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MATERIALS PLACEMENT

Having conveyed the materials, namely fertilisers, crop protection chemicals and seeds, over the field surface, it is necessary to place them.

The majority of fertiliser is now broadcast on cereal farms and therefore a switch to a truck rather than a tractor would create no problems. Indeed it is possible to buy demountable hoppers and spreaders built as one unit of the type commonly seen spreading salt on roads.

A similar situation obtains in the application of crop protection chemicals, whether at low or conventional volumes of liquid or as granules. The current range of applicators can be mounted on a truck chassis as easily as on a tractor, possibly more easily.

Only in respect of sowing seed into uncultivated soil is the attachment of a drill to a light truck an unknown quantity. Here there is still a need for R and D. The triple disc principle was originally developed to sow seeds into killed grassland during summer when compacted surfaces might be hard. This is in contrast to a surface of natural tilth, unwheel-marked, in autumn; a surface into which it is often possible to scratch one's index finger. Do we really need massive power and traction to place 20 rows of seed (each of which is only 7 mm long by 5 mm wide) to a depth of 3 cm in such soil? Yet current direct drills are designed to be pulled by tractors so farmers have no hope of avoiding the use of tractors at present.

OTHER TASKS

Many people would regard it as naive to think that vehicles such as have been described could provide for all the requirements of a cereal farm. What vehicle could cultivate the headlands to ensure safe burning? From what vehicle would the hedgetrimmer be operated? There are a multiplicity of tasks on the average farm which have been attached to the one vehicle known to be on the farm at present, the tractor. An analysis of these other jobs suggests that their principal requirement is a mobile platform and a power unit. Why cannot such a platform be a truck rather than a tractor? A medium-sized four-wheel-drive truck of, say, 6 tonne load capacity, has an engine power similar to a heavy tractor. If a light truck is the answer to many of the transport requirements for light tasks on the field, perhaps a medium truck might be the answer to some of the heavier tasks on the farm. But could such vehicles be operated without invoking the regulations relating to heavy goods vehicles?

CONCLUSION

In a short article such as this, it is not possible to venture into great detail. Until someone equips a farm with light vehicles no one will know what is possible. But the principle must surely hold that the modern tractor was designed primarily to provide traction. At around £100 a horse power the British arable farmer is paying heavily for this provision to the extent of £160 a hectare (Nix, 1978). Direct drilling offers the opportunity of avoiding this requirement and much of the capital expense that goes with it. Light vehicles could avoid the destruction of the natural tilth that ought to be exploited in a direct drilling system. Light vehicles are also capable of going fast over level fields with the minimum of wheelmarks and should mean greater work output at reduced cost of vehicle, fuel and labour. These are the real benefits that direct drilling has to offer. As long as farmers are encouraged to go on using all their heavy and expensive traction equipment for direct drilling it is not surprising that many see no tangible advantage in changing to this new technique.

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The control of groundkeeper potatoes

P. J. W. LUTMAN

The volunteer potato or groundkeeper has become a weed problem not only in Britain but also in other European countries, in N. America and in Australasia.

The origin of the groundkeeper problem is the inability of any existing potato harvester to remove all the tubers from the field. Investigations carried out under the WRO groundkeeper research project have shown that up to 367,000 tubers/ha may remain in the field after harvest (Lutman, 1977 a). Many of these tubers survive the winter and produce shoots that emerge in the next crop in the following spring and summer. If the crop offers little competition, like carrots, the potatoes will grow very vigorously and crop yield may be depressed. Volunteer potato plants can also contaminate pea and bean crops grown for processing and interfere with the harvesting of cereals, particularly if the latter become lodged early in the summer. As well as having direct effects on subsequent crops, groundkeepers may also adversely affect the health of following crops of potatoes by encouraging pests and diseases. The wide distribution and importance of volunteer potatoes within Europe and the need to maintain and increase liaison between the research workers studying this weed led to the establishment of a joint European Weed Research Society/European Association for Potato Research working group in 1977.

BIOLOGY OF WEED POTATOES

In order effectively to control volunteer potatoes it is essential to find out as much as possible about their biology. Over the past few years we have investigated most aspects of groundkeeper biology.

Winter survival

Potato tubers are susceptible to frost, but require 50 frost hours with temperatures below −2°C before they are killed (e.g. 25 hr at −2°C; 5 hr at −10°C) (Lumkes & Sijtsma, 1972). During the recent series of mild winters in Britain, most buried tubers were not exposed to frosts cold enough to kill them. However, our experiments indicated that up to 80% of the tubers left after the potato harvest died during these winters (Lutman, 1977a). Despite this, appreciable numbers of viable tubers were left to cause weed problems in the following crops.

Emergence and growth of volunteers

In the absence of a crop the emergence of potatoes depends primarily on the spring soil temperature and the depth of the tubers in the soil. In most years, provided that the tubers are not deeply buried, they start sprouting at the end of March and the sprouts emerge about one month later. However, the presence of a crop delays sprout emergence considerably. Our studies in winter wheat showed that potatoes were still emerging in June and, in one experiment in winter barley, many potatoes did not emerge until after the crop was harvested in July.

Daughter tuber production

The persistence of volunteer potatoes depends on the production of daughter tubers. The more daughter tubers/plant, the greater the weed problem and the performance required from a herbicide. In a competitive crop like a cereal, each potato plant produces up to three daughter tubers, seldom more than 1 to 3 cm in diameter. In less competitive crops like sugar beet, cabbage and onions the potatoes may produce many larger tubers.

HERBICIDAL CONTROL

It soon became apparent, both at WRO and in Holland, that volunteer potatoes are difficult weeds to kill with soil- and foliage-applied herbicides. The size of the food reserves in the parent tubers enables the plants to recover from damage lethal to other weeds. In addition, the observed late emergence of potatoes in many crops makes the successful timing of any potentially active foliage-applied compounds very difficult.

Soil-applied herbicides

Preliminary glasshouse studies indicated that the soil-applied herbicides trifluralin, propyzamide and chlorpropham might be sufficiently active against potatoes to achieve acceptable levels of control in the field (Lutman, 1974 b). Subsequent field experiments showed that chlorpropham was not sufficiently active while propyzamide and trifluralin would only control potatoes at doses not tolerated by subsequent crops (Lutman, 1977 b).

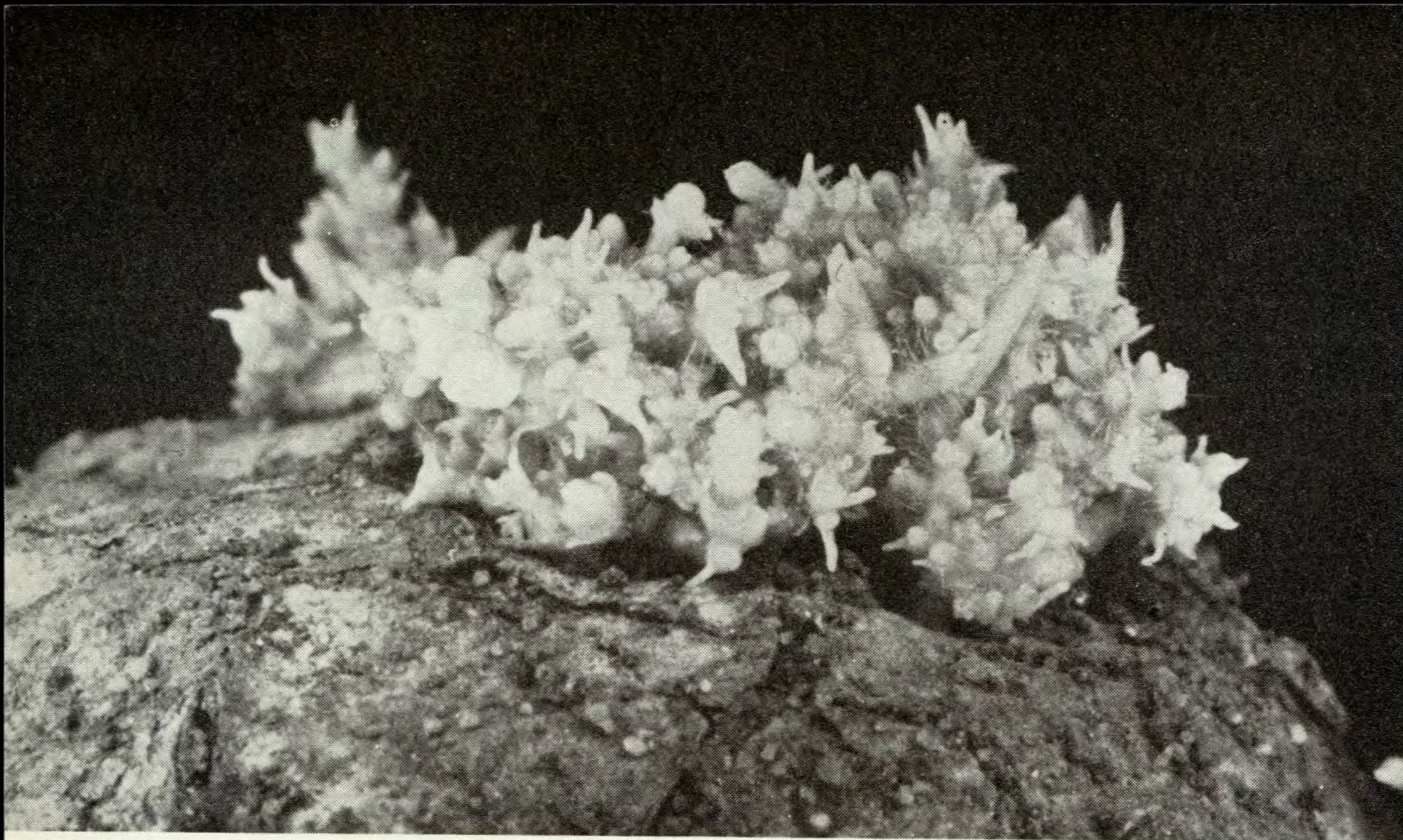

Fig. 1. Deformed sprouts produced by tuber of volunteer potato plant treated with sub-lethal dose of glyphosate.

Glyphosate and aminotriazole

Glyphosate is the most active of all the herbicides tested both at WRO and in Holland (Sijtsma, 1977; Lutman & Richardson, 1978). Our field trials have shown that excellent control of potatoes can be achieved with doses in excess of 1 kg/ha a.i., provided that all the potato sprouts are fully emerged when treated. These and other experiments show that glyphosate will not kill unemerged sprouts even though other treated sprouts on the same tuber may have a considerable leaf area. In addition to killing the haulm of potato groundkeepers, this herbicide at rates in excess of 1 kg/ha will also kill the daughter tubers.

Sub-lethal doses of glyphosate (0.25–0.5 kg/ha) resulted in the production of a large number of small tubers. Sprouting tests showed that these were not viable as their sprouts were severely deformed (Fig. 1). However, these low doses would probably not give reliable field control.

Amino-triazole also gives an acceptable level of control of groundkeepers but because, unlike glyphosate, it has some residual activity in the soil it cannot be used in as many situations as the latter.

Time of application. Both these two herbicides are non-selective, so they can only be applied to groundkeepers in the absence of a crop or by directed application between the rows of a crop. Our studies of groundkeeper biology indicated that probably the best time of the year to apply them is in the autumn, after the harvest of a cereal crop. Volunteer potato plants growing in cereals will regrow from the cut stem stumps left after the passage of a combine harvester. In our trials, regrowth was good following winter barley but poor after spring barley. The greater competitive effect of the winter barley seems to encourage more autumn regrowth than the less competitive spring barley. To achieve an acceptable level of control a high percentage of cut stems must regrow because, by harvest time, most plants will have produced daughter tubers and tubers attached to stems that do not regrow will not receive any herbicide. In our experiments following winter barley, over 90% groundkeeper control was achieved applying glyphosate at doses over 1 kg/ha. However, the control achieved after spring barley, where regrowth was weak, was unacceptably low (Table 1). Currently, experiments are in progress to compare the performance of glyphosate after winter barley, winter wheat and spring barley.

Table 1 Groundkeeper control in barley stubble with glyphosate

Year	Crop	Dose range (kg/ha)	% Control
73	Spring barley	0·5–2·0	29–34
74–75	Winter barley	0·5–2·0	72–80
75–76	Winter barley	0·75–3·0	90–95
76	Spring barley	0·75–3·0	7–48

Directed applications. Because glyphosate is so good at controlling groundkeeper potatoes, there has been considerable interest in developing other ways of using it, including applying it to potato plants prior to drilling late-planted crops, or as an inter-row treatment. The latter has been studied in Holland and the original prototype sprayer achieved excellent results, but more recent models have not been so successful. A new line of research now being pursued at WRO is the application of non-selective herbicides in a selective way based on exploiting the greater height of the weed potatoes in many vegetable crops.

Other herbicides

Apart from glyphosate and amino-triazole, few foliage-applied herbicides show much activity against potatoes. Metoxuron is used commercially to control volunteer potatoes in carrot crops but its performance is rather variable. In experiments at WRO the susceptibility of potatoes to this herbicide varied both with the variety and the size of the parent tubers (Lutman & Davies, 1976; Lutman, 1977 c). The overall conclusion was that metoxuron's performance declined as the vigour of the potato plants increased. We also screened a number of cereal herbicides for their activity against potatoes but, although some caused damage, the potatoes generally recovered.

MECHANICAL CONTROL

If the design of potato harvesters could be improved so that few tubers were left in the field after harvest, the groundkeeper problem would be solved. However, it is very difficult to separate the soil from the tubers without some tubers being returned to the field. Considerable research effort has already been expended in Holland on this problem and a number of harvesters are now available that retain and collect or crush the tubers normally left behind.

The level of mortality of potato tubers during the winter can be influenced by the type of tillage system used in the autumn and winter. Ploughing, which buries tubers deeper than straight tine cultivation, protects them from frost and thus increases survival. Dutch research has demonstrated that a straight tine cultivator with the tines set at approximately 60° buries fewest tubers (Lumkes & Beukema, 1973; Lumkes, 1974). Our own research confirmed that straight-tine cultivations bury fewer tubers (Lutman, 1974 a) but, in the recent mild winters, even shallow buried tubers have not been killed by the frost.

THE FUTURE

None of the existing methods of control are completely effective. To achieve high levels of control at the present time it is necessary to combine the use of harvesters with crusher attachments, non-inverting cultivations, and herbicide treatments in whatever combinations are practicable.

