CHAPTER 9

Chemical Control

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HERBICIDES

A wild oat herbicide must, by definition, kill wild oats. In practice, however, the requirements are much more exacting: they embrace not only the weeds but also the crop and the husbandry and management conditions under which it is grown. In brief, the ideal requirements are:

1. All species of wild oats, especially *Avena fatua, A. ludoviciana, A. sterilis* and *A. barbata,* should be susceptible to the herbicide at all stages of growth; activity and persistence in soil should be such as to deal with any seed which germinates after treatment; and the production of viable seed, which may produce future generations, should also be prevented.

2. Adverse effects on the crop should be minimal even when the crop is very closely related; also wild oat competition should be removed before crop yield and quality are affected.

3. Treatments should be easy to apply, with reasonable latitude in timing, volume rate, etc., and without the need for complex cultivations; other pesticides should be compatible and, finally, but increasingly important, cost should be appreciably less than the expected return.

The earliest wild oat herbicides were, not surprisingly, selective only in dicotyledonous crops. They were principally grass killers which had relatively little differential selectivity between grass species. In the 1950s, TCA, dalapon and the carbamates propham and chlorpropham were used to control grass weeds, including wild oats, in many broad-leaved crops such as peas, brassicae, potatoes and beet. Cereal crops, however, were very much at risk but only cultural means of wild oat control, such as cultivation, delayed sowing, and cropping sequences, could be recommended (British Weed Control Council 1958). The situation changed at the end of the 1950s when

Table 8.1. *Wild oat herbicides*

Active ingredient Code no. of experimental material	Chemical name
Haloalkanoic acids	
TCA	trichloracetic acid
dalapon-Na	sodium 2,2-dichloroproprionate
chlorfenprop-methyl (Bay 5710)	methyl 2-chloro-3(4-chlorophenyl) proprionate
Benzonitriles	
dichlobenil (2,6-DBN, H 133, Nia 5996, WL 3379)	2,6-dichlorobenzonitrile
Amino proprionic acids	
benzoylprop-ethyl (WL 17731)	ethyl *N*-benzoyl-*N*-(3,4-dichlorophenyl)-2-aminoproprionate
flamprop-isopropyl (WL 29762)	isopropyl(±)-2-(*N*-benzoyl-3-chloro-4-fluorophenyl-2-aminoproprionate
flamprop-methyl (WL 29761)	methyl analogue of above
Nitrophenyl ethers	
nitrofen (FW 925)	2,4-dichlorophenyl-4-nitrophenyl ether
Carbamates	
propham (IPC)	isopropyl *N*-phenylcarbamate
chlorpropham (CIPC)	isopropyl *N*-(3-chlorophenyl) carbamate
barban (S 847)	4-chlorobut-2-ynyl *N*-(3-chlorophenyl) carbamate
asulam (MB 9057)	methyl *N*-(4-aminobenzenesulphonyl) carbamate
Thiocarbamates	
EPTC (R 1608)	*S*-ethyl *NN*-dipropyl (thiocarbamate)
di-allate (DATC, CP15336	*S*-2,3-dichloroallyl *NN*-diisopropyl-(thiocarbamate)
tri-allate (CP 23426)	*S*-2,3,3-trichloroallyl *NN*-diisopropyl-(thiocarbamate)
cycloate (R 2063)	*N*-cyclohexyl-*N*-ethyl *S*-ethyl-(thiocarbamate)

Table 8.1. *cont.*

Active ingredient Code no. of experimental material	Chemical name
Ureas	
linuron (Hoe 2810)	*N*(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea
monolinuron (Hoe 2747)	*N*′-(4-chlorophenyl)-*N*-methoxy-*N*-methylurea
chlortoluron (C 2242)	*N*′-(3-chloro-4-methylphenyl)-*N*,*N*-dimethylurea
metoxuron (San 6602)	*N*′-(3-chloro-4-methylphenyl)-*N*,*N*-dimethylurea
isoproturon (Hoe 16410)	*N*-4-isopropylphenyl-*N*′,*N*′ dimethylurea
methabenzthiazuron (Bay 74283)	*N*-(benzothiazol-2-yl)-*N*,*N*′-dimethylurea
Triazines	
simazine	2-chloro-4,6-bisethylamino-1,3,5-triazine
atrazine	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
Miscellaneous	
difenzoquat (AC 84777)	1,2-dimethyl-3,5-diphenylpyrazolium methyl sulphate

barban (a carbamate) and di-allate (a thiocarbamate) were discovered. Both are remarkable for the high degree of selectivity which they show in their effects on cereals. Oats, both wild and cultivated, are susceptible, and wheat and barley relatively resistant.

At first it was thought that, between them, they would solve the wild oat problem, but in practice they both have drawbacks. Barban has a dual problem: some varieties of barley are not very resistant and wild oats are at their most susceptible for a relatively short period, between the 1 and 2½-leaf stage. Di-allate on the other hand is soil acting and, being volatile, has to be mixed with the soil. Thus soil type and condition, and the degree and depth of mixing critically affect activity, including selectivity. However, these two compounds, together with tri-allate, the analogue of di-allate, remained almost the only wild oat herbicides which could be used in cereals until the end of the 1960s. Towards the end of the period, some of the application limitations of tri-allate were removed by formulation as a granule, which eliminated the need for incorporation in many situations.

A later discovery, chlorfenprop-methyl, is remarkable in that it can be used to control wild oats in some varieties of cultivated oats. Since then several new wild oat herbicides such as benzoylprop-ethyl, flamprop-isopropyl and difenzoquat have become available, and the use of the broader spectrum grass- and broad-leaved herbicides, such as chlortoluron, has developed in winter cereals. However, although some of the herbicides satisfy a number of the requirements for the ideal wild oat herbicide, none satisfies them all.

A large number of herbicides, including many experimental materials that were never exploited commercially, have been evaluated against wild oats. This review, however, is largely restricted to those commercial products which have achieved importance at some stage during the development of chemical control of wild oats. It was found impossible to put these compounds into any completely logical order, so they have been grouped according to their chemical affinities and the groups placed in order of increasing complexity (Table 8.1). Within individual groups, the compounds (representing products) have been arranged more or less in chronological order. However, where compounds are closely related, these have often been dealt with together in the text and are therefore similarly grouped within the table.

Approximately 870 references have been consulted in the production of this chapter but only 000 are referred to in the text.

HALOALKANOIC ACIDS

TCA

Mode of action

The precise mode of action of TCA is not known but it is thought that it exerts its phytotoxic action by combining with protein molecules. It is not readily metabolised and so plants can accumulate high levels. Generally it is applied as an incorporated treatment, killing young seedlings before they emerge. If taken up by more mature plants it may inhibit shoot growth and can affect the production of leaf waxes.

Control of A. fatua *and crop tolerance*

Dose. Many authors refer to the control of *A. fatua* with TCA at a wide range of dose rates. Most references relate to its use in peas and sugar beet. At doses of 16.8 kg/ha and above, generally good control was reported (Gregory *et al* 1955, Canada 1955, Rijkslandbouwhogeschool, Gent 1960b, Hahne 1961, Kruger and Pallas 1965, West Germany 1968). These relatively high rates of TCA often damage pea and sugar beet crops. Thus Gregory *et al* (1955) reported that 5.6 kg/ha affected foliage of peas and 16.8 kg/ha retarded growth and reduced yields; Welte (1961) described early damage to peas as deformities of cotyledons and first leaves; Sexsmith (1960a) reported thinning of sugar beet stands and Welte (1961) deformities of seedling beet. In contrast, no damage to beet was reported by Bachthaler (1963) (16.8 kg/ha applied 1 day before sowing) and by West Germany (1968) and by Kampe (1967a) (15 kg/ha applied to the surface just before sowing, and not cultivated in).

Attempts to achieve greater selectivity using lower rates were not always successful due to inferior control of wild oats, or crop damage, or both. Holmes and Pfeiffer (1957) reported that wide scale testing of TCA applied at 8.4 kg/ha with two cultivations between application and drilling gave an average of 75% control of wild oats, but peas sometimes suffered a yield loss of 10-20%. It was suggested that TCA at this rate should be used in peas where wild oats were very dense and other cultural control methods were not possible. It was stated that TCA at this dose would not harm kale or sugar beet. Proctor and Armsby (1957) reported field trials with peas where the best results with TCA at 8.4 kg/ha were given by applications in late February or early March to ploughed land, and followed by 3 or 4 cultivations. It was suggested that peas be sown in wide rows to allow inter-row cultivations for broad-leaved weed control, because TCA destroys the wax 'bloom' on pea leaves making the peas susceptible to later applications of dinoseb.

Interval between spraying and sowing.
Crop damage may be reduced by lengthening the time between spraying and sowing the crop, and experiments were reported where different intervals were compared. Holmes *et al* (1955) described experiments where TCA at 5.6 and 8.4 kg/ha was applied to pea seedbeds 34, 20 and 11 days before sowing. In general the later applications gave better control of wild oats; yields were unaffected by 5.6 kg/ha and were reduced by 10% by 8.4 kg/ha; time of application had no effects on crop yield. In a report by the Home Grown Threshed Peas Joint Committee (Great Britain) (HGTPJC 1955), TCA at 5.6 and 8.4 kg/ha was applied 5, 3 and 2 weeks before sowing peas (the earliest treatment in late February); there was a tendency for the later application to reduce yields, particularly at the higher rate. The Pea Growing Research Organisation (Great Britain) (PGRO 1957) reported better control of wild oats with late February rather than late March applications of TCA at 5.6 and 11.2 kg/ha; here the early application allowed extra cultivations which were beneficial. The currently recommended intervals between spraying TCA at 8.4 kg/ha for wild oat control and sowing are: peas 14 days, kale and rape 5-7 days, sugar beet 5 days. Peas may suffer a check but it is likely that removal of wild oat competition will more than compensate for this. Because TCA treatment may make both peas and weeds more susceptible to scorch by dinoseb when applied for broad leaved weed control, it is recommended that the dose of dinoseb be halved (Fryer and Makepeace 1972).

An interval between spraying and planting is necessary when TCA is used in potatoes, Rijkslandbouwhogeschool, Gent (1960b) reported that TCA at 8.4 and 16.8 kg/ha applied at the end of January before ploughing and planting potatoes in mid-April gave 94% and 97% control of *A. fatua.* When applied 11-12 days before planting, TCA gave poor control of *A. fatua* and caused crop damage. Wilson (1970b) showed that yields of potatoes were unaffected by TCA at 33.6 kg/ha applied a fortnight before planting, but with some varieties, yields were significantly reduced by 5.6 kg/ha applied the day before planting. It was concluded that TCA is safer under wet conditions when cultivations may be dispensed with; under dry conditions with no leaching the chemical can remain concentrated in the surface layers and cultivations are necessary to dilute this concentrated layer and lessen the risk of crop damage. The currently recommended interval for potatoes treated with TCA at 16.8 kg/ha is 8 weeks or more between spraying and planting (Fryer and Makepeace 1972).

Flax. The use of TCA for controlling wild oats in cereals and flax is mentioned in reports from Canada. Flax appears more tolerant than wheat or barley: the Canadian Ministry of Agriculture (Canada 1956) reported that TCA at 22.4 kg/ha, applied either to summer fallow or autumn stubble, caused severe damage to cereals, and yields of wheat, oats and barley were reduced by between 50 and 100%; flax showed a 92% survival. Leggett (1954) reported that TCA applied at rates varying from 11.2 to 67.2 kg/ha caused only slight damage to flax but severe damage to wheat and barley. In contrast Chubb (1955) reported that TCA at 22.4 kg/ha applied in the autumn persisted, delayed germination of *A. fatua* and prevented any growth of flax. Lower rates were reported by Friesen (1960a) where TCA at 3.4-6.7 kg/ha resulted in significant increases in the yield of flax following the control of *A. fatua*. In one report from France (Jacquement and Poignant 1961) TCA was found to be insufficiently selective in both cereals and flax.

Peas and sugar beet. Several authors (Proctor and Armsby 1958, Murant 1958a, Butler 1958) compared the use of TCA with that of propham for controlling wild oats in sugar beet and peas. It was generally concluded that TCA at 8.4 kg/ha gave the most consistently satisfactory control of *A. fatua*, but that propham at 4:5 kg/ha was likely to cause less crop damage, particularly to peas, than TCA. Propham could be applied and incorporated during seedbed preparation while TCA needed a longer interval and extra cultivations before sowing the crop; this would favour the use of propham in early drilled crops. TCA had the drawback of making crops susceptible to dinoseb used for subsequent broad-leaved weed control; propham also controlled certain dicotyledonous species (*Stellaria media, Polygonum* spp.). On highly organic soils TCA was shown to be inactivated to a much lesser extent than was propham.

DALAPON

Mode of action

Dalapon is mostly taken up by the foliage of plants, but uptake can also occur from the soil through the roots. When applied at standard rates it persists in the soil for several weeks. Once in the plant it is slow-acting, and the main site of action is the growing point which is inhibited from making further growth. It is particularly effective against grasses. Van Overbeek (1964) suggested that dalapon acts by precipitating proteins within the plant, and that toxicity results from abnormal protein metabolism and the accumulation of metabolites. Tolerant species may be able to detoxify the breakdown products of the proteins resulting from dalapon action, rather than detoxifying the herbicide itself. A side effect is that the production of surface waxes on the leaves may be reduced; this can make dalapon treated plants more sensitive to other pesticides.

Symptoms and growth stage of wild oats

Andersen and Helgeson (1954) studied the effects of spraying dalapon on wild oats at varying growth stages. Seedling *A. fatua* sprayed with 4.5 and 6.7 kg/ha showed tip burn and stunting two weeks after treatment, and there was little further growth subsequently. Later applications at the early tillering stage showed leaf burn one week after treatment, with no further height increase after treatment with 4.5 and 6.7 kg/ha. There was less leaf burn when applied at the fully tillered stage; applications at the 'boot' stage were too late to affect vegetative growth but did result in more side tillers being produced. Sexsmith (1960b) also showed that 4.5 and 6.7 kg/ha applied up to tillering were effective in preventing the formation of panicles.

