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similar, unmixed areas. More work on this subject was in progress when the project finished.

WEED FLORA

No full weed surveys have been undertaken for the Black Fens but the annual broad-leaved weed flora appears to have changed little over the years. Those species such as large-flowered hemp-nettle (*Galeopsis speciosa*) and fig-leaved goosefoot (*Chenopodium ficifolium*) that are more common on the fens than mineral soils are still abundant. Large numbers of small nettle (*Urtica urens*) are still very common on areas with greater than 30% organic matter content. Field pansy (*Viola arvensis*) is becoming a problem in a number of crops, especially sugar-beet. This is partly because it is not always adequately controlled in cereals and partly because its very small cotyledons and first true-leaves cause it to be overlooked and treated too late by growers using the repeated low dose technique. Fool's parsley (*Aethusa cynapium*) is a local problem in sugar-beet and onions because, unless care is taken, it can survive repeated low-dose programmes. It has the ability to continue to grow even after its cotyledons have been killed. With better weed control systems in sugar-beet, potatoes and onions there has been a reduction in the problem of late germinating fat-hen (*Chenopodium album*) and black nightshade (*Solanum nigrum*) in these crops.

There have been changes in the annual grass weed flora. Wild-oat (*Avena fatua*) was virtually unheard of on fen soils in 1963 but is now common. Black-grass (*Alopecurus myosuroides*) is also creeping into the area. These two weeds are closely associated with the increase in cereals grown in the rotation on the more mineralised soils. Annual meadow-grass (*Poa annua*) is also more common, possibly because most of the other annual weeds have been removed. However, with the proper use of herbicides this weed can be contained.

CONCLUSIONS

In 1963, herbicides for use on organic soils were very limited and weed control was still a major problem; this was one of the main reasons that the WRO became closely involved with the EHF from the start. The main herbicides in use at that time were tractor vaporising oil, a few post-emergence herbicides for cereals and high doses of TCA for grass weed control. Now there are over 27 soil-acting herbicides (86 commercial products) whose labels do not preclude their use on organic soils, plus some 35 foliage-acting herbicides (245 commercial products). The Fen Soils

Project has worked on almost all the soil-applied herbicides and many of the foliage-applied ones. This work included studies of weed spectrum, selectivity and persistence in the soil. The Team is a source of data and information for numerous advisors, farmers, research scientists and chemical companies.

The approved products mentioned above cover the major crops (by area) of the organic soils but the minor crops are still without a sufficient choice of herbicides for season long weed control. In minor crops with a high value, mechanical tractor or hand-weed control can be employed, but where the returns for the crop are low, weed control can limit the crop to specialist or small growers.

It is regrettable that the project is ending because, apart from weed control in minor crops, there are a number of other problems still to be solved. Although there are now a large number of herbicides that can be used on organic soils many are applied without consideration of the subsequent treatments which together constitute the whole weed control programme for a given crop. Consequently, for most crops, there is a need, and the possibility, to reduce the amount of herbicide used. In the repeated low dose programmes used for sugar-beet and onions, work in progress when the project was stopped indicated that there was a lot of scope for reducing the amount of herbicide used, especially in the later post-emergence applications. Results were also showing that savings could be made in the use of pre-emergence herbicides when these were followed by low dose post-emergence treatments which included a residual component. Early indications were that these would also improve crop yield. Investigations on artificially or naturally mixed soils should be continued to determine how consistent herbicide performance can be achieved. At the time of writing the uncertainty over the future of WRO makes it hard to guarantee that the EHF, ADAS, fenland farmers, chemical companies, advisors, merchants and others who service this important area of British agriculture will still have the easy access to weed control information that they have previously had. However, we hope to maintain as close a liaison as is possible and to continue, albeit in a much reduced way, the partnership which has been so successful over the past 20 years.

ACKNOWLEDGEMENTS

The WRO Fenland Project would like to acknowledge the help and assistance received over the years from the Arthur Rickwood EHF. Especial thanks must go to Mr P. E. Cross, the first director of the EHF,

and his Farm Advisory Committee who first requested that a permanent WRO Fenland Team be established. Thanks must also go to Mr R. Wickens who always encouraged an atmosphere of friendly collaboration that resulted in much useful work. We also acknowledge Mr J. MacLeod, the present director, who has continued to encourage that close working partnership.

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TWENTY YEARS OF WEED CONTROL EXPERIMENTS ON ORGANIC SOILS

1963 —herbicides tested for weed control and selectivity in potatoes; linuron successful.
1965 —monolinuron, fenuron and chlorpropham controlled weeds.
—monolinuron selective in potatoes.
—weed emergence patterns in potatoes studied.
1966 —propham, chloramben, propachlor, alachlor and chlorpropham plus fenuron controlled weeds and selectivities indicated in a number of crops.
1967 —weed emergence patterns in sugar-beet studied.
—terbacil, diuron, benzthiazuron, aziprotryne, bromacil, karbutilate and asulam controlled weeds.
1968 —lenacil controlled weeds when incorporated into the soil.
—delachlor, medinoterb acetate, methazole, chlorbromuron, metoxuron, medinoterb-acetate plus propham and noruron controlled weeds and selectivities indicated.
—weed emergence patterns in carrots studied.
1969 —butachlor, carbetamide, haloxidine and buturon controlled weeds and some selectivities indicated.
—incorporated applications of both tri-allate granules and emulsion controlled *Avena fatua*.
—lenacil, placed as a layer below soil surface, controlled weeds.
—studies on mobility of lenacil started.
—persistence studies on lenacil started.
—studies on the selectivity of lenacil in sugar-beet started.
1970 —ethofumesate, chlortoluron, oxadiazon, cyanazine and cycloate controlled weeds and some selectivities indicated.
1971 —bentazone and metribuzin controlled weeds and some selectivities indicated.
—the effects of wetters and oils on herbicide activity evaluated.
—emergence and growth of *Avena fatua* on organic soil studied.
1972 —dinitramine controlled weeds on organic soils.
—selectivities of metribuzin in potatoes studied.
—Rotabar developed for accurate incorporation of herbicides.
—investigations started on weed control activity of herbicides on mixed soils.
—persistence studies with metribuzin started.
1973 —tebuthiuron controlled weeds.
—incorporated metribuzin selective in potatoes.
—weed control activity of herbicides on soils of differing pH studied.

1974 —metamitron, isoproturon and dimefuron controlled weeds and selectivities indicated.
—weed emergence on different organic soils and after various cultivations investigated.
—effect of addition of polyethylene glycol to simazine investigated.

1975 —ethalfluralin controlled weeds.
—isoproturon selective in radish.
—specific experiments investigated the control of *Poa annua*.
—effect of seedbed on herbicide performance studied.
—pre-harvest applications of MCPA gave good control of *Convolvulus arvensis*.
—glyphosate controlled actively growing *Polygonum amphibium* in cereal stubble.

1976 —triclopyr and oxyfluorfen controlled weeds.
—effect of irrigation on weed emergence and herbicide activity studied.
—first sample (50 tonnes) of topsoil taken to WRO and stored in deep outside pits for later use in glasshouse experiments.

1977 —combined effects of pre- and post-emergence herbicides in sugar-beet studied.
—pre-emergence herbicides applied by rotary atomisers gave good weed control.

1978 —synpernonic surfactants dramatically improved the weed control activity of simazine.
—investigations into horizontal movement of metribuzin started.

1979 —repeated low dose treatments of metamitron and phenmedipham showed promise in sugar-beet.
—laboratory and glasshouse studies showed effect of spray pressure on spray retention in sugar-beet.
—effect of different types of organic soil shown to affect herbicide activity.

1980 —in sugar-beet timing of repeated low doses to cotyledon weeds shown to be more important than spray pressure.

1981 —pre-emergence residual herbicides found to be undesirable for good weed control and crop yields with the repeated low dose technique in sugar-beet.

1982 —the use of residual herbicides in the post-emergence applications of the repeated low dose technique shown to be important.

1983 —the use of very low doses of post-emergence herbicides shown to have potential to increase yields of sugar-beet.
—reduced doses of pre-emergence herbicides in onions shown to have potential to improve weed control and crop yields and to reduce weed control costs.

Further studies on the potential uses of herbicides found to control weeds on organic soils were usually done by the EHF in collaboration with the WRO Fenland Team. Such uses are not listed above.

Formulation research at the Weed Research Organization

D J TURNER

A brief review of formulation research at WRO during the early 1970s was given in the 6th Biennial Report (Turner, 1976). This article updates that report. Most but not all of the programme relates to the use of additives with commercially formulated herbicides, notably glyphosate and difenzoquat, sold respectively as Roundup and Avenge. More recently, attention has turned to bentazone (Basagran) and to the phenoxyacids and their derivatives.

It may be asked why there is a need for official research in this field. Chemical firms spend a great deal of money on product development, which includes research on formulating herbicides. Is this insufficient? The answer is given by the facts: in most cases we find that efficiency can be enhanced by the use of additives, particularly when formulated herbicides are used under extreme conditions, or for special purposes. Why is this possible? There can be several reasons, but one important factor is the difficulty in making a formulation which is suitable for a wide variety of uses. Most herbicides are used against several weed species, in varying doses and in spray volumes varying from perhaps 20 l ha^{-1} to 500 l ha^{-1}. It is quite impossible to devise a formulation which is ideal for all possible uses. For example surfactant concentrations intended for 200-300 l ha^{-1} application may be far too high for very low volume controlled drop application. Similarly, a product designed for use in hot dry weather may be inappropriate for cool wet conditions. It is also worth emphasising that some additives discussed in this report are bulky or corrosive and can only be added just before spraying.

With relatively expensive herbicides, additives which allow reduced doses to be used are of most interest to farmers. With cheaper "commodity" herbicides such as the phenoxyacids, dose reduction is usually of less economic interest although it may of course be important from environmental aspects. The programme with phenoxy herbicides has concentrated on improving their reliability and widening their spectrum of activity against weeds. It is simplest to consider these herbicides separately.

Glyphosate. The earlier report discussed activation of low doses of Roundup by ammonium sulphate. This effect has now been examined more closely, especially in relation to the control of couch-grass (*Elymus repens*). Interactions with surfactants are of particular interest; it appears that ammonium sulphate has its maximum effect in mixtures with lipophilic surfactants, notably cationic products such as Ethomeen C12 or Ethylan TF. However, when ammonium sulphate is absent, hydrophilic types of surfactant such as Ethomeen T25 or Ethylan TT15 are more effective than the lipophilic types (Turner & Loader, 1980). Table 1 shows a typical result from a pot experiment with couch-grass.

Table 1. No. of viable buds per couch-grass plant 43 days after spraying 0.1 kg ai ha^{-1} glyphosate as Roundup

	No ammonium sulphate	+ 5% w/v ammonium sulphate
No added wetter	14.7 (a)	9.7 (a)
0.5% v/v Ethylan TT15	3.5 (b)	4.0 (b)
0.5% v/v Ethylan TF	10.5 (a)	0.5 (c)

Means with the same suffix do not differ significantly at the 5% level of probability.

Clearly, there are two methods of using these additives to enhance the effects of Roundup. Either ammonium sulphate with a product such as Ethylan TF or Ethomeen C12 can be used or alternatively activity can be enhanced by straight addition of a relatively hydrophilic surfactant. Surfactants suitable for both systems have been cleared for post-harvest use against couch-grass by PSPS and are available commercially. Ethokem and Frigate derived from Ethomeen T25 and Ethylan TT15 are intended for use without ammonium sulphate while Ethomeen C12 is only suitable for use in mixture with this salt. In practice, most farmers prefer to use a hydrophilic surfactant on its own even though the Ethomeen C12/ammonium sulphate mixture is generally more effective.

Both methods of enhancing activity may limit the adverse effects of rainfall after spraying (Turner, 1981, Table 2). As in Table 1, ammonium

Table 2. No. of viable buds per couch-grass plant 4 months after spraying glyphosate as Roundup. Mean effect of 1 kg ai ha^{-1} and 2 kg ai ha^{-1} doses.

	Time to simulated rain	
	1 h	4 h
No additive	63.0 (a)	23.8 (c)
5% w/v ammonium sulphate with 0.5% v/v Ethomeen C12	32.5 (b)	15.8 (c)
0.5% v/v Ethomeen T25	60.3 (a)	15.5 (c)

Means with the same suffix do not differ significantly at the 5% level of probability.

sulphate and a lipophilic surfactant affected phytotoxicity to a greater extent than did a hydrophilic surfactant, Ethomeen T25, used on its own.

It is emphasised that these effects of surfactants and ammonium sulphate have been recorded in experiments with couch-grass. In other species the responses may be different.

In the previous account of formulation research at WRO, experiments with phosphate additives were mentioned. Subsequent work has shown that other acids and their salts can also enhance the activity of foliage-applied glyphosate, polyvalent anions being most effective. For example, strong activation has been observed with oxalic, citric, lactic and tartaric acids (Turner & Loader, 1978). Monovalent acids have much less effect. It is now believed that the polyvalent acids act by sequestering di- or trivalent metal ions, which would otherwise inactivate glyphosate. In some circumstances additives of this kind have potential for improving glyphosate activity, particularly if they are used with a suitable hydrophilic surfactant. Fig. 1 shows the regrowth from couch-grass rhizomes collected from treated plots in a field experiment. Glyphosate at 0.25 kg ai ha^{-1} was

