ODM weed scientists in Ghana, Saudi Arabia and Bolivia. Staff of two other international institutes, IITA (*International Institute of Tropical Agriculture*) in Nigeria and the new ICARDA (*International Centre for Agricultural Research in Dry Areas*) in Syria visited WRO to exchange information. Contact with CIBC (*Commonwealth Institute of Biological Control*) led to the approval of a new project on *Mikania micrantha*.

LIAISON AND INFORMATION

LIAISON

From its inception in 1960, WRO has accepted a clearly defined responsibility to serve as a liaison centre for all concerned with the advancement of weed science and weed control in the UK. Considerable effort is devoted to ensuring co-ordination of WRO research with that taking place in other official, commercial and university research departments. Also of value to WRO are the various agencies whereby information about new methods of weed control is disseminated to farmers and growers, and from whom WRO receives early warning of incipient problems concerning weeds or herbicide usage in the field. To this end, close working relationships have been developed over the years, not only with the Agricultural Development and Advisory Service of MAFF, but also with the technical field staff of the herbicide manufacturers and the sales staff of the agricultural merchants.

Co-ordination of research with other organizations

Arrangements for liaison with other bodies engaged in weed research vary from formally arranged meetings with the co-operating organizations to personal discussion between research workers; whenever a need can be identified, WRO staff are encouraged to take the initiative. During the period under review, workers from WRO participated in a number of meetings which have become annual events. Amongst the most noteworthy of these are the following:

ARC Fruit Weed Control Group. The group consists of representatives from East Malling Research Station, Long Ashton Research Station, the Scottish Horticultural Research Institute and WRO with additional members from ARC Headquarters, Loughgall Horticultural Centre, Armagh and the Soft Fruit Research Centre, Clonroche, also herbicide specialists from MAFF. The group meets annually to discuss the future requirements for weed control research for fruit crops, the results from current investigations and possibilities for co-operation. The 1976 meeting was in East Anglia and the 1977 meeting at the Kinsealy Research Centre, Dublin. There have been collaborative experiments with soil and foliage-applied herbicides on strawberries and the effect of glyphosate on the suckers of tree fruits.

Herbage Seeds (Weed Control) Working Group. This group meets annually at WRO to review existing weed control problems in herbage seed crops and relevant research, also to consider appropriate action to promote the development of more effective control measures for growers. Membership consists of representatives of the following organizations: WRO, ADAS, National Institute of Agricultural Botany, United Kingdom Agricultural Supply Trades Association, Lincolnshire Seed Growers Association, West of Scotland Agricultural College, Nottingham University School of Agriculture, Welsh Plant Breeding Station, Grassland Research Institute and West Wilts, Hants and Dorset Seed Growers Association. During the 1976 and 1977 meetings the following were amongst the topics discussed: tolerance of rye-grasses to potential wild-oat herbicides, efficacy of herbicides for control of wild-oats, rough meadow-grasses and black-grass, use of growth regulators for modifying straw length and increasing seed yields, and work on paraquat-resistant rye-grasses.

Meeting on aquatic weed control and research requirements. This meeting, convened annually at WRO, met for two days on each of two occasions in 1976 and 1977 to discuss current research and developments in aquatic weed control and to learn of weed and weed control problems experienced by the water industry. It is organized by WRO as successor to the ARC Technical Committee on Aquatic Weeds which was discontinued in 1972. The meeting has no formal status but is an opportune occasion for representatives of government research institutes, universities, MAFF, ARC, British Agrochemicals Association, Water Authorities and Internal Drainage Boards to harmonize their research and initiate further action when required. The clearance of herbicide treatments under the Pesticide Safety Precaution Scheme has proved a particular difficulty and a special meeting was held at WRO in 1977 on behalf of the British Crop Protection Council and the National Water Council to discuss the problem. An outcome of the main meeting in 1977 at which the delegates supported the need for a national policy on the introduction of weed-eating grass carp was the formation of an interdepartmental steering committee sponsored by MAFF to promote co-ordination and execution of a field programme.

Meeting of soil microbiologists. Another rewarding meeting was that of soil microbiologists from official, university and commercial bodies which was organized at WRO in January 1977 by the Microbiology Group. The meeting, which was chaired by Dr J K Gasser (ARC Headquarters), considered 'measurement of microbial activity in soils and the effects of soil amendment'. Four speakers introduced the subject by talking about aspects of the characteristics of microbial activity in soils, test procedures for assessing the effects of agricultural chemicals on the soil microflora, and microbial problems associated with disposal of animal wastes on the land. Subsequent wide ranging discussions identified several areas where knowledge is scanty and which may be important in terms of interactions between agricultural chemicals and the soil microflora.

Liaison with ADAS

The responsibility for specific liaison with ADAS specialists and for advice to farmers and growers, which would otherwise made heavy demands upon the WRO research staff, is that of the two officers of the ADAS Liaison Unit based at WRO. In addition to providing their ADAS colleagues and other enquirers with technical advice, they serve as an invaluable link between the institute and ADAS in the identification of new problems requiring research, the selection of sites for experiments, and in promoting ADAS development of WRO research findings. Progress is reviewed twice a year at meetings of the WRO/ADAS Liaison Group.

In addition, the presence at Begbroke of the Herbicide Liaison Officer of the Agricultural Chemicals Approval Scheme, seconded from the MAFF Plant Pathology Laboratory, ensures close contact with the pesticide industry and provides information on the development of new herbicides and any practical problems in their usage. In turn, he has access to all the information emanating from the WRO research programme. The Director was appointed chairman of the ACAS Scientific Advisory Committee in 1977.

Contacts with the agrochemical industry

The older members of WRO who lived through the pioneering years of chemical weed control have long-established close personal contacts with the more senior members of chemical companies. However, there is a continuing need to foster personal contacts at the more junior level. In agreement with the British Agrochemical Association, an annual Chemical Industry Day was initiated in 1976 as a means of bringing together the younger members of WRO and the herbicide manufacturers and distributors to discuss recent developments and topical problems. These events have now become a firm part of the Begbroke Hill calendar and appear to be much appreciated by those who attend them.

As in previous years several senior members of WRO staff participated in the two annual Reviews of Herbicide Usage which were held in October 1976 and 1977 under the sponsorship of the British Crop Protection Council. These meetings provide an invaluable opportunity for representatives of the BCPC member organizations and other organizations to report and discuss progress in the use of herbicides during the previous season. Recommendations arising from these reviews are referred to BCPC for further action.

In November 1976, over 70 herbicide specialists from industry and elsewhere met for the second annual meeting organised by and held at WRO, to review research and developments in controlled drop application.

In November 1977, at the request of the sponsors, WRO was the venue for the final judging of the CDA Sprayer Competition organized jointly by BP and *Big Farm Management*. A panel of sprayer experts headed by Sir Charles Pereira, formerly MAFF Chief Scientist, awarded the £1000 trophy for the winning design to an Ongar farmer, Mr Robert White, for an ingenious adaptation of a rape harvester.

Liaison with agricultural merchants

WRO has continued to foster its close association with agricultural merchants, both personally and through the United Kingdom Agricultural Supply Trades Association (UKASTA). The annual Merchants' Day had become so popular by 1975 that, at the request of UKASTA,

The judges inspecting one of the candidate entries for the best CDA sprayer design at the BP/Big Farm Management competition held at WRO. The winning machine is in the background.

it was agreed to repeat the same programme on two separate days each year in future. During 1976 and 1977 a total of 263 merchants attended the days.

The National Wild-oat Advisory Programme

This programme is an interesting example of the way in which official and commercial organizations can collaborate in a national endeavour to control an important weed. The programme has been organized by a Steering Committee chaired by the Chief Agricultural Officer of ADAS, an Executive Group (on which ARC and BCPC were represented by members of WRO staff), and a network of Regional Committees. The programme involved a great deal of work, but it has been a stimulating experience to find how quickly the findings of research can reach farmers when backed by a well co-ordinated national programme.

The past two years have been occupied by the preparations for and conduct of a national survey of wild-oat and other grass weeds undertaken in July–August 1977. The Tactical Planning Group for this substantial survey was chaired by J G Elliott of WRO. It involved 1153 farms and 2250 fields of cereals throughout the United Kingdom. The completed forms were coded by the ADAS Extension and Development Unit at Reading and analysed by the Rothamsted Experiment Station Statistics Department. The preliminary report was written at WRO in October and November 1977 and some 3000 copies were distributed in January 1978. Those interested in the results of the survey can obtain a copy of the preliminary report* from MAFF Publications, Tolcarne Drive, Pinner, Middlesex, HA5 2DT.