Raynor (1958) and Andersen and Helgeson (1958) applied dalapon at a wide range of stages of panicle development. No treatment prevented seedlings emerging from seeds collected from treated panicles, but with all treatments of dalapon at 2.2 kg/ha and above, these seedlings failed to develop. Andersen and Helgeson (1958) also showed that dalapon at 2.2 kg/ha had no effect on yield of Ramsey durum wheat when sprayed at the dough stage but that earlier applications, and 6.7 kg/ha applied at all stages, reduced yields. Similarly May (1972) showed that seeds, obtained from panicles treated with localised applications of dalapon 10 and 15% w/v, germinated, produced a coleoptile but failed to develop. Applications at the 'milk' stage were effective in preventing the formation of viable seed on the treated panicles, but did allow some to form on secondary untreated inflorescences, whilst applications at the 'soft cheese' stage were slightly less effective. Rainfall at the time of treatment had a relatively minor effect on the activity of dalapon (see p. 209).

Control of A. fatua *and crop tolerance*

Considerable variation is reported in the effective doses of dalapon needed for good control of *A. fatua.* Chubb (1959) reported good control with 4.5 kg/ha applied post-emergence, while Sexsmith (1960a,c) reported ineffective control with 5.6 kg/ha applied to seedlings with 1½-2½ leaves. The margin for selective control in sugar beet is low; Murant (1959) reported that 6.7 kg/ha was needed for control but that the maximum dose tolerated by the crop was only 5.3 kg/ha. Elliott and Fryer (1958) reported that sugar beet tolerated 5.6 kg/ha, while Sexsmith (1961a,d) showed that the same dose delayed crop maturity and thinned the beet stands. Lower applications have been successful in controlling volunteer cereals and wild oats in winter sown rape (Clare and Castle 1968). A dose of 2.2 kg/ha applied at the 4 to 6-leaf stage of the rape in November gave useful control, and a split application of 2.2 kg/ha in November followed by 2.2 kg/ha in March gave excellent control of *Avena ludoviciana* and *A. strigosa.* In general 4.5 kg/ha gave good control except when applied in January. Applications in November and February caused no crop damage but those in December, January and March caused slight reductions in height. No adverse effects on rape yield were found with rates up to 9.0 kg/ha.

Other crops are generally more susceptible than sugar beet and rape to post-emergence applications. Chubb (1955) showed that flax yields were reduced by 20% when sprayed with dalapon at 1.7 kg/ha, with proportionally higher yield reductions at higher rates. The crop was most susceptible when sprayed 36 days after emergence. Leggett (1955a,c) and Elliott and Fryer (1958) reported the susceptibility of cereals to 5.6 kg/ha. Evans (1958) reported that beans tolerated 2.2 kg/ha but that higher rates reduced flowering and stunted the crop.

Higher rates appear necessary for controlling wild oats when dalapon is applied to the soil before the crop emerges. A report from the Netherlands (1960) stated that 12 kg/ha gave good control pre-sowing (wild oats had emerged when sprayed). Hinzsche (1966) showed that pre-emergence applications of 20 kg/ha controlled wild oats, but when applied preplanting damage to sugar beet and potatoes was related to the time interval between spraying and sowing. Another report from the Netherlands (1959) showed that sugar beet was not injured by 30 kg/ha applied 14 days before sowing; while later experiments (Netherlands 1960) showed that 12 kg/ha 10 days before sowing stunted the crop and delayed growth. Potatoes were damaged when treated with 5 and 10 kg/ha 12 days before planting, but dalapon applied earlier was safe to the crop (Rijkslandbouwhogeschool 1960b).

CHLORFENPROP-METHYL

Mode of action

At doses of chlorfenprop-methyl likely to produce herbicidal action, Fedtke (1972) found that none of the basic metabolic pathways in plants, such as protein and RNA synthesis, respiration and photosynthesis, were sufficiently affected to explain the activity. However, during the compound's toxic action on wild oat leaves autolysis of the cell occurred, cellular hydrolytic enzymes which are normally inactive were released, metabolism stopped and the polymeric proteins, starch and nucleic acids were rapidly degraded with a corresponding increase in amino acids and soluble reduciing sugars. Separation of the amino acids revealed a large increase in γ-aminobutyric acid. An increased leakage of chlorophyll indicated that the chloroplast membranes were broken down, presumably by lipases. How autolysis itself is induced remains unexplained.

In studies on translocation in *A. fatua* plants, Hack (1971) showed that susceptibility increased as droplets containing chlorfenprop-methyl were placed closer to the meristem. Differences in susceptibility of various biotypes became apparent as the distance from the meristem was increased.

Symptoms

The effects produced resemble those of a contact herbicide with collapse of the leaf cells and necrosis developing in the treated areas, generally within several days depending on weather conditions. This gradually extends to the whole plant. The speed of action is increased in conditions of high temperature and light intensity. Effects may be quite localised and if the spray cover is inadequate, all the areas of potential regeneration on the plant may not be killed. Chlorfenprop-methyl is unlike most other wild oat herbicides in that recovery, when it does occur, is generally complete and any increase in the proportion of small panicles is relatively minor.

Dose and growth stage of wild oats

Wild oat control seems to be satisfactory at doses between 4 kg and 5 kg/ha in most countries, although in Europe there are a number of resistant biotypes of *A. fatua*. Eue (1968) in Germany found that 3-4 kg/ha gave satisfactory control, with the lower dose being sufficient when the plants were of an even age. Other German workers (BBLF 1968, 1969) showed that 3 kg/ha was more effective on plants with $1\frac{1}{2}$-$2\frac{1}{2}$ leaves than 4 kg/ha on plants with 4-6 leaves, and Kampe (1969) obtained a 95% control of the panicle bearing culms with 4 kg/ha. He also mentions a considerable reduction in the vigour and viability of the seed produced by the surviving *A. fatua* plants from experiments in crops of spring barley and sugar beet. He noted that the thousand grain weight was also reduced. This effect is always difficult to interpret. Is the effect direct or indirect? Is it due to the reduced vigour of the plants surviving the treatment? If the latter, the size of the effect is likely to be somewhat unpredictable and dependent on growing conditions and the competitive ability of the particular crop. Nevertheless it can be a very useful bonus. Holroyd (1968a) and Holroyd and Bailey (1970) in field experiments in spring cereals over several seasons in southern England used doses which ranged from 2.25 kg to 9.0 kg/ha and found that *A. fatua* was severely affected at growth stages up to 4 leaves but most susceptible between the $1\frac{1}{2}$ and 3-leaf stages. A reduction of 93-95% in spikelet numbers was achieved in two experiments with 4.5 kg/ha. Forrest, Hodgson and Myram (1972) effectively controlled *A. fatua* with 1-4 leaves with doses of 4.8 kg/ha and commented that 'effective control was also obtained in some instances with treatment after tillering had begun but spraying criteria were much more critical'. Allen and Smallridge (1972) in New Zealand controlled wild oats at the 1-3-leaf stage in wheat and barley with 4.2 kg/ha. Bouchet and Faivre-Dupaigre (1968) however obtained unsatisfactory results in Northern France suggesting they were due to differences in the susceptibility of some biotypes. Stryckers and Himme (1972) found that differential susceptibility was shown by six biotypes of *A. fatua*. In Germany, there were similar findings with five biotypes (BBLF 1970). Hack (1973), however, stressed the need to consider physiological rather than morphological characteristics when examining resistance in wild oats. He found *A. ludoviciana* Dur. was less susceptible than *A. fatua*.

Application factors and formulation

Due to its contact type of activity both application and formulation are critical if consistent effective control is to be achieved with this herbicide. Stryckers and Himme (1972) added 1 kg/ha of an iso-octylphenol polyglycol ether to 3 kg/ha of the compound and controlled plants of *A. fatua* grown in pots as effectively as with 5 kg/ha without the surface active agent. Martin, Morris and Rieley (1972) in studies on its action, and efficiency against *A. fatua* concluded that the best results were obtained when it was applied at a dose of 4.8 kg/ha in 280 litres with fan nozzles at approximately 3 bars. Effectiveness increased as droplets of the compound were placed nearer to meristematic areas (Hack 1971) while, to obtain good control, spray should cover the base of plants (Hack 1973). He also suggested that this could be accomplished by spraying at a volume of 600 to 800 litres/ha and a pressure of 3.9-4.9 bars.

Crop tolerance

Most authors indicate that there are no problems of crop tolerance in wheat and barley at doses which give good control of *A. fatua* and are economically feasible. Eue (1968) reported that wheat, spring barley, beet, potatoes, peas and carrots tolerated 3-4 kg/ha. Holroyd (1968a) noted minor ephemeral necrosis on spring barley after the application of 9 kg/ha in 235 litres while Holroyd and Bailey (1970) found that doses up to 18 kg/ha in 314 litres had effects which were just visible on winter wheat at harvest. Kampe (1969) used 4 kg/ha on spring barley, winter and spring wheat, peas and carrots and noted that they showed good tolerance. The Processors and Growers Research Organisation (UK), however, reported that the control given by 4.8 and 9.6 kg/ha in peas was no better than that given by barban (PGRO 1973).

Perhaps the most remarkable selectivity was reported by Stryckers and Himme (1972) who found that certain cultivars of cultivated oats (notably Abed Minor, Astor, Bento, Condor, Diane, Espoir de Gembloux and Zeegold) were resistant whereas others (Noppe d'Argent, Solhavre, Vigor, Blanche de Wattines and Flamo) were very susceptible. They found that sowing depth and the addition of surface active agents did not alter the differential susceptibility pattern and concluded that it was genetically and not environmentally determined. Similar results were reported from Germany (BBLF 1970).

Fryer and Makepeace (1972) however recommend use only in wheat and barley. Recent work (Oswald and Haggar 1974) has indicated that ryegrass crops grown for seed are resistant. The manufacturers recommend its use in the following spring oat varieties: Astor, Condor, Leanda, Luxor, Mostyn, Nelson, Selma, Maris Oberon and Maris Tabard (Bayer Agrochem 1975, private communication); this is approved by the Agricultural Chemicals Approval Scheme (1975).

Mixtures

Chlorfenprop-methyl, unlike many wild oat herbicides, can apparently be mixed with other herbicides without reducing the effect on wild oats. Kampe

(1969) tested various mixtures and found that chlorfenprop-methyl, with a mixture of potassium salts of 2,4-D + MCPA damaged spring wheat, and with dinoseb acetate damaged peas; but phenmedipham contributed additively and linuron synergistically to *A. fatua* control in sugar beet and carrots, respectively. Holma (1970) in Sweden found that chlorfenprop-methyl with or without either dichlorprop or manganese sulphate or both gave greater than 90% control of *A. fatua* at the 2 to 4-leaf stage. Allen and Smallridge (1972) had good control of *Avena* spp. and broad-leaved weeds in wheat with a mixture of 3.5 kg/ha chlorfenprop-methyl and 2.24 kg/ha mecoprop in New Zealand. The manufacturers state that it can be mixed with soluble formulations of MCPA, 2,4-D and mixtures of MCPA with dicamba, mecoprop and 2,3,6-TBA (Bayer 1975).

Residues

There is little or no published work on the persistence of chlorfenprop-methyl either in treated crops or the soil. Jarczyk (1972) studied adsorption and leaching in soil columns and found a close relationship between adsorption and carbon content but none with clay content or exchange capacity. The compound also moved very little in the soil and remained in the surface layers even after 200 mm of simulated rainfall within 48 hours. The manufacturers however found no detectable residues at harvest in straw or grain of either barley or wheat; nor were residues detected in the soil (Bayer Agrochem 1975, personal communication).

Control of other Avena *spp.*

Hack (1971) found *A. ludoviciana* less susceptible than *A. fatua* while *A. sterilis* showed almost no response. Stryckers and Himme (1972) also found *A. sterilis* and *A. strigosa* resistant.

BENZONITRILES

DICHLOBENIL

Mode of action

This soil acting herbicide is very active against germinating weeds and has some post-emergence activity. Incorporation enhances its effect considerably, particularly under dry conditions. Although being fairly volatile, residues can persist for as long as 12 months. Its precise mode of action is not known.

Dose

Pre-emergence treatments can effectively control wild oats. Koopman and Daams (1960) obtained good control with 0.6-4.5 kg/ha, and Stovell (1962) achieved 60% control with 1.1 kg/ha, 71% with 2.2 kg/ha and 84% with 4.5 kg/ha. In these trials the dichlobenil was applied either before the wild oats emerged or when they were at the 1-2 leaf stage.

After emergence the wild oats become more resistant. A number of experiments have failed to achieve effective control with doses as high as 4.5 kg/ha (Corns 1960a) and 6.7 kg/ha (Rijkslandbouwhogeschool, Gent 1961b). Dryden (1960) found that post-emergence treatments of 2.2, 3.4 and 5.6 kg/ha reduced tillering but did not kill the plants.

Crop tolerance

As with the wild oats, large cereal plants were found to be more resistant to dichlobenil than small seedlings. Rijkslandbouwhogeschool, Gent (1961b) showed that 6 kg/ha applied 3 days before sowing barley killed all the cereal plants, whilst a similar dose applied 12 days later only damaged them. Trials by Stovell (1962) showed that although incorporated treatments of 1.1 kg/ha applied when the cereals were at the 1-3-leaf stage caused only slight damage, 2.2 and 4.5 kg/ha resulted in an unacceptably high degree of injury. In no experiments did treatments of dichlobenil applied to control wild oats result in increased cereal yields compared with the controls.

Dichlobenil is mainly used in bush and top fruit crops in which wild oats are only rarely a problem.

Environmental factors

Koopman and Daams (1960) suggested that the degree of control was affected by soil type and Stovell (1962) found that activity against both crop and weed was influenced by rainfall.