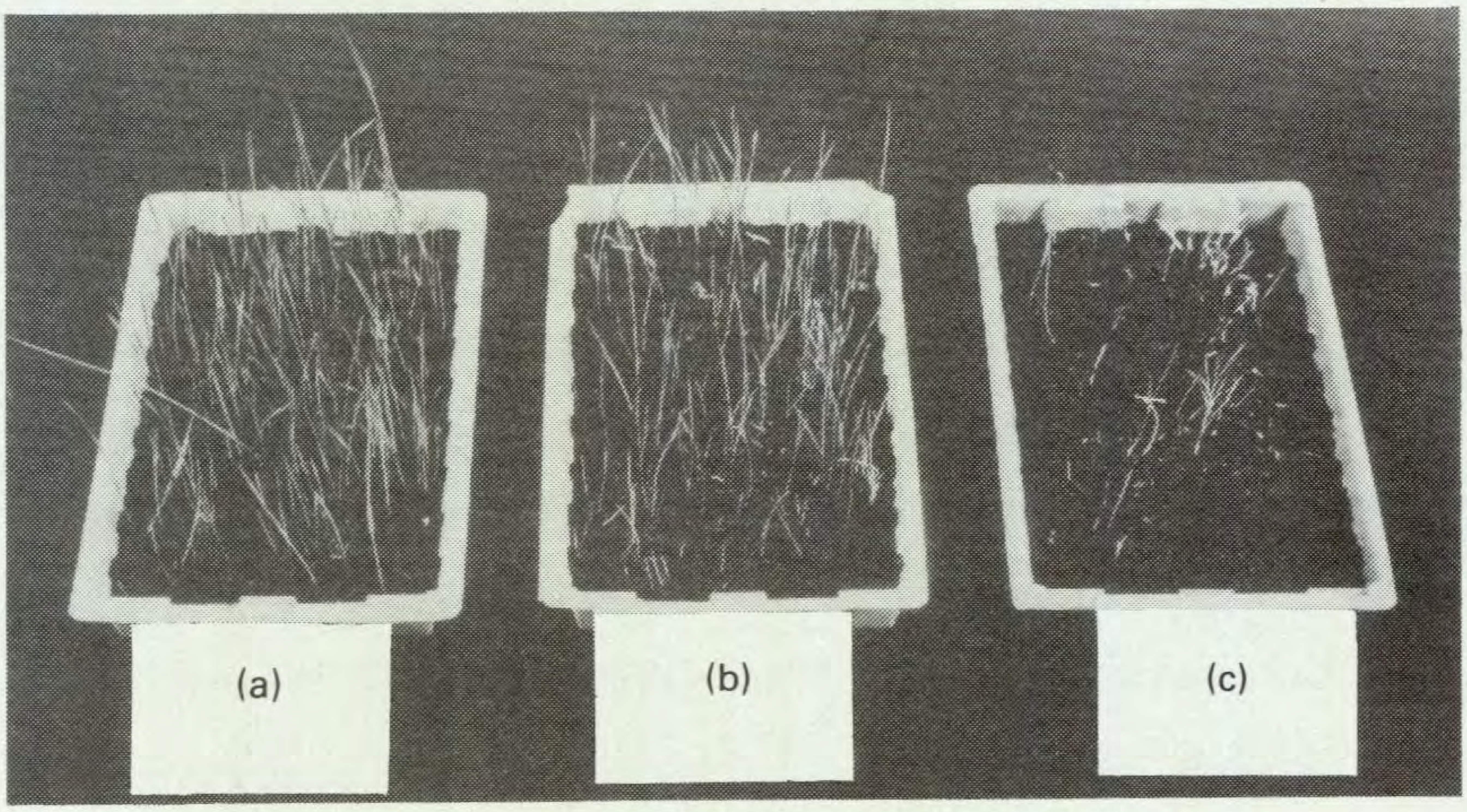

Fig. 1. (a) control, (b) glyphosate 0.25 kg ha^{-1}
(c) glyphosate 0.25 kg ha^{-1} + 2% H_3PO_4

applied without adjuvants and with 2% w/v of orthophosphoric acid. In contrast to ammonium sulphate, these acid additives do not interact to any large extent with sufactants, the effects of mixtures being approximately the sum of the effects of the separate components. Acidification of strong solutions of Roundup can cause precipitation of glyphosate as the free acid, but this can be avoided if the concentration of glyphosate is kept below 1% w/v acid equivalent.

In the earlier report solubilized preparations of glyphosate were mentioned. In these formulations, surfactants are used as cosolvents to make clear apparently single phase microemulsions of aqueous Roundup in oil. The microemulsions are completely stable and cannot be made to settle out by centrifuging. They are not true solutions, but have properties typical of molecular solutions in oil, including an ability to pass easily through thick leaf cuticle and bark. They may find practical uses, but follow-up experiments indicate that glyphosate formulated in oil by solubilization is relatively immobile within plants. An alternative method of formulating glyphosate as an oil solution has been devised, which involves reacting the free acid with a suitable cationic surfactant. Surfactants derived from amines which contain unsaturated fatty acids appear to be most suitable. Oil soluble salts of glyphosate prepared in this way appear to be at least as active as Roundup against herbaceous plants, and much more phytotoxic than the

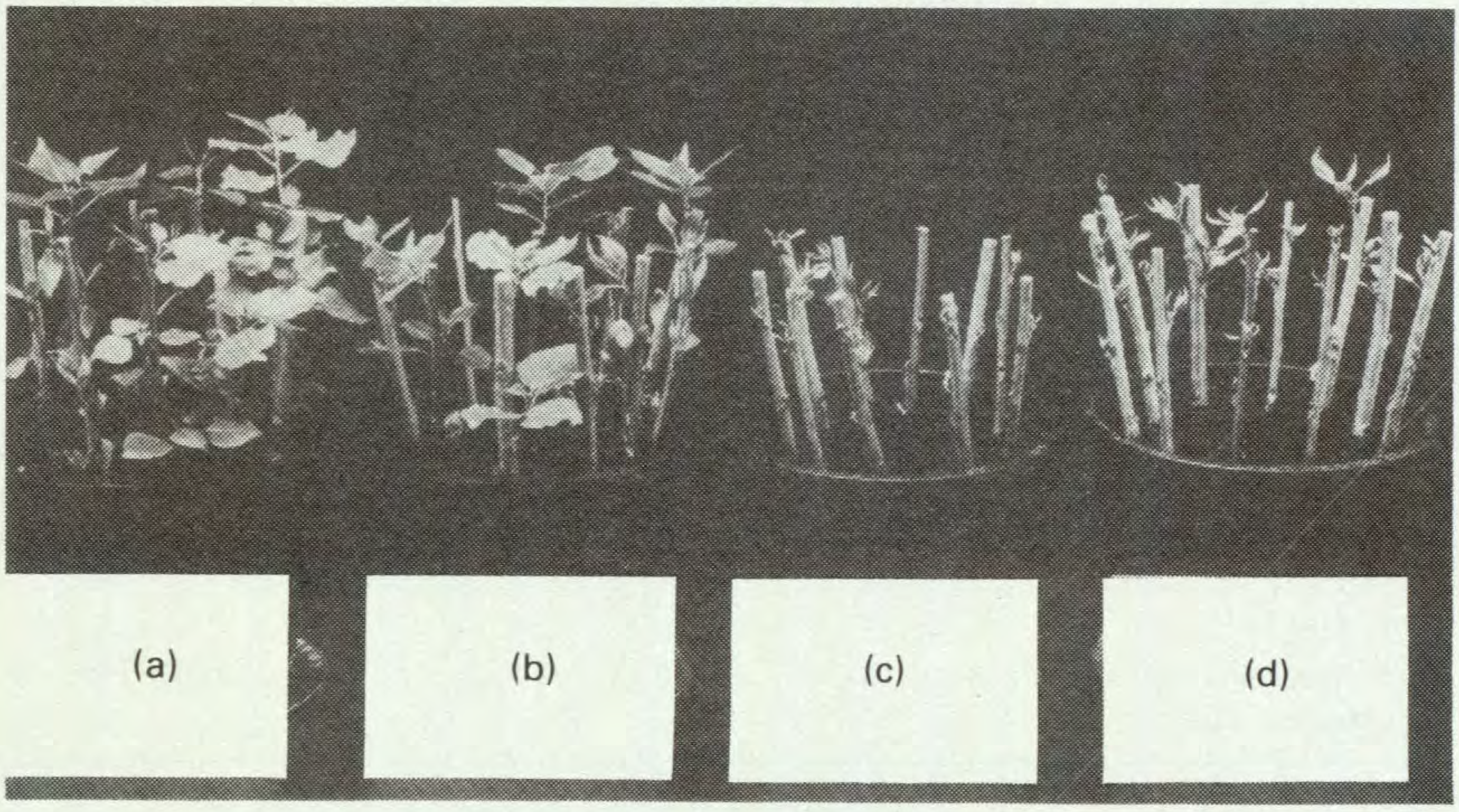

Fig. 2. (a) control, (b) glyphosate 20 g l^{-1} as Roundup in water, (c) glyphosate 20 g l^{-1} as Roundup solubilized, (d) glyphosate 20 g l^{-1} as S-12 salt in oil

standard formulation when applied to bark. Fig. 2 shows regrowth from poplar cuttings whose bark has been sprayed with 20 g ai l^{-1} glyphosate, as Roundup in water, as Roundup solubilized into oil, or as the surfactant salt in oil.

Difenzoquat. Studies with solublized oils, discussed in the earlier report, have continued in further pot trials and in the field. In the latter situation, addition of an oil-surfactant mixture improved the activity of medium volume (200 l ha^{-1}) and very low volume (20 l ha^{-1}) applications against wild-oats (*Avena fatua*) (Table 3, Taylor, Ayres & Turner, 1981). A mixture of Agral, Burtemul A2 and domestic paraffin, in the proportions 1:1:4 by volume, was used at 1 kg ha^{-1}. The solutions also contained the recommended surfactant, 0.5% v/v Agral. Other mixtures containing lipophilic (oil-soluble) and hydrophilic (water soluble) surfactants have been tested. It now appears that oil may be unnecessary if both types of surfactant are present. Different mixtures are required for very low volume controlled drop applications of difenzoquat and for addition to medium volume conventional sprays. When very low volumes are used, effects on drop spreading appear to be very important. With higher spray volumes, movement of spray deposits from the leaf laminae to the axils may occur and it is known that topical application of difenzoquat to leaf sheaths are much more phytotoxic than applications to the leaf blades (Caseley & Coupland, 1980). Addition of surfactant to difenzoquat spray solutions often increases phytotoxicity to cereal crops, as well as to wild-oats. However, there are indications that some mixtures may enhance difenzoquat activity against wild-oats but have little effect in increasing crop injury. Mixtures containing the surfactants Burtemul P2 and Burtemul N8 show promise.

Table 3. No. of wild-oat panicles m^{-2} (Taylor, Ayres & Turner, 1981)

	Difenzoquat, kg ai ha^{-1}				
	0.33		0.67		1.00
	Application method				
	Conventional	CDA	Conventional	CDA	Conventional
Surfactants	200 l ha^{-1}	20 l ha^{-1}	200 l ha^{-1}	20 l ha^{-1}	200 l ha^{-1}
0.5% Agral	66 (bc)	133 (c)	22 (a)	79 (bc)	10 (a)
0.5% Agral + 1 kg/ha^{-1} oil/ surfactant mixture	53 (b)	48 (b)	5 (a)	7 (a)	not tested
Unsprayed control 107 (c)					

Means followed by the same suffix do not differ significantly at the 5% level of probability.

Phenoxy herbicides. Mixtures of ammonium sulphate with suitable surfactants or oil-surfactant additives often increase the phytotoxicity of phenoxy herbicide salts to important weed species. Sometimes the additives increase crop injury, but this does not always happen and it is hoped to devise methods of improving weed control which do not adversely affect selectivity. There is preliminary evidence that surfactant mixtures such as those used to activate difenzoquat may improve the effects of mecoprop salt formulation against established cleavers (*Galium aparine*), a weed which is otherwise only moderately susceptible to mecoprop salts. As in the case of

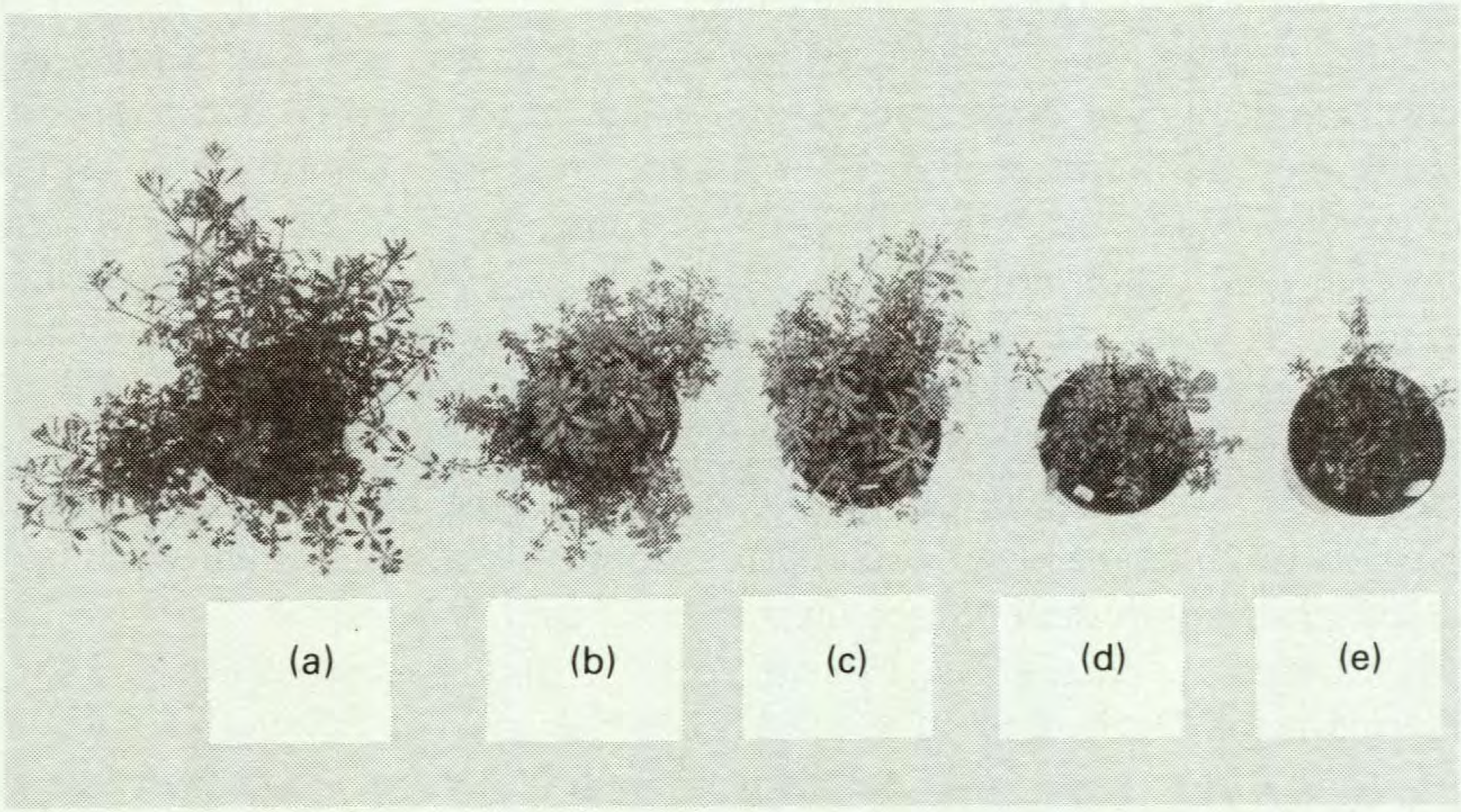

Fig. 3. (a) control, (b) mecoprop 0.25 kg ha^{-1}, (c) + 1% N8, (d) + 1% D256, (e) + 1% N8/C12 mix

difenzoquat, mixtures of a lipophilic and a hydrophilic surfactant appear to be more effective than either product used separately (Fig. 3). However, it must be emphasised that this use of surfactant mixtures with mecoprop has not yet been fully evaluated.

Some time has been spent examining alternative formulations, particularly preparations of free phenoxy acids formulated as wettable powders. There is preliminary evidence that these formulations may be slightly more effective than salts. Preparations containing the free acids are compatible with acid additives such as phosphoric acid. These enhance activity but are impracticable to use with salt formulations because they cause precipitation.