Support of scientific societies

Senior staff of the institute have continued to play an active part in the administrative councils, programme committees and editorial boards of several scientific societies including the British Crop Protection Council, the European Weed Research Society, the Society of Chemical Industry's Pesticide Group and the Weed Group of the Association of Applied Biologists.

The Director, who has been a member of the Weed Science Society of America (WSSA) for many years, was recently awarded Honorary Membership of the Society in recognition of meritorious services in the field of weed science. This rare privilege has only been awarded three times previously in the history of the WSSA.

Weed Workshop '77

Nearly 700 visitors, including many senior scientists from ARC, MAFF, industry and the universities, together with farmers and advisers, attended the fourth biennial display of WRO research achievement at Weed Workshop '77 which, preceded by a press preview, took place on 29–30 June 1977. The visitors viewed and discussed the numerous exhibits of current research into weed control in winter cereals, controlled drop application, research on potato groundkeepers, weed competition in nursery stock, and grassland weed control and manipulation. In all more than 70 panels were on display in addition to the live demonstrations.

*NATIONAL WILD OAT ADVISORY PROGRAMME. National Survey of Wild-oats and other Grass Weeds. Publ. MAFF, 1977, pp. 17.

Some of the 700 visitors to Weed Workshop '77 hearing about the latest research into improved control of docks in grassland.

Other exhibitions and displays

'Perennial Weed Control in the Garden' was the title of a 7-panel WRO contribution to the ARC corporate display at the Chelsea Flower Show in 1976. Other displays prepared that year included 7 panels on 'Controlling Potato Groundkeepers' for the Potato Marketing Board's Autumn Demonstration and 17 panels illustrating current research in controlled drop application, a new growth-room plot sprayer, and the recognition of cereal growth stages for the BCPC Weeds Conference exhibition at Brighton. In 1977 a 5-panel display entitled 'Weed Competition in Nursery Stock' comprised the WRO contribution to the ARC corporate displays at both the British Growers Look Ahead conference exhibition and the Chelsea Flower Show.

INFORMATION AND PUBLICATIONS

As the national centre for the dissemination of information on weed research, WRO continued to provide specialist library, current awareness and information retrieval services, both to its own research staff and other weed scientists in the UK. The demand in 1976–77 continued to grow and was reflected in nearly 1600 enquiries answered and the 10 new bibliographies of references to weed research topics prepared. Nearly 1200 requests for these and earlier bibliographies were received. The full list of WRO publications for 1976–77 appearing at p. 107 includes 96 journal and conference papers and 7 technical reports. The worldwide circulation of some 700 weed scientists and institutions with the half-yearly lists of WRO publications resulted in requests for nearly 8,500 reprints, 500 technical reports, and 1900 copies of the WRO 6th Report. The popular booklet *Chemical Weed Control in Your Garden* sold a further 3,700 copies and there were 41 external subscribers to the weekly Current Awareness Lists. The sale of the CAB data-base to Lockheed Information Systems in 1976 added computerised retrieval from the *Weed Abstracts* and other data bases to the services available to WRO staff, via one of the institute's tele-type terminals.

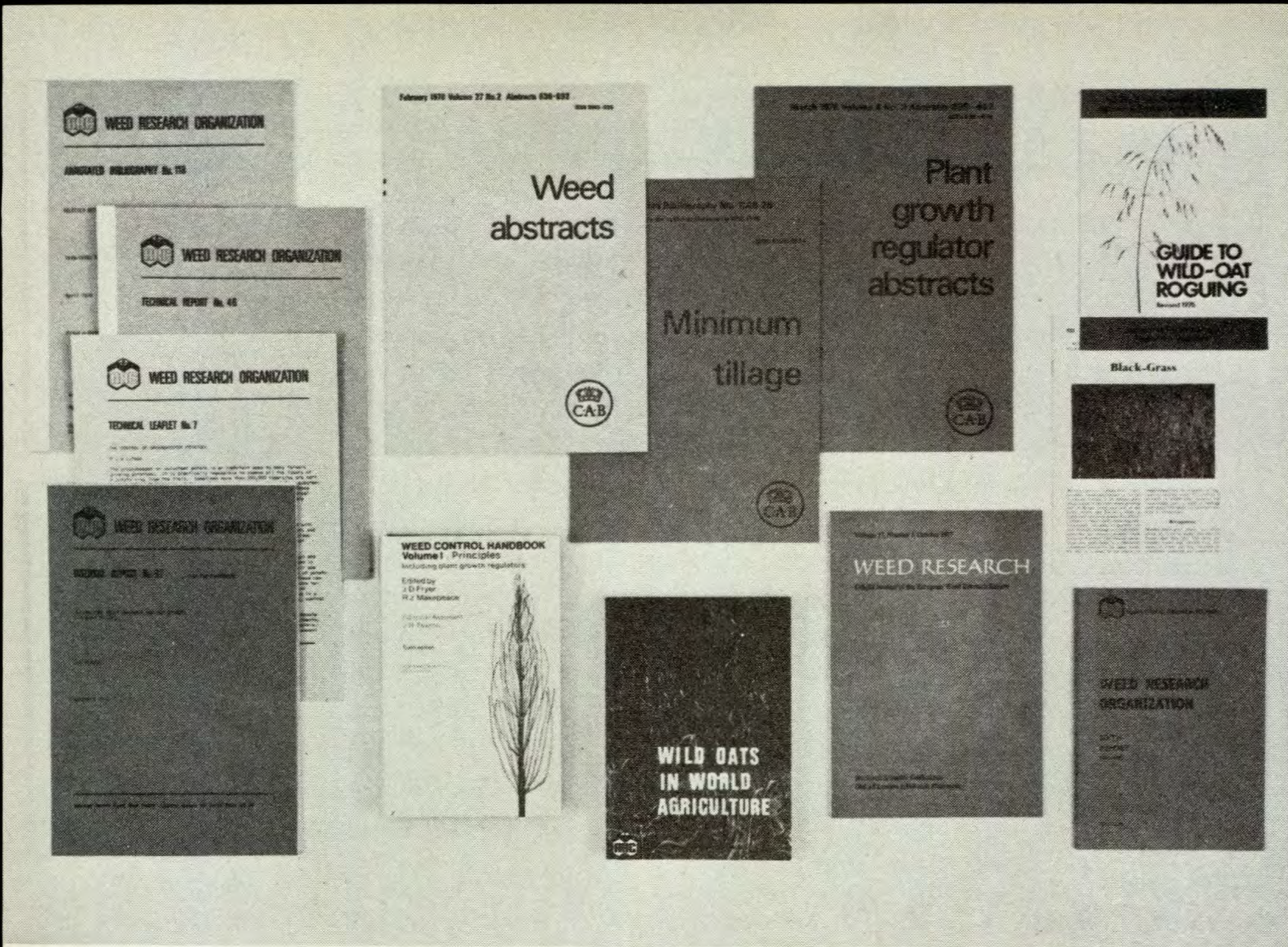
Publications

Whilst members of the WRO information staff continued to be closely involved in the production of several serial publications on weed science, a number of the research staff also found time, as indicated below, to make major contributions to both new and established reference works in this field.

Weed Abstracts. This journal, compiled on behalf of the Commonwealth Agricultural Bureaux (CAB) by the staff of the Information Department, has been the basis of the reputation of WRO as an international information centre for weed science for 27 years. Partially financed by CAB, which took over the printing and distribution of the journal in 1961, it remains, in these inflationary times, one of the few CAB journals with a continuously expanding circulation. A total of 7893 abstracts were published in 1976–77.

Plant Growth Regulator Abstracts, a 're-packaged' convenience compilation of abstracts culled from the whole of the CAB data base, and collated and edited at WRO, is still the most successful of its type with nearly 360 subscribers to date.

Weed Research. The Director continued to chair the 16-strong international editorial board of this journal in which 177 papers were published in



Some of the numerous publications on weed science with which WRO is closely associated and which have established its position as a world centre for the dissemination of information on weed control.

1976–77 by Blackwell Scientific Publications on behalf of the European Weed Research Society. A member of the Information Department became secretary to the editorial board in 1976.