AMINO PROPIONIC ACIDS

BENZOYLPROP-ETHYL

Mode of action

Chapman *et al* (1969) showed that inhibition of cell elongation rather than cell division was the cause of herbicidal activity on *Avena* spp. Jordan *et al* (1972) confirmed this and suggested that the metabolic pathway involved hydrolysis to the free acid which was probably the active agent. Jeffcoat and Sampson (1973) and Jeffcoat and Harris (1973), in laboratory studies, including work with radioactive tracers, found that foliar applications to oat were rapidly degraded by de-esterification to the biologically active des-ethyl acid, benzoylprop. This de-esterification was relatively low in wheat and, together with some detoxification, prevented the accumulation of phytotoxic levels of the acid. Detoxification was also observed in oat but it failed to prevent the accumulation of phytotoxic levels of the active metabolite. The des-ethyl acid, unlike the benzoylprop-ethyl, was mobile in the phloem and was thus capable of moving from the foliage to the stem where it inhibited stem elongation through an effect on cell expansion. This resulted in stunted wild oat plants which are not competitive with the wheat for light and nutrients. Beynon *et al* (1974a) also obtained evidence for the hydrolysis of the herbicide in wheat, oat and barley seedlings to its des-ethyl analogue which conjugated with plant sugars. A small degree of degradation of the herbicide by debenzoylation was found to occur, giving products which would also conjugate or complex. Beynon *et al* (1974b) confirmed that there was no evidence of appreciable movement within wheat plants after treatment of the foliage.

Symptoms

Most records of effects on *Avena* spp. agree that the major symptom is a severe stunting or inhibition of the leaves (Bowler *et al* 1972, Chapman *et al* 1969, Jeffcoat and Sampson 1973, Friesen and Dew 1972, Devot 1971, Stryckers and van Himme 1972). Chapman *et al* (1969) also observed that stunting could be accompanied by hyperchromism (intensification of the green colour) of leaves. These authors and Friesen and Dew (1972) also observed necrosis of the wild oat, this usually taking a long time to develop. Some recovery of leaves and production of tillers can occur, especially if applied too early or at doses below the optimum (Allen 1973, Chapman *et al* 1969, Friesen and Dew 1972). As a consequence of these effects, formation of panicles, spikelets and seeds is either prevented or severely reduced (Allen 1973, Breslin 1974, Devot 1971, Gummeson 1975). Susceptible varieties of wheat and barley exhibit a shortening of stem internodes (Bowden *et al* 1970, Devot 1971, Loubaresse *et al* 1971, Stryckers and van Himme 1972). Stryckers and van Himme (1972) also reported leaf chlorosis in oats, certain wheat varieties and barley, with some leaf scorch on the latter.

Dose

Bowler (1973a), commenting on the results of numerous field trials in Europe and North America, noted that the optimum dose for adequate control of *Avena fatua* appeared to be 1.0 kg/ha in Northern Europe, 1.25 kg/ha in the Mediterranean lands and 1.4 kg/ha in Canada. He correlated these doses with the denseness of the wheat crop. Thus, when a high rainfall allowed higher seeding rates as in Northern Europe, the greater the competition from the crop, the lower was the dose needed for wild oat control. Most of the work reviewed would tend to support the choice of doses suggested for each region. Thus in England, a dose of 1.0-1.12 kg/ha has been reported to give adequate control of wild oats (Proctor and Armsby 1974, Proctor and Livingston 1972, Mead *et al* 1974). Most of the work in France has shown that doses between 1 and 2 kg/ha are adequate (Mouillac and Jolie 1972, Bouchet 1972, Maynadier *et al* 1971, 1973, Loubaresse *et al* 1971, Jarry *et al* 1971). In German trials in 1971 and 1972, 1.6 kg/ha gave an average control of *Avena fatua* of 91% (Kampe 1973a,b). In Belgium good control of wild oats was found at 1 to 1.5 kg/ha (Stryckers and van Himme 1971, 1972). In trials in Spain in 1971 (Vincente and Bowler 1973) doses of 1.5 kg/ha reduced wild oat populations by 67-80%. In Canada, Bowden *et al* (1970) recorded that with doses of 1 and 1.5 kg/ha control of *Avena* spp. was 95 and 100% respectively.

Inhibitory effects on wild oat can occur at much lower doses than are needed for adequate control. Chapman *et al* (1969) found inhibition of plants even at 0.15 kg/ha. Stobbe and Holm (1972) in glasshouse studies found that 0.35 kg/ha of benzoylprop-ethyl in mixture with barban controlled wild oats satisfactorily, although higher doses were necessary in the field.

Several authors, as well as reporting effective control of wild oats, have also recorded the effect on the panicle or seed. Thus Proctor and Armsby (1974) reported that in panicle reduction benzoylprop-ethyl was the best of several herbicides tested. A dose of 1.0 kg/ha gave 93 to 95% mean reductions in panicle dry weight in winter wheat trials at several sites between 1972 and 1974. Mead *et al* (1974), using a dose of 1.12 kg/ha, obtained reductions in panicle dry weights of 77 to 91% in trials on ryegrass varieties at two different sites. Gummeson (1975) found that spraying, even at 1.0 and 1.2 kg/ha, at later dates than recommended can cause large reductions in the number of kernels of *A. fatua* due to many heads lacking fully developed kernels. He also pointed out that plants of *A. fatua* which survive treatment generally do not reach maturity and are usually green at harvest, a fact noted by others, eg Allen (1973), Allen *et al* (1974). It has been pointed out however that assessment of wild oat control by counting panicles may give similar results to panicle weights for some herbicides but that this was not the case with benzoylprop-ethyl, because a high proportion of very small panicles formed (Baldwin 1973). Breslin (1974) has measured the effect of annual application of benzoylprop-ethyl on populations of *A. fatua* and *A. ludoviciana.* Applying 1.0 kg/ha to the same area of winter wheat each year for 3 years in the United Kingdom, the number of panicles of *A. fatua* were reduced by 22% in 1972, 95% in 1973 and 87% in 1974. In consequence of this and of the lower numbers of spikelets present on existing panicles, calculated seed production diminished by 85, 99 and 88% respectively in each year. In France, panicle formation in *A. ludoviciana* was reduced by 91, 99 and 97%, resulting in a suppression of seed production of the order of 99% in 1972, 100% in 1973 and 99% in 1974. Skorda (1974) has shown that return of viable seed to the soil was prevented by benzoylprop-ethyl.

Application factors and formulation

Application in a wide range of volumes appears to be possible with benzoylprop-ethyl. Jordan *et al* (1972) reported successful results with as low as 55 l/ha in Canada to six times that volume in Europe. Some of the first field trials were successful at 500 l/ha (Chapman *et al* 1969, Bowden *et al* 1970). Aerial applications in Spain of 50 to 100 l/ha at a pressure of 4 bars gave adequate results (Bowler 1973a, Vincente and Bowler 1973) as did one trial at an ultra low volume of 7.5 l/ha (Bowler 1973a). Bowden (1971c) found no visual difference with volumes of 45, 67, 90 and 112 l/ha with two emulsifiable concentrate formulations but, in another test, volumes of 45 and 67 l/ha appeared to be better than volumes of 90 and 112 l/ha (Bowden 1971d). Stobbe *et al* (1971a) studying the effect of pressure and nozzle angle, found better wild oat control using the nozzle at an angle of 45° while a pressure of 2.47 bars was superior to 3.17 bars. Chapman *et al* (1969) reported that in a glasshouse study, a volume of 380 l/ha was better than at lower volumes, as was spraying with nozzles at 45° rather than vertically, but differences were marginal.

Taylor *et al* (1974) in a glasshouse study, sprayed *Avena fatua* at two different growth stages at 3 volume ranges between 50 and 450 l/ha using 3 pressures of application (1.41, 2.11 and 2.81 bars) within each volume range. Greater effect on the plants was found at the lower volumes and at the higher pressure within these volumes.

In Britain the current recommendation is to spray in volumes of 225 to 450 l/ha of water with fan jets operating at a minimum pressure of 2.81 bars, using the higher volume in dense crop or weed situations (MAFF STL 1975, British Farmer and Stockbreeder 1974).

In the early stages of development of this herbicide, it was formulated as a wettable powder which required the addition of an oil (eg Risella oil, FX 1834) to secure effect. Since then emulsifiable concentrates have been developed with varying quanties of active ingredient. A considerable amount of work has been carried out in Canada, comparing all the available formulations. Thus in growth chamber studies (Regina Research Station, 1971) the 40% wettable powder was compared with a 20% e.c. (FX 2000) and a 40% e.c. (FX 2062) for control of *Avena* spp. at the 2 and 4 leaf stages in spring wheat and barley. The 20% e.c. gave the best control at both growth stages and did not damage the wheat. Other Canadian work comparing a 20% e.c. (FX 2182), a 15% e.c. (FX 2039) and the wettable powder (40%) has shown that usually one or other of the liquid formulations is superior to the wettable powder (Ashford and Rahman 1971, Banting 1971, Bowden 1971b, Stobbe and Bowden 1971) although Molberg (1971a) reported no significant differences in wild oat control between all three.

Binchof and Walter (1975) examined the effect of benzoylprop-ethyl on wild oats in relation to its deposition on the plant. They applied the herbicide to the distal and proximal half of leaves, respectively, to the whole leaf sheath and to the whole plant. Herbicidal effectiveness increased as the distance between the site of application and the growing point decreased.

Environmental factors

Benzoylprop-ethyl has been shown to give better control of wild oat at low light intensities in glasshouse studies by Stobbe and Holm (1972). They claimed that at high light intensity the herbicide was detoxified by plants. Jeffcoat and Sampson (1973) also report a better effect in the shade and these and numerous other authors agree that the weakened wild oats compete weakly with the crop for nutrients and light and shading by the crop helps or is necessary for control (Stobbe and Holm 1972, Jeffcoat and Sampson 1973, Chapman *et al* 1969, Bowler *et al* 1972). Some authors (Jordan *et al* 1972, Bowler *et al* 1972, Bowler 1973a, Chapman *et al* 1969) have commented that in minimum rainfall areas, which are usually characterised by more open crop stands (ie low competition, eg in the Mediterranean) a greater dose was needed than in Nothern Europe where greater rainfall allows heavier sowing rates and hence greater competition of the crop.

Bowler *et al* (1972) noted that where heavy rain fell soon after application, wild oat control was still acceptable, suggesting that the herbicide is relatively rainfast.

Most of the work surveyed was carried out on arable soils of relatively low organic matter. No effect of soil type has been reported but Bowler *et al* (1972) say that recommendation for use varies with soil type. Stobbe *et al* (1971b) studied the effect of the herbicide at different levels of fertility and found that with late applications, wild oat control improved with increasing levels of nitrogen.

Growth stage of wild oats

Where the effectiveness of the herbicide has been examined after applying at different stages of development of the wild oat, most authors agree that more sensitivity is found at late rather than early growth stages, with the optimum time being near or at tillering (Bowden 1971a, Catizone 1974, Chapman *et al* 1969, Colbert and Appleby 1972a, Friesen and Dew 1972, Gummeson 1975, Kampe 1973a, Mead *et al* 1974, Nalewaja 1971b, Stobbe *et al* 1971b). Generally where spraying has been carried out at the appropriate growth stage, adequate control has been achieved (Bowden *et al* 1970, Bowden 1971g, Bowler 1973a, Cutuvilo 1972, Gummeson 1975, Holroyd 1972b, Jarry *et al* 1971, Jordan *et al* 1972, Maynadier *et al* 1971, Proctor and Livingston 1972, Stobbe and Holm 1972-, Skorda 1974). However, useful suppression can also be found at earlier growth stages (2 to 3 leaves) (Holroyd and Bailey 1970, Kampe 1973a, Nalewaja 1971b) while Banting (1971) in glasshouse studies found better control at the 2 rather than the 3 to 4 leaf stages. Holroyd and Bailey (1970) in their field trials at various sites sometimes found better control at early rather than late stages.

The ability of benzoylprop-ethyl to control wild oats at late stages of growth gives it some potential advantage over other wild oat herbicides used for post-emergence control. Macpherson (1975) has indicated the benefit of having such a treatment, eg for late season control, perhaps when the wild oat is above the crop. Although, in this situation in cereals, spraying the herbicide might not be practical it may be of some use for example in ryegrass pastures and it is of interest here to note the work of Allen *et al* (1974) who prevented the production of wild oat seed at harvest by treating as late as the stem swelling stage (Feekes scale 8 to 9). Earlier, he had sprayed the wild oats when they were shooting up and before ear swelling. Although there was some regrowth from the base, none of the spikelets had flowered by the time the crop was harvested (Allen 1973). Gummeson (1975) also reported that spraying later than recommended would reduce panicle and seed formation, and surviving plants usually were immature at harvest.

Holroyd (1972c) pointed out that, with recent evidence of severe competition from wild oats after they reach the 2 leaf stage, late removal of the wild oats was likely to be reflected in a reduced yield benefit. Several other authors have reported results with benzoylprop-ethyl which lends some support to this (Bowden 1971a,b, Friesen and Dew 1972, Molberg 1971b), greater wheat yields being obtained when the wild oats were sprayed in an early growth stage, although as mentioned above, better control occurred when they were sprayed later. Colbert and Appleby (1972a) got effective control of wild oats when they were sprayed very late (1 to 2 stem nodes) but obtained lower grain yields which they said was due to competition. The lack of herbicidal effect against other weeds can also be a disadvantage, for instance Proctor and Armsby (1974) found excellent control of wild oats but low crop yields, which they said were due to a heavy infestation of *Alopecurus myosuroides.*

Conversely, however, some authors have reported that benzoylprop-ethyl is of particular use where there is a high infestation of wild oats (Maynadier *et al* 1973, Mouillac and Jolie 1972, Devot 1971). Loubaresse *et al* (1971) and Bowden *et al* (1970) reported increased crop yields where wild oat density was high. Allen (1973) said that the yield response of ryegrass depended on the level of wild oat infestation. Catizone (1974) however, found that herbicidal effectiveness on *Avena ludoviciana* decreased with increasing populations. Kees (1975), as a result of 33 field experiments in Bavaria from 1971-1974, found a significant linear regression of yield of wheat on the number of *Avena fatua* plants/m^2 (before harvest), and calculated threshold values based on this.