Although glyphosate can eliminate potatoes almost entirely, our experiments have only achieved this level of control in winter barley stubble. Thus, some further development work is still required to determine more precisely those factors that affect the autumn regrowth of potatoes and subsequent success of control with glyphosate. In particular the activity of glyphosate in winter wheat stubbles will be studied in more detail.

Other uses for glyphosate including selective application and inter-row treatments will be followed up to determine their practical potential.

In association with colleagues in the Weed Science Department, the screening of new herbicides for their activity against potatoes will be continued. Preliminary experiments have indicated that two relatively new herbicides, triclopyr and 3,6-dichloropicolinic acid, may have some potential for groundkeeper control, but further work is required to determine their selectivity, particularly in cereals.

It is hoped that one or more of the Dutch potato harvesters, modified to reduce the numbers of leavings, will be tested under British conditions.

It is proposed that studies of a more physiological nature should be carried out by ex-members of the ARC Unit of Developmental Botany now working for WRO. A deeper understanding of the physiology of sprout growth and tuber initiation would undoubtedly assist with the development of more effective control measures.

ACKNOWLEDGEMENTS

I would like to express my appreciation of the close co-operation between WRO and the members of the Dutch Volunteer Potato Working Group. This liaison has avoided unnecessary duplication of research effort and assured that the study of this weed and the development of effective control measures have been carried out as efficiently as possible.

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The consequences of repeated applications of chlorthiamid and dichlobenil in blackcurrants

D. V. CLAY

Most fruit growers rely completely on herbicides for controlling weeds. Using foliage-acting and persistent soil-acting chemicals they are able to ensure the virtual absence of weeds for the whole year without recourse to cultivations. In blackcurrants this has lead to a considerable saving in production costs. Furthermore, improved bush growth and larger fruit yields result from the roots exploiting the surface layers of the soil unchecked by weeds or damage from cultivations. But there are still problems from resisistant weeds, particularly field bindweed (*Convolvulus arvensis*) which can spread rapidly in the absence of competition from other weeds. It not only competes with the crop but interferes with mechanical harvesting and pruning.

One solution to this problem is the use of high doses of the two related granular herbicides chlorthiamid and dichlobenil. At the rates currently recommended (about 10 kg/ha a.i.) they do not control the weed, but higher rates (20 kg/ha) are effective (Davision, 1970). Chlorthiamid itself is not herbicidally active but is rapidly converted to dichlobenil in the soil.

The use of higher doses raises a number of questions. Will the crop growth and yield be adversely affected? Will there be unacceptable residue levels in the fruit and changes in flavour? If applications are repeated for a number of years will herbicide residue levels build up in the soil and be a danger to subsequent crops? To provide some information on these questions a blackcurrant plantation established in 1966 at WRO was treated with high rates of chlorthiamid and dichlobenil each year from 1968 to 1972. The bushes were removed in 1973 and test crops sown over the area in 1974 and 1975. The results are summarised and discussed in this article. The work will be published in detail elsewhere.

CROP GROWTH AND YIELD

Doses of up to 54 kg/ha per annum of chlorthiamid or of dichlobenil had no effect on crop growth compared with untreated, handweeded plots or those receiving simazine annually. However, applications of 13 kg/ha or more of chlorthiamid produced marginal chlorosis of some leaves during the summer of 1969. The chlorosis was more severe with higher doses but was not much worse in later years. The symptom was less noticeable with corresponding rates of dichlobenil. This leaf margin chlorosis is produced by the major breakdown product of dichlobenil in the soil, 2,6-dichlorobenzamide (Verloop, 1972). The symptom is seen in many perennial crops following treatment but there is no evidence that any inhibition of crop growth results. Yield of fruit was unaffected by any herbicide treatment, both treated and untreated plots averaging about 14 t/ha of fruit each year. Established blackcurrants therefore appear to have a considerable degree of tolerance to these herbicides.

FRUIT QUALITY AND HERBICIDE RESIDUES

Samples of fruit from the 1971 and 1972 crop were canned in syrup and tested for treatment effects on flavour by the Fruit and Vegetable Preservation Research Association, Chipping Campden. No treatments caused taint; there were occasional flavour changes detected but these were not adverse. Similar results were obtained from tests on gooseberry fruit from plots receiving comparable treatments (McKone *et al*, 1971). Fruit from the 1971–1973 harvests was analysed by gas-liquid chromatography for residues of total nitrile (dichlobenil+chlorthiamid where present after oxidation to dichlobenil) and 2,6-dichlorobenzamide. Nitrile residues were not detected (limit of detection 0.008 ppm) except for 0.012 ppm found in one sample from the highest chlorthiamid rate. Residues of 2,6-dichlorobenzamide were found in fruit from all treatments; these reached a maximum of 1.6 ppm from plots receiving 54 kg/ha chlorthiamid but levels were lower with smaller doses and with comparable dichlobenil treatments. Amounts also declined considerably between the 1972 and 1973 seasons, no herbicide having been applied in 1973. This suggests that much of the benzamide residue in 1971 and '72 may have come from the breakdown of the freshly-applied herbicide. The levels of benzamide occurring in the fruit would not be considered a hazard to consumers since this compound is of low mammalian toxicity (Beynon & Wright, 1972). A similar pattern of residue levels in fruit was found in experiments with doses of these herbicides in gooseberries (McKone *et al*, 1971).

SOIL RESIDUES

Each spring, just before the next herbicide application, soil samples were taken from most of the WRO plots and analyzed for total nitrile and 2,6-dichlorobenzamide content. Gas-liquid chromatographic methods were used and minimum levels of detection were of the order of 0.01 to

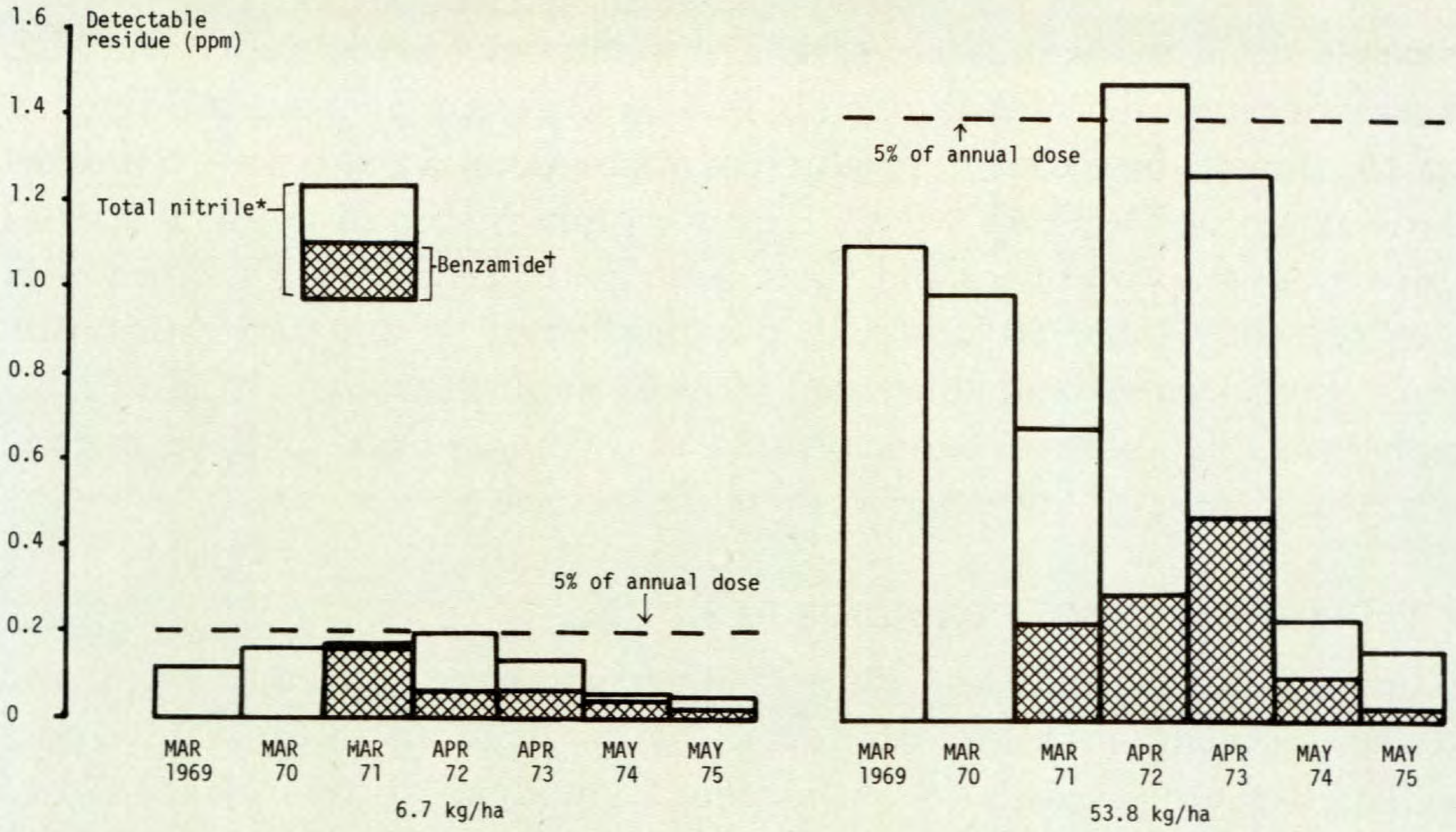

Fig. 1. Soil residues of total nitrile and 2,6-dichlorobenzamide from repeated applications of chlorthiamid at 6.7 and 53.8 kg/ha p.a. from 1969–72. Samples were taken from 0–15 cm depth each spring just before the next herbicide application.
*** Dichlobenil + chlorthiamid where present.**
† Not tested 1969, 1970.

0.02 ppm by weight. There was no indication of an accumulation of residues with repeated applications (Fig. 1). The amounts detected were never more than 10% of the dose applied. However, this proportion may have more phytotoxic significance than with most other herbicides since only a small proportion of the compound applied to the soil is active as a herbicide. It has been found that 80% of that applied may be lost in the month after treatment, much of it by evaporation (Verloop, 1972). Nearly all the total nitrile found was in the top 15 cm of the soil. Amounts were generally proportional to the dose applied and there was always less residue from dichlobenil than chlorthiamid.

Soil residue data from one site may not be typical of the situation elsewhere because of the effects of soil and climate on herbicide degradation. Therefore further information on soil residues was obtained from four other sites with different soil types where gooseberries had been treated with a range of doses of the same herbicides for up to three years. Total nitrile residues in the winter following the last spring treatment varied from 5 to 20% of the annual doses (Davison & Clay, 1972). The largest residues were found in the lighter soils and where applications were made in May compared with March.

Residues remaining in the plots of the WRO experiment one year after the final application disappeared more slowly than the freshly applied herbicide. This occurred in spite of ploughing and cultivations in the two years following the grubbing of the plantation. The apparently slower breakdown may result from the unavailability of such residues to microbiological breakdown or represent the slow release of residues not detectable by the analytical methods used. A similar reduced disappearance rate following repeated treatments was also found at Stockbridge House Experimental Horticulture Station, Cawood, Yorkshire in one of the experiments involving gooseberries. Residue levels were measured for three years after the last application. Loss of herbicide was small in the second year after final treatment but more rapid following grubbing of the bushes and cultivations. Some of the loss in the final period may be accounted for by dispersal to untreated plots during cultivations. Williams (1974) has also reported the slow rate of loss of small residues of dichlobenil in soil.

Residues of the breakdown product 2,6-dichlorobenzamide in the 0–15 cm layer were less than total nitrile for the whole period (Fig. 1). There was thus no accumulation in the surface layer but larger amounts were recorded from 15–30 cm depth. This compound is relatively stable in soil but only weakly adsorbed (Verloop 1972) and therefore loss by downward leaching by rain was possible. To check on this deeper samples were taken from two chlorthiamid treatments to 105 cm depth. One year after the last treatment residues were found at all levels (Fig. 2) but three and a half years after the last application most of the benzamide had disappeared at all soil depths. The results suggest that this persistent metabolite is gradually leached out of the soil; similar results have been reported following repeated applications of chlorthiamid to vines in Europe (Osgerby, 1972).

SUBSEQUENT CROPS

Following the final application of chlorthiamid and dichlobenil in spring 1972 the WRO plantation received an overall application of simazine in spring 1973 and was grubbed the following autumn. After autumn ploughing and spring cultivation, a range of crops were sown on the plots in 1974 to test for phytotoxic effects of herbicide residues. Crops differed markedly in their response. Barley and cabbage were unharmed by any treatment, being unaffected by residue levels of up to 0.24 ppm of total