PANS. Through the ODM Tropical Weed Group, WRO remains closely associated with the editor of the weed section of this quarterly journal which aims to keep scientists in tropical countries informed of the latest advances in all aspects of pest control. Financed by the Ministry of Overseas Development and published by the Centre for Overseas Pest Research, *PANS* publishes many reviews and original articles on weed control and news of new herbicides and application equipment. During 1976–77 its circulation increased to nearly 4000.

Wild Oats in World Agriculture. Published by ARC in 1976 this major critical review, initiated by WRO, set out to appraise the published research on wild oats and indicate the most promising avenues for further investigation. It was undertaken by a panel of authors, mostly drawn from WRO, but including contributions from Rothamsted, the Welsh Plant Breeding Station and the National Institute of Agricultural Botany. Favourably reviewed in the leading scientific journals, nearly 1000 copies have been sold to date.

Integrated Control of Weeds. The Director accepted an invitation by the Asian Pacific Weed Science Society to be co-editor, with Dr S Matsunaka of Kobe University, Japan, of this collection of papers presented at a special one-day symposium on this topic, held in Tokyo in 1975 during the 5th Asian Pacific Weed Control Conference. It was published by Tokyo University Press in 1977.

Weed Control Handbook. A completely revised edition of *Volume 1, Principles,* was published in 1977 and a revised edition of *Volume 2, Recommendations* is scheduled to appear in 1978. Sponsored by the British Crop Protection Council and published by Blackwell Scientific Publications, both volumes were the product of nearly 80 contributors including several members of WRO staff, under the voluntary joint editorship of the Director and the ACAS Herbicide Liaison Officer at WRO.

Major contributions by WRO authors appearing in other works published in 1976–77 included: four chapters in *Herbicides: Physiology, Biochemistry, Ecology,* edited by L J Audus; two major reviews in *Ecological Effects of Pesticides,* edited by F H Perring and K. Mellanby; a review on the prediction of weed problems in developing countries in *Plant Parasitic Diseases and Weed Problems,* edited by J M Cherrett and G R Sagar; and a review on herbicide effects upon micro-organisms in *CRC Critical Reviews in Microbiology.*

CONFERENCES

WRO staff have always been actively involved in the organization of the weed conferences and symposia which provide them with a major opportunity for the communication of research results. The years 1976–77 proved to be no exception. Members of WRO staff served on the programme committees of two BCPC symposia, one on the persistence of insecticides and herbicides held at Reading University in March 1976, and another on granular pesticides held at Nottingham University in July 1976.

The British Crop Protection Conference—Weeds, held in Brighton in November 1976, was the 13th in this series of biennial events, formerly known as the British Weed Control Conferences. Dr K Holly served as chairman of the programme committee, upon which two other members of staff also served. Nearly 1600 participants attended the conference, 45% of them from overseas. WRO contributed 27 of the 143 papers presented and several members of staff also served as session organisers.

Details of other conferences in which WRO personnel participated are given on p. 120–22.

EDUCATION, ADMINISTRATION, BUILDINGS AND EQUIPMENT

EDUCATIONAL ACTIVITIES

WRO is an Associated Institute of the University of Reading; the Director is a Visiting Professor and four members of staff are either visiting lecturers or higher degree supervisors. This status of the institute was once again reflected in the fact that three out of the seven higher degree students who enjoyed our facilities for jointly supervised research in 1976–77 were students of Reading University. Details of all post-graduate students are given on p. 124.

It is a pleasure to record that Miss Trudy Watt was awarded a D.Phil by Oxford University in 1977 for her work on the autecology of Yorkshire fog in grassland. Eleven undergraduate 'sandwich' students also carried out small research projects at WRO in 1976–77, in fulfilment of their degree requirements.

Regrettably, increasing pressure upon our limited bench space made it necessary to restrict the number of visiting research workers and overseas trainees accommodated in 1976–77 to five, less than half the number received in 1974–75. Details are given on p. 124.

The Director completed his three year appointment as Visiting Lecturer at the Department of Biology, Strathclyde. Two members of staff continued to lecture on weed biology and aquatic weed control to students of Chelsea College, University of London.

Once again WRO provided a two-day introduction to the principles and practice of weed control for the overseas plant protection students participating in the Silwood Park Pest Management Course financed by the Ministry of Overseas Development. This annual event is organised by the leader of the Tropical Weeds Group, who also served as external examiner for students reading for the MSc in weed biology of Brunel University and the MSc in crop protection of Reading University.

As in previous years many members of the research and information departments devoted considerable time, much of it their own, to talking about the broad spectrum of research on-going at WRO or about aspects of topical interest to particular groups. General audiences included school, college and university student groups, Women's Institutes, Townswomen's Guilds, Rotarians, gardening and allotment clubs; professional audiences included ADAS Divisional Officers, technical staff of agrochemical firms and agricultural merchants, and many groups of farmers and growers.

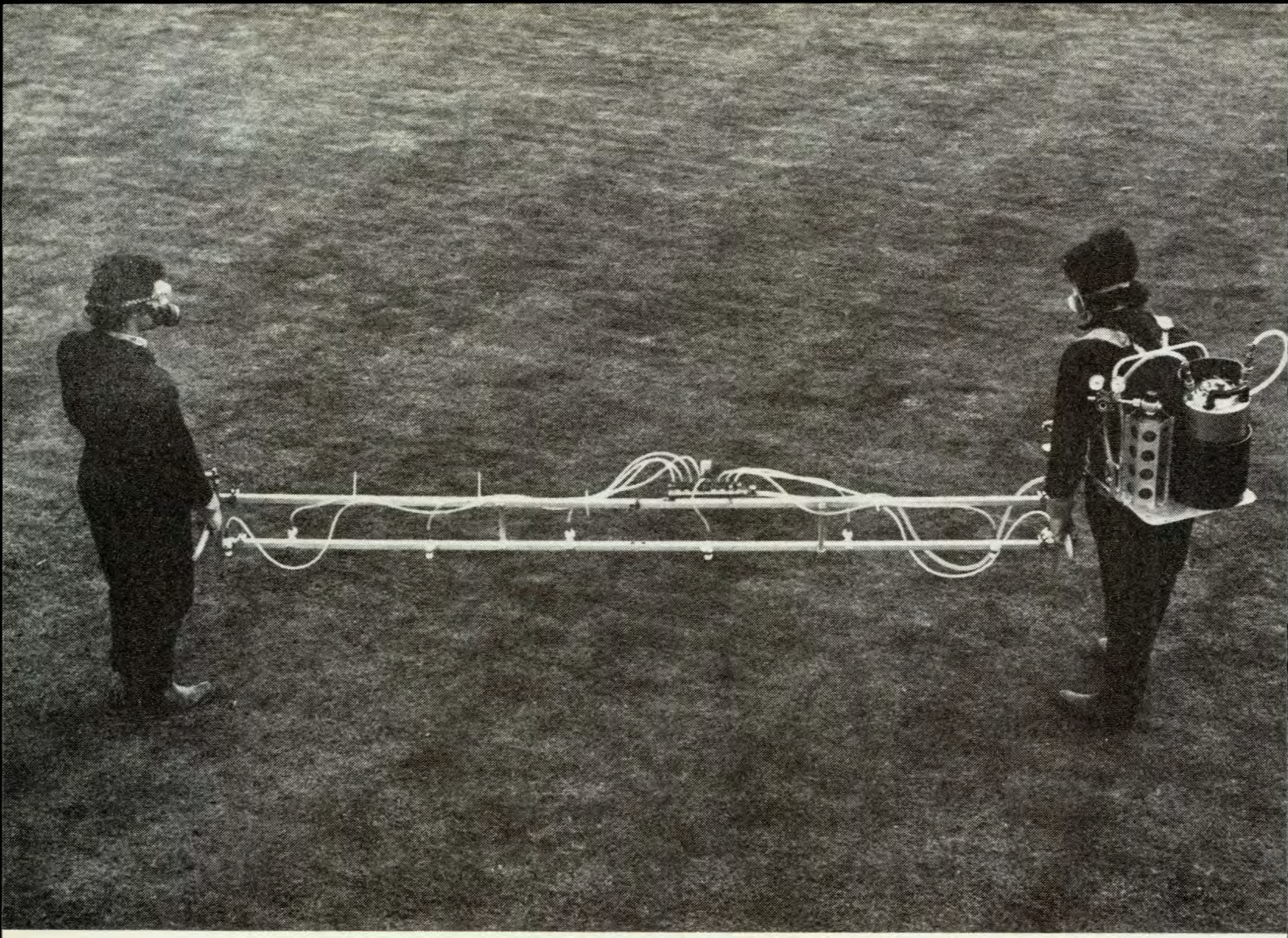
ADMINISTRATION AND TECHNICAL SERVICES

The Administration Department, led by the Secretary, continued to support the institute's scientific programme, not only through its office sections, but by providing technical services covering photography, and various branches of engineering. The load on the office section had greatly increased over the years as a result of new legislation and the introduction of new procedures at ARC. This led, following a Staff Inspection, to a new post at Executive Officer level to assist the Secretary. However, the increasing load on the technical services caused by the steadily increasing size of the institute staff and of its building stock, and the greater diversification of equipment remains unanswered.