Crop tolerance

The majority of authors agree that provided the correct dose is applied to a vigorously growing crop at the recommended growth stage, good tolerance is shown by wheat (Borges 1971a,b, Bowler *et al* 1972, Bowler 1973a,b, Bowden *et al* 1970, Chapman *et al* 1969, de Gournay *et al* 1973, Devot 1971, Friesen 1972, Friesen and Dew 1972, Skorda 1974, Vincente and Bowler 1973); spring wheat (Taylor *et al* 1974, Holroyd and May 1970, Regina 1971, Stryckers and van Himme 1972); winter wheat (Baldwin 1973, Baldwin and Armsby 1973, Colbert and Appleby 1972a, Catizone 1974, Cochet *et al* 1971, 1973, Livingston and Baldwin 1973, Proctor and Livingston 1972, Proctor and Armsby 1974a); winter and spring wheat (Gummeson 1975, Kampe 1973a,b, Mouillac and Jolie 1972, Stovell and Bowler 1972); soft and hard wheat (Bouchet 1973, Cochet *et al* 1971, 1973, Jarry *et al* 1973, Jordan *et al* 1972, Loubaresse *et al* 1971, Leonard *et al* 1973, Maynadier *et al* 1971, 1973).

Jordan *et al* (1972) reported that 124 cultivars of hard and soft wheat tolerated twice the recommended rate of benzoylprop-ethyl. Bowden *et al* (1970) summarised the results of 80 field trials in the United Kingdom, France and Canada. No yield reductions were found at doses four times those required for wild oat control.

Bowler (1973b) reported on yield increase from nine European countries and Canada, covering 160 cultivars of wheat. Safety of 150 cultivars was found at twice the normal dose and where trials were done in the absence of wild oats, there was no reduction in wheat at eight times the normal dose (Bowler 1973a). In the same paper he recommended that, in Europe, the best time for spraying winter wheat was from the end of tillering up to the 1st and

2nd node stage of the crop (Feekes scale 4-6). With spring wheat, application would be slightly earlier, ie between mid tillering up to the early shooting stage of the crop (Feekes scale 3 to 6). Current recommendations in Britain are to apply between crop growth stage 4 (fully tillered) and crop growth stage 7 (second node visible) (MAFF STL 1975). Reports of damage to wheat have been noted, usually where the dose has been excessive (Maynadier *et al* 1973, Loubaresse *et al* 1971, de Gournay *et al* 1973, Devot 1971) or where application has been at the wrong stage of growth (Bowden *et al* 1970). Loubaresse *et al* (1971) and Bowden *et al* (1970) point out however that crop reaction is only a shortening of straw length and was not always necessarily deleterious to the crop. The latter authors found the cultivar Capitole especially sensitive to this effect. Colbert and Appleby (1972a) found severe injury of the cultivar Wade when application was at early jointing. Borges (1971b) found 10 wheat cultivars to be tolerant but cv. Restauracao was markedly sensitive. Stryckers and van Himme (1972), working with different cultivars of spring wheat recorded damage on some varieties notably cv. Fylby and cv. Gaull. Holroyd and May (1970) also reported some adverse effect on spring sown wheat cv. Maris Ranger. Gummeson (1975) stated that, in Swedish trials, the herbicide seemed to be too aggressive on winter wheat.

Barley is generally regarded as being very sensitive to benzoylprop-ethyl (Baldwin and Finch 1974, Leonard *et al* 1973, Bouchet 1973, Cochet *et al* 1971, Jordan *et al* 1972, Taylor *et al* 1974, Friesen 1972, Friesen and Dew 1972, Regina 1971, Stryckers and van Himme 1972).

Cultivated oat has also been found to be highly sensitive (Stryckers and van Himme 1971, 1972, Bouchet 1973, Gummeson 1975, Kampe 1973b).

Certain other crops have shown some degree of tolerance to benzoylprop-ethyl: rape (Friesen 1972, Carriere 1974, Jordan *et al* 1972, Regnault 1973a,b, 1974; Regnault *et al* 1974; Big Farm Management 1974, Bowren 1974), yellow mustard (Gompf 1974), sugar beet (Kampe 1973a,b), beans (Jordan *et al* 1972, Big Farm Management 1975), forage legumes (Friesen 1974), perennial ryegrass (Allen *et al* 1973, 1974, Evans and Muncey 1974, Mead *et al* 1973, 1974, Oswald and Haggar 1974), spring rye (Hunter 1974b) and meadow fescue (Mead *et al* 1973).

Mixtures

A considerable amount of work has been done with mixtures of broad-leaved weed herbicides and benzoylprop-ethyl and it is generally agreed that such mixtures can result in a decrease in the level of wild oat control (Nalewaja 1971a, Colbert and Appleby 1972b, Friesen 1972, Friesen and Dew 1972, Kampe 1973a,b, Jordan *et al* 1972, Bowden 1971e,f). In Britain it is recommended that broad-leaved weed killers should not be applied within 10 days of spraying benzoylprop-ethyl (MAFF STL 1975, British Farmer and Stockbreeder 1975).

Colbert and Appleby (1972b) pointed out that in a glasshouse trial, benzoylprop-ethyl was less effective in reducing growth of wild oats when applied one or two weeks after 2,4-D amine, as were tank mixtures of the two herbicides. The closer the application dates, the less effective was the benzoylprop-ethyl on wild oats. Work by Canadian authors has questioned the seriousness of this loss of herbicidal efficiency. Thus Nalewaja (1971a) found that dicamba, 2,4-D, bromoxynil and SD 16389 all reduced wild oat control when mixed with benzoylprop-ethyl. However the level of wild oat control was still sufficient to compensate for this and resulted in similar wheat yields, except in the case of dicamba, which was injurious to the crop. Friesen (1972) and Friesen and Dew (1972) reported that mixtures with MCPA and MCPA/bromoxynil were physically compatible, and that although efficiency was reduced, this was not serious, as was the case of mixtures including 2,4-D amine or dicamba. Bowden (1971e,f) reported that MCPA ester, 2,4-D amine and 2,4-D ester were physically compatible with the two emulsifiable concentrate formulations of benzoylprop-ethyl (FX 2182 and FX 2034). However, an antagonistic effect was found in wild oat control, especially with the 2,4-D amine and 2,4-ester, but this effect was minimal with MCPA ester. Kampe (1973b) reported that mixtures with MCPA, 2,4-DP, mecoprop and ioxynil slightly changed herbicidal efficiency.

Stobbe and Holm (1972) have shown that mixtures of benzoylprop-ethyl and barban can have a synergistic effect when controlling wild oats. Although a higher dose of each was necessary in the field than in the glasshouse, nevertheless the mixture controlled the weed over a wider range of growth stages than either alone. Behrens *et al* (1973) comparing several treatments, found that a mixture with barban gave the best weed control in early post-emergence applications. Miller and Nalewaja (1973c) applied barban and benzoylprop-ethyl at the 2 and 4-leaf stage of wild oat, as a tank mix or as a split application, with barban applied at the 2 and benzoylprop-ethyl at the 4-leaf stage and found similar control at similar rates. At higher rates there was good control with no wheat injury. A 3-way mixture, also including difenzoquat, gave good wild oat control but injured wheat and barley. Banting (1974), summarising several reports, said that combinations with barban had been found antagonistic when applied at the 2 to 3-leaf stage of wild oat and synergistic at the 3 to 4 and 4 to 5-leaf stages.

Residues

Chapman *et al* (1969) reported that residues were not found in grain samples of wheat, the crop having been treated at the recommended growth stage at 4 kg a.i./ha (limit of detection by gas-liquid chromatography 0.01-0.05 ppm). Jordan *et al* (1972) reported that wheat grain harvested from plots treated at recommended rates did not contain more than 0.5 ppm of benzoylprop-ethyl as the corresponding acid, benzoylprop.

Beynon *et al* (1974b) applied an overall foliar and soil spray application of radio-labelled herbicide to spring and winter wheat, indoors and out. Residues were greatest in straw and particularly low in grain, being undetectable in the latter in crops grown outdoors (limit of detection 0.01 mg/kg). In other work (Beynon *et al* 1974c), where a dose of 1 kg/ha was applied to the soil, lower residues were found in wheat in the year of application than in previous studies with the overall foliar and soil application. Soil residues did persist into the following year, however, when residues in potatoes and wheat grown in these soils were generally below the limit of determination (0.005 mg/kg) or occasionally just above this limit (0.006 mg/kg). It was claimed that residues in rotational crops from soils treated in the previous year are unlikely to reach the limits of normal analytical determination.

Jordan *et al* (1972), studying soil residues, found that the level of herbicide and the corresponding acid fell by 50% in 5 to 10 weeks while, at the beginning of the following season they had fallen to near or below the limit of detection (0.01 ppm). These authors also said that there was no leaching from the top 100 mm of soil.

Beynon *et al* (1974b) also found no evidence of leaching below 15 cm and where soil residues were detected these were mainly in the 0 to 7.5 cm layer. Beynon *et al* (1974d) applied radio-labelled herbicide to four soils under laboratory conditions and found that persistence increased with increasing organic matter. The time for depletion of half of the applied compound varied from 1 week in sandy loam and clay loam soils to 12 weeks on peat soil. They found that the major degradation product at up to 4 months after treatment was the corresponding acid, benzoylprop. On further storage, this bound firmly to the soil before undergoing a slow debenzoylation to a number of products including N-3,4-dichlorophenylalanine, benzoic acid and 3,4-dichloroaniline (DCA), the latter being mainly complexed with humic acids and other polar products, which, it is claimed, were probably degradation products of DCA. No 3,3′,4,4′-tetrachloroazobenzene was detected in any of the soils at limits of detectability ranging from 0.01-0.001 ppm.

Control of other Avena *species*

Benzoylprop-ethyl has been shown to control other *Avena* species usually as effectively as *Avena fatua*. Bowden *et al* (1970), in his report on 80 field trials carried out in the United Kingdom, France and Canada, claimed that *A. fatua* and *A. ludoviciana* were controlled. Both of these species have proved sensitive in several trials in France and England (Regnault 1973a, Regnault *et al* 1974, Loubaresse *et al*, Breslin 1974). In Italy, Catizone reported good control of artificially seeded *A. ludoviciana* Durieu. In three trials in Portugal in 1971 (Borges 1971a), 85 to 90% reduction of *A. sterilis* was found. Vincente and Jordan (1971) found that *Avena loca* was controlled in Spain. Jeffcoat and Sampson (1973) reported control of *A. fatua, A. ludoviciana, A. sterilis* and *A. barbata.*

Stryckers and van Himme (1971, 1972) found that *A. strigosa* and *A. sterilis* were more resistant than *A. fatua* however, but all biotypes of the latter were controlled.

These authors also report the high susceptibility of certain oat cultivars while Mead *et al* (1974) also controlled cultivated oat (*Avena sativa* L.) satisfactorily in perennial and Italian ryegrass.

Jorgenson *et al* (1974) examined the effect of benzoylprop-ethyl on wild oat plants raised from seeds which had been collected and categorised according to their colour (grey, brown, light brown and white). Plants raised from light brown seeds were the most sensitive, followed by white, brown and grey.

Control of Agropyron repens

Some activity against this species has been reported (de Gournay *et al* 1973). In their experiments, a dose of 0.8 kg/ha reduced the plant population by 60%. Much better control was found at rates 2 or 3 times that needed for *Avena fatua* and although 4 times as much caused some thinning of wheat, couch grass was severely reduced and there were positive indications of lesser development of the rhizomes. Darrigand and Pondicq (1973) also reported effects on couch grass at doses of 2, 4 and 8 kg a.i./ha in maize. Recently, Haddock *et al* (1974a) reported a 50% growth depression of *A. repens* after spraying at the 1½ to 2-leaf stage in a glasshouse test with a dose of 0.65 kg/ha. In one field test in winter wheat, doses of 1, 2 and 4 kg/ha caused a reduction of flower heads of *A. repens* of 35, 49 and 51% and this was reflected in increased yields of winter wheat.

Chancellor and Parker (1972) found that benzoylprop-ethyl was one of 29 plant growth regulators which delayed to some extent the onset of a new dominance system in decapitated 7-node rhizome fragments grown in vitro.

FLAMPROP-ISOPROPYL

Mode of action

Growth and radioactive tracer studies by Jeffcoat and Harries (1975) have shown the basis of activity and selectivity to be similar to that of benzoylprop-ethyl. Activity depends on the high rate of degradation in oat to the biologically active acid, flamprop, which stunts growth by inhibiting cell elongation in leaves and stems. The rate of degradation is much slower in barley, and this in part explains its tolerance and hence selectivity. The acid is very mobile in the phloem of oats (five times as rapid as benzoylprop-ethyl) through which it can reach the elongating cells in the stem. Selectivity also depends on the subsequent detoxification of the acid to inactive conjugates. Although the relative rate of de-esterification of flamprop-isopropyl was lower than for benzoylprop-ethyl, similar quantities of the parent material gave comparable effects on oat. This was the result of flamprop being twice as active as benzoylprop. As with benzoylprop-ethyl, crop competition is essential for effectiveness. More activity is seen during the time when the crop is offering most competition. In fact the effect of flamprop-isopropyl on oats alone is only transient and can be over-come by supplying nutrients. Plants have been shown to be more susceptible if the nutrient or water supply is limited. Preliminary metabolic studies on flamprop-isopropyl with C^{14}-labelled nutrient were also described by Mouillac *et al* (1973).

Symptoms

As with the mode of action, symptoms due to flamprop-isopropyl are almost identical to those caused by benzoylprop-ethyl, described previously. Treated plants of *Avena* species exhibit a severe inhibition of leaves. Susceptible barley varieties can also exhibit some shortening of their straw (Jones and Mackenzie 1974, Mouillac *et al* 1973, Warley *et al* 1974).