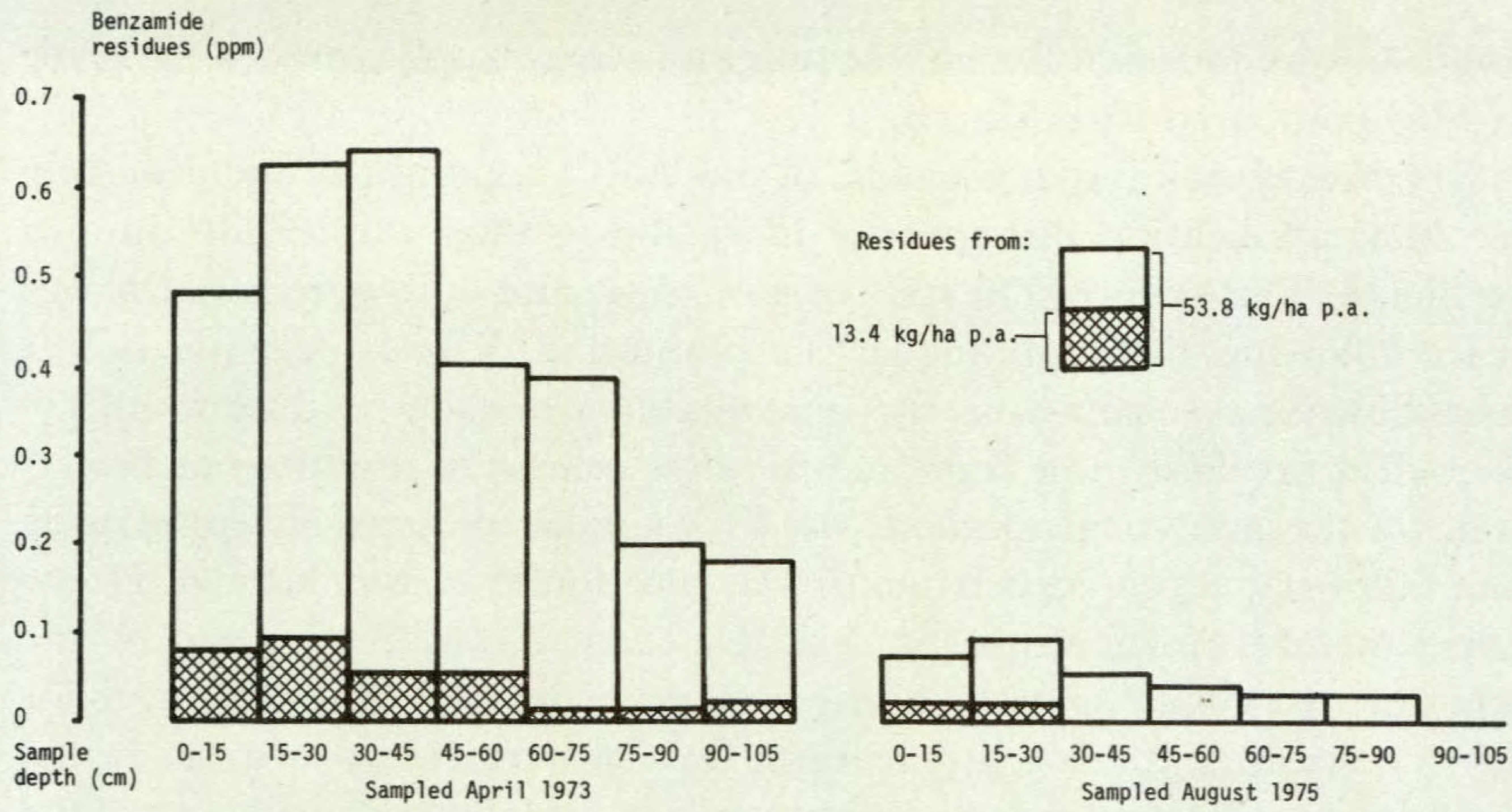

Fig. 2. Residues of 2,6-dichlorobenzamide at different soil depths, one and three years after the final annual application of chlorthiamid at two rates.

nitrile in the soil, whereas all treatments had severe effects on lettuce and carrots (Fig. 3). Wheat was intermediate in response. A similar pattern of crop response was found in earlier work (Clay & McKone, 1968; Williams, 1974). In the following year (1975) when carrots were sown over the whole area, only the two highest chlorthiamid rates caused a growth reduction.

The nitrile residues not only reduced the numbers and growth of carrots, they also affected their morphology. In many plants small horizontal ridges occurred over the whole tap root surface. This symptom was found on some roots in all treatments, even where there was no growth reduction. Compared with normal carrots, the outer cortex of affected roots had an increased number of cork layers and the pronounced ridges were composed almost entirely of cork cells. Splitting of tap roots was also observed in roots harvested in 1975 being most severe in plots treated with the two highest rates of chlorthiamid. Dichlobenil increases the brittleness of tissues (Verloop, 1972) and this may account for the increased root splitting.

These results highlight the need for care in the choice of following crops where persistent herbicides have been used. While on many holdings, a

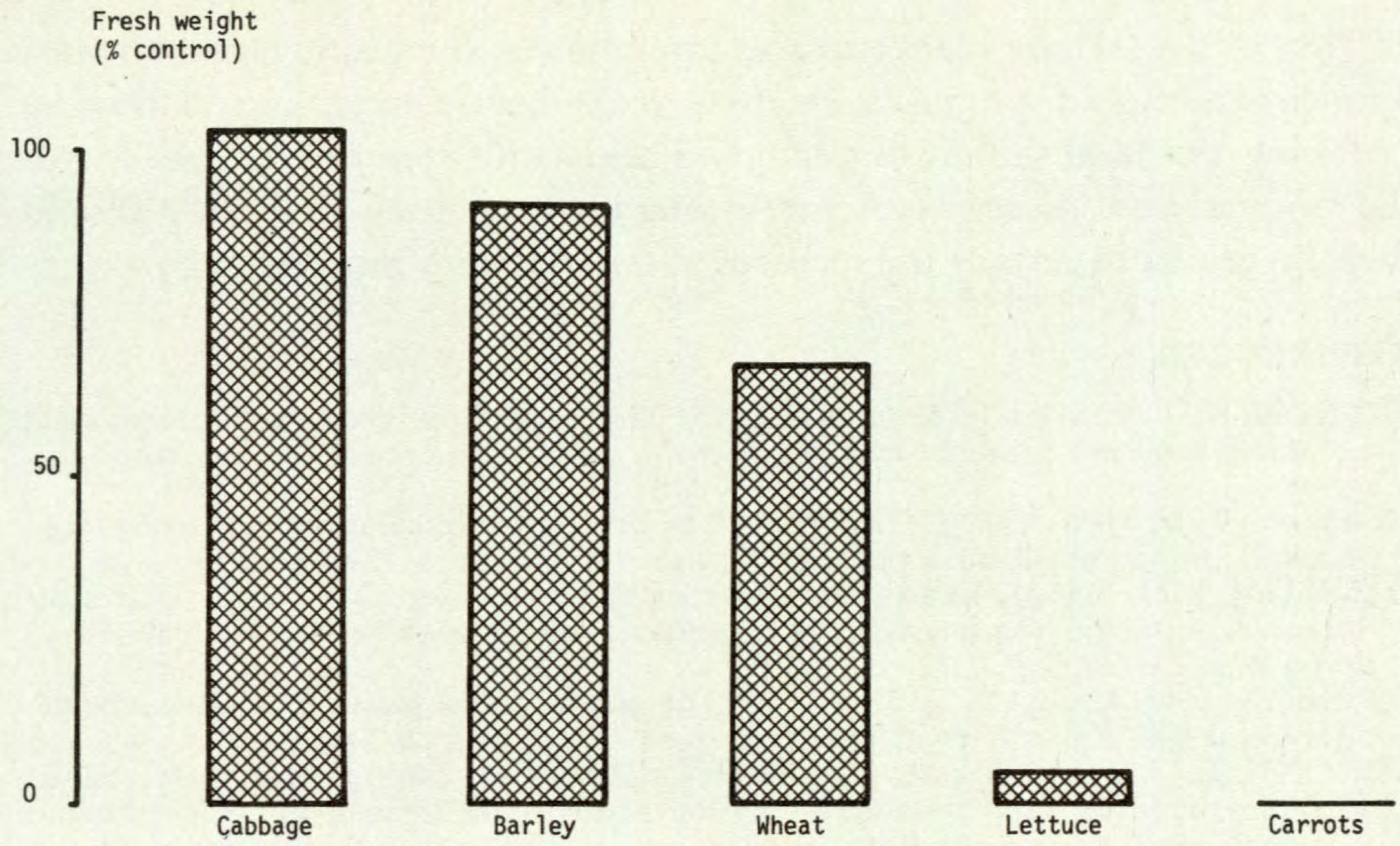

Fig. 3. Effect of chlorthiamid at 53.8 kg/ha applied annually from 1968 to 1972, on growth of test crops in 1974.

grubbed plantation will be re-planted with fruit and the chances of injury are less, blackcurrants are often grown by farmers on contract to processors and here arable crops can well follow. It is clearly important to choose resistant crops if there is any likelihood of damage.

CONCLUSIONS

Established blackcurrants clearly possess considerable tolerance of chlorthiamid and dichlobenil; the leaf margin chlorosis that occurs does not appear to be linked with growth or yield reduction. The high doses needed to control patches of resistant weeds should therefore be safe. Fruit quality also appears to be unaffected and residues in the fruit should not present a hazard. Overall applications at these rates would not be economic because of the cost of the herbicides but treatment of affected rows is feasible. Bindweed in the alleys can be effectively controlled in the early summer with carefully directed applications of MCPB.

The results have shown that residues from chlorthiamid and dichlobenil can persist in the soil for at least three years after the final application.

In view of this, where blackcurrants are followed by arable crops, the last application should probably be two years before grubbing; following grubbing the land should be ploughed and cultivated thoroughly across the original row positions. A more tolerant crop such as barley should then be grown to reduce the chances of damage to a minimum.

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Herbicides for use in forestry

D. J. TURNER and W. G. RICHARDSON

There are about two million hectares of woodland in Britain, much of which supports unwanted growth as well as useful species. In forestry, it is sometimes difficult to classify individual species as crops or weeds; woodlands are managed for many purposes and the status of a plant sometimes changes with the management objective. Woody undergrowth, for example, can be a nuisance in young plantations but provides valuable shelter for gamebirds and wildlife. Manipulating the balance of plant species is a requirement of most management objectives. Freeing young trees from competition is the usual aim but in special circumstances other forms of vegetation management may also be needed

In the past, vegetation management usually involved hand labour. This is now expensive: slashing unwanted growth in young plantations can for example cost £50–£80 per hectare (Crowther, 1976). Efficient herbicide treatments could often provide a cheaper and better way of managing vegetation but the cost of establishing new methods may prohibit their development. We know a great deal about a few well-established compounds like 2,4-D and atrazine but have little or no information about forestry uses of many other herbicides, the market being too small to attract much attention from manufacturers and distributors.

THE FORESTRY SCREENING PROGRAMME

A research programme aimed at filling these gaps in our knowledge and developing better methods of woodland vegetation control was started at the Weed Research Organization (WRO) in 1976, the work being financed by the Forestry Commission. This report outlines the scope of the project and summarises some recent results. The basic approach is to investigate the effects of herbicide treatments applied in spring, summer and autumn, to trees, grasses and heather grown in large (200–300 mm diameter) pots. Test plants are established outdoors during the previous autumn and winter and observed for at least ten months after treatment to assess longer term effects. Herbicides tested in the programme have included new products and also older out-of-patent compounds not examined previously from forestry aspects. Some mixtures with non-herbicidal adjuvants have also been tested. We have concentrated on overall spray treatments, often cheaper or easier to apply than granules or directed sprays. Conventional volume rates (200 l/ha) are mostly used but some very low volume (20 l/ha) controlled drop applications are also tested. Generally we first examine one or two moderately high rates of each herbicide, to obtain preliminary indications of resistance and susceptibility. Any materials which appear potentially useful are then re-examined more closely.

To date, we have examined about 25 herbicides, in experiments with up to eight crop and four weed species. The detailed results of this work are reported elsewhere (Turner & Richardson, 1978); only a summary of the more important effects with selected compounds and species can be given here. Although we believe that several new treatments may prove useful, recommendations for practical uses must await the outcome of field trials now being undertaken by Forestry Commission research staff.

It is convenient to summarise our results in relation to three important crop-weed situations: grass weed control in young plantations; selective heather control in conifers; and the control of woody weeds.

GRASS WEED CONTROL IN YOUNG PLANTATIONS

Herbicides now approved for this use include atrazine, chlorthiamid, dichlobenil and propyzamide (Brown, 1975). Only atrazine is applied as an overall spray, the other materials usually being formulated as granules. Paraquat and dalapon can also be used, but only as directed sprays. Of these alternative treatments, atrazine is the easiest to use. However, present recommendations stipulate that the atrazine should only be applied during the period from February to May (Brown, 1975). Furthermore, this herbicide is relatively inactive against several important perennial weed grasses, including *Calamagrostis epigejos, Deschampsia caespitosa* and *Molinia caerulea.*

Atrazine

In our pot trials, we found that summer applications of atrazine had little effect on several crop species, including oak, beech, Sitka spruce and Corsican pine (Table 1). It may therefore be possible to extend the recommended spraying season for this herbicide. This could have logistic advantages but, additionally, we believe that summer applications may control susceptible weeds more efficiently. Atrazine enters plants through leaves as well as by the roots, particularly when oil additives such as Actipron are present. In our experiments, oils enhanced activity against susceptible weeds but not against resistant grasses or most conifers. They slightly increased atrazine injury to oak.

Table 1 Response of some pot-grown forest crop and weed species to July/August herbicide applications

Herbicide	kg/ha	Oak	Beech	Sitka spruce	Corsican pine	Heather	Molinia	Deschampsia	Calamagrostis
Atrazine	4	R	R	R	R	MS	R	R	R
Atrazine (with 10% Actipron)	4	MR	R	R	R	S	R	R	R
Cyprazine	1	R	R	R	R	S	R	R	R
Glyphosate	1	R	MR	R	R	R	MS	MS	MS
Glyphosate (with 5% $(NH_4)_2SO_4$)	1	R	MS	R	R	R	MS	S	MS
Trifop-methyl	4	R	R	R	R	R	S	S	S
Hexazinone	4	S	MR	R	R	MR	S	MR	MS
Terbuthylazine	8	R	R	R	R	S	MS	S	S
Triclopyr	0·5	S	S	R	R	R	—	—	—
2,4-D as ester	4	MR	MR	R	R	MR	—	—	—
MCPA as ester	4	MR	R	R	R	MR	—	—	—
MCPA as salt (with 5% $(NH_4)_2SO_4$)	4	MR	R	R	R	MS	—	—	—

S — Susceptible. Complete or almost complete kill
MS — Moderately susceptible. Effective suppression
MR — Moderately resistant. Some effect but no mortality
R — Resistant. Little or no effect

Trifop-methyl

This is the most interesting herbicide yet examined. As Table 1 shows, the compound is very active against all three atrazine-resistant grasses but has no measurable effect on any crop species. Paradoxically, it is less effective against *Poa annua* and other annuals (Richardson & Parker, 1977). Annual grasses are, however, less of a problem in plantations and are in any case readily controlled with other herbicides. A more important defect is the absence of activity against dicotyledonous weeds, including annuals like chickweed. Trifop-methyl is therefore likely to be of use in mixtures rather than as a straight herbicide. It is mainly foliage-acting, but is also taken up from the soil.

Glyphosate

Summer applications of 1 kg/ha glyphosate severely injured larch and Western hemlock but were tolerated by other important conifer species, including Sitka spruce and Corsican pine (Table 1). High doses often caused damage but even 4 kg/ha applied in July did not injure Sitka spruce. Treatments applied in May tended to be more phytotoxic, autumn sprays less injurious to crop species. At 1 kg/ha, summer application of glyphosate controlled *Molinia* and *Deschampsia,* but not *Calamagrostis.* The addition of 5% w/v of ammonium sulphate to spray solutions markedly increased phytotoxicity to *Deschampsia* (Table 1). Activity was also enhanced when the herbicide was applied at 20 l/ha with a spinning disc applicator.