Although the institute had had a Safety Committee from its very earliest days, this committee was re-constituted in 1976 in anticipation of the requirements of the Health and Safety at Work Act 1974. With the Director as chairman, the committee now includes representatives of the recognised unions as well as those of management. During the coming months the committee will issue a revised Safety Manual, which has been edited by the senior member of staff appointed as the Safety Officer.

NEW BUILDINGS AND EQUIPMENT

Towards the end of 1977 a start was made on Phase II of the institute's building programme for the 1970s. This comprises a service building for the field experimental teams providing storage and processing facilities for soils and harvested crops and, for the first time since the institute was set up, properly planned accommodation for the calibration, decontamination and storage of sprayers. The opportunity is also being taken to move the field chemical laboratory and the vehicle and plant maintenance workshops from their present inadequate locations to more convenient sites. The space released will provide better accommodation for the electronics engineer and workshop supervisor, the central store, the



This prototype two-man portable spray boom and back pack has been designed and built at WRO to apply herbicides to experimental plots 3 to 4 metres wide, i.e., larger than those normally treated with most small plot sprayers but smaller than those requiring a vehicle mounted sprayer.

Biometrics Group and the Information Department's graphic art studio. It will also provide two writing rooms, an office for the use of the staff associations, and some accommodation for the staff club.

New offices have already been provided for the head of the Information Department and his personal secretary which, in turn, has allowed a much needed extension of the library.

Equipment

A 300kva standby generator has been provided to secure an uninterrupted electricity supply to the controlled environment facility, the sewage pump and the greenhouse boiler plant.

Other major items of equipment purchased and commissioned in 1976–77 included a scintillation counter and data logger for the Herbicide Group's controlled environment laboratory, a seed cleaner for the Grass and Fodder Crops Group, dissolved oxygen recording equipment for the Aquatic Weeds Group, a 7½-ton lorry, seed drill and fertilizer distributor for the Field Experiments Committee and 100m of extra library shelving for the Information Department.

However, much of the equipment required by the research groups is not available commercially and, in 1976–77 as in previous years, several specialized items were produced at WRO, their design and construction being a collaborative effort between the research workers and the staff of the engineering workshops. These included a mobile, controlled-environment pot spraying cabinet and a field scale CDA sprayer for the Herbicide Group, mobile plot irrigators for the Perennial Crops Group, constant temperature seed germinating 'thermobars' for the Botany Group, a flowing-stream simulator for the Aquatic Weeds Group, an automated N-analysis-sample preparation unit for the Microbiology Group, several modifications to the 'one-pass' seed drill for the Grass and Fodder Crops Group, and a 3-4 metre portable boom sprayer for the Annual Crops Group. The last two items have attracted considerable commercial interest and the portable 3–4 m boom sprayer is already being marketed by the same firm which made the WRO designed Oxford Precision Sprayer and its subsequent modifications available to weed scientists throughout the world.

Cereal growth stages and their relevance to the safe use of herbicides in winter wheat

D. R. TOTTMAN

Although soil-acting herbicides for autumn use are now available, most of the United Kingdom winter wheat acreage is still sprayed with 'hormone' herbicides in the spring. Because the removal of weed competition will often result in only a small increase in yield, any crop damage from the herbicide is unlikely to be acceptable. The crop's tolerance of these herbicides varies with its growth stage and correct spray timing is necessary to minimise the risk of damage. The results of WRO studies of the growth and development of winter wheat varieties and their tolerance of herbicides offer the farmer clearer and more reliable guidance on when he should spray to avoid crop damage.

DANGERS OF INCORRECT SPRAY TIMING

A series of experiments at WRO compared the relative tolerance by winter wheat of two commercial herbicide mixtures, widely used to control a range of broad-leaved weeds (Tottman, 1977a). MCPA, alone or in mixture, deformed the wheat ears whenever it was applied too early (Fig. 1a). Late applications of a herbicide containing dicamba, 2,3,6-TBA, mecocrop and MCPA, when nodes were detectable, interfered with grain swelling and severely reduced yields (Fig. 1c). A mixture of ioxynil and mecocrop, on the other hand, failed to produce such symptoms and depressed yields less. If late spraying is unavoidable it is evident that some herbicides will be safer than others. The results also suggested a difference in the tolerance of the dicamba herbicide mixture by different varieties. Maris Ranger appeared more sensitive than Cappelle or Maris Huntsman. This may be reflected in the reports of damage by dicamba herbicides to the closely related variety Kinsman in the 1977 season.

TIME AVAILABLE FOR SPRAYING IN THE SPRING

Winter wheat passes through the most tolerant stages during the rapid flush of early spring growth, usually around mid-April. The time for spraying is short, often about 10 days, and is further restricted by bad weather. At this time of year, wind and rain are likely to allow spraying on only one in every two or three days (Tottman & Phillipson, 1974).