Dose

The results of a considerable number of field tests in Europe and Canada have indicated that the optimum dose for wild oat control is 1.0 kg/ha (Bowler 1974, Bowler and Sampson 1974, Warley *et al* 1974, Jones and Mackenzie 1974, Mouillac *et al* 1973, Guillemenet 1973, Int. Pest Control 1974, PANS 1974). This dose gave 90-98% control if applied at the correct growth stage of the crop in 200 field trials in 9 European countries (Bowler 1974, Bowler and Sampson 1974), although 0.8 kg/ha was also adequate. From these tests, Bowler (1974) was able to construct a graph relating the percentage reduction in wild oat panicles to various doses and crop growth stages. Later Warley *et al* (1974) said that 1.0 kg a.i./ha gave good wild oat control in 256 field trials in 10 West European countries. The mean reduction in the total number of wild oat panicles was 80% in Spain, Portugal and Greece, 87% in mid Europe (Austria and South Germany) and 83% in the United Kingdom, Benelux, North Germany, Northern France and Denmark. The best result in the United Kingdom was an 89% reduction. These authors also compared total panicle counts with spikelet counts of wild oats from trials in the United Kingdom and Spain. In the United Kingdom, a 75% reduction in total panicle counts corresponded with a 97% reduction in spikelets. Jones and Mackenzie (1974) tested at 5 doses between 0.6 to 2.0 kg/ha in 4 replicated field trials in 4 different counties in Scotland and found optimum control of *A. fatua* at 1.0 kg a.i./ha with up to 98% eradication of visible panicles. Guillemenet (1973) in 10 tests in 1972 and 20 in 1973 in cereal growing areas of France used doses from 0.4 to 3.0 kg/ha. A dose of 1.0 kg/ha was needed for control when applied from the end of tillering to the first node stage of the crop, but 0.6 kg/ha was satisfactory slightly earlier. Baldwin and Finch (1974) reported over 70% control of *A. fatua* at 1.0 kg/ha in the majority of 18 trials in spring barley between 1973 and 1974. However, this was an average figure for the results of both years at several sites and with early and late applications in 1974. The dry weight of *A. fatua* panicles was reduced by 86% in 1973 (mean of all 7 sites) while with early and late applications they were reduced by 43 and 80% respectively. Mead *et al* (1974) reported moderate control of *Avena fatua* at 1.0 kg/ha (69 and 63% reductions in panicle dry weights). Skorda (1974) also showed that there was considerable reduction in the return of viable *Avena* spp. seed to the soil.

In some trials in North America higher doses have been used and have given varied results. Miller and Nalewaja (1973b,d) found that a dose of 2.24 kg/ha was necessary for effective wild oat control while other workers found this dose to be unsatisfactory (Lee and Alley 1974, Lee *et al* 1974).

Application factors and formulation

Spraying of flamprop-isopropyl can be carried out in a wide volume range from 225 to 450 l/ha of water at a minimum pressure of 2.81 bars (MAFF

STL 1975) using higher volumes in dense crop or weed situations. Generally, where spraying has been done within this volume range, good control of wild oats and/or crop safety was found (Baldwin and Finch 1974, Jones and Mackenzie 1974). In those cases where control of wild oats was less effective, the volume rate was either beyond or just at the extremities of the volume range recommended above. Thus Mead *et al* (1974) used a low volume at a pressure of 3.17 bars, Miller and Nalewaja (1973b,d) treated in 159 l/ha at 2.47 bars while Lee and Alley (1974) and Lee *et al* (1974) used 440 l/ha. However Behrens *et al* (1973) using exactly the same volume as Miller and Nalewaja (1973b,d) (159 l/ha) obtained excellent wild oat control, while successful application has been reported, using spray volumes of 25 to 50 l/ha (Shell Chemicals, technical information 1974).

All the work to date has been carried out with an emulsifiable concentrate formulation containing 200 g a.i./l.

Environmental factors

Flamprop-isopropyl has been tested in several European countries and in North America; with few exceptions it has performed well under these varying climatic conditions (Behrens *et al* 1973, Bowler and Sampson 1974, Guillemet 1973, Haddock *et al* 1974, Jones and Mackenzie 1974, Mouillac *et al* 1973, Warley *et al* 1974). However Zimdahl and Foster (1974) found an effect of location in their experiments in America, flamprop-isopropyl being totally unsatisfactory on a clay loam but superior even to tri-allate on a sandy loam. The work of Jeffcoat and Harries (1975) (in press) would suggest that nutrient status and water supply will be important factors but there is little evidence for this in the literature as yet. These authors also demonstrated the effect of shoot and root competition of the crop on stem elongation of oat plants sprayed with the herbicide, and underlined the necessity of competition for good control.

Jones and Mackenzie (1974) reported that heavy rain fell within 30 minutes at one site in their trials in Scotland, causing some chemical wash off which was reflected in poorer weed control, but only at the two lower doses of 0.6 and 0.8 kg/ha, doses of 1.0 kg/ha and above still giving excellent effects.

Growth stage of wild oats

As with benzoylprop-ethyl, there is some evidence that wild oat control is better closer to tillering than at earlier or later stages, although there are some exceptions to this. Behrens *et al* (1973) found better control of wild oat when treated at the 2 to 6-leaf rather than at the 1 to 3-leaf stages. Miller and Nalewaja (1973b,d) treated wild oats which had either 2 to 2½ or 4 to 4½ leaves and found better control at the latter stage. Baldwin and Finch (1974) obtained twice as effective control at late rather than early growth stages. Jones and Mackenzie (1974) controlled *A. fatua* more effectively with later applications.

Exceptions were found to this however. Mouillac *et al* (1973) found equal sensitivity of *A. fatua* and *A. ludoviciana* whatever their stage of development.

No difference in vigour reductions after spraying at the 2 or the 4 to 5-leaf stage were found in trials in Wyoming, USA (Lee and Alley 1974, Lee *et al* 1974), while Mead *et al* (1974) found little difference in reduction of panicle dry weights with early and late applications.

Very late applications have been reported to be less effective on wild oat (Bowler 1974, Bowler and Sampson 1974). However, Zimdahl and Foster (1974) found better control at the 6 to 7 rather than the 3 to 5-leaf stage, but at only one of their trial sites.

A feature of flamprop-isopropyl, as with benzoylprop-ethyl, is its better performance, at least in terms of crop yield, in situations where there is a high infestation of wild oats (Bowler and Sampson 1974, Warley *et al* 1974, Jones and Mackenzie 1974, International Pest Control 1974, PANS 1974, Guillemenet 1973, Mouillac *et al* 1973). Bowler and Sampson (1974) and Warley *et al* (1974) say that the yield increase in barley is proportional to the level of wild oat infestation. Increases in barley yields of up to 70% were achieved where the infestation level was very high (300 panicles/m^2) and averaged 10 to 30% in 50 large scale trials at lower infestation levels ranging from 40 to 200 panicles/m^2 (International Pest Control 1974, PANS 1974). Guillemet (1973) and Mouillac *et al* (1973) have suggested that a threshold level of 50 panicles/m^2 could be reckoned to give a 30% yield increase.

Crop tolerance

Provided that spraying is carried out as recommended, good tolerance can be found in: barley (Anderson 1974, Banting 1974, Bowler 1974, Bowler and Sampson 1974, Guillemenet 1973, Haddock *et al* 1974b, Lee and Alley 1974, Lee *et al* 1974, Mouillac *et al* 1973, Warley *et al* 1974, Zimdahl and Foster 1974); spring barley (Baldwin and Finch 1973, 1974, Jones and Mackenzie 1974, International Pest Control 1974); wheat and barley (Behrens *et al* 1973, Bouchet 1973, Leonard *et al* 1973, Miller and Nalewaja 1973, Leonard *et al* 1973, Miller and Nalewaja 1973b,d, Skorda 1974).

Forty of the newer barley varieties have been sprayed in trials in Europe at twice the recommended dose and only the French cultivar, Bettina, was slightly sensitive (Bowler 1974, Bowler and Sampson 1974). Sensitivity of this cultivar has been reported by other authors (Guillemenet 1973, Mouillac *et al* 1973, Leonard *et al* 1973), while Leonard *et al* (1973) also found some sensitivity with the cultivar Mazurka.

There is general agreement that the best time to spray barley is from the end of tillering to early shooting (Feekes scale G-I) just before formation of the second node (Bowler 1974, Bowler and Sampson 1974, Haddock *et al* 1974b, International Pest Control 1974, Jones and Mackenzie 1974, Guillemenet 1973, Mouillac *et al* 1973, Warley *et al* 1974).

Although most of the work has been done with barley, some authors have found that wheat also shows some tolerance. Thus Behrens *et al* (1973) found only slight effects on Era wheat while Miller and Nalewaja (1973b,d) detected little or no injury in Waldron wheat. In French trials, soft and hard wheats (Bouchet 1973) and hard wheats and soft spring wheats (Leonard *et al* 1973) were tolerant. Skorda (1974) in trials in Greece found wheat to be tolerant when sprayed at mid-tillering.

Cultivated oat *(A. sativa)* shows a similar degree of sensitivity to the wild oat, such that there is no possibility of its use in this crop (Bouchet 1973, Jeffcoat and Harries 1975).

Undersown crops are safe from herbicidal activity (Cutting 1974, Shell Chemicals, technical information 1975). Friesen (1974) found some formative effects on trefoil, alfalfa and sainfoin but dry forage yields were not depressed.

Mead *et al* (1974) found no visible effects on various varieties of perennial and Italian ryegrass. Oswald and Haggar (1974) found it to be safe on perennial and Italian ryegrasses and cocksfoot although timothy was checked at a high dose of 3.0 kg/ha.

Bowren (1974) has summarised the work of several authors in rape seed, where several cases of crop damage were recorded.

Mixtures

Very little has been published on flamprop-isopropyl in mixture with other compounds. However, as with benzoylprop-ethyl, it is recommended that other sprays should not be applied within 10 days after spraying (MAFF STL 1975, British Farmer and Stockbreeder 1975), neither should it be tank-mixed with any of the commonly used broad-leaved weed killers. It can be tank-mixed with commonly used cereal fungicides however (Shell Chemicals technical information 1974).

Residues

Analysis of barley grain from crops treated as recommended has shown that total residues of flamprop-isopropyl and its breakdown products are rarely above detectable limits. Also it has no effect on the malting characteristics of barley grown for brewing (Shell Chemicals technical information 1974).

Mouillac *et al* (1973) reported that residues in seeds from crops treated as recommended in tests in 1972 and 1973 rarely exceeded the detection limit.

Control of other Avena *species*

Bowler (1974) and Bowler and Sampson (1974) claimed that all species of wild oat were controlled as a result of 200 field trials in eight European countries and Canada. Guillemenet (1973) reported *A. ludoviciana* to be sensitive, while Mouillac *et al* (1973) found *A. fatua* and *A. ludoviciana* to be equally sensitive.

FLAMPROP-METHYL

Mode of action

Haddock *et al* (1974a) reported that flamprop-methyl works in a similar manner to benzoylprop-ethyl and flamprop-isopropyl, by arresting growth through the prevention of cell elongation (Jeffcoat and Harries 1973, 1975). They state that it is more active than the other two but its mode of action and translocation are being studied separately.

Symptoms

Symptoms are almost identical to those caused by the other two herbicides with dwarfing and necrosis of treated wild oat plants (Jordan *et al* 1974, Miller and Nalewaja 1973d). Slight stem shortening and/or a small amount of leaf tip necrosis has been observed on wheat (Jordan *et al* 1974).

Dose

Control of wild oat can be achieved with a lower dose of flamprop-methyl than is necessary with the two analogues, benzoylprop-ethyl and flamprop-isopropyl. Haddock *et al* (1974a) obtained good control at 0.45-0.60 kg/ha. All three analogues were compared for their activity on *Avena fatua* in the glasshouse and it was found that flamprop-methyl, flamprop-isopropyl and benzoylprop-ethyl caused 50% growth reduction with 0.20, 0.44 and 0.58 kg/ha, respectively. They also sprayed 150 oat plants with 0.25 and 0.5 kg/ha and the majority of plants were killed (21 and 15 plants survived, respectively). The mean number of seeds per surviving plant at these doses was 4.9 and 4.5, compared with 47.2 for the control, while the total seed production relative to control was 1.5 and 1.0%. In three field trials in 1973, doses between 0.2 and 0.8 kg/ha gave a reduction in panicles of 61 to 98% and in spikelets of 65 to 100%. In 23 field trials in 6 European countries in 1973, a reduction of total wild oat panicles of 74, 85, 91 and 95% was recorded at 0.2, 0.4, 0.6 and 0.8 kg/ha, respectively.

In North American field trials good wild oat control has been recorded with 0.28 and 0.56 kg/ha (Miller and Nalewaja 1973b,d, 1974b,c,d) while Strand and Smith (1974) found the number of wild oat shoots per square yard to be reduced by 96 and 98% respectively at these same doses. Miller and Nalewaja (1973b,d) also found flamprop-methyl to be more active than its analogues.

Application factors and formulation

From the limited amount of work done with this herbicide it is too early to say if application factors are of much importance. Miller and Nalewaja (1973a,b, 1974b,c) achieved good wild oat control in volumes of 80 l/ha or 160 l/ha at a pressure of 2.47 bars, as did Behrens *et al* (1973) and Strand and Smith (1974) at the latter volume. Behrens and co-workers also obtained good results using volumes of 103 or 206 l/ha. All the work to date has been carried out with the herbicide formulated as an emulsifiable concentrate containing 150 gm a.i./l.

Environmental factors

There has been no detailed study as yet on the influence of environmental factors on performance. However, similar doses have given suitable wild oat control in Europe and North America (Anderson 1974, Arnold and O'Neal 1973, Behrens and Elakkad 1974b, Behrens *et al* 1973, 1974, Haddock *et al* 1974, Miller and Nalewaja 1973b,d, 1974a,b,d,e, Strand and Smith 1974).