Hexazinone

Hexazinone is also active against the atrazine-resistant grasses (Table 1). When applied in July at 4 kg/ha it had little effect on pines, Douglas fir or Sitka spruce. *Molinia* was more susceptible than *Deschampsia* or *Calamagrostis.* Parallel studies show that this herbicide controls many other important grasses and broadleaved weeds, including *Agropyron repens, Holcus lanatus* and *Cirsium* species (Richardson & Parker, 1977).

Terbuthylazine

This older, out-of-patent herbicide may also be useful for grass control. It has not apparently been tested before in Britain for forestry use but but was examined in New Zealand by Bowers & Patterson (1974). It is more active than hexazinone against *Deschampsia* and *Calamagrostis* (Table 1); this last species was susceptible even to 2 kg/ha. We believe that terbuthylazine should be tried in the clayland forests where *Calamagrostis* occurs. The grass is not widely distributed but in favourable habitats competes strongly with conifers and presents a serious fire hazard. Like glyphosate and hexazinone, terbuthylazine is active against many other grasses and broadleaved weeds. It is more persistent than atrazine (Gast & Frankhauser, 1966). Like many other triazines, it can enter plants through leaves as well as by way of the roots; studies with oil and surfactant additives are therefore contemplated.

SELECTIVE CONTROL OF HEATHER IN CONIFERS

Heather (*Calluna vulgaris*) often drastically reduces conifer growth by competing for nutrients (Handley, 1963): it has been described as the most important weed of British forestry (Brown, 1975). Sitka spruce is particularly susceptible, growth sometimes being almost completely arrested by heather competition.

Phenoxy-herbicides

The recommended control is to apply an ester formulation of 2,4-D at 4 kg a.e./ha, between mid-July and early September (Brown, 1975). Earlier application may cause crop injury while later treatments are generally less effective. In our experiments with pot-grown test material, July applications only injured crops of known susceptibility, such as larch and Western hemlock. Effects on heather were, however, poor (Table 1). Ester or salt formulations of dichlorprop or mecoprop acted similarly. MCPA, however, appeared more promising, having significantly more effect on heather than 2,4-D. This result confirms earlier observations by Holmes & Barnsley (1953). There was little difference between MCPA ester or salt formulation when these were used alone but the activity of the salt was greatly increased by the addition of 5% w/v ammonium sulphate to the spray solution. With a salt formulation of 2,4-D, ammonium sulphate had less effect. Field trials with MCPA—ammonium sulphate mixtures have been recommended.

Triazine herbicides

The susceptibility of heather to triazine herbicides is of interest (Table 1); so far as is known, this effect has not been reported previously. With some herbicides of this group, there appears to be selectivity between heather and conifer crops (Table 1). In two successive experiments, 1 kg/ha of cyprazine killed heather without noticeably affecting any conifer species. Unfortunately, cyprazine is now withdrawn by its manufacturers. However, its activity appears to be shared by some related triazines (Table 1); the results obtained with atrazine and terbuthylazine are to be followed up. Other triazines will also be examined. The addition of an emulsified oil (Actipron) significantly increased atrazine activity towards heather. Most conifers were unaffected by sprays applied in July but treatment earlier in the summer, which had more effect on heather, sometimes caused crop injury. Fortunately, Sitka spruce is resistant to both atrazine and terbuthylazine.

CONTROLLING WOODY WEEDS IN CONIFERS

In lowland forests, hardwoods often compete strongly with planted conifers. Seedling birch, sallow and other quick growing species frequently become established within the crop. Woody growth can also arise from old stumps; much land which formerly produced hardwood timber or poles is now being converted to conifer plantations. Some form of woody weed control is usually required for 2–5 years after planting conifers in lowland areas.

At present, only 2,4-D and 2,4,5-T are recommended for overall foliage spraying. These treatments must be applied only during a limited season in later summer, when conifer shoot growth has ceased and resting buds have formed. Not all conifers tolerate phenoxy-herbicides: it is unsafe to treat larch, Western hemlock and certain other species at any time (Brown, 1975). These foliage sprays effectively control many hardwood weeds. Oak, beech and a few other species are however resistant. They can be controlled by basal bark or 'cut-bark' applications, but these treatment methods are relatively expensive and time-consuming (Brown, 1975).

MCPA

Recently, Bärring (1975) has shown that aspen (*Populus tremula*) is more susceptible to MCPA than to 2,4–D or 2,4,5-T. Similar results have been obtained in trials at WRO with hybrid poplar (*X Populus Gelrica*) and willow (*Salix fragilis*). As with heather, an MCPA salt is often as active as an ester formulation, particularly when ammonium sulphate is added (Turner & Loader, 1972). We have recommended that MCPA should be tested in the field, alone and in mixtures with 2,4-D. Mixtures may control a wider range of hardwoods without incurring extra crop injury.

Glyphosate

When applied at 1 kg/ha, glyphosate was moderately phytotoxic to beech but less active against oak (Table 1). The addition of 5% w/v ammonium sulphate significantly increased injury to beech without enhancing effects on conifer species. Application in low volume with CDA equipment had similar effects (data not presented). Glyphosate, of course, controls most herbaceous weeds as well as hardwoods, an important advantage where species like bracken occur. In Norway, where the use of 2,4,5-T is now prohibited, glyphosate is considered 'a more suitable weed-killer than any phenoxy-herbicide' (Lund-Hoie, 1977).

Hexazinone

This compound may also find uses for broad-spectrum weed control in conifers. It is very active against oak, a species resistant to many other herbicides. Hexazinone may provide a wider margin of selectivity between broadleaved species and conifers than do phenoxy-herbicides or glyphosate. High doses of 6 kg/ha and above are, however, very damaging to crop species.

Triclopyr

This herbicide is related to picloram but is much less persistent (Haagsma, 1975). In America its main use is for total weed control along roadways and rights-of-way. Moderate doses, however, may be of use for controlling hardwoods in conifers. In our trials, 0.5 kg/ha was selective between weed and crop but 2 kg/ha injured Corsican pine and Douglas fir. Sitka spruce was more resistant. Perhaps the most interesting property of triclopyr is its activity against phenoxy-resistant species. We have shown that it can kill oak and beech while American studies indicate activity against ash and hawthorn (Byrd *et al*, 1975). Unlike glyphosate and hexazinone, triclopyr is ineffective against grasses. It may therefore find uses for controlling woody weeds of rangeland. In subsidiary experiments we have found triclopyr to be very active against gorse (*Ulex* spp). As it has little effect on heather, the herbicide maybe useful for vegetation management on grouse moors and along hill paths in National Parks, etc.

CONCLUSIONS

After only three seasons of experiments, it is encouraging to be able to report progress. We now have several promising leads to follow up. Our experiments are of course only a first stage in the process of developing new methods of weed control and much additional work is required before recommendations can be made for practical use by foresters. Unforseen difficulties may yet arise but there appear to be several exciting possibilities for developing new methods of vegetation management.

As many herbicides have never been examined, the field for innovation is almost clear. We have suggested some new uses for herbicides but there are many other possibilities; our programme includes only a restricted range of compounds and test species. The ever increasing cost of hand labour and the development of efficient low volume 'controlled-drop' sprayers (Taylor & Holly, 1976) combine to make further research an attractive proposition. We believe that forestry may be an important future growth area for vegetation management by herbicides.

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The biological control of water weeds

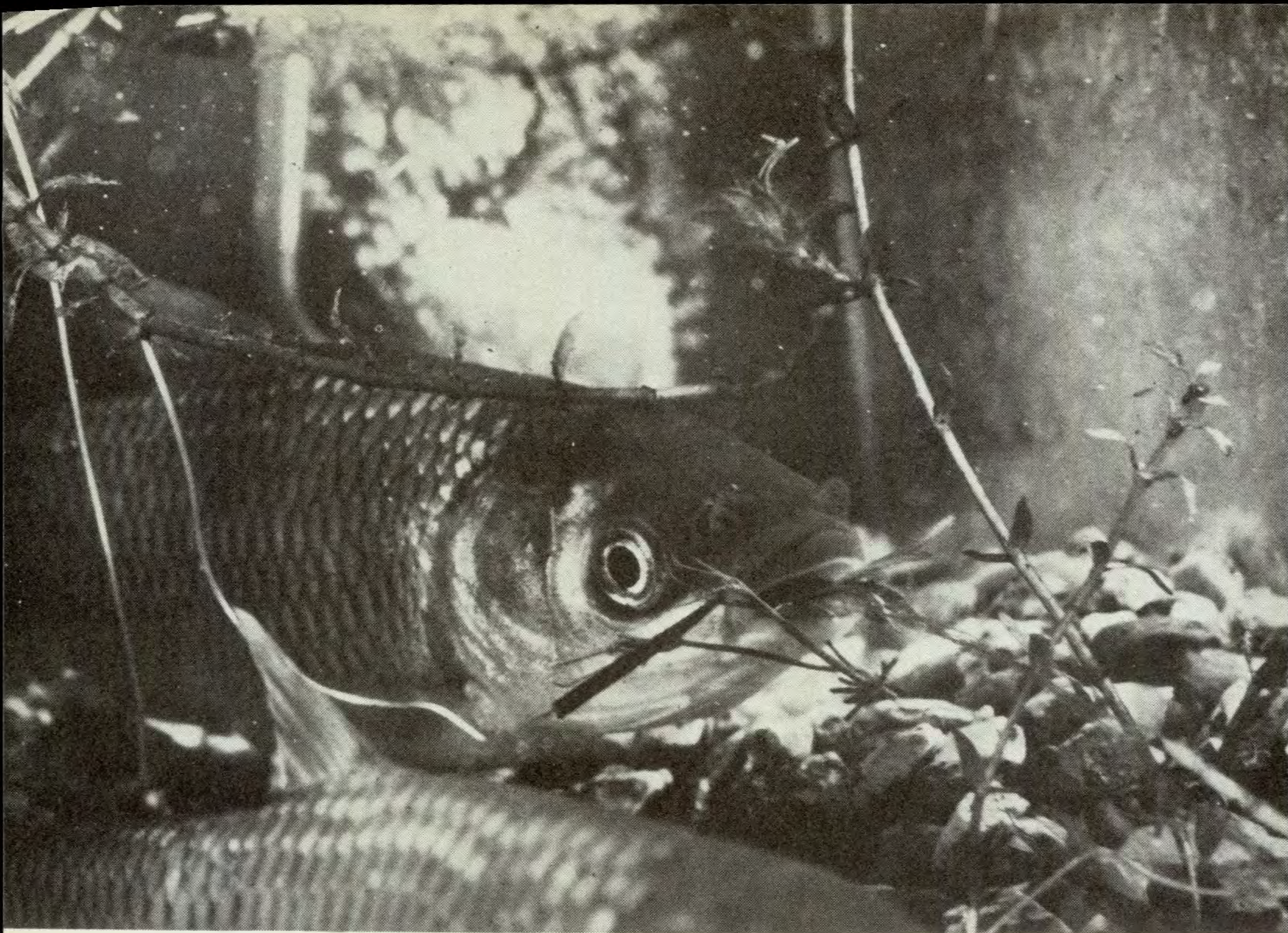
M. C. FOWLER

In the United Kingdom weeds in or near water are still cut by hand or machinery, although in recent years the rising cost of labour has led to an increasing use of chemical herbicides as well. All these methods have their limitations and much interest is now being shown in the use of biological agents as means of controlling water weeds. The most promising of these is the herbivorous Chinese grass carp (*Ctenopharyngodon idella* Val) which has been the subject of world wide research for many years. This fish originates from the Amur river in China and has already been successfully introduced into lakes and drainage channels in Russia and the USA. In many parts of the world it is also cultivated in special ponds to provide a source of protein for human consumption. Although trout and salmon are the only freshwater fish commonly eaten in Britain, it is possible that, in the near future, grass carp might come to be regarded as a welcome and economical addition to the diet. Meanwhile the main attraction of the fish is that it can consume large quantities of water weeds.

Since 1968, WRO has worked with the Salmon and Freshwater Fisheries Laboratory of MAFF on an initial assessment of the potential of grass carp for weed control in this country (Stott & Robson, 1970). Specially adapted ponds in Lincolnshire were used in the first trials and the fact that the fish happily ate some of our British plants and survived our conditions encouraged us to continue the work. MAFF research has since concentrated mainly on the effects of grass carp on indigenous fish populations, and on their resistance to disease and tolerance of herbicides, while we at WRO have looked more closely at the food preferences of the fish and their effect on the growth of plants.

FOOD PREFERENCES

The object of the first experiments carried out at WRO was to determine which plants the fish preferred eating and what, if any, was the order of preference. Various species of plants were grown to maturity in 8–10 inch plastic pots in polythene-lined circular ponds outdoors. Each pond held 2.7 m^3 water. A number of one-year-old fish, each weighing on average 13g, were placed in the ponds at five different stocking levels, from 125 to 500 kg/ha (i.e. between 5 and 14 fish per tank). By day 4 it was obvious that stonewort (*Chara* spp.) and fennel pondweed (*Potamogeton*



The Chinese grass carp could make a valuable contribution to integrated programmes of weed control in drainage channels, canals and small lakes.

pectinatus) were the favourite foods, closely followed by small pondweed (*P. berchtoldii*), Canadian pondweed (*Elodea canadensis*) and opposite-leaved pondweed (*Groenlandia densa*). Species that were eaten reluctantly or not at all were spiked water millfoil (*Myriophyllum spicatum*), broadleaved pondweed (*Potamogeton natans*), mare's tail (*Hippuris vulgaris*), and thread-leaved water crowfoot (*Ranunculus trichophyllus*). The only difference attributable to the stocking rate was that the greater the number of fish the quicker the favourite weeds disappeared.

EFFECTS ON VEGETATION

The next step was to find out what effect the fish—with their definite grazing preferences—would have on a free-growing mixture of plant species, where the roots were not restricted by pots. The same ponds were used and five different weed species were planted in mud and allowed to establish over winter and during spring and early summer. Plants used were *Chara* spp., *E. pectinatus*, *E. canadensis*, *M. spicatum* and *P. natans*. In August 1975, two-year-old fish, average weight 24g, were introduced at two stocking rates: 150 kg/ha (3 fish/tank) and 450 kg/ha (8 fish/tank). Each treatment was replicated four times and four control ponds containing no fish were included in the experiment, making 12 ponds in all. After one month all the fish were netted and weighed. Fish were then returned to three only of the four replicates of each treatment. In each fourth replicate, the plants were harvested and the dry weight of each species measured. These four ponds were then left undisturbed. The fish were weighed again in early February 1976 and a third time in July when they were removed altogether. All the plants were harvested (including the regrowth from the fourth replicates) and the dry weights calculated. All the ponds were then left undisturbed for one more year and the regrowth was harvested and weighed in August 1977.