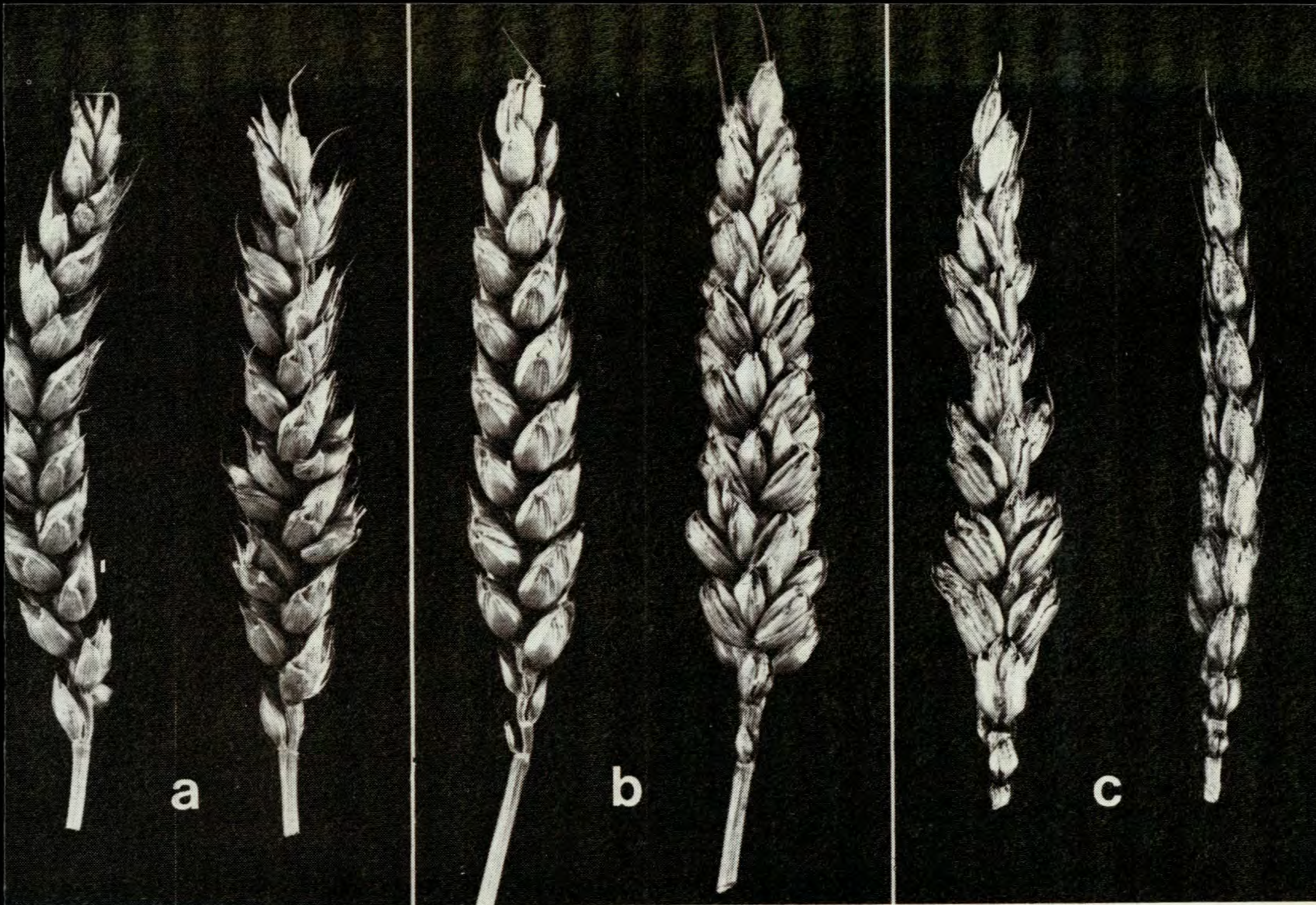


Fig. 1 Wheat ears: (a) deformed by early spraying with MCPA with opposite and extra spikelets; (b) normal, sprayed at correct time; (c) narrow, with shrivelled grain, sprayed too late with a dicamba herbicide mixture.

To spray large acreages of winter wheat at the right time demands an efficient farm spraying operation. With so short a time available the farmer must recognise the stage at which he can safely begin to spray. Only then can he allow sufficient time to take account of weed development and weather conditions and still spray before the crop is too advanced.

WRO RESEARCH ON GROWTH STAGE IDENTIFICATION

Before the recent introduction of the decimal code of Zadoks, Chang & Konzak (1974) there was no universal standard for growth stage descriptions and the published results of many experiments are difficult to interpret. There is, however, agreement that herbicide tolerance is determined by the stage of development of the young ears at the stem apices. At the stages critical for herbicide timing the apices are hidden among the leaf sheaths at the base of the plant and can be exposed and identified only after dissection under a microscope. The aim of our study at WRO has been to provide farmers and agronomists with a guide to apical development based on easily-defined external characters of the plant (Tottman, 1977b), Although intended mainly for herbicide users the value of such a guide extends to other aspects of cereal agronomy. For example, the plant's response to nutrient applications, weed competition, disease attack and environmental conditions may all be related to its stage of apical development.

Plants from field plots of a wide range of varieties were sampled, described and dissected for three seasons at WRO and then from ADAS experiments throughout the country. The results confirm the inadequacy of the growth stage descriptions presently used in herbicide recommendations and point to some clearer alternatives which better reflect the stages of the plants' apical development.

The standard phrase, used to describe the stage at which spraying with 'growth regulator' herbicides can safely begin on winter cereals in the spring, is 'the fully-tillered stage'. The WRO study showed little correlation between tillering and the early stages of ear differentation. In practice the farmer probably times his spraying more by experience and the incidence of suitable weather conditions than by any attempt to interpret the instructions on the herbicide label. While such an approach may have been satisfactory with familiar and established wheat varieties, it is doubtful whether it will prove satisfactory for newer varieties with different growth habits. A more precise and objective criterion is needed.

Leaf number offers a guide to spray timing in spring cereals, but is not normally used in winter wheat where ear initiation is determined by cold winter temperatures followed by increasing day length in spring rather than the number of leaves unfolded. The data collected at WRO showed only a weak correlation between leaf number and apical development, and there were marked seasonal and varietal differences. The difficulty in counting the leaves on a winter wheat plant in the spring, when the older leaves are dying and often shrivelled, rules out the use of leaf number as a practical guide to spray timing.

A relationship was noted between apical development and the length of the true stem. Unfortunately, the stem at the relevant stages is less than one centimetre long and the necessary plant dissection, although possible in the field, requires practice.

The length of the leaf sheaths proved a much more practical guide. The longest leaf sheath on the main shoot is measured from ground level, where its colour changes from white to green, to the base of the last unfolded leaf (Fig. 2). This character showed a remarkably high correla-

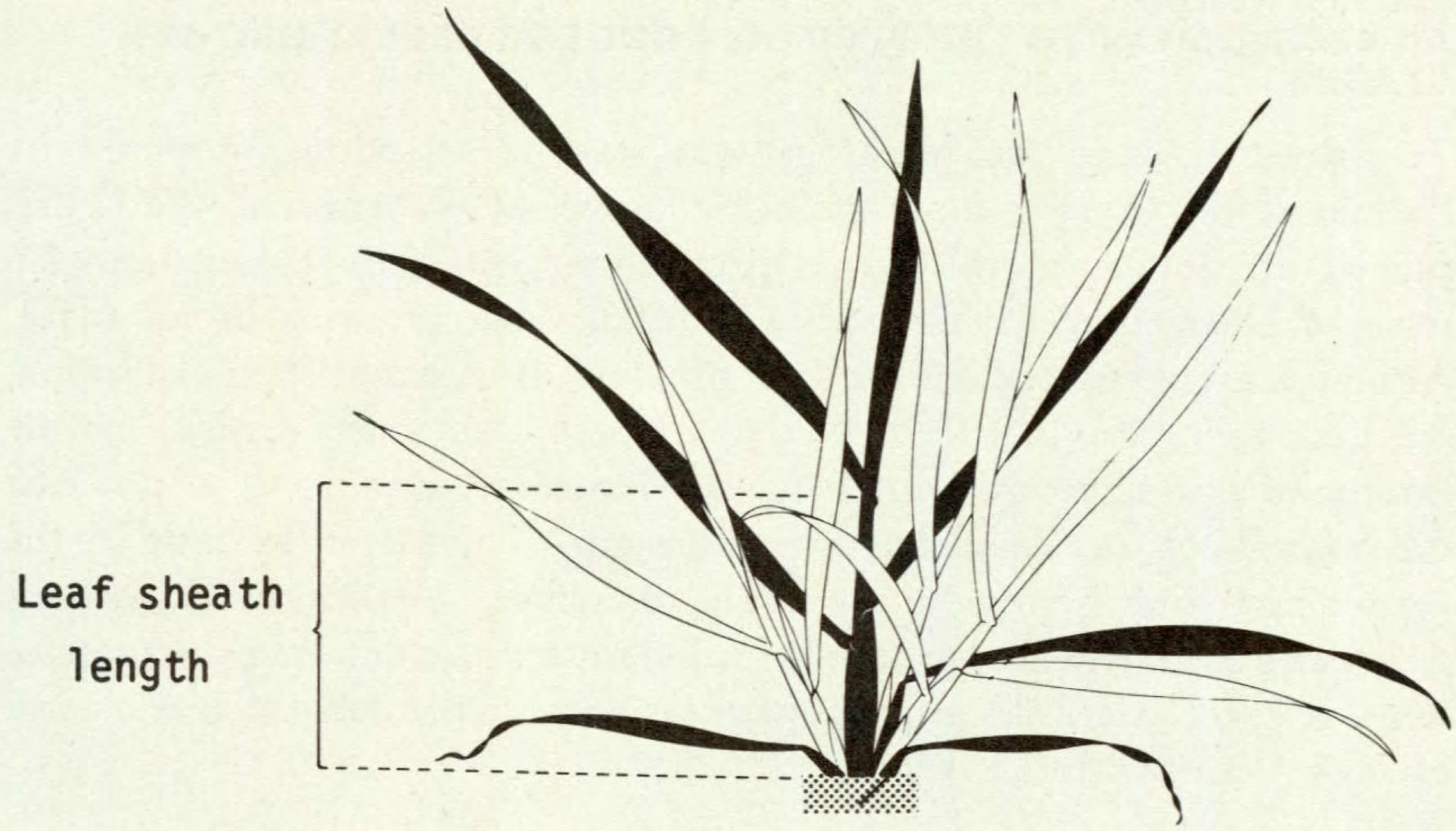


Fig. 2. Leaf sheath length: measure from ground level to uppermost ligule on main shoot.

lation with apical development and this has now been confirmed for a wide range of varieties with different growth habits in three seasons and at sites throughout the cereal growing areas of the U.K. When the leaf sheaths exceed 5 cm the positions of all the spikelets on the shoot apices will have been determined and serious ear deformity will be unlikely. This simple objective criterion enables the farmer to decide exactly when to spray. All he needs is a plastic ruler and an explanation on the herbicide can of what he has to measure. It also offers the agronomist a non-destructive method of estimating the stage of apical development.