Growth stage of wild oats

Flamprop-methyl can control wild oats at early and late stages of growth but there is some evidence that more activity occurs as the plants approach tillering. Thus Arnold and O'Neal (1973) got better control at the 4 to 5 rather than the 2-leaf stage. Behrens *et al* (1973) achieved excellent control but with treatment at the 2 to 6-leaf stage being better than at the 1 to 3-leaf stage. In their later field trials, plants were sprayed when they had either 3 to 4 or 4 to 6 leaves, and they concluded that more activity could be expected at the 4-leaf stage (Behrens *et al* 1974). Miller and Nalewaja (1973b,c,d) reported that control was better at the 4 to 4½ rather than the 2 to 2½-leaf stage. In their 1974 trials (Miller and Nalewaja 1974d), wild oats were sprayed at the 2, 3½ and 5-leaf stages and they found that 2 to 3 times as much chemical was necessary for control at the early as opposed to the late growth stage. However Strand and Smith (1974) achieved good control when plants were treated early (2 to 3 leaves).

Crop tolerance

Wild oat control has been investigated in: barley and wheat (Behrens *et al* 1973, 1974, Miller and Nalewaja 1973b,d, 1975, Banting 1974); barley (Anderson 1974, Strand and Smith 1974); wheat (Arnold and O'Neal 1973, Haddock *et al* 1974, Miller and Nalewaja 1974a,b,d).

From the literature reviewed, there appears to be good tolerance in wheat and barley, but more cases of damage have been reported in barley than in wheat.

Behrens and co-workers found only slight effects on wheat (cv. Era) in 1973 but barley (cv. Cree) was less tolerant than this wheat cultivar in 1974 tests (Behrens *et al* 1973, 1974).

Banting (1974) summarised several reports in which barley was tested at doses ranging from 0.42-1.68 kg/ha and wheat from 0.42-2.52 kg/ha. Wheat was generally very tolerant. Anderson, 1974, obtained a lower yield of barley after treatment at 1.12 kg/ha although the difference was not significant, possibly because mainly broad-leaved weeds predominated, while wild oats were absent. Strand and Smith (1974) injured barley and obtained lower yields with doses of 0.28 and 0.56 kg/ha. Miller and Nalewaja (1973b,d) found some injury on barley (cv. Paragon) but little or none on wheat (cv. Waldron).

In 1974 they reported no injury or stand reduction on wheat (cvs. Ellar, Waldron and Chris) with doses as high as 1.12 kg/ha in tests at three different sites, while cv. Waldron tolerated 0.56 kg/ha in other tests (Miller and Nalewaja, 1974b,d). Later, however, these authors again found barley cultivars more susceptible than wheat but pointed out that large differences in susceptibility in cultivars within a crop existed (Miller and Nalewaja, 1975). Haddock *et al* (1974), as a result of extensive field trials in Europe during 1973 and 1974, claimed that wheat crops showed good selectivity at doses four times that necessary for wild oat control, although some minor effects were seen in a few instances. They also suggested that the optimum time of application appeared to be from the end of tillering up to early shooting of the crop.

Investigating possible use in flax, Behrens and Elakkad (1974b) reported that flamprop-methyl injured the crop with some kill of plants (cvs. Lindt and 2776) after spraying with 0.56 or 1.12 kg/ha when the crop was 6 to 8″ high. Miller and Nalewaja (1974e) found severe retardation of growth with doses of 0.56 and 0.84 kg/ha. Dexter and Nalewaja (1974) found no damage on flax, sugar beet or corn with 1.12 kg/ha.

Crop tolerance in oil seed crops has been investigated by Bowren (1974), who commented in his summary of North American trials that several cases of crop damage had been reported. Gompf (1974) found severe crop damage in yellow mustard.

Darwent (1974) reports good wild oat control in several forage grasses, but several cases of crop damage and occasionally yield loss also occurred.

Mixtures

Even from the limited work done on this subject, it appears that there are some reservations about mixing with herbicides which control broad-leaved weeds. Miller and Nalewaja (1974a) found bentazon to be the only one which did not reduce wild oat control, the others examined being 2,4-D, MCPA, bromoxynil, Dowco 290, metribuzin and dicamba, the latter causing a 50% reduction in control. In the same work, a tank-mix with cyanazine and metribuzin injured wheat although the stand was not affected. In other tests, 2,4-D or cyanazine reduced wild oat control, and although this did not occur when bentazon or bifenox were used, the mixture with bifenox increased crop injury (Miller and Nalewaja 1973b,d). A three-way mixture with bentazon and dalapon reduced control by 27% (Miller and Nalewaja 1974e). Behrens *et al* (1974) found that bromoxynil reduced wild oat control. Miller and Nalewaja (1974b) investigated the possible use of mixtures with 2,4-D (dimethylamine salt) either as a tank mix or as split applications. They applied the 2,4-D over a 16 day period for 8 days prior to and after spraying flamprop-methyl. They found that wild oat control was reduced when 2,4-D was added in the tank or applied 2 days before application of flamprop-methyl. If the 2,4-D was applied 4, 6 or 8 days prior to or 2, 4, 6 or 8 days after, there was little effect on the level of wild oat control. No crop injury occurred with any of the treatments.

Compatibility with barban has also been reported by these authors (Miller and Nalewaja 1974d). If 0.14 or 0.28 kg/ha of barban was added to 0.25 kg/ha of flamprop-methyl, slightly better wild oat control was obtained than with the latter alone at the same dose.

Control of other weeds

Agropyron repens. Haddock *et al* (1974a) have reported that when 2 node sections of *A. repens* were raised in the glasshouse and sprayed at the $1\frac{1}{2}$ to 2-leaf stage, flamprop-methyl caused a 50% growth depression at a dose of 0.42 kg/ha (compared with 0.65 and 5.26 kg/ha for benzoylprop-ethyl and flamprop-isopropyl respectively). In a field test, *A. repens* was considerably suppressed and this was reflected in increased yield of wheat. Doses of 1, 2 and 4 kg/ha reduced the flower heads of *A. repens* by 41, 50 and 75% respectively (compared with reductions of 35, 49 and 51% for benzoylprop-ethyl and 17, 5 and 28% for flamprop-isopropyl at the same doses).

Alopecurus myosuroides. Activity against *Alopecurus myosuroides* has also been reported (Haddock *et al* 1974a). A glasshouse test showed it to be three times more active than benzoylprop-ethyl (50% growth depression by 0.6 to 0.7 kg/ha compared with 1.6 to 1.7 kg/ha for benzoylprop-ethyl). In some field tests in 1973, earlier applications were observed to give better control. Thus 1.0 kg/ha gave 68% control in winter wheat cv. Nimrod sprayed at stage F/G, 67% in cv. Cappelle sprayed at stage I/J and 26% in cv. Ranger sprayed at stage J.

Residue risks

No results are available as yet on residue studies.

NITROPHENYL ETHERS

NITROFEN

Mode of action

The activity of nitrofen is probably due to its interference with ATP production through inhibition of the Hill reaction and mitochondrial electron transport. Matsunaka (1969) suggested that nitrofen is more active in the light, and thus may be acting by inhibiting photosynthesis, a view supported by Kratky and Warren (1971). Moreland *et al* (1970) were not able to support this, while Pereira *et al* (1971) claimed that nitrofen was less active in the light than in the dark.

Symptoms

Nitrofen applied pre-emergence controls susceptible weeds by contact with the young shoot during emergence, but there is little or no evidence of phytotoxic symptoms on wild oats when sprayed at the 1 or $2\frac{1}{2}$-leaf stage.

Dose

Doses of between 0.56 kg/ha and 4.48 kg/ha have been used in trials for the control of wild oats, however the most effective rates of control have been achieved with doses of between 2.0 and 4.0 kg/ha. Bouchet (1969b), Bouchet and Faivre-Dupaigre (1968) achieved 60-90% control in winter wheat crops with these doses, but activity varied according to time of planting, with earlier planting and application giving better results in terms of control and persistence of effect. Other work with nitrofen in spring cereals has given 78 to 80% control in spring wheat, and 60 to 71% control in spring barley at 2.24 kg/ha (Bartlett *et al* 1968).

Environmental factors

The degree of activity and persistence of nitrofen seems to vary according to soil type and pH, extent of seed bed preparation, seed bed moisture, level of organic matter, amount of rainfall after application and temperature. Rognon and Poignant (1969) stated that selectivity of nitrofen was reduced when the top layer of soil was excessively crumbly or if the ground had not been well prepared, and that the chemical had restricted use on sandy or chalky soils. Lhoste and Vernie (1967) in trials with nitrofen on winter wheat showed that any injury to wheat following treatment, applied pre-sowing, was not serious and was confined to crops on soils liable to surface compaction following prolonged heavy rain, and on calcareous clay soils with pH between 7.8 and 8.4. Additional evidence from Rognon (1966) supported this, although Perrot and DeSarjas (1967) claimed that good consistent results were found year after year in most soil types and under diverse climatic conditions. Crop injury might however be expected to arise from soil puddled at the time of emergence, and thorough preparation and levelling of a seed bed would be prudent.

Persistence of nitrofen would seem to be related to dose and temperature, with 2.0 to 4.0 kg/ha in the spring persisting for only 30 days, whereas 2.0 to 3.0 kg/ha applied in the autumn was still giving control five months later (Bouchet and Faivre-Dupaigre 1968).

Growth stage of wild oats

The majority of work carried out using nitrofen on wild oats has been either pre-emergence or at the 1-leaf post-emergence stage. One experiment (Holroyd and Bailey 1970) gave good control of wild oats with doses of nitrofen above 2.24 kg/ha with little evidence of crop damage where the wild oats were 0 to $2\frac{1}{2}$-leaf stage and the crop, winter wheat, was at the 3 to $3\frac{1}{2}$-leaf stage.

Crop tolerance

Crop tolerance of nitrofen is greatest when the chemical is applied pre-emergence and when certain agronomic conditions are satisfied. Rognon (1966) showed that at 3.0 kg/ha pre-emergence, wheat tolerated nitrofen but, at 4.0 kg/ha, thinning of the crop occurred in one third of the trials, mainly those on capping silty soils and on very cloddy soils. Yields were only significantly decreased by 6.0 kg/ha, and 3.0 and 4.0 kg/ha did not impair yields. Bouchet and Faivre-Dupaigre (1968) stated that wheat well tolerated 3.0 kg/ha of nitrofen applied at the time of sowing but 4.0 kg/ha caused a visual depression, estimated at 30% in May, and this was still visible at time of harvest in more than half the trials. Signs of phytotoxicity at crop emergence were recorded by Perrot and DeSarjas (1967) with 2.0 kg/ha producing white and brown necrotic spotting on the first two leaves, sometimes accompanied by a yellowing of the plant. These symptoms disappeared rapidly when other leaves formed. At 4.0 kg/ha the same symptoms were more marked.

Lhoste and Vernie (1967) claimed that the nature of the soil and quality of the seed bed affected the activity of nitrofen but there might be transient crop damage if heavy rain fell on a finely worked soil 72 hours after application. Bartlett *et al* (1968) observed crop damage in spring barley at the 3-leaf stage after heavy rain fell on soil, already at field capacity, and where treatment had been applied 12 days after drilling.

Mixtures

Most mixtures with nitrofen are concerned with improving the performance against broad-leaved species. Mixtures of nitrofen and linuron and nitrofen and neburon have given contradictory results (Jarry *et al* 1971), but mixtures of nitrofen and linuron gave better control than did nitrofen alone (Lhoste *et al* 1969) although damage to the crop, soft wheat, was attributed to the nitrofen. Bouchet (1969a) showed that mixtures of nitrofen and linuron, and nitrofen and neburon, could be selective in soft winter wheat varieties, although leaf scorch was observed. The mixtures, primarily for use for the control of grasses in cereals, were neburon (33%) + nitrofen (16.7%) at 3.0 and 6.0 kg/ha and linuron (6.25%) + nitrofen (17%) at 1.94 and 3.88 kg/ha. The addition of surfactants or aqueous nitrogen did not enhance effectiveness and sometimes reduced selectivity to cereals.

Bouchet *et al* (1969) conducted trials throughout France using mixtures of nitrofen (25%) + neburon (33%) at rates of between 3.5 and 5.25 kg/ha applied pre-emergence. The best results using the mixture were achieved when *A. ludoviciana* was present, and when the lower rate of nitrofen and the higher rate of neburon were used. A wettable powder formulation of nitrofen and neburon was used in trials for pre-emergence weed control in crops of winter wheat, the best results being obtained from a rate of 1 + 2 kg/ha applied 3-11 days after sowing (Rognon and Poignant 1969).

Results using mixtures with tri-allate for the control of *A. fatua* in wheat suggested this mixture merited further evaluation (Yana 1969).

Residues

Under normal conditions there is very little movement of nitrofen down through the soil and persistence seems to be related to dose and temperature. In the autumn, doses of between 2.0 and 3.0 kg/ha were giving between 80 to 90% control, and applications in October in Southern France were still killing wild oats emerging in February, whereas in Northern France nitrofen was not sufficiently active to kill wild oats emerging in April after application in March and 4 kg/ha was only giving 80% control (Bouchet and Faivre-Dupaigre 1968).

CARBAMATES

PROPHAM

Mode of action

Propham, a phenyl carbamate herbicide, has been shown to inhibit photosynthesis and to affect mitosis (Corbett 1974). *In vitro* studies carried out by Canvin and Friesen (1959) demonstrated that it could totally inhibit cell division. Practically, it is used to control germinating weeds and is relatively ineffective on larger plants.

Wild oat control

The activity of propham against wild oats is rather variable but in general effective control has been achieved with doses of 3.4-4.5 kg/ha (Nelson 1954, Friesen 1955a, Dunham 1957, Murant 1958a,b, Proctor and Armsby 1958, Sexsmith 1960a,b). Many of the trials with propham have included higher doses which increased the reliability of control but often led to crop damage (Smirnov and Orishenko 1956, Butler 1958, Sexsmith 1960c). Several factors have been shown to affect its activity, including soil type (Murant 1958b), weather conditions (Nelson 1954), and the efficiency of incorporation. As propham is a volatile herbicide, poor incorporation results in the rapid loss of the chemical and thus poor activity. It has been reported that propham is more active on light soils than on heavy soils (Fryer and Makepeace 1972) and that it is inactivated by fen soils (Murant 1958b).