Bentazone. In pot experiments mixtures of ammonium sulphate with suitable surfactants or emulsified oils markedly increase the effects of the commercial formulation of bentazone, Basagran. Promising results have been obtained with chickweed and mayweed (*Matricaria perforata*).

Mixtures of both additives had more effect than either used alone. Phytotoxicity to important crops including clover, french beans, cereals and ryegrass was almost unaffected. It is possible that the use of additives will reduce the cost of bentazone treatments so that they become commercially viable for use in young leys containing clover, a situation where chickweed is often troublesome.

The interaction between ammonium sulphate and surfactants or emulsified oils has been studied by the use of ^{14}C-labelled herbicide. In chickweed, the additives interact, markedly increasing the rate of leaf entry of labelled bentazone. They also enhance uptake by clover leaves. However, they have little or no effect on the ability of clover plants to degrade bentazone: this is the main cause of resistance to the herbicide.

This report of formulation research at WRO ends with the warning that many of the treatments discussed have not yet been adequately tested or cleared by the Pesticides Safety Precautions Scheme. Some of the additives mentioned may become available to farmers but this will depend on commercial interest from firms in the agrochemical industry.

During the past years I have received much assistance from the Agricultural Development and Advisory Service (ADAS), in particular from the ADAS liaison officer at WRO, Mr J. H. Orson, who has arranged for many treatments to be tested in ADAS trials programmes. I am most appreciative of this help.

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Recent research on the effects of soil moisture on weed control

A M BLAIR, J C CASELEY and C R MERRITT

INTRODUCTION

The growth and development of crops and weeds and their response to herbicides are all affected by the water status of the soil. During spring, summer and autumn the water content of the soil frequently falls below field capacity and crop and weeds are subjected to water deficit stress while over-wintering plants may experience stress due to excess of water in the soil.

Both in the field and in pots, soil physical properties such as bulk density influence the water-holding capacity of the soil and this in conjunction with variations in water contents within the soil profile makes both the measurement and control of soil moisture difficult.

This report is mainly concerned with the effect of soil moisture on plants, their seeds and herbicide performance, but also illustrates the techniques being used at WRO to measure and control soil moisture.

EFFECTS ON SEEDS AND PLANTS

Seeds. In the work of Peters (1982), contrasting moisture status was achieved in wild-oats (*Avena fatua*) by adequately watering one set of plants and reducing water application on another to 'just prevent the uppermost leaves from wilting'. He showed that drought stress applied to wild-oats during spikelet emergence halved the number of viable seeds, but also altered their subsequent germination. Immediately after collection, 20% of the stressed but none of the unstressed seeds germinated. Following burial in the soil after collection 66% of the viable seed from stressed plants germinated that autumn as compared to 4% from unstressed. Most of the viable seeds from the unstressed plants germinated in the second spring.

Another method of controlling moisture is to place a standard weight of soil with known moisture content into pots with sealed drainage holes. The pots of soil can then be weighed on an electronic balance at regular intervals and the required water to achieve the desired water content added by comparison with a calculated 'tare' weight. This can be adjusted to compensate for plant growth. Such a system can be used to study the influence of soil moisture on the subsequent germination of seeds. Thus burial of barren brome (*Bromus sterilis*) seed in dry (15% field capacity) compared to wet (150% FC) soil favoured subsequent germination under standard conditions. In contrast, seeds of canary-grass (*Phalaris minor*) germinated well following burial under both these extremes of moisture, but germination was depressed around field capacity (Okereke *et al.*, 1981).

The above examples illustrate that soil moisture status has a major influence on the dormancy and germination of seeds with concomitant effects on the seed bank in the soil and this should be borne in mind when devising weed control strategies.

Plants. Following emergence the influence of soil moisture status on subsequent development of the plant differs from species to species.

The canary-grasses *Phalaris paradoxa* and *P. minor* were grown for two weeks after emergence with soil moisture close to field capacity. Thereafter surface watering was adjusted to give three levels of soil moisture until assessment three weeks later (Table 1).

Table 1. Effect of soil moisture on *Phalaris paradoxa* and *P. minor*

	P. minor		*P. paradoxa*	
Moisture regime	shoots	roots	shoots	root
% field capacity		dry wt. (g)		
40	0.21	0.09	0.15	0.05
80	0.61	0.22	0.29	0.12
120	0.65	0.21	0.47	0.19

These results show that soil moisture deficit diminishes shoot and root production of both species, but while 80% FC was sufficient for optimum shoot and root growth in *P. minor*, growth of *P. paradoxa* was substantially depressed at this level illustrating that species may differ widely in their soil water requirements (Yaḍuraju, pers. comm.)

When couch-grass (*Elymus repens*) was maintained close to 25% compared to 100% FC for five weeks no wilting occurred, but foliage and rhizome weight and the number of nodes were approximately halved. However, the viability of the nodes was unaffected by moisture stress (Ismael *et al.*, 1983).

In the studies described up to now, water was applied to the soil surface of pots and it moved down the profile as occurs after rainfall in the field. During rainfree periods in the field, water is often available to the plant from lower sections of the profile while the surface zone of the soil becomes

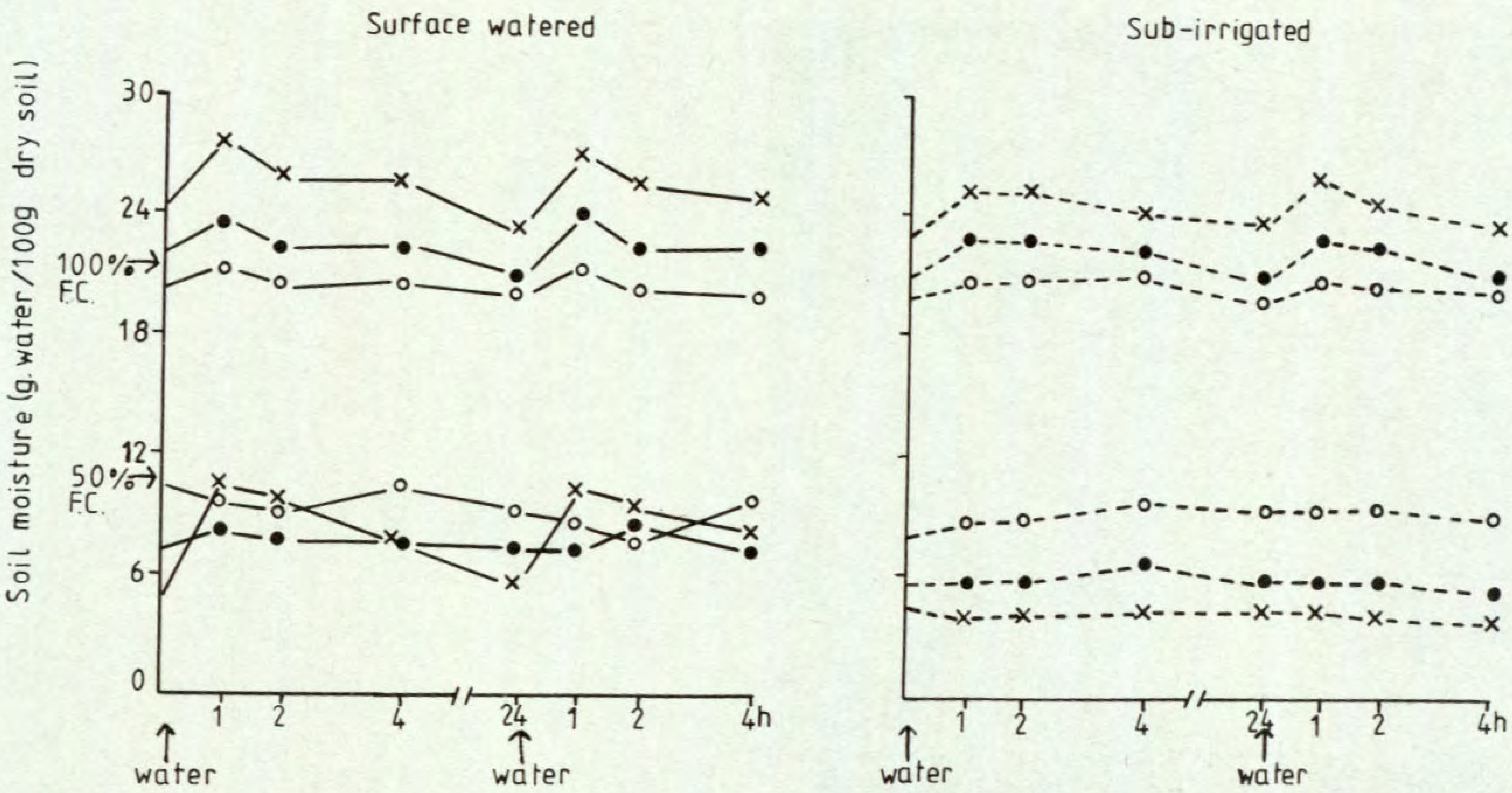


Fig. 1. Wetting and drying cycle in the surface 3 cm of soil profile following surface and sub-irrigation. Here, as elsewhere in this article, field capacity is approximately 21.5 g water 100 g^{-1} dry soil.
[0–1 cm (×), 1–2 cm (●), 2–3 cm (○)]

Table 2. Some effects of soil moisture on *S. media*.

Moisture (%FC)	Total leaf area (cm^2 $plant^{-1}$)	Cuticle thickness (mm)	Pigment content (μg/4 leaves) chlorophyll a	β-carotene	lutein
22	15.1 (± 1.18)*	23.5 (± 2.93)	500 (± 30)	32 (± 6.7)	50 (± 1.2)
11	6.7 (± 0.48)	37.0 (± 1.42)	840 (± 46)	45 (± 1.5)	70 (± 3.3)

* SE in brackets

dry. In order to simulate this situation in small pots we apply water *via* a central, vertical tube perforated below soil level. The way in which the watering regime can affect wetting and drying close to the soil surface is illustrated in Fig. 1. The most marked cycling of soil moisture in the surface 1 cm zone occurred when the soil was dry (50% FC) and water was applied to the soil surface. In contrast, sub-irrigation of this dry soil resulted in the 1 cm surface zone remaining dry. Under both these conditions adventitious roots of black-grass (*Alopecurus myosuroides*) are poorly developed. At 100% FC and above, regardless of the method of watering, this surface zone remained wet and adventitious roots grew rapidly with up to 320 mm $plant^{-1}$ recorded in 8 days (Blair, in press).

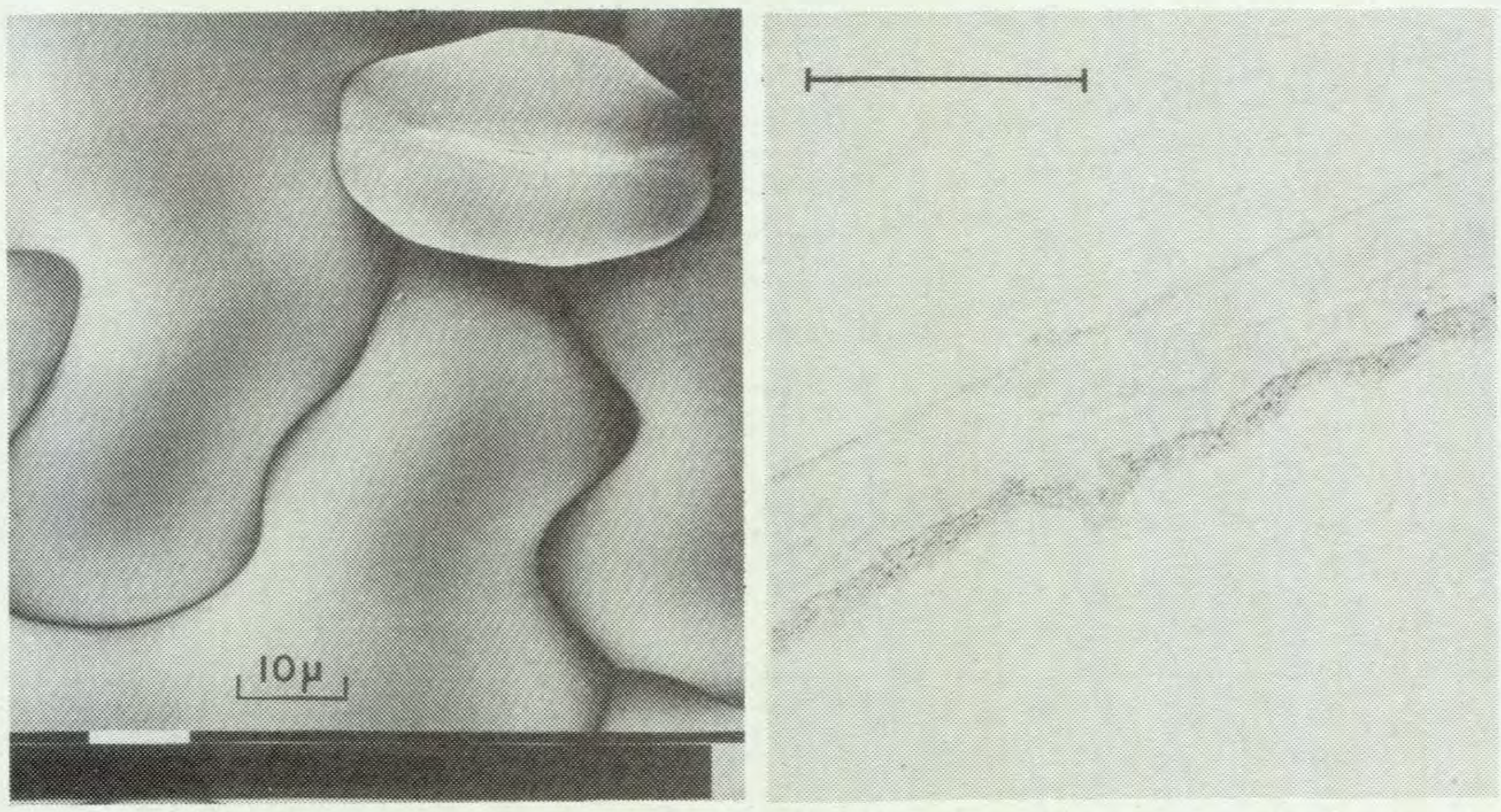
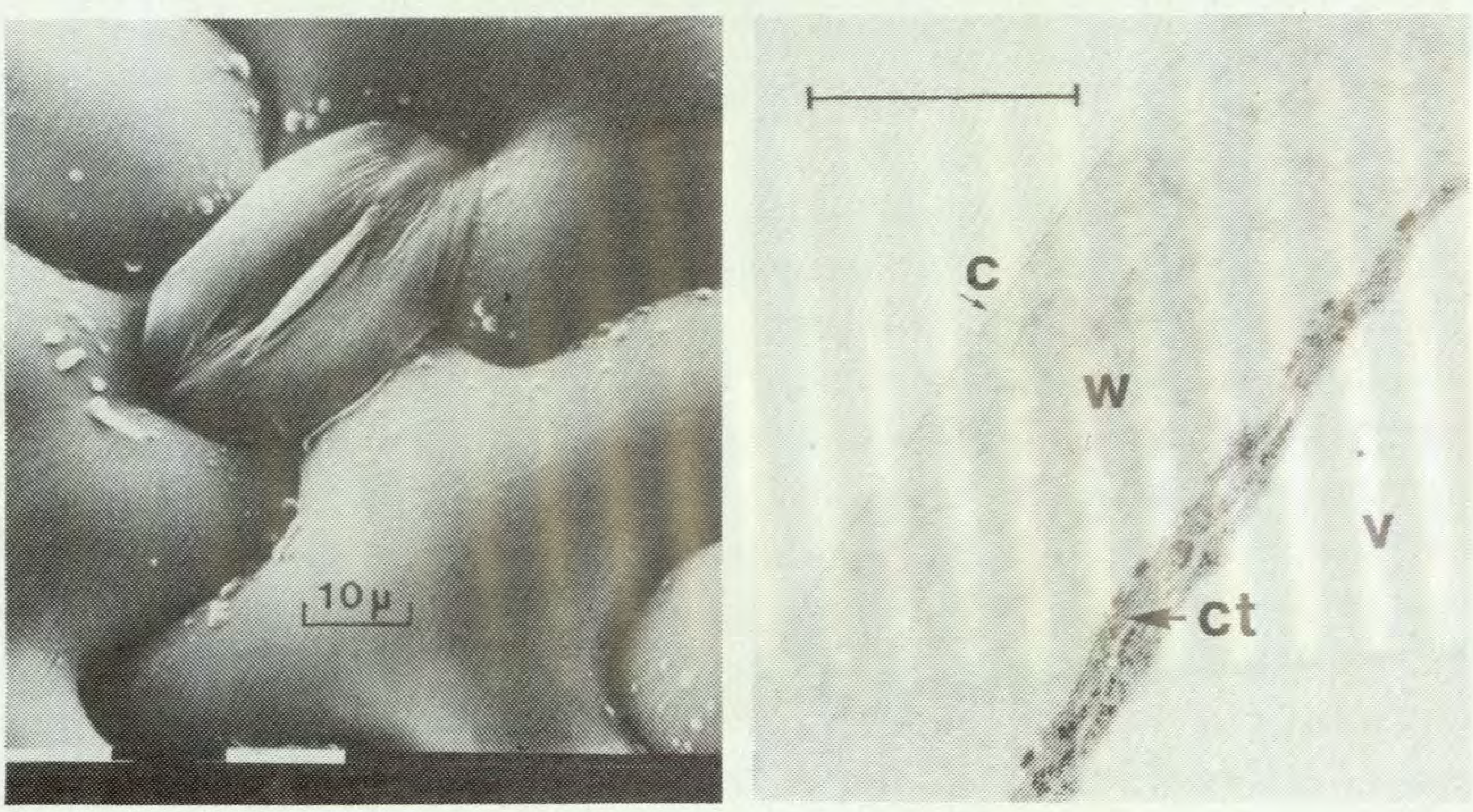