Results

In the more heavily stocked ponds, all the *Chara* spp. and *P. pectinatus* had been eaten within one month of the start of the experiment. By the winter when low temperatures caused the fish to stop eating, there was still some *Chara* spp. and *P. pectinatus* in the lightly stocked ponds. This soon disappeared when the fish resumed eating the following spring. Ten months after the start of the experiment *P. natans* in all the fish ponds had spread to the same extent as it had in the control ponds, but *M. spicatum* had increased dramatically. The fish ponds contained only these two species. In the heavily stocked ponds the fish had begun to break off the plants near the surface of the mud in their search for something to eat. This vegetation then floated on the water surface and began to disintegrate. Figure 1 shows the biomass of the plant species measured at the three assessment dates expressed in dry weight of the preferred plant species (*Chara*, *E. canadensis*, and *P. pectinatus*) and the avoided species (*P. natans* and *M. spicatum*). The right hand histogram shows the dry weights of the weed which regrew in the year after the fish had been removed and indicates the re-establishment of some previously eaten species. The fish at the higher stocking rate gained 73% of their original weight while those at the lower stocking rate gained 224%, having had more food to eat per fish.

Many interesting facts emerged from these experiments, greater detail of which is included in a paper being published elsewhere (Fowler & Robson, 1978). The grass carp's food preferences may result in a dramatic increase in population of the disliked plants and a previously mixed plant

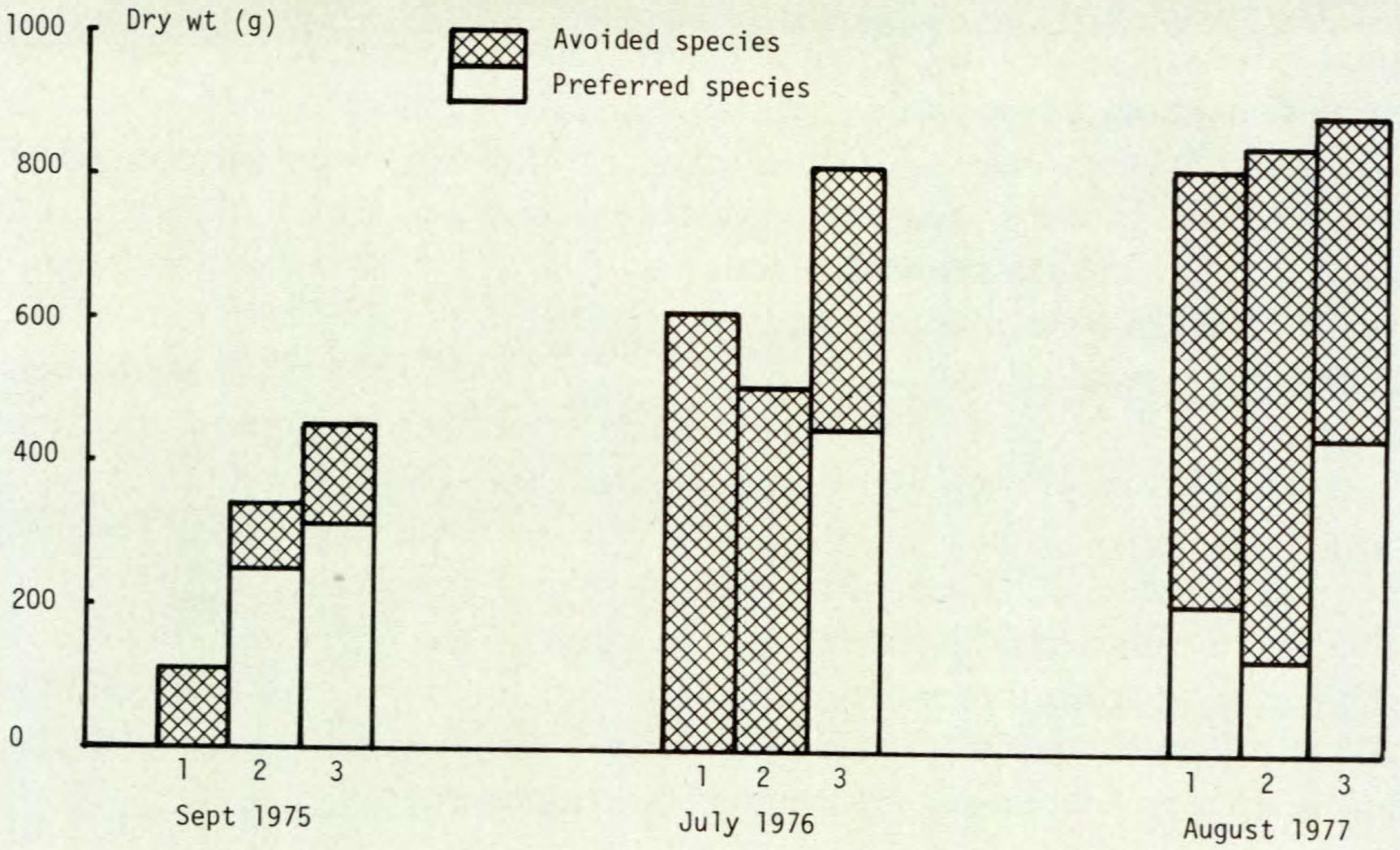


Fig. 1. The mean dry weight of aquatic vegetation recorded during and after grazing by grass carp at three stocking rates: (1) 450; (2) 150; (3) Nil kg/ha live fish.

community may become dominated by a few species which might make the weed problem worse. However, we used small fish in these experiments, and while there is some evidence that larger fish have the same effect this needs more confirmation. The degree of weed control appears to depend not only on stocking rate, size of fish, and plant species present, but also on the time of year the fish are introduced and the length of time they remain. Field trials to determine the importance of these factors practical in weed management are being planned and two have already been started by WRO.

IN CONCLUSION

Clearance of weeds in drainage channels is a very important part of maintenance. The grass carp offers an attractive addition to the tools available. They could make a valuable contribution to an efficient programme of weed management involving also the use of herbicides and mechanical methods. The fish may also be the answer to weed problems in irrigation reservoirs where herbicides cannot be used and in canals and small lakes. It is not proposed that they be used in river systems because of the difficulty in controlling their movements.

Many Water Authorities have shown great interest in the potential of grass carp for weed control, but at present the fish are only available from abroad and very severe restrictions govern their importation. However, some Water Authorities have now obtained a limited number of fish with which to carry out their own investigations. It is hoped that if the present co-operation between WRO and the Water Authorities is maintained much useful data will become available. Then, providing the fish are available in the UK and subject to the agreement of any regulating agency, it will be possible for owners of private waters to take an informed decision whether or not to use grass carp for weed control.

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Herbicides and crop quality

R. J. HANCE, J. D. FRYER and P. D. SMITH

Under normal circumstances herbicides do not produce obvious changes in the crops to which they are applied. The tolerance of the crop may depend on several factors, for example, the compound may not penetrate the plant for some reason or the plant may be able to detoxify it. Herbicides work by upsetting some aspect of plant biochemistry and, since all higher plants have the same basic biochemical processes, we must expect that sometimes the herbicide will interfere with the biochemistry of the crop without actually killing it or causing visible symptoms. This poses the question of whether or not sub-lethal biochemical effects can change the composition of the produce.

One view is that in societies such as ours, where a mixed diet is normal, such changes as may occur are unlikely to be of significance in human nutrition unless a potentially toxic compound is involved. Hence research on them should have a low priority. In general this is the attitude taken at WRO. However, the long-term field experiment laid down at Begbroke in 1963 has provided an opportunity to obtain information on the effects of repeated herbicide use on crop quality as well as on soil fertility, crop yield and health. Reports of the progress of the experiment (Fryer & Kirkland 1970, J. D. Fryer *pers. comm.*) have been produced but they do not include the results of quality assessments.

THE FIELD PLOTS

Four herbicides, chosen to represent important chemical groups, are applied every year to the same plots at the normal time and rate of application. They are MCPA and tri-allate with wheat and barley, simazine with maize and linuron with carrots. Control and treated crops are weeded manually.

THE QUALITY ASSESSMENTS

Since WRO does not have facilities to carry out many of the determinations, other organisations have been involved and we acknowledge their help with gratitude. This has meant, however, that all tests have not been made every year and indeed some have been made only once. Nevertheless the amount of data is so large that only a summary is possible here. Detailed results are available in Fryer *et al* (1978).

Recording field data in the long-term herbicide experiment at Begbroke. No important effects of herbicides upon crop quality were ever observed.

Barley

The cultivar grown is Zephyr. Samples of milled grain from the 1968 harvest were analysed at the Lord Rank Research Centre for protein, carbohydrate and a number of amino acids and minerals. In addition a net protein utilization value determination using rats was carried out as well as a 30-day feeding trial which included observations of live weight gain, feed intake, protein efficiency ratio, liver weight to body weight ratio and any abnormalities of organs including dissected liver and kidney tissue. No differences between treated and control samples were found in either of the animal trials or in chemical composition.

Although the barley was grown as a feed crop, malting qualities were examined in 1969 by the Brewing Industry Research Foundation. As expected the nitrogen content was high (around 2%) so the malts obtained were low in extract irrespective of herbicide treatment. There were no differences between treated and control samples in any assessment, which included germination capacity and energy, diastatic power, water extractability, tint and malting loss.

Wheat

The cultivar grown was Sirius from 1971–74 and Sappo from 1975. Assessments of milling and baking quality have been made since 1971 at the Flour Milling and Baking Research Association. Although year to year variations have been large, no differences between plots have ever occurred in flour yield, extensiometer-resistance, extensiometer-extensibility, loaf score, protein content or water absorption. In 1972 only there was a decrease in bushel weight of tri-allate treated wheat.

In two years, 1971 and 1972, there was an increase in the Hagberg falling time in flour made from wheat off the tri-allate-treated plots. This test gives a measure of α-amylase activity, with lower activities giving longer falling times. Low α-amylase activity is associated with high baking quality. In addition, in 1971 the flour colour grade of wheat from the tri-allate plots was lower than that of the control, again a 'desirable' effect.

Since these differences were not consistent through the years they are not of commercial significance, at least for cv Sirius. However, the results have stimulated subsequent trials with other varieties but again the effect is neither consistent enough nor large enough to be practically useful.

Maize

The cultivar grown was Kelvedon 59A until 1972. In 1968 the Lord Rank Research Centre analysed maize samples for the same components as the barley except that the amino acid analyses were omitted. Moisture content was higher and oil and chloride lower in maize from simazine treated plots. The difference in average oil content, 2.72% compared with 1.48%, is probably of little significance in terms of feed value but may be worth exploring further in areas where maize is grown for oil production.

All other components, including protein content, were unaffected by simazine except for a decrease (0.87% compared with 1.02%) in the nitrogen content of simazine treated plants in 1968. Other workers have often shown that triazines can affect the nitrogen metabolism of many plants (see the review by Ries, 1976). For this reason total nitrogen was measured in the leaf, stem and cob of plants every year at four different growth stages from 1973 onwards. At this time the cultivar was changed to Maris Carmine. The results were consistent with the majority of the earlier analyses as no differences appeared except in the stem in 1972 and the leaves in 1973 which were respectively lower and higher than controls.

Kelvedon 59A is not normally grown for consumption as sweet corn but on three occasions samples were tested for taste on the grounds that if differences were shown in this variety, examination of sweet corn varieties would be justified. Ears were harvested in early September in 1969–71 and then canned for storage at —40°C. Before tasting the ears were pressure cooked and the grains stripped from the cobs. Samples were presented in a triangle test to trained panels at the ARC Food Research Institute. There were no treatment differences in 1969 but in the succeeding years the panels sometimes detected slight differences in texture rather than flavour. They were not discerned consistently, however, so although the differences were statistically significant they could not be clearly defined.

Carrots

The cultivar Autumn King was grown alone until 1974, thereafter the plots were divided and Chantenay was grown as well. Nitrogen contents were measured in the crops from 1968–75. The only differences occurred in 1968 when the nitrogen content of linuron-treated carrots was significantly lower than that of the controls (0.87% compared with 1.02%). From 1969–71 samples were analysed for volatile aromatic oils at the Food Research Institute. The levels tended to be lower in linuron-treated carrots (3-year mean 128 ppm) than in the controls (152 ppm) but the difference was not statistically significant. Taste tests of cooked carrots, also carried out at FRI, showed no differences.

Carotene levels were measured from 1972 onwards. Levels in the first year, particularly of β-carotene, were higher in carrots from the linuron plots. Subsequently, although the tendency remained, it was not of statistical significance except with cv Chantenay in 1974.

CONCLUSIONS

As few differences appeared in any of the measurements it seems reasonable to conclude that no consistent change in the quality of the crops can be attributed to the herbicides used. It seems likely that, in commercial practice, serious effects would not escape detection in the distributing and processing industries, so the policy of according low priority to research on the effects of herbicides on crop quality seems justified. Nevertheless, there are a number of reservations to make. The crops were grown on only one soil type and some tests were carried out on cultivars normally grown for a different purpose (e.g. feed barley was subjected to brewing tests). Hence other cultivars grown elsewhere may behave differently. Another point is that the crops were grown in monoculture so the comparisons were between different methods of maintaining the same monoculture. Comparisons between the same crops grown in different cropping systems, with and without herbicides, might be different.

The information to be extracted from the long-term experiment seems, for at least the time being, to be virtually exhausted. Therefore, the plots have now been reduced in size although they will be maintained, albeit with fewer assessments. Other workers who can make use of them, or material from them, will be welcomed as will suggestions for further research.

ACKNOWLEDGEMENTS

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Problems and progress in the evaluation of herbicide safety to the soil microflora

M. P. GREAVES

In recent years governments, international authorities and the general public have become increasingly aware of the potential hazards to man and his environment from the necessary widespread use of chemical agents to increase agricultural productivity. It was recognised that agricultural pesticides could pose a threat to non-target organisms and registration authorities quickly imposed on manufacturers the requirement to appraise the risks to wildlife, including mammals, birds, fish and insects (Papworth, 1971). More recently concern has been expressed for the safety of the soil microflora. The Wildlife Data Guide of the Pesticides Safety Precautions Scheme (1971) refers to the possible need to measure major effects on soil microbiological processes. Similarly, the Council of Europe booklet 'Agricultural Pesticides' includes advice on testing soil and soil organisms and guidance on data to be supplied when registering pesticides. Perhaps of most significance to the agricultural chemical industry, and the environmentalist, are the draft guidelines recently published by the Environmental Protection Agency (EPA, 1977), which specify a number of tests to be made to assess the effects of pesticides on the soil microflora.