Several experiments carried out in North America have achieved good wild oat control with propham applied in the autumn. Andersen and Helgeson (1955) obtained excellent control with an October application of 13.4 kg/ha and the results of Canadian trials (Canada 1956) showed that 11.2 and 16.8 kg/ha applied in late autumn reduced wild oat populations by approximately 50 and 90% respectively.

Crop tolerance

Peas. Many of the trials investigating the control of wild oats with propham have been caried out in pea crops (Spencer 1954, Evans 1955, 1957, Friesen 1955a, Butler 1958, Proctor and Armsby 1958, Sexsmith 1960d). The susceptibility of the crop depends on the dose, soil type and the time from application to the drilling of the peas. Spencer (1954) demonstrated that peas on fen soils could tolerate 22.4 kg/ha but on clay soils were damaged by 4.5 kg/ha. The longer the period between application and sowing the lower the danger of crop damage, but if the time is too long the effectiveness of the propham against the wild oats will be decreased (Proctor and Armsby 1958). Butler (1958) showed that 9.0 kg/ha applied 15 days pre-sowing damaged the pea crop, whilst application 27 days pre-sowing caused little damage. Proctor and Armsby (1958) suggested from the results of a number of trials that application of 6.7 kg/ha three days pre-drilling might be unsafe and lead to crop damage. Hence for optimum wild oat control with the least risk of crop damage propham should be applied 1-2 weeks pre-sowing peas.

Sugar beet. This crop is somewhat less susceptible to propham than the latter (Nelson 1954, Friesen 1955a, Butler 1958). Columbia Southern Chemicals (1960) demonstrated that 3.3-4.5 kg/ha applied two days pre-drilling did not damage sugar beet. Butler (1958) showed that 9.0 kg/ha applied 11 days pre-drilling damaged the crop but that 4.5 kg/ha was not damaging. However, the higher dose applied 20 days pre-drilling did not cause a significant amount of damage.

Other crops. Potatoes and flax have been reported to be tolerant to pre-planting treatments of 6.7 kg/ha (Dunham 1954, Sexsmith 1961c). Cereals are less tolerant. Dunham (1954) and Wiese and Dunham (1954) showed that 2.8 kg/ha applied pre-emergence was damaging.

CHLORPROPHAM

Mode of action

The mode of action of chlorpropham, a phenyl carbamate herbicide, is thought to be similar to that of propham, inhibiting photosynthesis and blocking cell division. It is active mainly against germinating seedlings and should be incorporated to ensure good activity.

Wild oat control

Pre-emergence treatments of between 4.5 and 6.7 kg/ha resulted in good wild oat control in a number of trials (Fox 1954, Evans 1955, Freeman 1955, Friesen 1955a, Shebeski 1955, Sexsmith 1960b). In some cases 2.2 kg/ha gave an acceptable degree of control whilst in others it was found to be unsatisfactory (Dunham 1954, Wiese and Dunham 1954, Evans 1955, Butler 1958). A number of experiments carried out by Wiese and Dunham (1954) showed that whilst good control of wild oats was achieved with 2.8 kg/ha on a light loamy soil, 5.6 or 9.0 kg/ha were required to achieve a similar degree of control on heavier clay loam soils. In the experiments reported by Evans (1955, personal communication), 2.2, 4.5 and 6.7 kg/ha resulted in 60, 78 and 84% control, respectively.

In one experiment 5.6 to 22.4 kg/ha applied post crop emergence gave 30 to 100% wild oat control but damaged wheat, barley and oats particularly at the higher rates (Leggett 1954).

Crop tolerance

The results of many of the experiments demonstrated that the damage caused by chlorpropham was dependant on the dose and the period of time between application and drilling. Soil type also affected crop damage and Bachthaler (1961) suggested that the soil water levels might influence activity.

Peas. One experiment showed that the application of both 2.2 and 4.5 kg/ha 15 days pre-drilling appreciably reduced the vigour of the pea crop (Butler 1958). Even after 27 and 42 days the higher rate affected the peas although the lower rate did not damage them significantly (Butler 1958). However, Wiberg (1959) found that 5.6 kg/ha applied 14 days pre-sowing caused only slight damage, and Wiese and Dunham (1954) demonstrated that doses as high as 16.8 kg/ha caused little damage.

Sugar beet. In general, found to be more tolerant to chlorpropham than peas. Evans (1955, personal communication) reported that, although 2.2 kg/ha was tolerated by sugar beet, 4.5 and 6.7 kg/ha damaged the crop. Wiese and Dunham (1954) found only slight damage following treatments of 5.6 kg/ha but serious damage followed application of 11.2 and 22.4 kg/ha. In more detailed studies, Butler (1958) demonstrated that 2.2 kg/ha applied 20 days pre-planting was tolerated by the crop, but that 4.5 kg/ha reduced vigour by more than 7%. Both doses reduced vigour if applied only 11 days pre-planting.

Cereals. Both laboratory and field experiments showed that cereals were more susceptible to chlorpropham than the previous two crops (Dunham 1954, Wiese and Dunham 1954, Aberg and Wiberg 1957). In one trial application of 5.6 kg/ha two days pre-sowing spring wheat resulted in a 90% reduction in the wheat stand (Wiese and Dunham 1954).

BARBAN

Mode of action

Barban like most phenylcarbamates interferes with cell division. Dubrovin (1959), who treated wild oats at the two leaf stage, observed that the shoot apices became swollen and distorted due to the presence of enlarged cells containing numerous groups of chromosomes. These groups had no nuclear membrane or nucleoli.

In physiological studies Chesalin and Timofeeva (1965) found that plants of both wheat and *Avena fatua* treated at the two and three leaf stages with 0.6 kg/ha increased their chlorophyll content very markedly. In wheat however it returned to normal after 20 days. Photosynthesis in the *A. fatua* plants declined progressively from five days after treatment until death although respiration remained very much above normal until shortly before death. In enzyme studies there were marked increases in the activity of both catalase and peroxidase as a result of treatment.

Ladonin (1967) in metabolic studies with etiolated seedlings of wild oats measured marked increases in nucleotide synthesis and suggested that treatment stimulated andenine triphosphatase activity in the tissues. In another paper Ladonin and Svittser (1967) noted marked increases in RNA, protein and, to a lesser extent, nucleotides and suggested that disruption of the synthesis of messenger RNA caused abnormal cell division. In a further paper Ladonin and Beketova (1973) studies the effects of doses of 0.5 and 1.0 kg/ha on green wild oat plants at the 2-leaf stage and noted marked fluctuations in the RNA and DNA contents of the cells. Kobayashi and Ishizuka (1974) in glasshouse studies of effects on seven day old cultivated oats (cv Victoria) and wheat (cv Ushio) found that the incorporation of ^{14}C-methionine and leucine into protein was strongly inhibited in the oats but only slightly in the wheat. In addition, uracil incorporation into RNA was prevented in the oats but not in the wheat. Neither species showed a reduction in respiration or photosynthesis one day after treatment. They concluded that there was marked inhibition of protein and RNA synthesis in susceptible plants. Studies of the adsorption, translocation and metabolism of barban in wild oat and wheat were made by Shimabukuro, Walsh and Haerauf in 1972 who found little translocation away from the treated zones. They concluded that selectivity may depend on the penetration of barban through succeeding layers of coleoptile and leaf sheaths surrounding the apical meristems of grasses.

It seems likely that older wild oat plants are more resistant due to the increased number of meristematic areas from which recovery can occur, and the greater protection of these areas by leaf bases through which barban can penetrate only slowly. Plants may be checked, and some shoots even killed, but growth can soon be resumed from tillers.

Symptoms

Wild oat plants treated with an appropriate dose of barban cease to grow and form a characteristic rosette of short, broad, bluish-green leaves (Holroyd 1960a, Friesen 1961). Affected plants may remain in this condition for several weeks before death finally occurs.

Occasionally a seminal tiller may be produced by plants with deeper seeds in the soil or as mentioned above from normal tillers if the plant is old enough for these to be present. Panicles produced by survivors are almost always smaller and shorter probably because of the more severe crop competition. Maturation may be delayed but seed produced is otherwise normal (see p. 209).

Dose

The degree of wild oat control given by any particular dose of barban is very dependent on the amount of competition to which the plants are subjected after treatment, a much higher level of control being achieved in the more competitive crops. It is possible to offset lower competition with increased dose and this is the reason for the higher dose which is recommended in a poorly competitive crop such as the field bean. In cereals an increased dose can be self-defeating as it brings with it the possibility of crop damage which will in turn reduce crop competition, as was shown by Pfeiffer, Baker and Holmes (1960).

A large proportion of the early work in North America was published by numerous individual authors in Research Reports of the Western Section of the National Weed Committee, Canada, the North Central Weed Control Conference, United States of America. the Western Canadian Weed Control Conference and joint conferences of the two latter. In the early years (1958, 1959 and 1960) most of the authors of these papers suggested that doses of 0.56 or 1.12 kg/ha were required to give adequate control in cereals, although in some experiments delays in the maturation of the crop were noted. In 1960 Banting, summarising forty-four reports, noted that the optimum doses for wheat ranged from 0.28 to 0.56 kg/ha but reductions in yield occurred in some instances from the higher dose. Summarising twenty reports in 1961, Banting commented that increasing the dose from 0.28 kg/ha to 0.56 kg/ha gave improved wild oat control but no commensurate increase in the yield of wheat, presumably because of crop damage.

In the United Kingdom it was soon accepted that the optimum dose in wheat and barley was 0.28 to 0.35 kg/ha (Pfeiffer, Baker and Holmes 1960, Pfeiffer and Phillips 1960, Holroyd 1960a, Evans 1960, Pfeiffer and Holmes 1961). The reason for this early difference between North American and the United Kingdom results was probably that cereal crops generally in North

America are less dense and lower yielding, thus offering less competition to the wild oats. However there was general agreement that wild oats were most susceptible between the 1 and 2.5 leaf stages and that competition from the crop was an important factor (Hoffman, Hopkins and Pullen 1958, Leggett 1958, Carder 1959a,b, Forsberg 1959, Sexsmith 1959d, Banting 1960, Bingham 1960, Fisons 1959). It was also realised at an early stage in the development of the compound that application factors, formulation and the addition of other herbicides could have marked effects on its activity and hence the optimum dose. This is discussed later (p. 181).

Biotypes of *A. fatua* which are less sensitive to barban have been noted. Stryckers and Himme (1971) in the Netherlands found five biotypes which showed differential susceptibility. Jacobson and Anderson (1972) studied two particular biotypes with a known differential response and found that this was more evident from leaf than root uptake. They suggested that the difference was due to the reduced ability of the susceptible plants to degrade barban.

Application and formulation

The wild oat at its most susceptible stage to barban (1-2½ leaves) is paradoxically a difficult target. Application and formulation factors such as volume rate, pressure, nozzle type or surface-active agent, which are known to influence spray retention and distribution on the foliage, are therefore particularly important.

Volume rate. In North America, Hoffman *et al* (1958, 1960), Sexsmith (1959d), Friesen (1961) and Banting (1960) all came to the conclusion that barban was more effective when applied at lower (50-60 l/ha) rather than higher (330-450 l/ha) volume rates.

Pressures. Most of the applications were done at pressures of 2.8 bars, although this is not always reported, and Bingham (1960) states that activity was the same at pressures of 3.1, 4.1 and 6.2 bars when the volume rate was 56 l/ha. Nozzles working at higher pressures and lower volume rates as a general rule produce spray swathes containing a higher proportion of smaller droplets, and Lake and Taylor (1974) in experiments with droplets of 110, 220 and 440 μm found that the smallest droplets were the most effective.

Early workers examined the influence of nozzle type but their results were inconclusive. Friesen (1961) found that 'hollow' or 'solid cone' nozzles were more effective than 'fans', Gull *et al* (1959) that 'hollow' cones were twice as effective as 'fans' with 'solid cones' intermediate, Carder (1960) that 'hollow cones' were 10% better than 'fans' and, Corns (1960b), Forsberg (1959) that there was no consistent difference between the three types. Unfortunately all the necessary details of pressure and volume rate etc. are not always given in the reports.

Formulation. Most experimental work has been with 'Carbyne' the normal commercial formulation, a 12.5% emulsifiable concentrate. Various other formulations have been tested under manufacturers' code numbers but in general the selectivity and/or activity of these alternative formulations has been less. In 1972 a 25% formulation (B.25) was introduced which gave more reliable control of wild oats (Holmes 1972) but due to risk of crop damage it is only approved for use in spring barley (ACAS 1972). Allen and Smallridge (1972) in New Zealand also found that the 25% formulation was less selective in wheat than the 12.5% formulation. Details of the composition of the various formulations are not available. However, Stryckers and Himme (1972) found that increasing the proportion of surface active agent increased activity but reduced selectivity.

Environmental factors

Very little work has been published on the effect of environment on the activity of barban. Holmes and Pfeiffer (1962) were unable to reach any definite conclusions about the effect of temperature on the amount of damage caused by barban on winter wheat. They found that damage could occur over a wide range of day and night temperatures (4°C-18°C). Neidermyer and Nalewaja (1974), however, in growth chamber studies, showed that the susceptibility of wheat and wild oat (*A. fatua*) to barban increased as the post-treatment temperature decreased from 32°C-10°C, and barban selectivity against wild oat in wheat was greater at 27°C and 21°C than at 16°C and 10°C. Nalewaja and Dobranzski (1971) found that changes in air temperature influenced the activity of barban more than changes in soil temperature. However, treatments were equally effective whether applied immediately or four days after frost. The temperature during the intervening period was kept at a constant 18°C. Parker (1963) found that in a range of winter wheat varieties the crown nodes of plants grown at 10°C were deeper in the soil than those of plants grown at 20°C. If the crown node is the main site of action, plants in which it is deeper in the soil will tend to be more resistant.