Fig. 2. Scanning (left) and Transmission (right) electron micrographs of *Stellaria media* grown at 50 (lower) and 100% FC (upper) showing more wax on surface and thicker cuticle and epidermal cell wall in dry grown plants. C = cuticle, W = cell wall, Ct = cytoplasm, V = vacuole. Scale bars represent 10 μm (SEM) and 1 μm (TEM).



A study of chickweed (*Stellaria media*) plants grown in soil in which the moisture content was controlled by weighing at either 50 or 100% FC showed that stressed plants took longer to reach a particular growth stage although the rate of dry matter production differed little. The dry-grown plants had smaller leaves, thicker cuticles and higher pigment contents than their moist-grown counterparts (Table 2), and scanning electron microscopy revealed a more waxy surface on the dry-grown plants (Fig. 2).

EFFECTS ON HERBICIDE PERFORMANCE

Foliage applied herbicides. Some herbicides such as glyphosate and ioxynil enter the plant exclusively through the foliage and interception, retention and penetration are of key importance in achieving optimum herbicide performance.

The characteristics of chickweed foliage described earlier (Table 2, Fig. 2) play a major role in reducing spray interception, retention and herbicide uptake (Table 3). Since the phytotoxicity of ioxynil is at least partly due to inhibition of photosynthesis, the increased pigment content of water-stressed plants is probably of importance. Chlorophyll is associated with the

Table 3. Ioxynil performance against *S. media* grown at 2 moisture levels.

Moisture (%)	Spray retention ($\mu l\ g^{-1}$dry wt)	% uptake of ^{14}C-ioxynil after 6 h	24 h	72 h	Fresh weight of foliage after 15 days (% of untreated)	% reduction of CO_2 exchange after 24 h
22	364	0.52	1.15	4.42	55	85
11	288	0.39	1.05	3.47	70	15
S.E.	18.6		0.31		4.0	—

site of action of ioxynil and carotenoid pigments are known to protect membranes from the highly reactive forms of oxygen generated in the light as a result of treatment with this type of herbicide. Thus, in addition to reduced entry of herbicide in the stressed plants, higher content of pigments may also have contributed to reduced herbicide performance indicated by carbon dioxide fixation and fresh weight of the treated plants (Table 3). It should be emphasised these responses resulted from contrasting soil moistures before spraying. Similar moisture stress imposed during the period from spraying to assessment (3 weeks) had no significant effect on the level of activity (Merritt, 1984).

In contrast, the wild-oat herbicide diclofop-methyl was markedly affected by soil moisture stress imposed just prior to spraying until harvest. At approximately field capacity 1 kg ha^{-1} diclofop-methyl applied to the foliage, with the soil protected, reduced wild-oat foliage fresh weight to 40% of untreated controls. This level of herbicide activity was approximately halved under the dry regime (30% FC) and doubled on plants in the wet, but not flooded, regime (200% FC) (Hassawy & Caseley, 1983).

Under the wet conditions (200% FC), the fresh weight of winter wheat cv. Score, treated with 1 kg ha^{-1} of diclofop-methyl, was significantly depressed compared with untreated controls. The spring wheats Sicco and Maris Butler also sustained more damage under wet soil conditions when treated with 3.2 kg ha^{-1} of difenzoquat (Pillmoor & Caseley, 1983). Crop tolerance was increased following treatment with either diclofop-methyl or difenzoquat when the wheat plants were subjected to soil moisture deficits during the pre- or post-spraying periods.

Couch-grass plants grown at 50% FC until they had 2-3 tillers were then maintained at 100, 50 and 25% FC for five weeks prior to spraying glyphosate and the 3 weeks thereafter until assessment. A significantly higher percentage of nodes survived in the water deficit stressed plants (Ismael *et al.*, 1983).

Using the same species, studies on the foliage activity of fluazifop-butyl and sethoxydim showed that allowing the soil water content to drop from 100% to 50% FC compared to remaining at 100% FC during the week before spraying significantly reduced bud kill assessed 24 h later (Coupland, pers. comm.)

Herbicides with soil activity. The activity of many herbicides including isoproturon is largely dependent on uptake from the soil. Soil moisture is of the utmost importance as it affects herbicide availability and distribution in the soil and distribution and development of plant roots through which much, though not necessarily all the herbicide, enters the plant.

Application to soil surfaces with a low moisture content tends to reduce herbicide activity. Addala (1982) found pre-emergence applications of chlortoluron for wild-oat control were less effective when applied to dry (11% FC) compared to moist (100% FC) soil. These results concur with those of Hance & Embling (1979) who measured a decreased extraction of 3 herbicides from a soil solution in a pressure membrane apparatus after herbicide application to dry soil.

As might be expected from these results, post-emergence application of isoproturon for black-grass control was less effective when treatment was made to soil at 50 compared to 100 and 150% FC and these water contents maintained until assessment. This effect was most marked when water was applied by sub-irrigation (Blair, in press). A similar trend was observed for isoproturon and AC 222, 293 applied to *P. minor* and *P. paradox* (Yaduraju, pers. comm.)

At soil moistures below 100% FC surface application of water plays a vital role in moving isoproturon down the soil profile and promoting adventitious root development in black-grass (Blair, 1983). A delay of up to 21 days between the overall application of isoproturon to black-grass in soil maintained at field capacity by sub-irrigation and start of surface watering did not affect final herbicide performance, but a delay of even 7 days following a similar herbicide treatment to plants in soil at 50% FC resulted in diminished phytotoxicity (Blair, in press).

THE FUTURE

Usually we use pots of 0.1-0.4 l capacity. With this relatively small volume of soil the roots have become confined by the time assessments are made in post-emergence experiments. This is an acceptable limitation in experiments concerning foliage activity (where the pots are regularly weighed and their water content adjusted), but for soil applied treatments a confined root system has increased probability of coming into contact with the herbicide. In order to study herbicide soil moisture interactions with plants in larger soil volumes, 27 l tanks with an appropriate weighing system are being employed. These are weighed weekly and realistic intensities of rain applied by the WRO rain simulator (see 8th Report) to create typical wetting and drying cycles in the surface layers of the soil. Soil moisture and herbicide profiles will be measured and correlated with data from predictive models such as that of Nicholls & Buxton (1982).

At the physiological level we need to quantify the role of individual parts of the root system in their ability to take up herbicide at different stages of growth of the target weed. For this purpose small double boxes with wax barriers have been developed which allow division of the root system. In the case of isoproturon-treated black-grass the inhibiting effect of this herbicide on photosynthesis will be followed using infra-red gas analysis while accumulation of active ingredient and degradation products will be followed using ^{14}C-isoproturon. Contrasting temperatures can be imposed on the nutrient solutions in the boxes and polyethylene glycol can be added to impose water deficit stress.

CONCLUSIONS

These few examples illustrate that soil moisture stress plays a key role in determining dormancy of seeds, their germination and effectiveness of seedling establishment. At later stages of plant development soil moisture status influences the size, shape and physiological condition of the plant and its response to herbicides.

Herbicide treatments, dose and adjuvants should be chosen bearing in mind the preceding and current moisture status of the soil.

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Abscission in agriculture

DAPHNE J OSBORNE

Plants have evolved elegant abscission mechanisms for the orderly separation of one plant part from another enabling ripe fruits and seeds to be dispersed and senescent leaves and floral parts to be rejected (Addicott, 1982). Each separation event takes place at a precisely defined layer of cells positionally differentiated at the base of the organ that is destined to shed. The time at which these cells are differentiated determines the time when abscission can first take place.

Although successful agriculture means good yields it also means the efficient and successful harvest of the growing crop, so the tonne that is gathered in from the field is more than worth the promise of the two still growing on the plant. Crops can fail through many causes and not least of these is by premature shedding during plant development or at the time or harvesting.

Although leaves are not a world crop priority, fruits and seeds certainly are, and their preharvest shedding has been a source of concern to man from the time of his first tentative efforts in agriculture. Legume seeds (the pulses) and cereals (the food grasses) were always staple foods and losses from untimely abscission are as important in agriculture today as they were to early man.

Today's major grain crops rarely suffer these losses because discriminating selection by modern breeding programmes has produced cereals that no longer possess functional abscission zone cells below the fruit. This is in contrast with the native grasses which constitute so many of the world's most prevalent weeds. These have not been subjected to man's selective interference and for this reason the grass weed seeds shed each year by abscission continually replenish the weed seed bank in the soil (Schafer & Chilcote, 1969).

In the abscission zones of all the dicotyledonous plants so far studied, the initiation of metabolic processes that lead to loss of cell to cell adhesion are induced by critical levels of the hormone ethylene produced in tissues close to the zone cell region (Jackson & Osborne, 1970). Recent research carried out by us at the Weed Research Organization has revealed that native grasses possess an unusual mechanism for abscission which is regulated by a different hormonal system. In the Gramineae we find that abscisic acid, not ethylene induces the events that culminate in cell separation (Sargent, Osborne & Edwards, 1981). We can currently recognise, therefore, two basic types of abscission in plants and two different control mechanisms that regulate the shedding process—one in dicotyledons and another in the Gramineae. The understanding of these processes opens up new opportunities for the control of grass weeds in non-grass crops and affords new prospects for shedding control in a wide range of economically important agricultural plants.

MECHANISMS FOR ABSCISSION CONTROL IN PLANTS

The majority of broad-leaved plants (there are exceptions) differentiate only one abscission zone which develops at the base of every leaf stalk where it joins the stem. An example of this type of zone is present in cotton plants

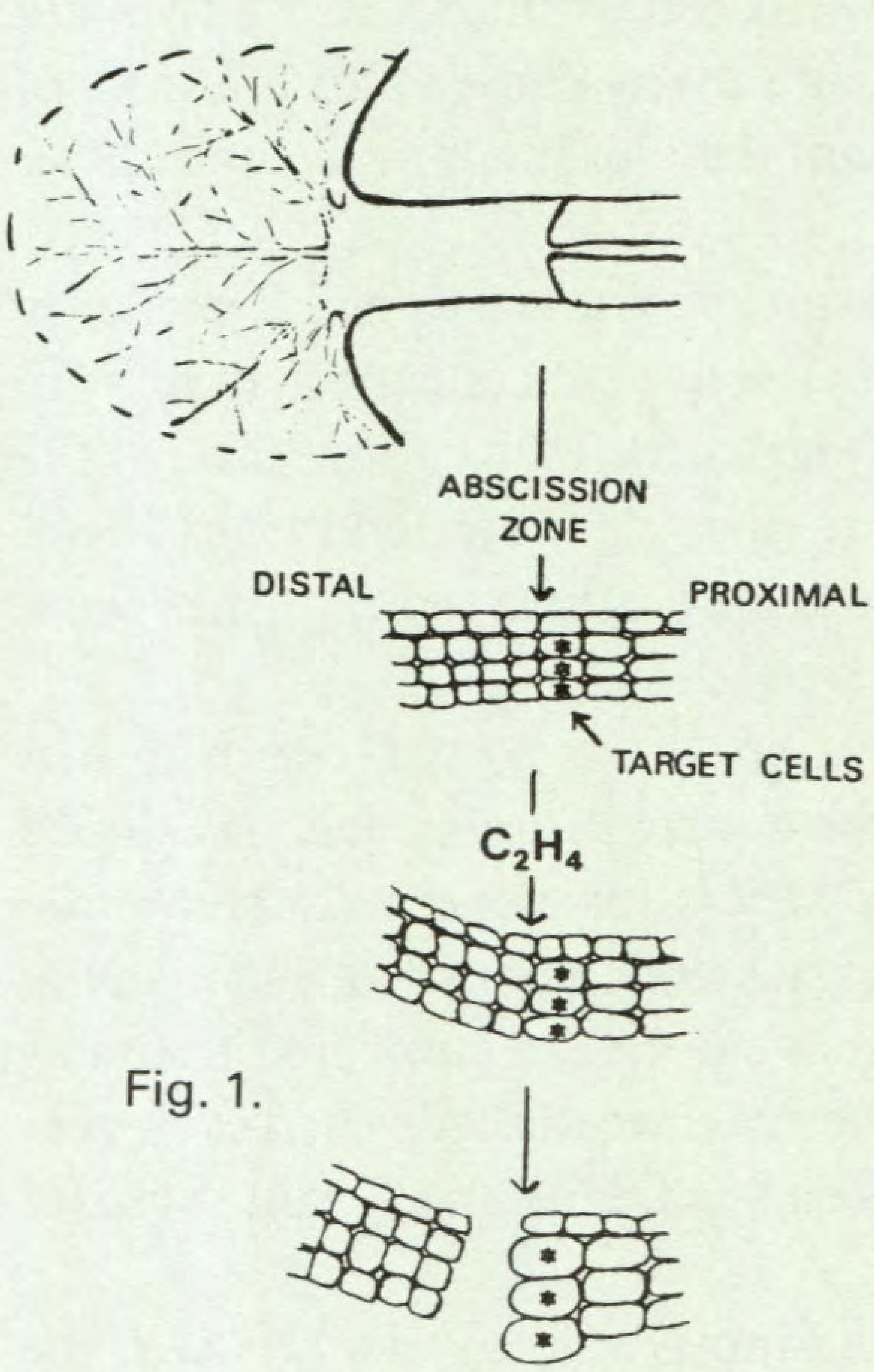

Fig. 1.