Registration requirements of this kind assume that soil micro-organisms play an important role in maintaining soil fertility which may be harmed by pesticides. Undoubtedly micro-organisms are important in soil but it is not possible to quantify their contribution. This is a major problem when trying to assess and evaluate the potential of a chemical to harm the soil microflora. The problem has not been reduced by EPA specifying particular tests to provide the required data for registration. On the contrary, the development and introduction of legislation has emphasized the inadequate nature of present-day methods and shown a need for intensive research to develop sound scientifically based evaluation techniques.

Since its formation in mid-1966, the Microbiology Group at WRO has given priority to research designed to improve evaluation techniques. In particular many aspects of the basic ecology of soil organisms are being investigated in order to establish tests based on sound scientific principles. Without such a basis, the evaluation of herbicide side-effects can be only subjective and often misleading.

Evaluation of the potential risk to micro-organisms contributing to soil fertility, arising from the use of herbicides, poses three broad questions. Which organisms and microbial functions are important to soil fertility? How can herbicide effects on these best be measured? What do the results mean? At present, owing to a lack of basic data on microbial ecology it is impossible to answer these questions fully. Nonetheless it is necessary to provide such answers as are possible to aid fulfilment of current registration requirements.

Which functions and organisms to measure?

The best chance of detecting side-effects of herbicides on soil micro-organisms of likely agronomic significance comes from studies of the major microbiological processes occurring in the soil. Although the products of many of these processes obviously contribute to fertility, the contribution cannot be quantified. Thus, nitrogen fixation by legumes, nitrogen transformations in soil, organic matter decomposition and phosphorus transformations all come in this category. In general the methods for following these processes are well established, reproduceable and apparently reliable. At WRO we have given priority to examining such processes, in particular nitrogen transformations and fixation, organic matter degradation and carbon turn-over.

The EPA guidelines state a preference for this 'functional' type of approach. At the same time they offer the alternative of presenting data on the effects of herbicides on pure cultures of those micro-organisms known to be directly involved in the processes, for example, the *Rhizobium* spp. involved in nitrogen fixation. A technique developed at WRO (Cooper *et al*, 1978) may prove very useful to industry in this respect as it allows the toxicity of a chemical to several hundred different soil micro-organisms to be tested rapidly and cheaply. A chemical which is of low toxicity to the pure cultures of micro-organisms in liquid media employed in this toxicity test, is most unlikely to cause any effect in soil. In this instance it would be unnecessary to subject the chemical to further complicated and expensive examination. A similar initial screening test has been tentatively proposed by the World Health Organization (1974) for judging the hazard involved in the use of pesticides. This sort of rapid screening technique is likely to be essential if, as is proposed, the EPA registration requirements are to be made retrospective. In the UK alone there are about 450 herbicide formulations which could be potential

Table 1 Some parameters used at WRO for assessing the effects of herbicides on soil micro-organisms and their activities. Effects are measured in two soils at herbicide concentrations of x 1 and x 10 'field rates'

Microbial populations	Enzymes	Processes
Total bacteria	Phosphatase	Carbon dioxide evolution
Sporeforming bacteria	Dehydrogenase	Oxygen uptake
Fungi	Urease	Nitrogen mineralization
Actinomycetes	Cellulase	Nitrification
Algae and diatoms		Cellulose degradation
Ammonifying bacteria		
Phosphatase producers		
Cellulolytic bacteria and fungi		

candidates for testing and re-registration by EPA for sale on the American market. The total number of chemicals in use in agriculture, food processing and other areas, which would require re-registration in America has been estimated at 45,000!

In addition to evaluating the side effects of herbicides on major processes and on pure cultures, the programme at WRO includes studies of the effects on natural populations of micro-organisms in soils and on the activity of soil enzymes. While some of this work may lead to the development of improved test methods the main purpose is to provide basic information to help in the interpretation of the effects on major processes. The full range of evaluation tests which can be applied to a chemical is shown in Table 1.

How best to measure effects?

Just as there are difficulties in deciding which aspects of microbial activity should be measured to determine side-effects of herbicides, there are also difficulties in establishing the best methods of measuring the effects. Of the many methods available, each has its advocates and each has its particular merits and disadvantages. In practice the choice is often determined by the availability of equipment in a laboratory, the training of the staff or, indeed, the personal bias of the senior experimenter. When the side- effects measured are important to the commercial fate and safe usage of a chemical it is essential that any methods used are above reproach. Therefore, before any new method is used at WRO it is first examined to determine its suitability and its reproduceability. This is particularly important when tests have to be done in a number of laboratories by staff at different levels of training. Particular emphasis has been placed on automated methods, partly to increase the number of samples handled,

Fig. 1. Sample preparation unit developed at WRO, linked to double channel autoanalyser.

and thus the replication of experiments, but mainly to reduce the chances of operator error to as low a level as possible. A particularly useful development in this context is an automatic sample preparation unit (Fig. 1), details of which are to be published shortly. The unit is linked to an autoanalyser which uses many methods developed, at least in part, at WRO.

Possibly the greatest difficulties in methodology arise because of the nature of the test medium, the soil. This shows tremendous variation, both within one soil type and between soil types. The EPA guidelines attempt to indicate how soils should be selected, suggesting that from 5 to 15 soils will be required depending on the chemical and its intended usage. There is less guidance on how the soil should be handled once it is sampled. The post-sampling treatment, however, may be a critical factor which affects the results obtained in a test. Recent work at WRO (Wingfield, Davies & Greaves, 1977) has shown that the effects of a herbicide on soil enzymes or bacterial populations may be greater when the soil sample is air-dried and sieved than when it is collected and used as an 'undisturbed' core. This modification of herbicide side-effect by soil treatment has wide-ranging implications and must cast doubts on the validity of some current laboratory tests.

Similarly, laboratory tests can produce varying results depending on the combination of soil moisture and temperature level used. Usually in such experiments, constant conditions are maintained which may bear little relationship to those in the field at the time when chemicals are normally applied. In laboratory experiments where the soil moisture was 60% of holding capacity and the temperature 20°C, we have shown that high concentrations of dalapon can severely inhibit nitrification in some soils. On the other hand, when the moisture was raised to 90% of holding capacity, such as may occur during autumn or spring applications of herbicides, no inhibition occurred. Further, this work revealed a complicated web of interactions between the type of soil used, the herbicide, the soil moisture and temperature, all of which modified the effects on nitrogen transformation considerably.

These results indicate that there are deficiencies in the techniques which are now being used to assess the side-effects of herbicides on micro-organisms. It is possible that serious side-effects are being missed, or relatively innocuous effects exaggerated. This unsatisfactory situation can be overcome only by further research into the factors affecting the reliability of existing tests.

Interpreting the data

In the last 12 years the Microbiology Group at WRO has examined the effects of over 70 commercial herbicides on microbial activities in soil. The data obtained have been widely published and the opinion expressed that, if used in the way recommended by the manufacturer, none will harm soil micro-organisms sufficiently to affect soil fertility. This opinion, however, is based on little more than a subjective assessment of the data, owing to the lack of a basic understanding of microbial ecology. Obviously, such assessments will also vary between individuals according to their standpoint and level of training and experience. Thus, some may consider that the inhibition of nitrification, and the resultant increase in ammonium-nitrogen and reduced production of nitrates, is a harmful effect. Others may take the opposite view, arguing that both are available as plant nutrients and, while ammonium is not leached, nitrate is and can be lost or enter water supplies and pollute them.

The relative importance of effects within the agricultural system has also to be considered. For example, a reduction in the mineral nitrogen released from organic matter can occur following the use of some soil-applied herbicides. The significance of this decrease must be judged in terms of the crop requirement and the current availability of mineral nitrogen. Thus, the effect may be considered to be less serious if it occurs when fertilizer nitrogen has just been applied than if it occurs later in the growing season. Similarly, if the herbicide causing this effect is confined to the top two or three centimetres of the soil profile, the reduction in mineral nitrogen will be less serious than if it occurred at the lower depths explored by crop roots.

In order to arrive at a more objective interpretation of the results of WRO research, we are now trying to provide an experimental 'base-line' for assessing the significance of the effects measured. The assumption is made that the natural fertility of the soil is the product of variation in microbial processes, themselves subject to fluctuations in climate and other environmental factors. Variation in microbial productivity can be measured and used as a background against which the significance of the magnitude and duration of herbicide-induced effects can be judged. For instance, the natural variation in mineral nitrogen levels, in the absence of fertilizers or crops, can be as large as four-fold. Thus, any decrease of less than this magnitude in a laboratory experiment following herbicide treatment is probably not significant. As yet it is too early to say that this research has produced a useable 'baseline' but the indications are promising and it is hoped that at least short term effects can be interpreted more objectively as a result.

THE FUTURE

A recurring criticism of the usual evaluation techniques in use at present is that they employ root-free soil as the test medium. In practice herbicides are applied to a crop, or to a soil where a crop will soon be present. At the same time the purpose of evaluating the side-effects of herbicides on soil micro-organisms is to ensure no harm to soil fertility results, so that we can continue to grow healthy, productive crops. Consequently, it is argued, we should evaluate these side effects in a soil in which a crop is growing. This argument is reinforced by our knowledge that the micro-organisms associated with plant roots, which are different in many ways to those in root-free soil, can have a marked, direct, effect on plant growth.

Bearing this in mind we are now investigating the possible effects of herbicides on the root microflora, and hence on root development and plant growth. So far, attention has been focused on those herbicides known to damage roots as the root microflora can be predicted to respond

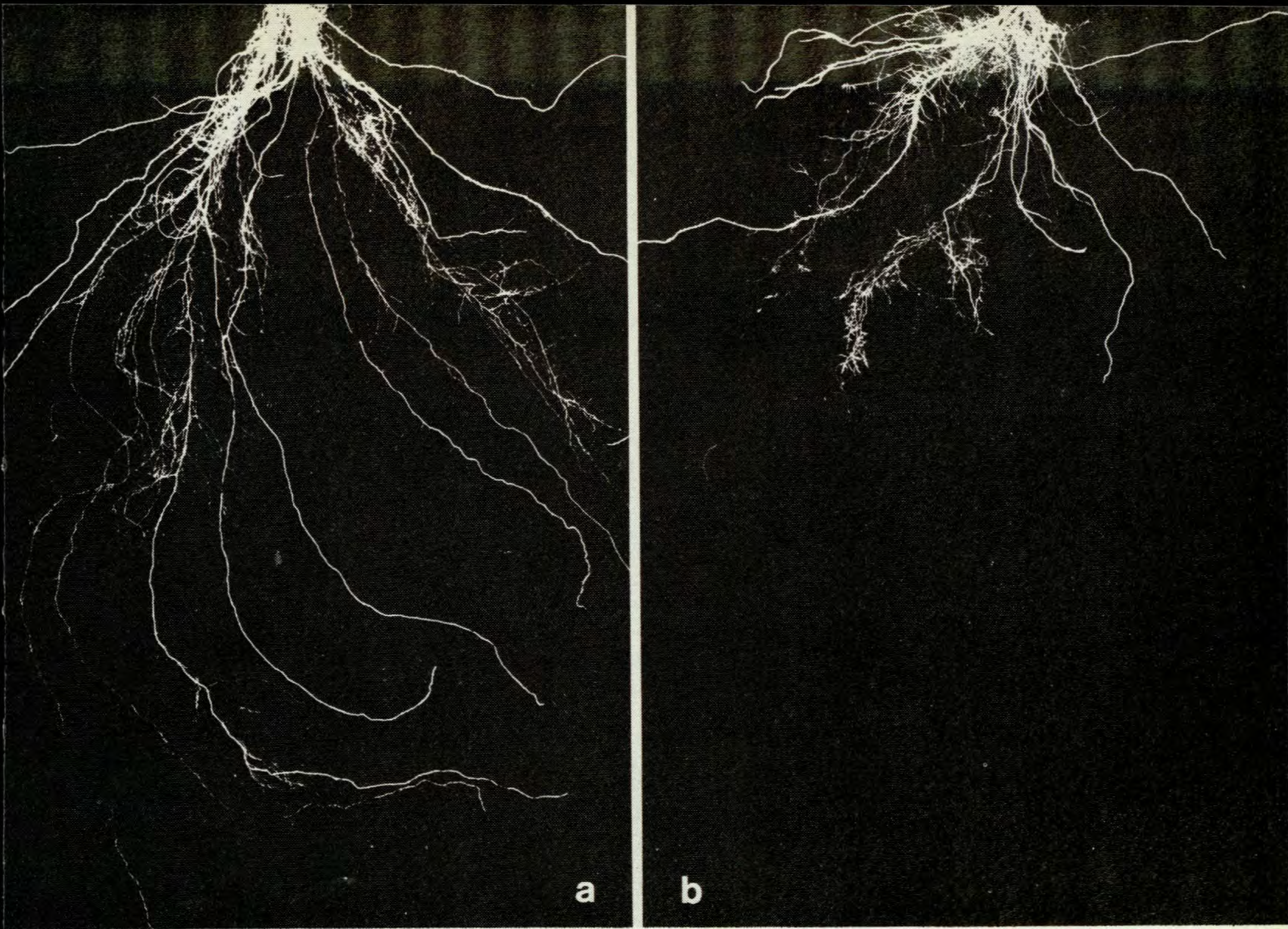

Fig. 2. The effect of mecoprop at 2.5 kg/ha on the root morphology of wheat cv Sappo. Control (a); Treated (b).

to such an effect in a major way. In the first experiments in this programme it has been shown that foliar application of mecoprop, by damaging the roots of wheat (Fig. 2), is indirectly responsible for causing a massive increase in the numbers of bacteria which can invade the root tissues. In wheat grown in sand culture this increase resulted in serious and prolonged root stunting and, consequently, in reduced growth and grain yield of the cereal. In a clay-loam soil on the other hand, while root stunting occurred immediately following herbicide application, the plant quickly produced new roots which remained healthy. Thus, the final growth and yield of the plant were unaffected. Similar results have been found in wheat and other crops with other herbicides.