There is again confusion at the latter end of the spray period over the identification of the beginning of jointing. The WRO study also showed a close parallel between the detection of the first nodes and a longest leaf sheath length of 10 cm. However, this observation is based on less evidence than the 5 cm measure and still needs confirmation. If it is confirmed future instructions for the use of 'growth regulator' herbicides in winter wheat may well be rephrased in terms of leaf sheath lengths, for example, 'spray when the leaf sheaths exceed 5 cm but before they reach 10 cm'.

AN AMENDMENT TO THE DECIMAL CODE FOR CEREAL GROWTH STAGES

The decimal code for cereal growth stage descriptions proposed by Zadoks *et al* (1974) is now achieving universal recognition. WRO has played an important role in its promotion with the preparation of a series of illustrations for the code (Tottman, Makepeace & Broad 1976). Although more comprehensive than previous attempts at standardisation, the code in its original form fails to pinpoint the stages critical for the timing of herbicides in winter wheat. However, Zadoks *et al* describe the main shoot leaf sheaths as a 'pseudostem'. The use of the code by the agronomist and herbicide user can, therefore, be improved without detracting from its value as a universal standard, by defining the pseudostem as erect (decimal growth stage 30) when the longest leaf sheath exceeds 5 cm (Tottman, 1976).

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Progress in the development of controlled drop application of herbicides

G. W. CUSSANS and W. A. TAYLOR

The WRO contribution to the development of controlled drop application (CDA) was reviewed in the 1974–75 WRO Biennial Report (Taylor & Holly, 1976). Since this last review, there has been growing awareness of the need to raise the often deplorable standard of operation of conventional spraying equipment (Rutherford, 1976), to re-appraise existing methods of applying herbicides, and to encourage new approaches to the application of agricultural chemicals.

Controlled drop application has been defined as the production of sprays with a drop size spectrum controlled to a greater extent than is possible with conventional hydraulic nozzles. In practice, most interest in CDA has centred upon the reduced water volumes that, without undue risk of drift, the technique makes possible. Thus, at WRO, we have worked within a closely controlled drop-size-range of 150 to 350 μm, and with volumes of 3 to 50 l/ha in contrast to the 200 to 300 l/ha commonly applied through hydraulic nozzles.

It is now widely realised that the reduction in spray volume consequent upon the introduction of CDA could enable much better use to be made of the limited time available to the cereal grower to apply the ever-increasing quantity of crop protection chemicals required to maximise yields. The logistic advantages are such that low volume methods of application are likely to be commercially successful even if they only achieve existing standards of chemical performance although, clearly, improved performance would be a desirable attribute.

WRO has made a significant contribution to the agronomic development of CDA but this needs to be seen in the context of the increasing volume of research activity elsewhere, from the fundamental studies at NIAE to other agronomic work by ADAS and by commercial companies. In addition, substantial progress has also been made at WRO in investigating the effects of herbicide concentration, formulation, deposition, and environmental factors on the plant response to controlled drop application. However, this article reviews only the agronomic research on this topic which has taken place at WRO and elsewhere in the last two years.

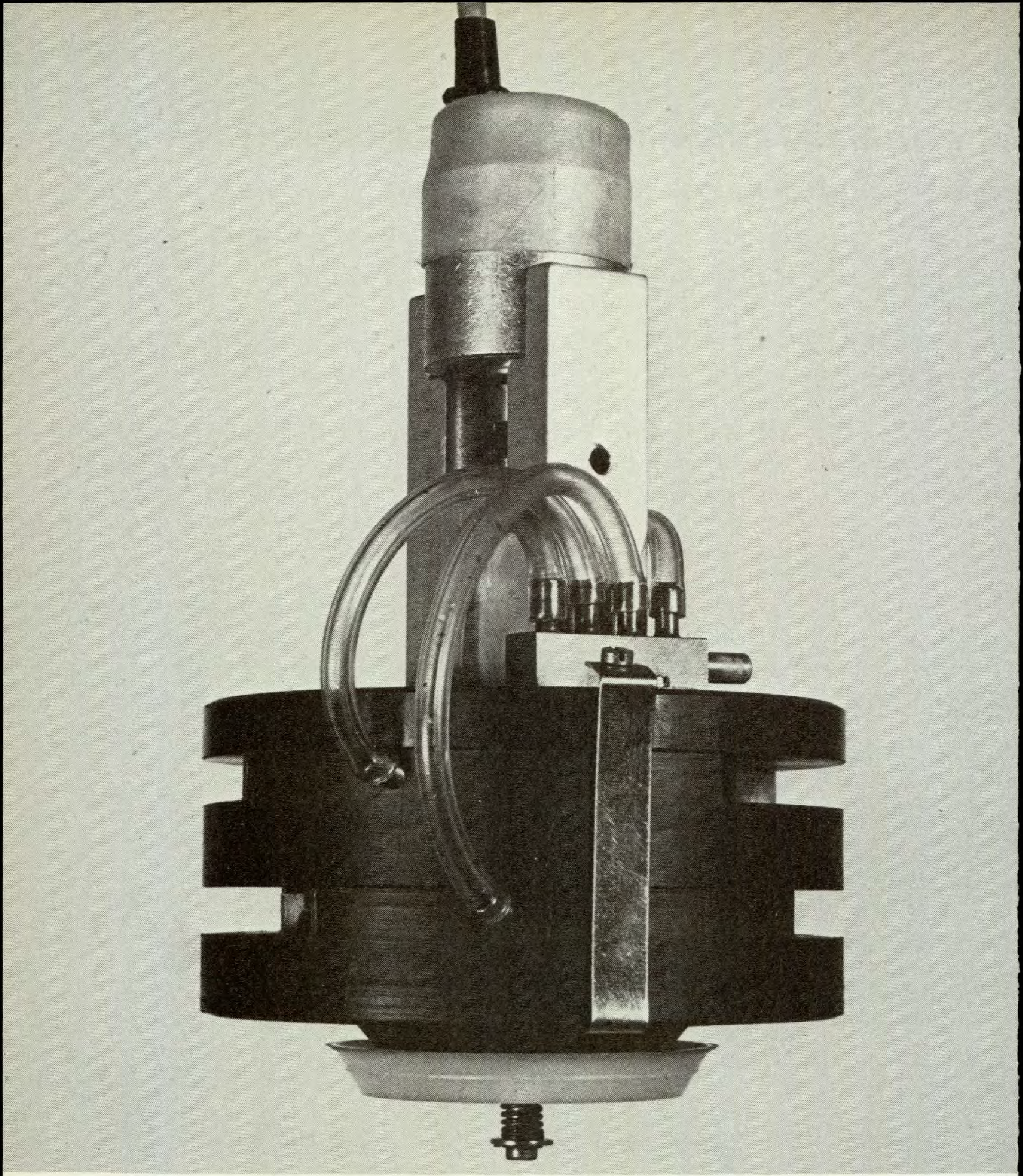

Fig. 1. This controlled drop application unit, initially designed and built at WRO, comprises three rotating discs, the upper two shrouded, the lower fully exposed. Units of this type are used on an experimental sprayer now produced by Cropsafe Ltd. Speed of rotation, and hence drop size and flow rate, can be monitored and controlled easily and accurately.

RECENT DEVELOPMENTS IN EQUIPMENT FOR CONTROLLED DROP APPLICATION

The 1974–75 WRO Biennial Report described the experimental spraying units developed at WRO in 1974/75 using the 'Herbi' discs, developed by Micron Sprayers Ltd., stacked vertically to achieve adequate throughput and shrouded to even out the horizontal distribution. These formed the basis of a tractor-mounted experimental sprayer for the treatment of large field plots. For the 1976 programme of field experiments we employed modified units developed and loaned to us by Horstine Farmery Ltd., embodying twin discs of which the upper disc only was shrouded, the liquid being fed on to these discs by gravity. These proved a success but required considerable care and experience to ensure accurate application. For the 1977 experimental programme therefore a new unit was developed collaboratively by WRO and Cropsafe Ltd. embodying three discs stacked vertically, the upper two being shrouded and the lowest one unshrouded (Fig. 1). This machine incorporated control of disc speed and flow rate of spray liquid and was thus versatile and accurate enough for experimental use. Concurrently, Horstine Farmery Ltd developed a wide-boom field sprayer employing a similar configuration of stacked and shrouded discs. This is now under commercial development as the Micro-drop sprayer.