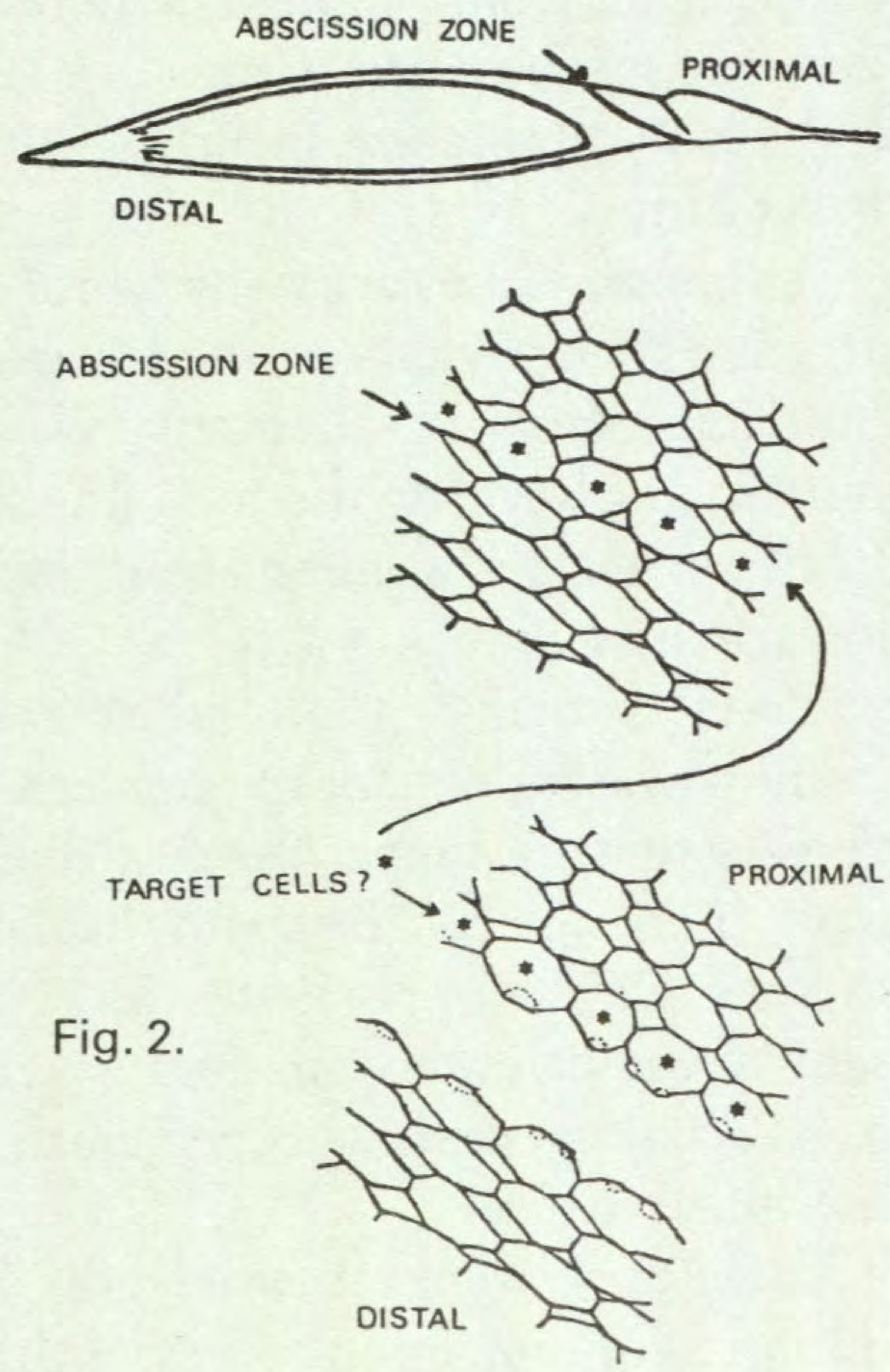

Fig. 2.

Fig. 1. Abscission in the primary leaf of a typical dicotyledon, the dwarf bean (*Phaseolus vulgaris*). Diagramatic representation of the position of ethylene responsive target cells in the abscission zone.

Fig. 2. Abscission in a fruit of the Graminea, wild oat (*Avena fatua*) Fruit with outer glumes removed to show the abscission zone at the fruit-pedicel junction. Diagramatic representation of the position of abscisic acid (ABA) responsive target cells in the abscission zone.

(*Gossypium sp*) (Bornman, *et al.*, 1968). Seedlings of one particular plant, the dwarf bean (*Phaseolus vulgaris*), have proved especially useful for abscission work in the laboratory for each primary leaf possesses two abscission zones—one at the base of the leaf blade at the pulvinus-petiole junction (Fig. 1) and the other in the usual position where the leaf stalk joins the stem. Excised segments of tissue which include the abscission zone at the pulvinus-petiole junction are a favoured "model system" for research (Webster, 1968). The ready availability of such material has facilitated physiological, biochemical and ultrastructural studies of the cell separation processes that lead to abscission. It is from studies with these and other similar "model systems" that much of our present knowledge has been assembled (Sexton & Roberts, 1982).

ETHYLENE CONTROLLED ABSCISSION IN DICOTYLEDONS

The abscission zone and the specialised cells that constitute the zone are usually differentiated quite early in leaf development and as long as the blade remains green and photosynthetically active the abscission zone remains quiescent. As the leaf ages, the levels of hormonal substances that pass from the blade through the petiole to the stem decline. Of these, auxin (indole-3-acetic acid), is probably the most important for maintaining the quiescence of zone cells so that they remain in intimate contact with their neighbour cells on either side.

During senescence (yellowing) of the blade the cells distal to the zone produce increasing amounts of ethylene and the immediate biosynthetic precursor of ethylene, 1-aminocyclopropane-1-carboxylic acid (ACC). The specialised cells differentiated at dicotyledon abscission zones are ethylene-responsive targets (Osborne, 1982). In the presence of the sufficiently high levels of ethylene, the zone cells are induced to enlarge and also to synthesize and secrete a novel isozyme of β-1:4-glucanhydrolase (a cellulase) (Reid *et al.*, 1974). The action of this enzyme (and probably also of other newly produced enzymes) results in loss of cohesion in the polysaccharide matrix of the middle lamella connecting the walls of the zone cells to their immediate neighbours. In *Phaseolus* (Fig. 1) only the distal end walls of the single layer of zone cells separates from the proximal walls of the cells above, so that the position of cell separation is strictly prescribed (Wright & Osborne, 1974).

The abscission process can be initiated prematurely if, auxin levels at the zone become reduced, or the concentration of ethylene around the zone is raised. Senescene or yellowing of tissues distal to the abscission zone is not then an essential requirement for shedding. Imbalances in auxin and ethylene levels can occur when plants experience unfavourable environments such as drought, flooding and extremes of temperatures or when ethylene or an ethylene precursor is applied externally. However, if the level of *auxin* present at the zone is raised by external applications, then the concentration of ethylene required to overcome the auxin-maintained quiescence of the target cells is correspondingly raised. The opposing effects of the two hormones can readily be demonstrated experimentally. Even when very high, abscission-suppressive levels of an auxin are supplied, abscission zone cells retain, unimpaired, their competence to respond as target cells for ethylene. Although they then require higher levels of ethylene to initiate the abscission process, their determinant characteristics as ethylene target cells are not altered.

Abscisic acid is also a potent accelerator of senescence and although abscisic acid does not increase ethylene production directly, it can cause a premature rise in senescence-associated ethylene levels and so initiate separation in the zone cells (Jackson & Osborne, 1972). Many trials have shown that abscisic acid is a poor accelerator of abscission in intact plants and this may relate to the speed with which it is metabolized. It is not surprising therefore that abscisic acid is not of special use in agriculture for regulating abscission in dicotyledonous crops.

ABSCISSION IN THE GRASSES

From an evolutionary point of view it is interesting that monocotyledons have generally few sites at which abscission can occur. In the Gramineae those that are present are confined to the floral parts and to the fruits and seeds. Leaves and subtending floral bracts rarely abscise and the seed (the caryopsis) is normally shed while still enclosed within glumes and seed covers. Together, these parts constitute the fruit, sometimes termed a "disseminule". The fruit separates from the panicle at a clearly defined abscission zone where an active cell from cell separation process occurs in two quite distinct stages. In the first stage, an inner core of cells in the proximity of the zone separate from each other along most of their length but remain attached in the region of the plasmadesmata. In the second stage, which may be many days later, the outer cells separate from each other and abscission takes place by the final dissociation of the plasmadesmatal junctions. The mechanism therefore differs from that in dicotyledons where zone cells separate from their neighbours in a single cell continuous event (Sargent, Osborne & Edwards, 1981; Osborne, 1983).

Grass fruits reach the critical stage of shedding only when maturation, senescene and dehydration of the caryopsis and its enveloping appendages are well advanced. As in the dicotyledons, increasing the auxin supply to the zone retains the quiescent state of the cells and retards abscission. Because abscisic acid, not ethylene, initiates the second stage of cell separation, dehydration rather than senescence may be critical for providing the correct hormonal balance to activate the zone target cells. Tissues subjected to water deficits are potential sites for increased abscisic acid production (McKeon, Hoffman & Yang, 1982) (and decreased auxin content) and the glumes, seed coat and the seed itself all desiccate as the fruit ripens. The sequence of abscission in a typical member of the Gramineae, the wild-oat (*Avena fatua*) is outlined in Fig. 2.

Since most cereal crops do not possess functional abscission zones, grass weed competitors could in theory, be caused to shed prematurely without affecting the crop. If this were achieved when the embryo in the weed seed was too immature to be viable the soil weed seed bank would not be replenished. Alternatively weed fruits could be retained until the crop is gathered, provided the weed seeds could then be separated from the crop. Improved retention of grass fruits (seeds) in certain forage crops such as the rye grass could however prove valuable as an aid to harvesting.

TIMING OF ABSCISSION

Legumes (and most other dicotyledons) produce flower buds in which an abscission zone is differentiated at the base of the flower stalk from a very early stage in bud development. Abscission can therefore be induced even before the bud has opened and in field beans (*Vicia faba*) such early bud shedding is a frequent cause of crop failure. Unfavourable environmental conditions can be the cause of increased ethylene production by young buds or neighbouring tissues (Lürssen, 1982) so the threshold necessary to evoke the separation can readily be exceeded. Shedding of unopened flowers is therefore common in plants that are flooded or droughted, or subjected to extremes of temperature. At later stages of development strong vascular connections are formed between the enlarging pod and the stem so that abscission zone cells, even if evoked, can no longer lead to shedding of the pod. The ripe pod is therefore maintained on the plant (Hodgson & Blackman, 1957).

DEHISCENCE AND SEED DISPERSAL

The ripe pods of legumes and the siliques of crucifers break open along defined lines of cells to liberate the fully developed seeds. They open with varying degrees of explosiveness and so despatch their seed to different distances from the parent plant. Where the seed is harvested, as for example in oilseed rape, serious loss of crop can occur from premature "pod shatter". Research is underway at the Weed Research Organization to discover the mechanisms that control cell performance at the line of dehiscence in rape seed "pods" so that seeds will remain enclosed throughout the harvesting procedures.

THE FUTURE

Man has successfully eliminated abscission in the ears of cereal grasses and can manipulate the development of abscission zones in other species. He has produced mutant lines of tomatoes that lack the abscission zone at the base of the unopened flower bud and has induced the formation of additional or "secondary" abscission zones in stems and petioles of other plants by hormonal and by surgical procedures. All these modifications have potential uses in agriculture. At the present state of knowledge of genetic manipulation, we could now develop new lines of crop plants that would shed the part we want, how we want and when we want.

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Aquatic weeds and their control—recent progress by WRO

P R F BARRETT

Aquatic weeds invade and colonize almost any water body where suitable growth conditions exist. They are seldom introduced deliberately by man and, even where this is done, a mixed natural community usually develops in association with the introduced species. Man's activities often have a major impact on the density and composition of the plant community. Agricultural fertilizer, sewage effluent, dredging, impounding and draining have all been blamed for affecting aquatic ecosystems, often adversely by stimulating weed growth.

The enormous size of the potential problem to the water industry is obvious when it is considered that there are some 30,800 km of main rivers and 32,300 km of intermediate water courses which are maintained by Water Authorities (WA) and Internal Drainage Boards (IDB) in the UK. In addition there are of the order of 100,000 km of drainage ditches maintained by occupiers of the land served (Robinson, 1971).

A recent survey by the Aquatics Group at WRO showed that more than 40% of the water area maintained by WA's and IDB's suffers from serious weed problems requiring regular weed control. A variety of methods, principally mechanical and chemical, are used for this purpose many of the latter being developed in the past by WRO. The survey further revealed that weed problems are increasing and that currently the major problems are caused by submerged species and filamentous algae. The increase in these weeds is not surprising as the introduction of new herbicides such as glyphosate has resulted in effective control of many of the emergent and floating weeds (Barrett, 1974, 1976). The rapid growth rates of submerged weeds and, particularly, of filamentous algae allow them to respond quickly to increased light penetration following removal of emergent or floating vegetation. They can respond equally quickly to any increased eutrophication. The survey also indicated that economic constraints have resulted in a reduction in the last 10 years in staff employed to deal with weed problems. At the same time, increasing demands for the use of water, as potable or irrigation supplies and for recreational purposes, are putting greater pressure on existing water bodies, which frequently results in the creation of new ones. For example, in 1977 and 1978 some 355 new farm reservoirs with a median capacity of 14,000 m^3 (or a surface area of approximate 0.33 ha) were constructed with the aid of MAFF grants (Trask, 1981).