Many reports have suggested that herbicide usage has been associated with an increased incidence of plant disease. In the UK, 'Take-all' disease of cereals has frequently been mentioned in this context. Laboratory experiments at WRO have indicated that several herbicides used in cereal growing can directly affect the causative fungus of this disease in several ways. Changes in growth rate, enzyme activity and competitive ability against other soil organisms are all brought about. Such changes may be implicated in instances when the disease increases following herbicide application. On the other hand there are many other factors which may be involved.

These types of interaction between herbicides and root micro-organisms indicate strongly that the future development of evaluation procedures for registration purposes should consider the effects on the root microflora. The present research programme on this topic at WRO goes some way towards elucidating these effects.

CONCLUSIONS

Pesticides, including herbicides, will rightly continue to be scrutinized by registration authorities and to be the subject of critical concern by the public. The increasing attention now being given to the side-effects of herbicides has emphasized the deficiencies of existing evaluation techniques and the need for a more objective basis for interpreting the data obtained. The research programme at WRO has been developed in response to this situation and is aimed at providing the required information. At the same time needs for the future have been identified and efforts are being made to improve the approach to evaluation by investigations of the root microflora and its response to herbicides.

Hopefully, as a result of research at WRO and elsewhere, future registration requirements concerning herbicide safety will be based on sound scientific principles rather than on political or emotive considerations.

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LIST OF RESEARCH PROJECTS 1976–77

WEED CONTROL DEPARTMENT

Head of Department: J. G. Elliott

ANNUAL CROPS GROUP (Leader: J. Holroyd)

1. Herbicide treatments for the control of wild oat and blackgrass in cereals: M. E. Thornton, J. Holroyd.
2. Development of economic long term systems for the control of wild oats and blackgrass in cereals: B. J. Wilson, G. W. Cussans.
3. Effect of changes in tillage systems on the growth and control of unwanted plant material in cereals: G. W. Cussans, S. Moss.
4. Growth of cereals in reduced tillage systems: J. G. Elliott, J. Holroyd, F. Pollard (Part of joint project with the ARC Letcombe Laboratory and ADAS).
5. Growth and control of *Agropyron repens* and *Agrostis gigantea* in cereal and other cropping systems: G. W. Cussans, P. Ayres.
6. Effect of high organic matter soils on activity of herbicides: J. Holroyd, M. J. May.
7. Control of potato groundkeepers: G. W. Cussans, P. J. Lutman.
8. Cereal tolerance of herbicides: J. Holroyd, D. R. Tottman.

GRASS AND FODDER CROPS GROUP (Leader: R. J. Haggar)

1. Competition between cultivated grasses, legumes and weeds; autecology of grassland weeds: R. J. Hagger, T. W. Watt.
2. Herbicidal control of grassland weeds including bracken and the manipulation of grasses and clovers for improved productivity; R. J. Haggar, A. K. Oswald.
3. Systems of herbicide use and minimum cultivations for the establishment of grass and fodder crops: N. Squires, R. J. Haggar, J. G. Elliott.
4. Weed control in herbage seed crops: R. J. Haggar, A. K. Oswald.

PERENNIAL CROPS GROUP (Leader: J. G. Davison)

1. Fruit crop tolerance of soil- and foliage-applied herbicides: D. V. Clay, J. G. Davison.
2. Effect of important weeds on fruit production: J. G. Davison, J. A. Bailey.
3. Response of newly planted fruit crops and nursery stock (ornamental) to weed competition and herbicides: J. G. Davison, D. V. Clay.
4. Evaluation of new herbicides for the control of annual and perennial weeds in strawberries: J. G. Davison, D. V. Clay.

SPECIAL SERVICES

1. Survey and analysis of information about weeds and weed control in agriculture: J. G. Elliott.
2. Supervision, development and maintenance of application equipment for experimental use: M. E. Thornton.

WEED SCIENCE DEPARTMENT

Head of Department: K. Holly

HERBICIDE GROUP (Leader: K. Holly)

1. Evaluation of biological activity, selectivity and soil persistence of new herbicides: W. G. Richardson, A. M. Blair.
2. Evaluation of additives to improve performance of herbicides: D. J. Turner, M. P. C. Loader.

3. Improvement of methods for the application of herbicides: W. A. Taylor (Part of joint project with National Institute of Agricultural Engineering).
4. Effect of environmental factors on the activity of herbicides: J. C. Caseley, D. Coupland.
5. Development of experimental techniques and equipment for monitoring the environment; establishment of controlled environment systems: R. Simmons.
6. Effect of environmental factors on the activity of growth regulators: J. C. Caseley.
7. Evaluation of antidotes and protectants to increase selectivity of herbicides A. M. Blair.

CHEMISTRY GROUP (Leader: R. J. Hance)

1. Analysis of herbicides in soil, water and plant material: T. H. Byast.
2. Development of analytical methods for herbicides and their decomposition products: T. H. Byast, E. G. Cotterill.
3. Effect of herbicides on soil and crop quality: T. H. Byast.
4. Soil factors affecting the availability of soil-applied herbicides: R. J. Hance.
5. Effect of repeated applications of MCPA, tri-allate, simazine and linuron on 'fertility' of soil: P. D. Smith.
6. Persistence in soil of paraquat applied repeatedly to plant cover or soil: P. D. Smith.
7. Persistence in soil of picloram applied annually: P. D. Smith.
8. Effect of high application rates upon the rate of decomposition of simazine and linuron: P. D. Smith.
9. Effect of repeated applications of glyphosate on fertility of soils and growth of cereals at Begbroke Hill: P. D. Smith.

MICROBIOLOGY GROUP (Leader: M. P. Greaves)

1. Effect of herbicides and breakdown products upon microbial activity of soil: J. A. P. Marsh, H. A. Davies.
2. Effect of herbicides and breakdown products upon microbial populations and species composition in the soil: M. P. Greaves, G. I. Wingfield.
3. Development of techniques to measure microbial activity in the soil and the influence of herbicides thereon: J. A. P. Marsh, G. I. Wingfield, H. A. Davies.
4. Effect of herbicides and breakdown products on the microflora of the root region of plants: M. P. Greaves, G. I. Wingfield.

BOTANY GROUP (Leader: R. J. Chancellor)

1. Periodicity of germination of weed seeds. Chemicals for breaking seed dormancy: R. J. Chancellor.
2. Vegetative regeneration of weeds: R. J. Chancellor.
3. Inter-action of factors affecting competition between crops and weeds: R. J. Chancellor, N. C. B. Peters.
4. Weed ecology: R. J. Chancellor.

EXTRA-DEPARTMENTAL RESEARCH GROUPS

DEVELOPMENTAL BOTANY GROUP (Leader: D. J. Osborne)

1. Dormancy and viability of weed seeds: D. J. Osborne, J. A. Sargent, M. Wright.
2. Importance of stress conditions in seed germination and seedling establishment: D. J. Osborne, J. A. Sargent, M. Wright.
3. Factors regulating perennation and regeneration of plant parts: D. J. Osborne, J. A. Sargent, M. Wright.
4. Control of seed shedding in weed species: D. J. Osborne, J. A. Sargent, M. Wright.

AQUATIC WEED AND UNCROPPED LAND GROUP (Leaders: T. O. Robson and P. J. Terry (acting))

1. Development of methods for the control of emergent weeds: T. O. Robson, P. R. F. Barrett.
2. Development of chemical methods of controlling submerged and floating vascular plants and algae: T. O. Robson, P. R. F. Barrett.
3. Assessment of potential of grass carp for the control of aquatic weeds: T. O. Robson, M. C. Fowler (Joint project with MAFF Freshwater Fisheries Laboratory).
4. Herbicidal control of weeds in flowing water: T. O. Robson, P. R. F. Barrett.
5. Advisory service on aquatic weed control: T. O. Robson, P. R. F. Barrett.

ODM TROPICAL WEED GROUP (Leader: C. Parker)

1. New herbicide treatments for use in tropical crops against annual and established perennial weeds: C. Parker.
2. Study of the resistance of sorghum and millet varieties to a range of *Striga* species and strains: C. Parker.
3. Liaison and advisory work on weed control in developing countries: C. Parker, A. K. Wilson.

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Annotated Bibliographies 1976–77

(Apply to Information Department for current conversion of price codes)

		Price Code
91	Selected references to the use of activated charcoal and other absorbents in conjunction with herbicides, 1965–1975 (152 references)	I
92	Selected references to the utilisation of aquatic plants, 1969–1975, (93 references).	G
93	Selected references to the biology and control of wild rice and red rice (*Oryza* spp.), 1949–1976, (62 references).	F
94	Selected references to jute *(Corchorus capsularis* and *C. olitorius)* and and kenaf *(Hibiscus cannibinus* and *H. sabdariffa)*, 1955–1976, (95 references).	G
95	Selected references to the biology and control of *Convolvulus arvensis,* (1970–1976, (181 references). A supplement to No. 40.	I
96	Selected references to *Cassia tora (= C obtusifolius),* 1956–1976 (76 references).	G
97	Selected references to *Paspalum distichum* and *P vaginatum,* 1966–1975, (70 references).	F
98	Selected references to *Imperata* spp. (supplement to Bibliographies Nos. 28 and 75), 1972–1976, (58 references).	F
99	Selected references to the toxicity and carcinogenicity of bracken, 1954–1976, (78 references).	G
100	Selected references to the biology and control of *Cuscuta* spp. (a supplement to Bibliographies Nos. 32 and 51), 1972–1976, (81 references).	G
101	Selected references to glyphosate, (supersedes Bibliography 71), 1971–1976, (344 references).	K
102	Selected references to the biology and control of wild oats. (A supplement to Bibliographies Nos. 43 and 44), 1972–1976, (298 references).	J
103	Selected references to herbivirous fish (replacing Bibliography No. 31), 1957–1976, (162 references).	I
104	Selected references to the biology and control of *Oxalis* spp. (replacing Bibliography No. 39), 1958–1976, (220 references).	J
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111	Selected references to the biology and control of *Mikania* spp. (Replacing bibliography No. 34), 1960–1977, (59 references).	F

112 Selected references to the biology and control of *Paspalum conjugatum*, 1956–1977, (100 references). G

113 Selected references to the biology of *Cirsium arvense*, 1956–1976 (81 references) (See also No. 68). G

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116 Selected references to reviews and surveys of weed control in tropical and temperate crops, 1970–1977 (76 references). G

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Secretary
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Agricultural Chemicals Approval Scheme Liaison Officer

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Students

N. Johnston — T. Burghers

CHANGES IN RESEARCH, TECHNICAL AND ADMINISTRATIVE STAFF

NEW APPOINTMENTS

Mrs. S. L. Cooper *(on internal promotion)*	SO	Microbiology Group	1.4.77
R. J. Froud-Williams *(on internal promotion)*	SO	Botany Group	1.4.77
F. W. Kirkham *(on internal promotion)*	SO	Grass and Fodder Crops Group	1.4.77
Mrs. A. K. Wilson *(on internal promotion)*	SO	Tropical Weeds Group	1.4.77
E. D. Williams *(on transfer from Rothamsted Experimental Station)*	SSO	Botany Group	1.9.77
Daphne J. Osborne	SPSO	Developmental Botany Group	1.10.77
J. A. Sargent	PSO	Developmental Botany Group	1.10.77
M. Wright	HSO	Developmental Botany Group	1.10.77
(all on transfer from ARC Unit of Developmental Botany)			
A. D. Whelton	EO	Administrative Department	7.11.77

RESIGNATIONS

Miss C. R. Deans	Indexer	Information Department	31.1.76

STAFF VISITS OVERSEAS

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

1976

January	C. Parker	Sudan and Swaziland to advise on *Striga* in cane for Kenana Sugar Co. Ltd. and on weeds in rice for Commonwealth Development Corporation.
January February	R. J. Hance	USA to visit universities and research centres.

* Part time

March	J. D. Fryer J. E. Y. Hardcastle B. A. Wright	Netherlands, for EWRS.
April/May	C. Parker	Philippines to advise International Rice Research Institute on their weed research programme and India for discussions on *Striga* with International Crops Research Institute for the Semi-arid Tropics(ICRISAT).
May	R. J. Hance J. D. Fryer	Netherlands for EWRS.
June	R. J. Hance	Israel, to attend International Soil Science Society meeting 'Agrochemicals in Soils'.
June/July	C. Parker	Egypt for FAO, to advise on weed control on experiment stations.
July (to December 77)	T. O. Robson	Indonesia, attached to BIOTROP, advising on research programmes and techniques for ODM.
September	R. J. Chancellor	France, to attend Fifth International Colloquium on Ecology and Biology of Weeds.
	J. G. Davison	Belgium, Netherlands and Germany to discuss current weed research on fruit.
October	J. D. Fryer	Switzerland, to participate as member of Expert Group on feasibility of use of herbicides for destruction of illicit narcotic crops, United Nations Organization.
November/ December	W. A. Taylor	Canada and USA to attend North Centra Weed Control Conference and visit universities. Sponsored by Canadian Weed Committee, University of Saskatchewan and Union Carbide.
November/ December	R. J. Hance	Italy, to lecture at CNR Laboratories at Pisa, sponsored by CNR.
1977		
January	P. J. Kemp	Philippines, Indonesia, Malaysia and Thailand for discussion with information scientists at research institutes.
	W. A. Taylor	France, for discussion on herbicide application techniques, sponsored by Evrard Sprayer Co.
January	C. Parker	India, for ODM, to attend Indian Weed Science Conference and to advise ICRISAT on their weed research programme.
March	C. Parker	Jordan, for ODM, to advise the University of Jordan on weed research priorities.
March	J. D. Fryer J. E. Y. Hardcastle B. A. Wright	Netherlands for EWRS.
	R. J. Chancellor	Netherlands, to lecture at (and sponsored by) Wageningen University.
March/April	R. J. Hance	Thailand and Indonesia, to participate in Southern Asia Workshop on Pesticide Management and to lecture at BIOTROP for ODM.
April/May	C. Parker	Italy, to attend FAO meeting en route to India, to advise Tea Research Institute, Assam on weed research work; sponsored by British Council.