All of this equipment embodied the same basic principle of direct drop formation. Drops are produced immediately from the circumference of the 'Herbi' disc within a very narrow spectrum of drop size. This system has the advantage that drop size can be closely defined and controlled, and also varied for experimental purposes. The main disadvantage is that direct drop formation occurs only at relatively low flow rates. Greater flow rates can be achieved by employing the process of ligament drop formation but the control of drop size is not then so precise. However, this process can reduce the number both of very large and inefficient drops and of the very small drift-prone drops, characteristic of hydraulic nozzles. Currently, both NIAE and Micron Sprayers Ltd are working on the development of a rotary atomizer based on ligament formation and the latter has now produced a new cone-shaped unit operating at higher flow rates. So far we have no information on the performance of this interesting device.

FIELD RESULTS WITH CONTROLLED DROP APPLICATION

Over the past 7 years we have completed over 200 experiments on pot-grown plants and over 70 experiments in the field comparing the performance of a range of herbicides applied conventionally and by CDA in volumes ranging from 5 l/ha to 100 l/ha and at drop sizes ranging from 150 μm to 350 μm.

The results of this extensive programme of work support the general conclusion that herbicides, as they are formulated at present, fall into three categories of behaviour in relation to low volume CDA applications.

(i) Herbicides showing an improved performance at very low volume controlled drop application. The best example in this category is glyphosate, which in pot and field experiments at WRO has shown a consistent trend to improved performance, generally of the order of 25–30% (Caseley *et al* 1976; Turner & Loader 1978). Although all our experiments included doses below those which are normally recommended, we have never been able to show the dramatic improvements in herbicide performance which have been claimed elsewhere for other crop protection chemicals.

(ii) Herbicides the performance of which remains substantially unchanged. It appears that most soil-acting herbicides, and those foliage-applied herbicides which are efficiently translocated throughout the plant, exhibit this response. We have worked extensively with the broad spectrum mixtures of MCPA and dicamba, with barban, and with tri-allate and other soil-acting materials (Ayres 1976; Ayres & Merritt 1978; May & Ayres 1978; Merritt & Taylor 1977; Taylor & Merritt 1974 (2); Wilson 1976; Wilson & Taylor 1978). Chemical companies have also had extensive experience with these materials, with growth-regulator herbicides, and with benzoylprop-ethyl, flamprop-methyl, etc. (Mayes & Blanchard 1978; Robinson 1978; F. R. Stovell, *pers. comm.*; O. Grosjean, *pers. comm.*). To date (May 1978) some 30 herbicides have been cleared under the Pesticides Safety Precautions Scheme for application at reduced volumes of 20–50 l/ha and with a controlled drop size of the order of 250 μm. A number of companies are developing commercial recommendations for these materials.

(iii) Herbicides showing a definite reduction in performance with very low volume controlled drop application although frequently giving an acceptable level of control. Into this category we must place those herbicides which have been consistently poorer in performance or unpredictable in their response to CDA. Our experience is largely with ioxynil and bromoxynil, with or without dichlorprop, but other evidence suggests that phenmedipham, bentazone and benazolin may also be reduced in activity at these very low volume rates (Cussans & Taylor 1976; M. J. May, *pers. comm.*). Difenzoquat is rather inconsistent in its response, sometimes giving better and sometimes much poorer performance (particularly in the summer of 1976) than when sprayed with conventional equipment (Wilson 1976; Wilson & Taylor 1978).

In general, the results which we have achieved in the field at WRO have been confirmed by those obtained by many chemical companies including The Boots Co. Ltd., Shell Chemicals (UK) Ltd., Union Carbide Ltd. There have, however, been some discrepancies between our results and those of ADAS (Bailey 1978).

THE DEVELOPMENT OF LIGHT-WEIGHT, LOW-GROUND-PRESSURE VEHICLES

The suggestion that the use of lower spray volumes with a consequent lower payload requirement could lead to the development of special purpose light-weight spraying vehicles was first put forward by Cussans and Taylor (1976). Such vehicles should be able to travel at speeds greater than are possible with normal tractors so that increased output could be maintained. In close collaboration with NIAE and their ADAS Liaison Officer, a number of small, rough-terrain transport vehicles were examined for this potential. Two vehicles were chosen, one equipped with tracks and the other with eight low-pressure tyres. A granular applicator was mounted on the tracked machine and a conventional boom with hydraulic nozzles on the wheeled vehicle. It was the latter which was used most extensively in the winter of 1977. A photograph appears on page 61. Nearly 20 ha of winter wheat and barley were treated with isoproturon or chlortoluron and limited applications of clofop-isobutyl were made to winter oats. This experience rapidly confirmed the potential of vehicles of this type. Spraying speeds of up to 20 km/h were shown to be feasible and herbicides applied in volumes of 60 l/ha gave excellent weed control. Even at these high speeds, boom stability was excellent and, most impressive of all, access was possible onto wet soils on which normal tractors could not possibly have worked.

FUTURE PLANS

Controlled drop application is now progressing steadily towards commercial exploitation and all concerned with herbicides have to face the implications of this for new and existing materials. In the past year we have already seen the development of one completely new atomizer and, with the interest this has generated throughout Europe, one can expect that there will be more to come. Our work with low-ground-pressure vehicles suggests that we shall have to accept that speed is a variable parameter of spraying comparable to pressure, nozzle size, drop size and other factors of atomization. The possibilities for future research are great and of growing complexity. However we shall continue, so far as we are able, to contribute towards the advancement of the agronomy and weed science of this complex though fascinating subject.

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The WRO/Letcombe Joint Tillage Project* in its closing stages

J. G. ELLIOTT and F. POLLARD
ARC Weed Research Organization
in collaboration with
R. Q. CANNELL, F. B. ELLIS, B. T. BARNES
and K. R. HOWSE
ARC Letcombe Laboratory

After nine years the field work of the joint tillage project is coming to an end. The experiments on sandy loam and Oxford clay soils have been completed after four and five years of measurements respectively (Elliott *et al*, 1974, 1976). Only the experiment concerned with the growth of winter wheat on a silt loam over chalk at Compton is still in progress.

With a decline in the field work emphasis has moved to the interpretation and reporting of results. Two papers describing the background to the project as a whole and reporting the growth of spring barley on sandy loam soil were published in the *Journal of Agricultural Science* (Elliott *et al*, 1977, Ellis *et al* 1977). Now attention is being focussed on the wheat and barley experiments on the clay soil; the results are currently being prepared for publication. It is likely that the joint project will yield several other papers in due course.

WINTER WHEAT EXPERIMENT AT COMPTON

On the site of the winter wheat experiment on silt loam over chalk at Compton the straw was burnt at the end of August 1976 and paraquat was applied in mid-September immediately before primary cultivations. Seedbeds were prepared and the crop drilled in satisfactory conditions on 20 October. There was uniform seedling emergence and little difference existed between treatments on 3 December, when there was a mean plant density of 253 plants/m^2. Thereafter, the number of plants on direct drilled plots began to decline until, by 14 April 1977, there were only 196 plants/m^2 compared with 267 plants/m^2 on the other plots. The spring growth was normal and there were no significant differences between the final yields of grain from direct drilled, shallow tined, deep

*By agreement between WRO and ARC Letcombe Laboratory, a report of the past year's progress is published each year, appearing alternately in the reports of the two Institutes. This report reviews the results for the 1977 cropping season.

tined and ploughed plots which were 5.72, 5.56, 5.39 and 5.67 t/ha respectively.

Although no significant differences in grain yield have occurred in any one year, over the three years 1975–77 the ploughed treatment has significantly out-yielded the other treatments by about 5%. It was not expected that ploughing would be superior on this easily managed, well drained soil. In the spring barley experiment on similar soil concluded in 1973 (Elliott *et al*, 1974), ploughing provided no advantage. In the coming year, we shall try to identify the possible causes of the apparently superior performance of ploughing on this site.

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Are tractors limiting the expansion of direct drilling?