The contracting economy and increasing demands on water, emphasise the urgent need for new, more effective and economic means of dealing with excessive weed growth. WRO has kept abreast of these demands through its intimate contact with the Water Authorities, IDB's and other interested parties. An especially useful contact has been maintained by the annual aquatics meeting organized by WRO and attended by delegates from all sectors of the water industry and research centres. By this means WRO has been able to respond in a timely and effective fashion to the needs of the Water Industry. It has, consequently, become recognized as an important national centre for research and information on aquatic weed problems.

The needs for effective methods of weed control are complicated by a growing public awareness of the potential for pesticides and other methods to have harmful side-effects on the environment. This apparent conflict of

Fig. 1. Applying diquat alginate. The knapsack sprayer is specially modified to cope with the viscous formulation. The spray nozzle is replaced with a straight orifice which produces a jet with a range of up to 10 m.

interest emphasises the importance of continued, detailed research of the type done by WRO's Aquatic Weeds Group. The group has always recognized the environmental considerations which can affect the acceptibility of potential new techniques. Thus, it plays a major role in the production of the guidelines for the use of herbicides on weeds in or near water courses and lakes (UK, MAFF, 1980), which are designed to help ensure safe and correct use of herbicides. More particularly, it has a research programme which emphasises reduction of herbicide inputs to water while aiming for increased effectiveness of control and which also looks for alternative approaches involving no chemical input.

A most productive approach is to formulate a herbicide so that it can be accurately placed in those areas where weed control is required while its effects are prevented from spreading to surrounding areas. These can be left undisturbed as habitats for fish and other organisms. This localized control has been achieved in different ways. Laboratory studies indicated that a formulation of diquat with sodium alginate produced a viscous, sticky compound which would adhere to submerged weeds and release the herbicide into the weed beds where it was rapidly absorbed. Field trials in 1977 confirmed the potential of this formulation (Barrett, 1978) and, with the support of the Plant Protection Division of ICI, it was developed rapidly (Barrett, 1981a; Barrett & Logan, 1982; Barrett & Murphy, 1982) and a commercial formulation called Midstream was marketed by Midox Ltd in 1982. It has shown considerable success in controlling weeds in both static and flowing water and is the only herbicide in Britain to carry recommendations for use in water flowing at more than 90 m h^{-1}.

Another research study by the Group has investigated dichlobenil as a candidate for localized control of weeds. This herbicide is preferentially absorbed by plant roots and is normally formulated as slow release granules. It was shown that when applied to water these granules sink rapidly into the sediments. The herbicide is released there and is taken up by the weed roots, with ony small amounts being released into the water above the sediments. Excellent control of a range of submerged weeds was obtained, particularly of species with well developed root systems, such as mare's tail (*Hippuris vulgaris*), which tend to be less susceptible to diquat (Terry *et al.*, 1981). As a result of these studies, in collaboration with Midox Ltd, the label recommendations for this herbicide (Casoron G S-R) were amended to include specific recommendation for its use for localized control. Rather than competing with diquat, dichlobenil is complimentary, extending the range of species that can be controlled. Both formulations can reduce the amount of chemical needed in any individual water body where localised control techniques are applicable.

An alternative approach to using herbicides is to limit the growth of weeds with plant growth regulators. These chemicals restrict the height of plants without killing them thus preserving the habitat while keeping weeds down to acceptable levels. Recent research by the Aquatic Weeds Group has been investigating this approach to weed management. One of the chemicals tested so far, paclobutrazol, has shown extremely promising results. Outdoor tanks containing a mixed community of submerged plants were treated with the chemical in 1980. Growth was severely suppressed although the majority of the plant species remained green and healthy. A few species were unable to withstand the treatments and died out gradually over the 3 year period of the experiment. Further experiments with this,

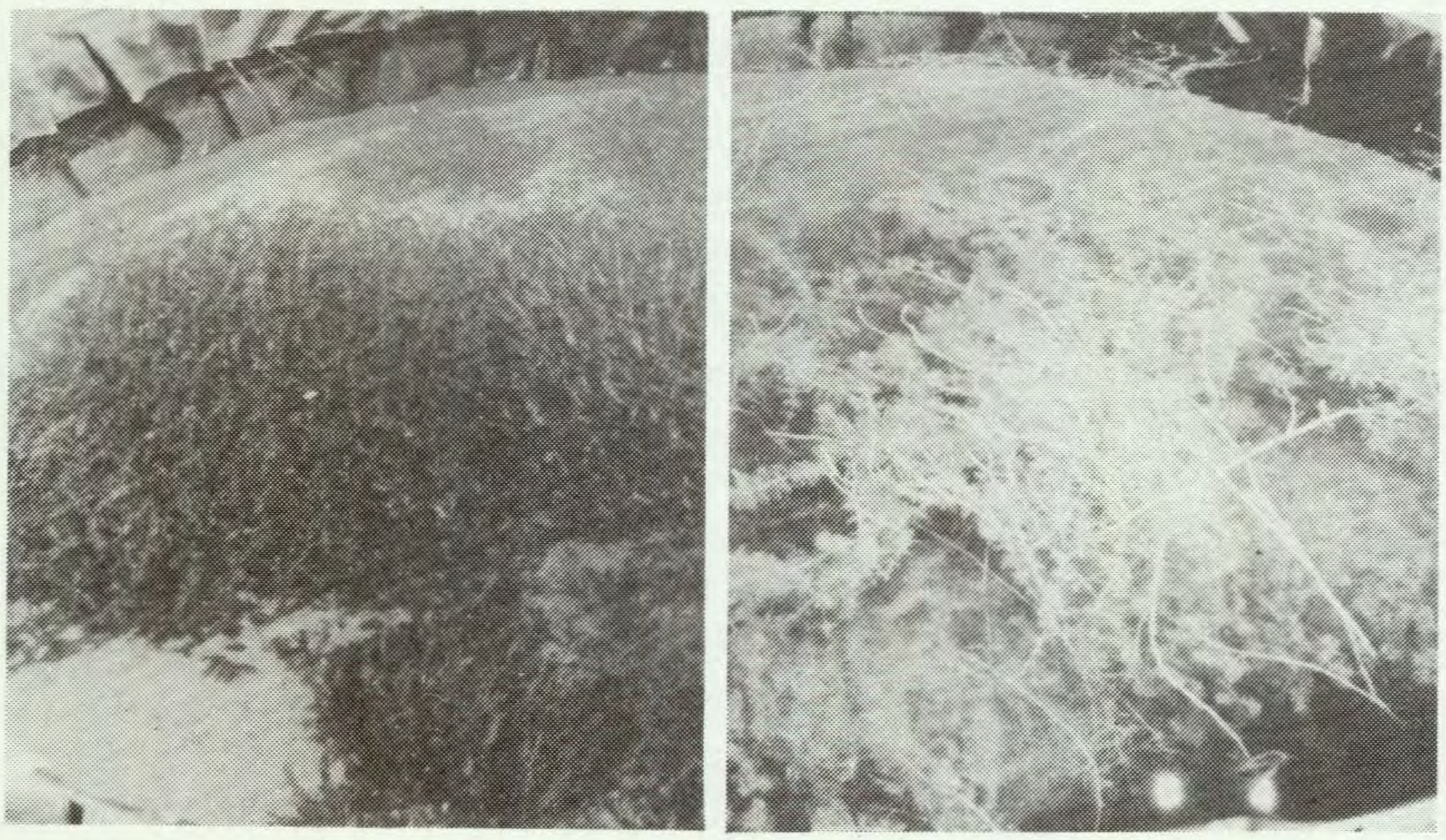

Fig. 2. The effect of a plant growth regulator. The tank on the left was treated with paclobutrazol and the plants are forming a dense mat on the bottom. The untreated control plants on the right have reached the water surface.

and other experimental growth regulators, are continuing to provide promising results. Treated tanks contain a carpet of 'miniaturized' weeds at the bottom with clear water above. If similar results are obtained in the field trials being done during 1984 there is considerable hope that plant growth regulators will make valuable contributions to water weed management and habitat conservation. The low dense vegetation which is produced provides an ideal habitat for aquatic fauna, effective stabilization of the sides and bottom of drainage channels, and still permits adequate water flow and good access for boating, fishing and other recreational uses.

These examples of how research at WRO has resulted in effective techniques of aquatic weed management illustrate the importance of research for this area being funded by the public sector. All the chemicals involved have been developed by the agrochemical industry for use in agricultural crops. Although of local and national importance, the aquatic market is too small to encourage companies to invest the considerable amount of money required to develop chemicals specifically for aquatic use, or even to develop aquatic uses for those chemicals previously developed for other purposes. Thus, the necessary development of chemicals for aquatic use is, at present and in the foreseeable future, dependant on research such as that at WRO. Only when this research has proved the potential of a chemical can industry be persuaded to undertake the final development and clearance for sale.

In addition to developing chemical techniques of aquatic weed control, the Aquatic Weeds Group is also actively developing other methods. Grass carp, (*Ctenopharyngodon idella*), the herbivorous fish originating in China, has been studied for the last 15 years (Stott & Robson, 1970). Aspects such as food preferences, effects of stocking rate and effects of water temperature have been investigated in detail. (Mugridge *et al.*, 1982). Water temperature was identified as causing a particular problem. These fish are sluggish and do not feed actively until water temperatures reach about 16°C (Fowler, in press). Above this level they are voracious feeders and can double their weight in one season (Fowler & Robson, 1978). Thus, their success in controlling weeds depends to a large degree on spring temperatures. In a warm spring the fish consume the weeds as they appear and prevent them from reaching problem proportions. On the other hand, in a colder spring the fish feed poorly and weed growth may not be controlled effectively. Despite such problems, WRO research has indicated that these fish could confer considerable benefits, particularly in enclosed waters where the stocking density can be maintained. Either alone, or in combination with other methods, they could represent a considerable saving in costs of weed control. The results of this research are now being used by several Water Authorities, some of whom collaborated with WRO in this research programe, for practical weed control operations.

Mention has already been made of the ways in which WRO ensures it can respond quickly to developments in the water or chemical industries. A good example of this sort of response is given by recent investigations of a potential means of reducing or eliminating growth of filamentous algae in water. A local engineer wrote to WRO reporting several instances of filamentous algae apparently being controlled or reduced when bales of rotting hay had been thrown into lakes or ponds and asking for an explanation of the phenomenom. The Aquatics and Microbiology Groups collaborated in seeking an explanation. One possibility was that the micro-organisms colonizing the decomposing hay were absorbing nutrients essential for algal growth from the water. In particular, microbial immobilization of phosphorus seemed most likely to affect algal growth. A series of laboratory experiments, using straw instead of hay, confirmed this as a likely explanation (see p. 94) and indicated that the immobilized phosphorus could be incorporated into a food chain culminating in fish or waterfowl and by-passing algae. Field trials are being done this season to determine if the potential shown in the laboratory can be exploited in practice.

An important function of the Aquatics Group is to develop the methods necessary to allow effective progress of the research programme. A particular problem encountered in most aspects of aquatic weed research is that of accurate measurement of the amount and distribution of weed in the water. Conventional techniques for measuring weed biomass and distribution on land are not suitable for underwater use. The group has developed a technique using echosounders (Hanley, 1982). When coupled with a micro-computer the data from the echosounder can be processed to produce maps of weed density and distribution. This technique shows much promise for measuring the effects of control practice in reducing weed biomass. It is currently being refined and tested under a variety of field conditions.

The successful management of aquatic ecosystems is essential not only to maintain effective land drainage and wholesome potable water supplies but also to conserve important aquatic habitats for flora and fauna. Without appropriate management water courses can rapidly become choked with weed, stagnant and, sometimes, deoxygenated. The work of the Aquatic Weeds Group at WRO has already demonstrated that some of the problems can be overcome without adverse side-effects. However, many problems still remain to be solved (Barrett, 1981b). Indeed, the indications are that problems are increasing in number and complexity faster than solutions can be found. Increasing eutrophication of water, increasing use of water for more purposes, identification of more areas of special scientific interest and other conservation projects will all produce new problems demanding research. The effectiveness of present control methods will result in ingress of new weed species particularly the filamentous algae. Consequently it will be essential to develop balanced integrated water management systems which will allow effective use of the water body as well as maintenance of an ecosystem containing a rich and interesting flora and fauna. Such developments will only be possible through appropriate research and, at present, the Aquatics Weeds Group at WRO is the only public sector group doing this.

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PROGRESS REPORT

REVIEW OF RESEARCH BY GROUPS

ANNUAL CROPS GROUP

Some of the group's work is reviewed elsewhere in this Report in the articles by May, Lutman, Wilson and Moss and a further selection is described below.

Life span of barren brome seed

Barren brome (*Bromus sterilis*) is a weed associated with continuous winter cereal cropping by minimum tillage techniques. Light is known to inhibit the germination of the seeds. In an experiment to determine how long seeds could survive in the field, seeds were placed on the soil surface or buried at depths of 5 and 15 cm. Most "surface" seeds germinated and emerged in the first autumn but after a year more than 2% of the original seeds had survived ungerminated. Few plants resulted from buried seeds and after a year no seeds survived.

Effect of cultivations on weed seed distribution in soil

The vertical distribution of seeds in the soil is of fundamental importance in determining changes in populations of many weeds. Although the maximum depth from which weeds can emerge varies considerably according to weed size, most weeds can only emerge from seeds within 5 cm of the soil surface. Different cultivation systems can therefore have a large influence on weed populations, mainly by affecting the vertical distribution of seeds.

Ploughing can be very efficient at burying weed seeds, depending on type of plough, depth of working, soil type and moisture and amount of trash. Subsequent ploughing can bring many of the buried seeds back to the surface. The importance of these buried seeds depends largely on their longevity. Rotational ploughing, once every 4-5 years, should result in lower populations of weeds such as black-grass (*Alopecurus myosuroides*) and wild-oats (*Avena fatua*), because relatively little viable seed would be returned to the surface due to seed mortality during the period of burial.