May	A. K. Oswald	Netherlands, for discussions on research in herbage seed crops.
June	G. W. Cussans P. J. Lutman	Netherlands, to attend Symposium on Control of Volunteer Potato Plants.
	J. D. Fryer	Germany, to liaise with (and sponsored by) Biologische Bundesanstalt fur Land—und Forstwirtschaft, Institut fur Unkrautforschung, Braunschweig.
July	C. Parker	Indonesia and Malaysia, for ODM, to attend the Sixth Asian Pacific Weed Conference and to study a *Striga* problem in rice.
July/August	R. J. Haggar	USA and New Zealand to speak at International Conference on Energy Conservation in Crop Production, to visit research institutes and attend New Zealand Weed and Pest Control Conference. Sponsored in part by Monsanto Ltd, Palmerston North University and ICI (New Zealand).
August	J. D. Fryer R. J. Hance J. E. Y. Hardcastle B. A. Wright	Sweden, to attend Symposium on Different Methods of Weed Control and their Integration and meetings for EWRS.
	G. W. Cussans	Sweden, to attend Symposium on Different Methods of Weed Control and their Integration.
	J. L. Mayall	Hungary, to visit the Plant Protection Institute.
September	P. J. Terry	The Gambia, for ODM, to survey weed problems.
October	C. Parker	Senegal, Mali, Upper Volta, Ghana, Niger and Nigeria to study the *Striga* problem and collect seed samples for ODM Research Scheme R 3327.
October	R. J. Hance	Germany for EWRS.
	W. A. Taylor	Denmark, for discussion on herbicide application techniques, sponsored by Hardi Sprayer Co.
December	W. A. Taylor	France, to attend Ninth COLUMA Conference, sponsored by Micron Sprayers Ltd.

STAFF COMMITTEE SERVICE

Members of WRO have served on the following Committees:—

ADAS/WRO Liaison Group

ADAS
- Pesticide Committee
- Sward Renovation Exhibit Co-ordinating Committee

Agricultural Research Council
- Secretary's Policy Advisory Committee (SPAC)
- Working Group on Direct Drilling and Reduced Cultivation
- Working Party on Suitability of Soils for Direct Drilling
- Working Party on Information Services via Computer-based Networks
- Fruit Weed Control Group

Annals of Applied Biology
- Editorial Board

Aquatic Botany
- Editorial Panel

Aquatic Weed Control Training Working Party

Association of Applied Biology
- Council
- Weed Group Committee

B A A Wildlife Research Panel

British Crop Protection Council
- Council
- Conference Organising Committee
- Decimal Growth Stage Publication Sub-Committee
- Finance and General Purposes Committee
- Education and Communications Committee
- Recommendations Sub-Committee (Weeds)
- Handbook Study Group
- Persistence of Insecticides and Herbicides Symposium Programme Committee
- Programme Committee—Weeds
- Programme Policy Committee
- Research and Development Technical Committee
- Research and Development Technical Sub-Committee (Weeds)
- Weed Control Handbook Committee

British Grassland Society
- Executive Committee
- Programme Committee
- Working Party on Sward Destruction
- Working Party on Downland Improvement
- Working Party on Sward Deterioration

British Standards Institution Technical Committee PCC/1

European Weed Research Society
- Council
- Editorial Board *Weed Research*
- Executive Committee
- Scientific Committee
- Research group on aquatic weeds
- Research group on annual grass weeds
- Research group on herbicides/soils
- Research group on herbicide application
- Research group on parasitic weeds
- Symposia organizing and programme committees

EWRS/EAPR Volunteer Potato Working Group

FAO Committee of Experts on Pesticides in Agriculture

IX International Congress of Plant Protection
- Programme Committee

International Standards Organization Technical Committee TC/81

International Weed Science Society
- Steering Committee
- Executive Committee

JCO Arable Grass and Forage Board
- Cereals Committee
- Plant Science Committee

Maize Development Association Research and Development Committee

Ministry of Agriculture Fisheries and Food
- Agricultural Chemicals Approval Scheme Science Advisory Committee
- CDA/ULV Ways and Means Panel
- Grass Carp Field Trials Steering Committee
- National Wild Oat Advisory Programme Steering Committee
- NIAB Official Seed Testing Committee
- NIAE Consultative Group on Cultivation

ODM Sub-Committee on Pesticide Application Overseas

Oxford Agricultural Trust

Society of Chemical Industry
- Pesticides Group Committee
- Physiochemical and Biophysical Panel

Sugar Beet Research and Education Committee
- Weed Beet Sub-Committee

University of Reading Plant Sciences Joint Committee

W H D Herbage Seeds Committee

POST GRADUATE RESEARCH STUDENTS AT WRO 1976–77

Name	*University and Higher Degree*	*Period at WRO*	*Topic of Research*
Boatman N.	Reading PhD	1/10/77–31/12/77	Factors affecting the establishment of white clover
Cairns A. L. P.	Reading PhD	1/1/76–8/11/77	Mechanisms of dormancy in *Avena* spp.
Cole D.	Bath PhD (CASE award)	1/7/77–1/10/77	Mode of action of glyphosate
Howe C. D.	Reading PhD	1/1/76–31/12/77	Autecology of grass weeds of grassland
Kowalczyk, B.	Oxford D Phil	1/10/76–31/12/77	Effect of pre-spraying environment on herbicide performance
Mudd P. J.	Bath PhD (CASE award)	1/10/77–31/12/77	Degradation of isoproturon in rhizosphere of winter wheat
Watt T.	Oxford D.Phil	1/1/76–1/10/77	Autecology of Yorkshire fog in grassland

VISITING RESEARCH WORKERS AND OVERSEAS TRAINEES AT WRO 1976–77

Name and Origin	*Period at WRO*	*Topic of Research or Training*
Hunyadi K. Research Institute for Plant Protection University of Agricultural Science Keszthely Hungary	19/5/76–11/9/76	Effect of external factors on the growth and development of *Agropyron repens*
Siriwardena T. G. D. University of Peradeniya Sri Lanka	1/1/77–31/12/77	Herbicide movement in the soil (British Council Training Fellow)
Van der Vet W. Agricultural University Wageningen The Netherlands	4–12/3/76	Organization of weed research in UK
Wetala P. Ministry of Agriculture Tanzania	1/5/76–31/7/76	Application of granular herbicides
Wirjahardha S. BIOTROP Indonesia	1/6/76–15/8/76	Control of wild and red rice

GLOSSARY OF CHEMICALS MENTIONED IN THIS REPORT

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

aminotriazole	3-amino-1,2,4-triazole
asulam*	methyl (4-aminobenzenesulphonyl)carbamate
barban*	4-chlorobut-2 ynyl *N*-(3-chlorophenyl)carbamate
benazolin*	4-chloro-2-oxobenzothiazolin-3-ylacetic acid
bentazon*	3-isopropyl-2,1,3-benzothiadiazin-4-one 2,2-dioxide
benzoylprop-ethyl*	ethyl-*N*-benzoyl-*N*-(3,4-dichlorophenyl)-2-aminopropionate
bromoxynil*	3,5-dibromo-4-hydroxybenzonitrile
chloroxuron*	*N*-4-(4-chlorophenoxy)phenyl-*N*,*N*-dimethylurea
chlorthiamid*	2,6-dichlorothiobenzamide
chlortoluron*	*N*'-(3-chloro-4-methylphenyl)-*N*,*N*-dimethylurea
clofop-isobutyl*	isobutyl 2-[4-(4-chlorophenoxy)phenoxy]-propionate
cyprazine*	2-chloro-4-cyclopropylamino-6-isopropylamino-1,3,5-triazine
2 4-D*	2,4-dichlorophenoxyacetic acid
dalapon*	2,2-dichloropropionic acid
dicamba*	3,6-dichloro-2-methoxybenzoic acid
dichlobenil*	2,6-dichlorobenzonitrile
diclofop-methyl*	methyl 2-[4-(2,4-dichlorophenoxy)phenoxy]-propionate
dichlorprop*	(±) 2-(2,4-dichlorophenoxy)propionic acid
difenzoquat*	1,2-dimethyl-3,5-diphenyl-pyrazolium
dinoseb*	2-(1-methylpropyl)-4,6-dinitrophenol
ethofumesate*	2-ethoxy-2,3-dihydro-3,3-dimethylbenzofuran-5-yl methylsulphonate
flamprop-methyl*	methyl (±)-2-(*N*-benzoyl-3-chloro-4-fluoroanilino) propionate
glyphosate*	*N*-(phosphonomethyl)glycine
hexazinone*	3-cyclohexyl-6-dimethylamino-1-methyl-1,3,5-triazine-2,4-dione
ioxynil*	4-hydroxy-3,5-di-iodobenzonitrile
isoproturon*	*N*'-(4-isopropylphenyl)-*N*,*N*-dimethylurea
lenacil*	3-cyclohexyl-6,7-dihydro-1*H*-cyclopentapyrimidine-2,4-(3H,5H)dione
linuron*	*N*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea
MCPA*	4-chloro-2-methylphenoxyacetic acid
mecoprop*	(±) 2-(4-chloro-2-methylphenoxy)propionic acid
metamitron*	4-amino-3-methyl-6-phenyl-1,2,4-triazin-5 (4H)-one
methabenzthiazuron*	*N*-(benzothiazol-2-yl)-*N*,*N*'-dimethyl urea
metoxuron*	N'-(3-chloro-4-methoxyphenyl)-*N*,*N*-dimethylurea
oxadiazon*	3-(2,4-dichloro-5-isopropoxyphenyl)-5-*t*-butyl-1,3,4-oxadiazolin-2-one
paraquat*	1,1'-dimethyl-4 4'-bipyridylium
pendimethalin*	*N*-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine
phenmedipham*	3-(methoxycarbonylamino)phenyl *N*-(3-methylphenyl) carbamate
propachlor*	α-chloro-*N*-isopropylacetanilide
propyzamide*	3,5-dichloro-*N*-(1,1-dimethylpropynyl)benzamide
simazine*	2-chloro-4 6-bisethylamino-1,3,5-triazine
2,4,5-T*	2,4,5-trichlorophenoxyacetic acid
2,3,6-TBA*	2,3,6-trichlorobenzoic acid
TCA*	trichloroacetic acid
terbuthylazine*	2-chloro-4-ethylamino-6-t-butylamino-1,3,5-triazine
terbutryne*	4-ethylamino-2-methylthio-6-t-butylamino-1,3,5-triazine
tri-allate*	*S*-2,3,3-trichloroallyl *N*,*N*-di-isopropyl(thiocarbamate)
trichlopyr*	3,5.6-trichloropyridyloxyacetic acid

trietazine*	2-chloro-4-diethylamino-6-ethylamino-1,3,5-triazine
trifluralin*	2,6-dinitro-*N*,*N*-dipropyl-4-trifluoromethylaniline
trifop-methyl*	methyl[4-(4-trifluoromethylphenoxy)phenoxy] propionate

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

ACAS: Agricultural Chemicals Approval Scheme
ADAS: Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food
ARC: Agricultural Research Council
BCPC: British Crop Protection Council
CDC: Commonwealth Development Corporation
CSG: Chief Scientist's Group of Ministry of Agriculture, Fisheries and Food
DES: Department of Education and Science
FAO: Food and Agriculture Organization of the United Nations Organization
JCO: Joint Consultative Organization
Letcombe: ARC Letcombe Laboratory
MAFF: Ministry of Agriculture, Fisheries and Food
NWOAP: National Wild-oat Advisory Programme
ODM: Ministry of Overseas Development
PSPS: Pesticides Safety Precautions Scheme
RSC: Research Strategy Committee, WRO
UDB: ARC Unit of Developmental Botany
UKASTA: United Kingdom Agricultural Supply Trades Association
USF: ARC Unit of Systematic Fungicides
WRO: ARC Weed Research Organization

INSTITUTES FOR AGRICULTURAL RESEARCH IN GREAT BRITAIN

The research programmes of all the following Research Institutes, supported from public funds, are co-ordinated by the Agricultural Research Council. Most of them publish reports annually and details can be obtained from the Secretaries of the Institutes concerned.

ARC Institutes

Animal Breeding Research Organization	West Mains Road, Edinburgh, EH9 3JQ
Animal Research Station	307 Huntingdon Road, Cambridge, CB3 0JQ
Food Research Institute	Colney Lane, Norwich, NR4 7UA
Institute of Animal Physiology	Babraham, Cambridge, CB2 4AT
Institute for Research on Animal Diseases	Compton, Nr Newbury, Berks, RG16 0NN
Letcombe Laboratory	Wantage, Oxfordshire, OX12 9JT
Meat Research Institute	Langford, Bristol, BS18 7DY
Poultry Research Centre	King's Buildings, West Mains Road, Edinburgh, EH9 3JS
Weed Research Organization	Begbroke Hill, Yarnton, Oxford, OX5 1PF

State-aided Institutes in England and Wales

Animal Virus Research Institute	Pirbright, Woking, Surrey, GU24 0NF
East Malling Research Station	East Malling, Maidstone, Kent, ME19 6BJ
Glasshouse Crops Research Institute	Worthing Road, Rustington, Littlehampton, Sussex, BN16 3PU
Grassland Research Institute	Hurley, Maidenhead, Berks, SL6 5LR
Houghton Poultry Research Station	Houghton, Huntingdon, PE17 2DA
John Innes Institute	Colney Lane, Norwich, NR4 7UH
Long Ashton Research Station	Long Ashton, Bristol, BS18 9AF
National Institute of Agricultural Engineering	Wrest Park, Silsoe, Bedford, MK5 4HA
National Institute for Research in Dairying	Shinfield, Reading, RG2 9AT
National Vegetable Research Station	Wellesbourne, Warwick, CV35 9EF
Plant Breeding Institute	Maris Lane, Trumpington, Cambridge, CB2 2LQ
Rothamsted Experimental Station	Harpenden, Herts, AL5 2JQ
Welsh Plant Breeding Station	Plas Gogerddan, Aberystwyth, Dyfed, SY23 3EB
Wye College, Department of Hop Research	Ashford, Kent, TN25 5AH

State-aided Institutes in Scotland

Animal Diseases Research Association	Moredun Institute, 408 Gilmerton Road, Edinburgh, EH17 7JH
Hannah Research Institute	Ayr, Scotland, KA6 5HL
Hill Farming Research Organization	Bush Estate, Penicuik, Midlothian, EH26 0PH
Macaulay Institute for Soil Research	Craigiebuckler, Aberdeen, AB9 2QJ
Scottish Institute of Agricultural Engineering	Bush Estate, Penicuik, Midlothian, EH26 0PH
Rowett Research Institute	Greenburn Road, Bucksburn, Aberdeen, AB2 9SB
Scottish Horticultural Reseach Institute	Invergowrie, Dundee, DD1 5DA
Scottish Plant Breeding Station	Pentlandfield, Roslin, Midlothian, EH25 9RF

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