J. G. ELLIOTT

WRO and direct drilling are closely associated, partly because they were born about the same time but mainly because a virtual avoidance of soil disturbance represents an ultimate in the impact that herbicides can have on crop production methods. In brief, if it is unnecessary to cultivate for weed control, perhaps it is unnecessary to cultivate at all. For 15 years or more this has been the great prize that has motivated our research on reduced cultivation and direct drilling in cereals and grassland. It is a prize worth winning: when the farmers of Britain cultivate their land they move enough soil each year to build an earthwork 40 m high and 300 m wide stretching from Exeter to Inverness: the saving in capital, energy and labour could be enormous.

A great deal of research, commercial and official, has been done on direct drilling over the past 15 years and the results have been well publicised, so why is it that the technique is employed on only a minute proportion of the nation's cropped land? There is no simple answer to this question but our research indicates one possible reason.

A great deal of experience has been gained by our staff in managing direct drilled and cultivated soils over some nine years. We have learned as a farmer does, the hard way, how to prepare land for sowing. Particularly important is the avoidance of mistakes in soil handling on land to be direct drilled because, where no cultivation occurs, mistakes cannot be buried by ploughing or forced into some sort of tilth by discs. The key to success in direct drilling is the avoidance of mistakes.

ERRORS IN DIRECT DRILLING

There are two common causes of error, one superficial and often easy to prevent, the other complex and the subject of this article; but first a word about the easy one—straw.

A straw-littered surface obstructs the passage of drills, may release toxins to affect the germinating cereal, encourages slugs and may smother the emerging crop. The use of a box of matches to burn straw properly in accordance with the NFU Code is straightforward and should be

This article is based upon a submission to the Crop Engineering Committee of the Engineering and Buildings Board of the Joint Consultative Organisation.

carried out wherever possible on fields to be direct drilled. If the straw cannot be burnt successful crop establishment is more difficult but not impossible, particularly with spring cereals (Pollard, 1977). However, a clean soil surface is a major advantage when direct drilling.

The other and more difficult problem is caused by wheelmarks. Over many years and on many—but not all—soils we have observed the development of a natural surface tilth which, if it can be preserved, provides a ready-made seedbed for the next crop (Elliott *et al*, 1974). It is our impression that this tilth builds up in summer under the crop canopy and declines when the surface is bare and exposed to rain during winter. With the preservation of surface tilth in mind we have been perturbed at its destruction by the wheels of tractors, trailers, drills and combines: this has encouraged us to question the suitability of the present range of vehicles and machines for direct drilled soils. Our conclusion, after much field observation and exploration of the literature, is that the requirements of machines for direct drilling are very different from those of conventional tillage and that this is an issue of great importance to farmers and engineers.

THE UNSUITABILITY OF TRACTORS

The engine power, the weight, the tyre design of a modern tractor and much of the equipment associated with it have evolved over the years to meet its most demanding task, traction for cultivation. The advances in traction have been achieved at the expense of soil compaction, as the following extracts from the literature show.

> 'Numerous studies have shown that loaded wheels compact most moist soil, reduce porosity and so reduce permeability to both water and air. There is also much evidence from field observations and experiments relating restricted root growth to the over-compaction caused by machinery in general, and field tractors in particular' (Davies *et al*, 1973).

> 'Of the many variables involved in the soil/vehicle interaction, wheel slip is one of the most important, producing a higher density in the soil during machinery operation. Compaction was found to reach a maximum between 15% and 25% slip and was less at higher slip rates, the soil being pushed sideways causing deep ruts. The usual operating value of 20% slip was in the slip range causing the greatest compaction' (Raghaven *et al*, 1977).

'Slip occurs, not between tyre and surface, but within the soil itself. So your tyres must penetrate the harder foundation' (Dunlop leaflet).

'The specific surface pressure and the total weight of the vehicle and machinery are of decisive importance for the extent of the compaction' (Danfors, 1977).

'The most important method of avoiding soil compaction by agricultural equipment is to restrict equipment generating high soil pressures to soils which are sufficiently dry that little or no further compaction can take place' (University of California, 1976).

'Remoulded soils compress more rapidly than undisturbed soils at the same initial density and water content. Soils that are not tilled would be less susceptible to compaction and tractors and other vehicles would cause less compaction when travelling at high speeds' (Dexter & Tanner, 1974).

In order to provide traction, tractors have relatively high axle loadings on tyres that are designed to work in loose soil, penetrating it and slipping causing compaction or ruts. These effects are increased in wet soil and decreased in dry soil: they are accentuated in tilled soils with slow moving traffic, and lessened on untilled soils with traffic going fast. A reduction in vehicle weight and surface pressure is vital to a reduction in compaction.

It is no criticism of agricultural engineers who have done so much to improve tractor performance on tilled soils, to suggest that tractors are inappropriate for untilled soils on which the most demanding task is no longer traction in soil but the carriage of materials over the surface (Table 1) and where compaction and slip are the reverse of what is required.

Table 1 Task rating of field work involved in the production of cereals: high (H); medium (M); low (L)

Task	Traction in soil	Materials		
		carriage	placement	processing
Ploughing	H	L		
Tine and disc cultivation	H	L		
Drilling	L	M	H	
Fertiliser broadcasting		H	H	
Spraying		H	H	
Combine harvesting		L		H
Grain transport		H	L	
Straw baling		L		H
Bale carrying		H	M	

So what alternative to the tractor is there? To answer this question let us analyse the loads involved in growing a direct-drilled crop of cereal, which are:

Carriage and placement		*Weight of material (kg) per 5 ha.*
seed	(1 pass)	800
fertilisers	(2–3 pass)	2000
sprays	(3–6 pass)	1100 (conventional), 110 (low volume)

LOAD CARRYING VEHICLES

A vehicle designed primarily to carry loads does not look like a tractor: it usually contains the load centrally with a wheel at each corner and engine and driver at the front. It can usually carry a payload of more than its own weight, unlike a tractor which may weigh 3 tonnes unladen. Many load carriers are capable of greater speeds than can be achieved by a tractor. And most important, load carriers are made in vast diversity to meet the varied requirements of our society and are often relatively cheap because they are mass produced.

To a truck designer the loads to be carried for growing a cereal crop are relatively light: a payload of 2 tonnes is usually the upper limit of a light commercial truck. Even the 6 tonnes output of grain from a combine could be carried by a medium category truck. Could it be that mass-produced trucks could provide minimum useless weight, maximum efficiency in load-carrying and speed over the field at an economical cost? If fitted with terra tyres designed for low pressure, could they not carry the required loads with less wheel-marking? Surely the possibility is worth detailed study.

At WRO we have recently had the opportunity of testing a four-wheel-drive truck with 1.75 tonne load capacity and fitted with a new device to prevent wheel spin*. The cross-country tests of this vehicle on radial tyres suggest that it could have a place in agriculture for such tasks as sowing, fertiliser distribution and conventional spraying at speeds up to 25 kmh. In its present form this truck would minimise the carriage of unnecessary weight (1146 kg, unladen) and provide adequate power (60 kW), but it would not necessarily reduce wheelmarking. However, were it or a similar vehicle fitted with terra tyres operating at 350 g/cm^2 and designed for speeds up to 48 kmh, it might do all that is required with much less wheelmarking than a tractor.

*The vehicle was a Bedford C-F 340 truck modified to Ferguson Formula All-Wheel-control by FF Developments Ltd., and made available by Tractor Research Ltd.

The Argocat, a lightweight low ground pressure vehicle made available by All Terrain Vehicles Ltd, has been extensively used in trials of high speed, low volume spraying at WRO in soil conditions which would immobilize ordinary tractors.

WRO has also been using another light-weight vehicle, the Argocat, which is described on page 53, for low volume spraying at high speeds with light loads. Its performance indicates that is is complementary to the light truck described above and that if properly developed the two vehicles could provide for most of the tasks needed in growing cereal crops by direct drilling. With their moderate cost (say £4000–£5000 for each) and enhanced capacity to cover large areas at high speed, these vehicles offer a major opportunity to get more work done each day by less labour at a lower capital cost that is now possible. Since both vehicles would operate at low ground pressure it should be possible to use them in a wider range of soil moisture conditions than would be achieved with a conventional tractor. If this were the case then the potential for working an increased number of days during the critical autumn and spring periods would greatly enhance cereal farmers' capacity to manage their crops.

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