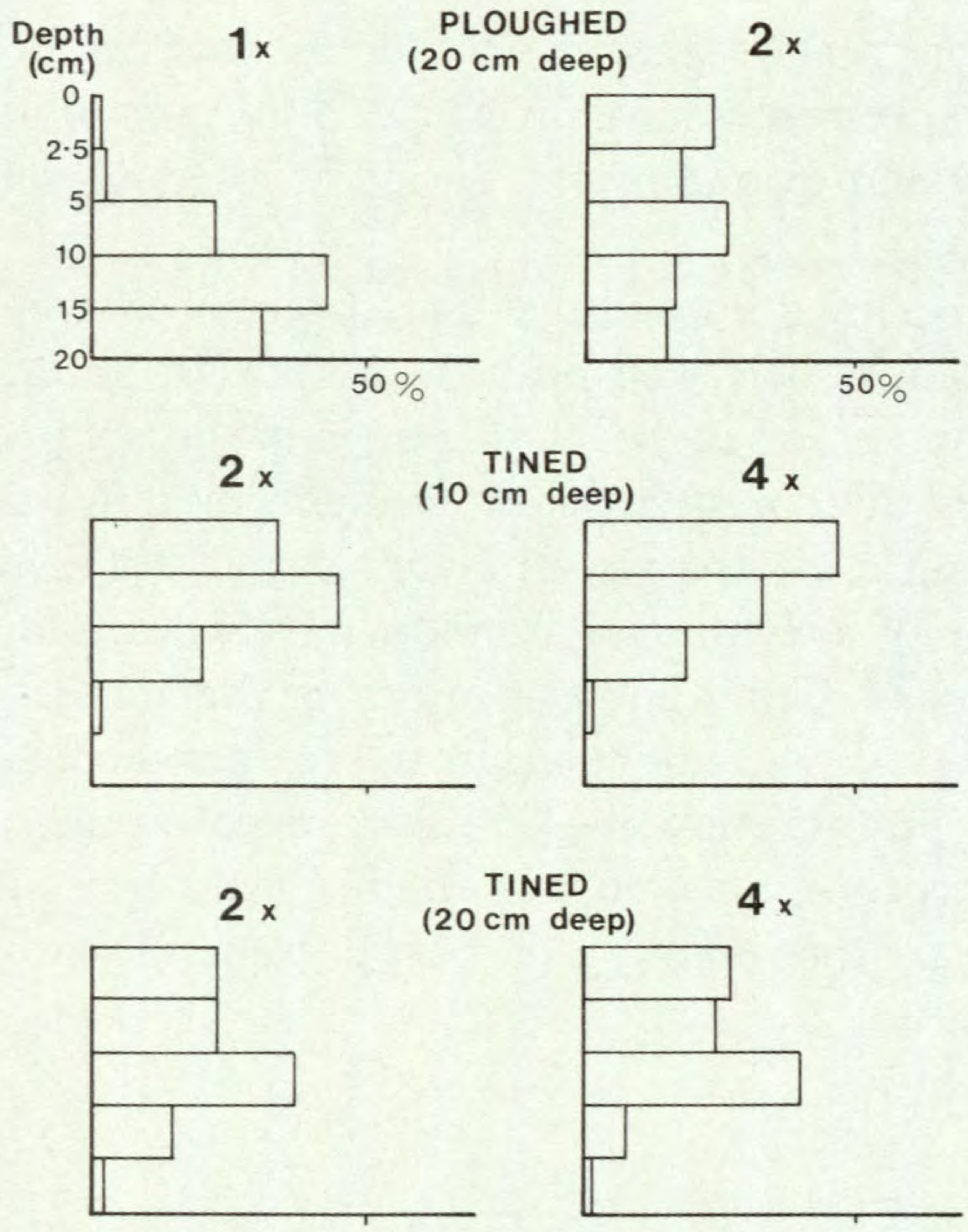

Fig. 1. Distribution of weed seed substitutes (plastic beads) after cultivation (percentage in each depth fraction).

Tine cultivations result in much less vertical movement and relatively few surface seeds are incorporated to more than half the depth of cultivation. There is little additional burial after subsequent tine cultivation and the majority of weed seeds remain close to the soil surface.

This work provided data for inclusion in weed modelling programmes involving predictions of long-term population responses to the use of different cultivation systems and sequences.

Black-grass control with diclofop-methyl

The Annual Crops Group has, for the past two years, examined the use of diclofop-methyl (Hoegrass) for post-emergence control of black-grass in winter cereals. The herbicide exhibits both root and foliar uptake but the foliar activity is generally considered to be most important. Although the main use of this compound is for wild-oat control, we felt there was great potential for the use of a foliage-applied herbicide, particularly where there is a risk of poor performance from current soil-applied black-grass herbicides. Our experiments have investigated the possibility of increasing biological activity and extending the period of effective control by using surfactants.

Initial field experiments indicated that the best control was obtained before the black-grass was well-tillered. Additional surfactant (Ethylan D256) markedly increased the level of control in the field and subsequent pot tests confirmed this. In these pot experiments there appeared to be little advantage in adding an alternative surfactant, Agral, but in mixture with an ester formulation of ioxynil and bromoxynil (Deloxil) diclofop-methyl activity was enhanced. Other pot tests indicated that increasing the level of D256 beyond 0.5% v/v did not result in any further increase in activity of diclofop-methyl. The addition of D256 also improved the performance of diclofop-methyl when applied to well-tillered black-grass in early spring and further investigations on this aspect are currently in progress.

Control of cleavers

In the last two seasons the activity of both pre- and post-emergence herbicides on cleavers (*Galium aparine*) in winter cereals were studied.

1981/1982

Recommended doses of pendimethalin and of linuron with bifenox or trifluralin applied pre-emergence in 4 winter cereal trials failed to achieve more than 60% reduction of cleaver shoots in the following June on sites with heavy soils. An additional sequential treatment of a full recommended dose of mecoprop increased the level of control to over 90% at some sites but had little effect on others. On sites with lighter soils all pre-emergence treatments were more active, particularly pendimethalin. On these soils, only linuron with trifluralin required a sequence of mecoprop to achieve over 90% control of cleaver shoots.

Post-emergence treatments of recommended mixtures of mecoprop with bifenox, with cyanazine, or with ioxynil and bromoxynil all achieved over 80% control of cleaver shoots at all sites. Mecoprop alone was not so satisfactory. A single application of the herbicide failed to control cleavers at the majority of sites, a second full dose was required to achieve acceptable control.

1982/1983

Six field experiments were conducted to study the variability in performance of mecoprop and an ioxynil/bromoxynil mixture between sites and application dates, alone and in mixture. The treatments were applied between November and May.

Control from the individual herbicides was variable and often unsatisfactory even at the higher of the two doses studied. Differences in activity between sites and between times of application were frequently greater than the differences between doses (higher dose 2 × lower dose). It had been expected that mecoprop would be more effective in the warmer weather at the later spray dates but there was little evidence that this had occurred. The performance of the ioxynil + bromoxynil mixture tended to decline as the cleavers became larger, especially at the lower dose. The tank mixtures of mecoprop with ioxynil + bromoxynil were always more active than the two constituents alone. Control from the mixtures mostly exceeded 90%.

Hence mecoprop alone cannot be relied upon to give the high levels of cleavers control frequently required. The tank mixture with ioxynil + bromoxynil appears to provide adequate control. This investigation continues.

Crop safety of mecoprop

Increases in the area of winter cereals and early autumn drilling have encouraged herbicide spraying at times of the year and at crop growth stages previously thought undesirable. The development trials for mecoprop, some 30 years ago, concentrated on spring applications to cereal varieties long since superseded. Treatment of winter cereals at early growth stages sometimes deforms the ears but it is not clear to what extent yield is affected.

Mecoprop, especially in mixtures with contact herbicides like ioxynil and bromoxynil, can scorch crop leaves. This occurs most frequently after winter applications and is generally associated with frosty weather. A combination of field experiments, controlled environment studies and observation suggests that the effect is most marked when spraying is preceded by rapid growing conditions but followed by sub-zero temperatures, within a few days. The precise relationship between weather and the degree of crop damage is not yet clear but prediction is likely to depend on an accurate forecast of the post-spraying weather.

Table 1. Winter wheat — an example of herbicide damage and recovery. Mecoprop/ioxynil/bromoxynil and isoproturon applied in November. (% differences from isoproturon alone; * significantly different, P = 0.05)

	April	June	July	August
Shoot/ear nos.	−13*	−11*	−8	+4
Dry weight/area	−37*	−19*	−9*	+2
Leaf area/plant	−28*	− 3	+3	—
Spikelets/ear	−15*	0	0	0
Grains/ear	—	—	—	+4
1000grain wt.	—	—	—	+4
Yield	—	—	—	0

Winter wheat has shown a remarkable capacity for recovery from leaf damage during the winter and yields may not be affected. Table 1 gives an example of crop recovery from severe herbicide injury caused by a November application of isoproturon and mecoprop/ioxynil/bromoxynil mixture followed by a period of sharp frosts. At the time of application the shoot apices were still producing leaf initials. Growing conditions later in the season were very good. Had they not been so, yields might have been depressed. Winter barley begins reproductive development much earlier than wheat and such crop damage during the early stages of spikelet formation could have a greater affect on yield.

Modelling

A need has been recognised for more rational, cost-effective weed control in order to maximise profit rather than yield. A prerequisite for this is the ability to predict the yield loss caused by a given weed infestation. Past competition experiments by both the Annual Crops and Weed Biology groups have been analysed and mathematical models are being developed. These are being used to examine the short-term economics of herbicide use. Experiments to test the models are to be carried out in spring 1984. Long-term build-up of wild-oat and black-grass populations have been examined previously through the development of population dynamics models by the Annual Crops group. These long-term models are being combined with yield loss prediction models in order to investigate the long-term economics of weed control. Topics currently under investigation are the economics of weed control using reduced herbicide doses, break crops, and various methods of cultivation and straw disposal.

PERENNIAL CROPS GROUP

New herbicides for blackcurrant and plum crops

Both blackcurrant and plum crops require more effective herbicide treatments particularly in the first two years after planting when weed competition is most severe and herbicide tolerance least. Pot and field experiments at WRO have indicated the likely safety of a number of new herbicides and, with plums, this has been confirmed in experiments on growers' holdings in Kent and the West Midlands.

At doses required for weed control pendimethalin and napropamide applied as tank mixes with simazine before bud burst were safe on newly-planted and older blackcurrants and plums. Oxyfluorfen + simazine caused damage in spring to low-growing foliage of blackcurrants and plums. Leaf necrosis appeared to result from oxyfluorfen-treated soil splashed onto expanding leaves by rain. This damage was rapidly outgrown except on newly-planted blackcurrants.

Aminotriazole (1.1 kg ha^{-1}) applied under young plums in spring and early summer was also safe providing no leafy suckers were sprayed. All treatments with herbicide mixtures gave improved control of annual weeds compared with simazine alone, oxyfluorfen giving the most persistent control. Collaborative experiments on the tolerance of young and established plums to normal and high doses of these herbicides were also carried out at East Malling Research Station, Long Ashton Research Station and Luddington Experimental Horticulture Station during 1982/3.

Factors affecting susceptibility of fruit crops to herbicides

In strawberries crop vigour, timing of herbicide application and herbicide mixtures and formulations were all found to affect response. Strawberries severely affected by *Verticillium* wilt were damaged by winter treatment with simazine + pendimethalin whereas vigorous plants were unaffected. Clopyralid caused yield reduction in some trials when applied during early September, the time of flower initiation, but later applications were safe. Synergistic activity was found with mixtures of lenacil and the grass herbicides alloxydim-sodium and fluazifop-butyl. Overall sprays of the individual herbicides had no adverse effect whereas mixtures caused severe leaf damage. In sand culture experiments suspension concentrate formulations of both propachlor and simazine applied to the roots caused more damage than wettable powders. When sprayed over the foliage high doses of propachlor s.c. also gave more damage than the w.p. Further work is in progress to determine the conditions in which these effects may be important in practice.

Control of perennial weeds

Glyphosate applied to cereals pre-harvest was found to give long-term control of most deep-rooted perennial weeds e.g. creeping thistle (*Cirsium arvense*) and field bindweed (*Convolvulus arvensis*). The control of *C. arvensis* with pre-harvest glyphosate was much better than that achieved in fallow situations — there was virtually no regrowth in the two seasons following application in cereals. This improved control may result from the better target presented by the weed when it is supported by the cereal crop. However, field horsetail (*Equisetum arvense*) is not controlled by glyphosate in any situation and experiments to date have shown that only aminotriazole applied in summer can give long-term control. This weed continues to be a serious problem in crops where aminotriazole cannot be used.

Several perennial weeds that spread mainly by seed are increasing in perennial crops despite the use of herbicides. Probably the most widespread and troublesome are the willowherbs (*Epilobium* spp.), especially American willowherb (*E. ciliatum*). This species was found to be tolerant of simazine whereas five other species were susceptible. However, *E. ciliatum* is particularly susceptible to diuron at all growth stages, being controlled in pots with doses as low as 0.5 kg ha^{-1}. Other herbicides with activity on this species were terbacil, bromacil and chloroxuron. Work is continuing on other weed species including mallow (*Malva sylvestris*), St. John's-wort (*Hypericum perforatum*), fleabane (*Erigeron canadensis*) and stonecrop (*Sedum acre*).

Further work on direct contact applicators, used for treating tall weeds in low-growing crops, has mainly involved studies of herbicide retention. Deposition on plants from rope-wick applicators was much more variable than from hydraulic nozzles; the amount deposited depended not only on the particular machine but on the physical nature of the plant itself. Also a double pass of the machines always failed to deposit twice as much chemical as a single pass.

GRASS AND FODDER CROPS GROUP

Grassland, which occupies some three-quarters of the UK agricultural land area, has tended to be a neglected crop both in terms of on-farm management and R&D inputs. However, research is gradually identifying the needs and benefits of improved weed control and there are distinct signs that commercial companies are increasingly prepared to market new products for grassland.

Establishing weed-free leys

Survey information shows that young leys become contaminated with unwanted species, especially when old grassland is reseeded. Common chickweed (*Stellaria media*), which is present in nearly two-thirds of autumn sown leys, is proving extremely damaging to newly sown grasses and clovers, even at densities as low as 50 plants m^{-2}.

With the continuing trend towards late summer seeding of grass/clover leys problems of controlling chickweed during the autumn are made more difficult, particularly where long-term clover survival is important. With such sowings, research is showing that clover seedlings are too vulnerable to virtually all the commercially available herbicide mixtures. However, improved flexibility of timing and clover safety are possible using bentazone and benazolin and it has been demonstrated that these two herbicides can be applied well into the autumn to kill chickweed without damaging clovers. Moreover, the addition of cyanazine seems to provide the bonus of selectively controlling annual meadow-grass (*Poa annua*).

Improved control of important broad-leaved weeds in permanent swards

Docks (*Rumex* spp.) which infest some 600,000 ha of UK grassland, have been shown to reduce grass yields by up to 30% when present at densities of 10 plants m^{-2}. Working jointly with the Grassland Research Institute, a mathematical model has been constructed to simulate dock reproduction, growth and competition with grass. The model, which has proved useful for comparing long-term strategies for controlling docks, has highlighted the need for more information on the nutritive value and population biology of docks in grassland.

Studies on smearing herbicides onto exposed dock leaves have shown that when a selective herbicide, such as dicamba, is used, it is possible to lower the height of application — thus resulting in a greater proportion of weeds being killed in the sward. This approach has also been used successfully to control creeping thistles (*Cirsium arvense*).

A major breakthrough in the control of several broad-leaved weeds in grassland now seems possible through the development of chlorsulfuron-based herbicides. Used at rates as low as 20 g ha^{-1}, these herbicides are proving very effective in killing docks and bracken (*Pteridium aquilinum*).

Advances in slot-seeding

Research on refining the principles of introducing desirable species of grasses and clovers into permanent swards has determined: (a) the importance of overcoming root competition during early stages of establishment (by band-spraying grass suppressants and placement of phosphate below the seed); (b) the need to protect the introduced species from slugs, insects and, to a lesser extent, fungi; and (c) the crucial role that post-sowing management plays in the encouragement of white clover to spread from the slots, e.g. the use of grass-suppressing propyzamide.

A study of factors influencing the development of white clover stolons confined by slot walls or the presence of neighbouring grasses is demonstrating the remarkable ability of these stolons to penetrate the surrounding turf and circumvent barriers. It was also found that direct contact between main stolons of one plant appears unlikely, although indirect links may be maintained by main stem activity through resource reallocation or via a hormonal effect.

New approach to grass growth regulation

The concept of using a plant growth regulator to inhibit seed head formation and so retain herbage quality for improved livestock productivity has been studied, based on the evaluation of mefluidide applied in spring to 8 grasses. Although first-cut yields were greatly reduced by an average of at least 35%, there was evidence of compensatory growth during mid-season, so that total yields were roughly similar. Transferring peak growth in spring to later in the year makes it much easier to match animal needs with grass production.

Further studies are in hand to establish whether mefluidide can be used to improve sward compositions, by reducing the proportion of tall growing grasses and so increasing the content of white clover.

HERBICIDE GROUP

The potential of new herbicides

During the two-year period, 25 new herbicides were studied in glasshouse and outdoor pot activity tests with the object of assessing their potential in the UK.

Evaluation work with safeners has expanded with emphasis on the problem of controlling wild-oat (*Avena fatua*) in oats. This is particularly funded by a grant from the Home Grown Cereals Authority. NA (1,8-napthalic anhydride) remains the compound with the broadest spectrum of activity, frequently giving useful protection against TCA, acetanilides, ethofumesate, tri-allate and EPTC, although work carried out with the assistance of the Welsh Plant Breeding Station has shown differences in response between oat cultivars. NA also protects perennial ryegrass from alachlor and benfuresate.

Attention is also given to weeds that are not included in the general evaluation programme but which can be problems in specific circumstances. As a result treatments can now be suggested for the control of American willowherb (*Epilobium adenocaulon*), Indian balsam (*Impatiens roylei*) and mignonette (*Reseda luteola*) in horticultural crops and crane's bills (*Geranium molle and G. rotundiflorum*) and field pansy (*Viola arvensis*) in cereals and oilseed rape. There is, in addition, a continuing effort to identify compounds which could be useful to control well established perennial weeds. Promising results have been given by chlorsulfuron and fluroxypyr on broad-leaved dock (*Rumex obtusifolius*), bracken (*Pteridium aquilinum*) and by mixtures of bentazone and pyridyloxy acid herbicides, which seem to be synergistic on creeping thistle (*Cirsium arvense*).

Understanding interactions between chemicals in the plant

The work on the antagonism of diclofop-methyl by other xenobiotics has developed and diversified to include further studies on chemical structure/antagonism relationships, the correlation between antagonism and enhanced herbicide degradation, the use of 'antagonists' as potential herbicide safeners, and research with conventional safeners. Observations that the response to spray applications of diclofop-methyl varies very markedly between different oat cultivars have also led to studies on crop tolerance.

Certain chemical structures are usually associated with strong herbicide antagonism while other compounds which lack them may be relatively compatible. Using this information it is possible to predict the compatibility of certain pyridyloxy and picolinic acids with diclofop-methyl in glasshouse tests. This suggests that broad-leaved weed herbicides, which include fluroxypyr and clopyralid may be mixed safely with diclofop-methyl and flamprop-methyl to give a broad spectrum of weed control.

Explanations for these different interactions are being sought in studies on the rates of detoxification of $[^{14}C]-(\pm)$-diclofop. A correlation between increased detoxification (by conjugation) and antagonism has been observed with a wide range of xenobiotics. However the series of conjugates formed by oat tissue is complex and they have not yet all been characterised.

The antagonism of diclofop-methyl by some xenobiotics is so great as to suggest their use as potential herbicide safeners for the oat crop. Unfortunately, the most effective antagonists, the substituted benzoic acids, have serious side-effects upon germinating oat seeds and may not be used as conventional seed dressings. An alternative approach is to apply the safener as a spray to the parent plant, so that the chemical is transported into the developing seed. Oat seeds have been produced in this way and the safener content established, after extraction with organic solvents, using GLC-MS. Such seeds show a reduced sensitivity to both diclofop-methyl and flamprop-methyl. The principle, thus established, may be useful in other situations, but further research is required before its commercial practicability is proven.

Research funded by the Home Grown Cereals Authority (complementary to the evaluation work described above) has begun into the safening of cultivated oats using NA. One notable finding is the apparent tolerance of at least one spring oat (Elen) to foliar application of diclofop-methyl. While the basis of the tolerance of Elen is not yet understood, the prospect of breeding oats, from selected parental lines for herbicide tolerance is attractive.

Drop characteristics affect spray deposition

Using the pulsed microjet developed at WRO, sprays of uniformly-sized drops can be generated and applied to the target at different speeds. The quantity of spray retained by broad-leaved species such as radish and mustard is much less sensitive to drop speed and size than the quantity retained by a cereal. For example, both barley and radish retained approximately equal amounts of 205 μm diameter drops of surfactant solution applied at 1.4 ms^{-1} but radish retained over seven times as much as barley if the drops were 310 μm in diameter, travelling at 3.4 ms^{-1}. The difference was even greater if the spray liquid did not contain surfactant.

Using 260 μm drops of water moving at 4.45 ms^{-1} the ratio of retention by radish to retention by barley rose to 28. Thus there is a clear opportunity to enhance herbicide selectivity by manipulating the properties of the spray drop.

This programme also includes work with the ICI 'Electrodyn'. This produces relatively small highly charged drops so it is of interest to know how target configuration affects deposition. Small, widely spaced, (artificial) targets collected relatively more spray than large or closely spaced targets, an effect which increased as the charge/mass ratio of the spray drops was raised. This inter-target competition was also demonstrated in the field, where spray deposition in artificial targets was less when they were placed between the rows of young cereal plants than when placed on bare ground. Again the higher the charge/mass ratio (which implies smaller drops), the lower the quantity reaching the target. The loss seemed to be due not only to the attraction of drops to the cereal plants but also to spray drifted away from the target area.

Vapour phase activity studies begin

A new project was started in 1983 to study the activity of herbicides reaching the plant as vapour. The initial object is to define properties of a herbicide which can be used to predict the likelihood of it causing damage by drift of its vapour.

Long-term field studies

Paraquat has been applied at an annual rate of 4 kg ha^{-1} to the same plots for 16 years. Residue analysis shows that only about 50% of the total quantity of paraquat applied during this period can be extracted from the soil. To check that this was not a consequence of changes in extractability ^{14}C labelled paraquat was applied to small areas of the plots and the persistence of total radioactivity monitored. After 15 months about 25% of the applied radioactivity had been lost, a decline that agrees reasonably well with the rate of loss of unlabelled paraquat in the main plots. This is one of very few, if any, experiments in the world that is capable of demonstrating whether or not paraquat can be broken down in the soil, a problem that is assuming importance in the minds of the registration authorities in several countries. This work has raised another issue of both scientific and legislative interest. Although radioactive paraquat was lost in the field, when it was incubated in the laboratory with soil from the same plots there was no loss after 12 months. There are a number of possible explanations for this difference but whatever the reason this result casts doubt on the validity of extrapolating into the field conclusions obtained in laboratory experiments.

Other long term studies have been in progress for over 20 years with linuron, MCPA, simazine and tri-allate. This work continues to show no measurable effects on crop production that can be attributed to the long term use of herbicides.

Straw ash and herbicide performance

As reported in the previous Biennial Report, poor control of black-grass (*Alopecurus myosuroides*) by substituted urea herbicides is often associated with minimum tillage and seems to be at least partly related to the increased adsorptive capacity of the surface soil brought about by an accumulation of straw ash. Freshly burnt straw is very adsorbent but it has been known for some time that this activity declines with time. Work at WRO has shown that ash applied to the soil surface and kept dry in the laboratory loses 20–30% of its activity in 3 days but thereafter the level stays fairly stable. By contrast if the ash is wetted or is kept out of doors then the activity declines to some 15% after a similar period. However, the residual activity seems to be fairly stable so that over a period of years the adsorptive capacity of the surface soil can increase substantially. Limited results obtained so far suggest that in some circumstances this accumulation can bring a soil close to the condition in which compounds like chlortoluron and isoproturon may be unreliable after 3–5 years of zero-tillage.

The mechanism by which the ash is deactivated remains unknown. Although water is clearly involved it seems unlikely to be a simple leaching or solution effect because adsorption measurements are made by shaking slurries of soil and ash in water overnight but this does not deactivate newly prepared ash.

The chemistry of diquat alginate

The diquat alginate formulation developed for the control of weeds in flowing water by the Aquatic Weeds Group has been shown, using ultrafiltration methods, to be diquat associated with two alginate carboxyl groups rather than diquat bromide alginate where one anionic group would be alginate carboxyl and the other would be bromide. When diquat alginate is extruded into water, diquat is gradually displaced by the calcium and magnesiun ions that occur in most natural waters. Thus some diquat is released initially but the calcium and magnesium alginate forms a relatively insoluble gel on the surface of the alginate so that a controlled release formulation is created *in situ*.

Effect of formulation constituents on herbicide performance

Work on the ways in which the adjuvants in formulations influence herbicide activity and selectivity have continued to be an important part of work on herbicide performance. It is the subject of a feature article (p. 48).

Water extraction gives good indication of availability of soil residues

A programme of field and glasshouse experiments with 11 compounds, complementary to similar work at the Biologische Bundesanstalt für Planz- und Fortswirtschaft at Braunschweig, has shown that measurement of herbicide residues in the soil that can be extracted with water, taken together with phytotoxicity data obtained in solution culture, can be used to predict whether or not herbicide residue levels in the soil will be damaging to a crop. The advantage of this approach is that it automatically takes account of soil type, unlike methods based on total residue levels which usually require the use of some sort of weighting factor based on the adsorption characteristics of the soil.

Weed control in forestry

A total of 9 new compounds were examined during the period of the report as candidate materials for controlling weeds in young plantations, as part of the programme supported by the Forestry Commission. Two new compounds may have potential and are being tested further: these are Dowco 453 and FBC 32197. Both may control grass weeds selectively in coniferous crops.

New herbicides are also being examined for use in forestry seedbeds. At present no new material shows particular promise, at least by comparison with diphenamid and napropamide, whose activity is well established. The effects of soil pH on herbicide activity are being investigated. The activities of diphenamid and napropamide are relatively unaffected by liming but this treatment appears to influence the activity of some other herbicides quite markedly. Atrazine, for example, is more phytotoxic to crop species at pH 6.5 than at pH 4.2. This may obviously have practical implications when nursery soils are treated with lime.

However, most attention has been given to methods of increasing the efficacy of established herbicides. This may be achieved by modifying the application technique or by making formulation changes. In particular, attention has been given to the use of oil and surfactant additives with foliage applied materials. In pot experiments with the woody weed *Rhododendron ponticum* a mixture of Agral, Ethylan D 252 surfactant and domestic paraffin has markedly improved the activity of hexazinone and glyphosate. Studies with ^{14}C-labelled herbicides show that the additive increases rates of leaf entry: in *R. ponticum* there is almost no penetration when hexazinone is applied as the commercial formulation Velpar L. However, when 10% of the additive mixture was added to the treatment solution uptake over a 48 h period rose to more than 80% of the applied dose. The additive had little effect on spray retention but caused up to 35% of the intercepted spray to run down the leaf blades and petioles to the area of the axillary buds. This is believed to be a factor contributing to the additive effects: buds in the area of the leaf axils give rise to the following season's new growth. The Agral-Ethylan D 252-paraffin mixture also enhanced the effect of glyphosate against grasses and *R. ponticum* and improved the activity of propyzamide. With this herbicide, there was no effect on selectivity between woody species and grasses.

Finally, seed treatment with herbicides has been tested to follow up reports of the success of this treatment with lucerne and soyabean seed in the USA. Some degree of success has been achieved: it is possible to control annual meadow-grass (*Poa annua*) and common chickweed (*Stellaria media*) sown with seed of a crop species with little or no injury to the latter.

MICROBIOLOGY GROUP

Interactions between herbicides and the microflora of soil and root region of plants

Further characterization of mecoprop interaction with wheat root microflora confirms that mecoprop treatment induces a series of morphological and physiological changes in the root. These result in proliferation of the root microflora and predispose the root to invasion. Similar effects on black-grass (*Alopecurus myosuroides*) roots follow treatment with dichlofop-methyl, though this chemical has no effects on wheat. Root exudation is a factor in the microbial response. At high light intensity, when root exudation is high, invasion by bacteria is limited. At low light intensity invasion is extensive suggesting that autumn sown crops may be more susceptible to mecoprop enhanced root invasion than spring grown crops. The effect of mecoprop on root exudation and its interaction with the root microflora are being investigated in collaboration with the Letcombe Laboratory. It has been confirmed that mecoprop effects are greater in sandy soils than in those containing high organic matter. Latest experiments show that amendment of soil with lucerne meal reduces the microbial invasion of roots. The mechanism of this is not yet understood.

Many herbicides, alone or in mixtures, produce similar effects to mecoprop. 2,4-D-amine, dichlorprop and difenzoquat all change root morphology and increase invasion. 2,4-D-ester, bromoxynil, ioxynil, chlorsulfuron, isoproturon, bentazone, dicamba, pendimethalin and dinoseb-acetate do not affect the microflora even if they affect root morphology.

Understanding microbial interactions in the plant rhizosphere may indicate methods of exploiting beneficial associations between microorganisms and roots and reducing adverse effects of plant pathogens. Experiments using combinations of two *Pseudomonas* spp. have shown that low cell numbers of one reduce the growth rate of dense cell suspensions of the other. This work is in collaboration with Dr R Hall, University of Oxford. Interactions between microorganisms from the wheat rhizosphere and herbicides are also being investigated.

The Group has reduced its research on side-effects of herbicides on the microflora of unplanted soil. However, some development of methods is still done. Side-effect studies have concentrated on effects on major soil functions and little is known of the consequenses of differential effects on components of the microflora. Accordingly, microwave treatments to remove different organisms from soil have been studied. Relatively short treatments (up to 4 mins) in a domestic microwave oven can kill the entire fungal population is some soils while having minimal effects on bacteria and actinomycetes. Treatment from 4 to 8 min kills actinomycetes while bacteria are only markedly affected after 12 to 16 min. Treatments of up to 4 min have little effect on the soil's chemistry.

Effects of fertilisers on herbicide — microflora interactions

As in previous experiments in the absence of fertilizer, paraquat (20 $\mu g\ g^{-1}$ soil) has both inhibited and stimulated the degradation of ^{14}C-labelled powdered green maize. Immobilization of soil nitrogen may be associated

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