Growth stage of wild oats

Most authors who have examined the effectiveness of barban applied to wild oats at a range of growth stages agree that the wild oats are most susceptible at the 1 to 2.5-leaf stage (Hoffman, Hopkins and Pullen 1958, Leggett 1958, Carder 1959, Forsberg 1959, Sexsmith 1959, Banting 1960, Pfeiffer, Baker and Holmes 1960, Holroyd 1960a, Holly 1960). However the resistance of the wild oats increases progressively and plants beyond the 2.5-leaf stage are affected, although only temporarily in the absence of crop competition (Holroyd 1960a).

As mentioned under 'mode of action', one explanation of the increased resistance of wild oat plants beyond the 2.5-leaf stage is that tillering begins and the number of potential 'recovery' areas is consequently greater.

Crop tolerance

Early research showed that some varieties of barley were as susceptible to barban as *Avena* species. Pfeiffer, Baker and Holmes (1960) obtained evidence on the inherent nature of the tolerance factor from an experiment in which they compared the responses of Proctor barley (susceptible), Rika barley (resistant) and an F.4 unselected cross of Proctor x Rika. The cross gave an intermediate response between the clearly different responses of the parents. They observed two types of toxicity on barley. The typical effect was a stunting of the main shoot but this was sometimes preceded by a yellow mottling leading to 'scorch'. The occurrence of scorch depended on variety and environment as well as on dose of herbicide. They also noted that where scorch occurred stunting was less severe or absent. Holroyd (1960a) also noted the inverse relationship between scorch and stunting in work with mixtures of barban and MCPA in spring wheat and barley. Barley suffered more scorch and less stunting and the wheat no scorch but more stunting.

Barley varieties can be divided into susceptible and tolerant groups but in winter wheat varieties the distinction is much less clear-cut. Most winter wheats have a susceptible period when treatment will produce typical symptoms of barban damage. However the severity of the damage and the duration of its effect seem to be influenced by environmental factors before and after treatment, the stage of growth and the particular variety. Recovery can be complete from damage which appears to be relatively severe (Pfeiffer and Phillips 1960, Holroyd 1960a, Evans 1960). Nalewaja and Dobranzski (1971) as emntioned under 'environmental factors' found that barban activity on wheat increased with a decrease in temperature. Holroyd (1962a) in a study of the susceptibility of three varieties of winter wheat, Banco, Professeur Marchal and Hybrid 46, found that all three varieties became more susceptible when they reached the growth stage with 4.5 to 5 main stem-leaves although the severity of the damage was also influenced by the date of drilling. Fiddian (1962) summarised the results of a series of experiments over a three year period. Barban was applied at a dose of 0.96 kg/ha to the winter wheats at ten day intervals on 17 and 27 March and 6 April, and to the spring wheats and spring barleys at the 3-leaf stage in 1960, 3 and 6-leaf stages in 1961 and at the 1 to 2-leaf stage in 1962. The differences in reaction between the spring barleys was very marked, with Proctor, Pallas and Maris Badger being the most susceptible; varietal differences between the spring wheats were also found to be fairly marked and consistent. The varieties Atle and Atson were found to be very much more susceptible than others such as Jufy. All the varieties of winter wheat were damaged to a greater or lesser extent, particularly by the treatments applied on 17 March. Although there was no clear cut segregation into susceptible and resistant varieties, Elite Lepeuple, Professeur Marchal and Hybrid 46 were stunted and delayed in heading more than Cappelle, Champlein and 14431.

However, at the present time the manufacturers recommend the use of barban (Carbyne) for use in all varieties of winter and spring wheat with the exception of the varieties Maris Dove and Maris Butler, but warn that, 'if spraying is preceded or followed by conditions which place the crop under stress, the crop may be checked and yield may be reduced, sometimes severely.' Such stresses may be induced for example by cold frosty conditions, substantial day to night temperature change or soil moisture or fertility deficiencies' (Fisons 1973a). Its use is also recommended in field and broad beans, sugar beet and vining peas but at doses up to 0.7 kg/ha because of the lower competition of these crops (Fryer and Makepeace 1972). However, peas may be damaged temporarily due to scorch at doses of 0.56 kg/ha; this damage may be accentuated by cold weather and wind after treatment but generally recovery is complete (Armsby and Gane 1962). Bachthaler (1961) found that the yield of sugar beet was unaffected by doses up to 10 kg/ha. Sexsmith (1960a,b,c,d, 1961a,b) reported that sugar beet, red beet, potatoes, cucumbers, carrots, mustard were unaffected by doses of 0.56 and 1.12 kg/ha, peas, beans and sunflower were very slightly injured by the same doses and Redwood flax and maize suffered slight to moderate damage. In more recent work Berkenkamp and Friesen (1973) found indications that in Canada a spring application of barban to oil seed rape (*Brassica campestris*) increased the amount of stem rot (*Sclerotina sclerotiorum*) present in the autumn. The more concentrated formulation 'Carbyne B 25' is recommended by the manufacturers for use in certain varieties of spring barley only (Fisons 1973b).

Mixtures

Early field trials by Gull *et al* (1959) in North America suggested that the activity of barban on wild oats was unaffected if it was applied as a mixture with the amine salt of MCPA. However, Holroyd (1960a) found in field trials that although MCPA-triethanolamine applied at 1.68 kg/ha, when the crop (spring wheat and barley) had 5 leaves did not interfere with the effect of barban applied one week earlier; if the MCPA was applied at the same time as the barban the control of wild oats was reduced. Pfeiffer, Baker and Holmes (1960) in more detailed studies found that 2,3,6-TBA was one of the strongest antagonists, followed by 2,4-D, mecoprop and MCPA. A mixture of MCPB with a small amount of MCPA was not antagonistic. They also found that barban activity was reduced by applications of 'growth regulators' up to 4 days before treatment with barban. It was not reduced by applications made after treatment.

Holroyd (1960a) and Evans (1960) both noted that mixing barban with MCPA increased the degree of scorch on spring cereals and winter wheat. Friesen (1961) reported that in trials in Canada mixtures of barban with 2,4-D butyl ester, or MCPA amine or MCPB were all less effective against wild oats than barban alone. However, Mantle (1973) reported that CR 13781 (a mixture containing activated barban with specific esters of dichlorprop, mecoprop and MCPB) gave good wild oat control and a suppression of a range of annual broad-leaved weeds. Subsequently the use of this mixture has been approved by the Agricultural Chemicals Approval Scheme (1974).

Investigating mixtures between barban and other compounds, Stobbe and Holme (1972) found evidence of synergism between benzoylprop-ethyl and barban. In greenhouse studies a mixture of 0.35 kg/ha benzoylprop-ethyl and 0.07 kg/ha barban gave satisfactory wild oat control. In the field slightly higher rates were necessary but control was achieved over a wider range of growth stages than with either compound alone. In 1970 Griffiths reported that a mixture of barban at 0.34-0.67 kg/ha with phenmedipham at 1.12 kg/ha was very effective for the control of *Avena fatua* and *Polygonum* *aviculare* in sugar beet. Finally Chang *et al* (1974) found that they could control wild oats with 0.4 kg/ha of barban selectively in cultivated oats if the seed of the cultivated oats had been treated with NA (1,8-naphthalic anhydride) at rates of 0.5 to 1% by seed weight before planting.

Residues

At normal rates of application barban does not seem to have presented any problems. However, Quilt (1972) using doses higher than those normally used in agriculture found indications that 'Carbyne' interfered with the respiratory processes of soil organisms. Nitrification was inhibited for at least 18 weeks in spite of the periodic introduction of fresh soil, and neither *Nitrosomonas* nor *Nitrobacter* could be detected. The balance of populations in the soil was upset and failed to return to the control state for a considerable period.

ASULAM

Mode of action

Asulam is a benzenesulphonyl carbamate herbicide which acts by inhibiting cell division so that the growing points of shoots cease to function normally. This results in morphological effects similar to those produced by the N-phenyl carbamates, propham, chlorpropham and barban (Cottrell and Heywood 1965).

Use in flax

Field trials showed that asulam was effective in controlling wild oats in flax (Molberg 1963, 1964, Cook 1963, Clarke and Cook 1964). 1963 trials showed satisfactory control with substantial increases in flax yields, but 1964 trials were disappointing with poor weed control. Clarke and Cook reported severe chlorosis of both wild oats and crop which they attributed to uptake through the roots following heavy rain which fell 3-6 hours after spraying asulam. They showed that the addition of 'wetter' to the spray solution reduced the dose rate needed for wild oat control and improved selectivity. Molberg (1964) reported that wild oat control, ranging from 43% (1.1 kg/ha) to 89% (3.4 kg/ha) was accompanied by flax yield increases, but these increases were substantially below those obtained on the hand-weeded plots. Later field trials in Canada (Hardisty 1971) showed that asulam at 0.9 and 1.1 kg/ha without wetter increased crop yields by 30% and 50% with moderate wild oat control, while with 0.1% wetter added both these doses increased crop yields by 70% and wild oat control by over 90%.

Growth stage of wild oats

In the trials reviewed above the most successful results were obtained with applications of asulam when the majority of wild oats were at a more advanced stage (up to 5 leaves) than that recommended for barban. Hibbitt, (1969) suggested that greater selectivity at a fairly advanced stage was due to differences in retention between wild oats and flax. Both plants have waxy leaves, which are relatively water repellent. However, in wild oats most of the spray is retained by the leaf axils, whereas in flax most is retained by the cotyledons. In consequence the amount retained per unit weight increased with wild oats and decreased with flax as growth progressed.

Formulation

The importance of adding wetter to asulam to improve selectivity was confirmed by Hibbitt *et al* (1974). Greenhouse and field trials showed that a wetter concentration of 0.125% added to asulam considerably increased the activity against wild oats and at rates of 0.5 and 1.1 kg/ha there was little increased activity on flax. They also showed that asulam can be absorbed both through the leaves and through the roots of wild oats, but root uptake was only important in the case of seedling plants.

THIOCARBAMATES

EPTC

Mode of action

EPTC, a soil-applied herbicide, is highly volatile and thus must be efficiently incorporated to achieve good activity. Its mode of action is not clearly understood but it has been shown that EPTC affects plant metabolism, blocking essential reactions particularly in the roots where it can cause rapid local injury (Crafts 1964). It is a highly mobile herbicide, moving in both xylem and phloem. Although mainly active against germinating seedlings, experiments have shown that EPTC severely inhibits wax production of leaves of more mature plants and may impair the functioning of the cuticle (Corbett 1974).

Dose

Many references refer to the control of *A. fatua* with EPTC applied to the soil and incorporated at doses ranging from 1.1 to 11.2 kg/ha. Some workers reported good control with 2.2 kg/ha (Selleck 1959b, Sexsmith 1960b, 1961a), but generally better and more reliable control has been achieved with rates of 4.5 kg/ha and above (Friesen 1958, 1959a, Carder 1958, 1959c, Chubb 1959, Wilson and Cussans 1970).

Crop tolerance

A wide range of crops was found to be susceptible to EPTC at 4.5 kg/ha, wheat and barley being particularly sensitive to rates of 2.2 kg/ha and less (Stauffer Chem. Co. 1956, Dunham 1957, McCurdy 1959, Sexsmith 1959, Selleck 1959a). Peas, beans and sugar beet were generally less susceptible, although reports vary on the extent of damage incurred by these crops. A report from the Stauffer Chem. Co. (1956) showed that peas would tolerate 5.6 kg/ha, but the majority of workers reported damage by rates of 4.5 kg/ha and less (Dunham 1957, Lee 1958, Sexsmith 1959, 1960c,d, 1961a,b, Armsby and Gane 1962). Beans were slightly injured by 2.2-3.4 kg/ha

(Sexsmith 1959), and more severely injured by 2.2 and 4.5 kg/ha (Wilson and Cussans 1970) where emergence was delayed and the stand was thinned. A Canadian Ministry of Agriculture report (Canada 1959b) described experiments that showed that sugar beet was not injured by 4.5 kg/ha. However trials carried out by Chubb (1959), Sexsmith (1960a,b) and Wilkerson (1961) resulted in varying degrees of damage, ranging from stand reductions (Sexsmith 1960b), delayed maturity of the crop (Sexsmith, 1960a) and yield reductions (Chubb 1959) from rates of 4.5 kg/ha and less. In one report (Sexsmith 1959), potatoes tolerated 3.3 kg/ha without damage.

Agronomic and environmental factors affecting activity

Factors such as the time interval between spraying and planting; method, depth and speed of incorporation of the chemical into the soil after spraying; and soil temperature and moisture may all account for some of the variable results mentioned above. Jacquemet and Poignant (1961) discussed the variable response to EPTC in relation to depth of incorporation, soil humidity and texture. In one experiment EPTC was incorporated 1, 2, 3 and 4 weeks before sowing oats, barley and wheat. A dose of 3 kg/ha was selective except when applied one week before planting oats, while 6 kg/ha reduced stands of all crops. Oats were the most susceptible, barley the least. It was concluded that delayed drilling, to extend the interval between spraying and planting, was not practicable due to yield reductions, and the control of wild oats could be achieved by cultivations before planting late sown crops. Wilson and Cussans (1970) reported severe damage to beans when EPTC was applied near to the date of planting, indicating little inherent tolerance by this crop, selectivity depending on the disappearance of the chemical before the beans had reached a susceptible stage. Less damage occurred with early spring plantings where soil temperatures were low and the beans did not germinate immediately they were sown. It was concluded that the rapid germination and early growth associated with high soil temperatures would necessitate a longer interval than 14 days between spraying and planting in late spring. Methods of incorporation were compared by McCurdy (1959) who found little difference between rotary cultivation and discing. The persistence of EPTC throughout the winter was indicated by Friesen (1959b) who reported that 4.5 and 8.9 kg/ha sprayed on to the stubble before discing, and incorporated by discing again in the autumn, gave good control of wild oats in the following spring. This resulted in increased yields of barley and flax.

DI-ALLATE AND TRI-ALLATE

Mode of action

Di-allate and tri-allate are closely related thiocarbamates differing only by one chlorine atom. Their patterns of selectivity and the symptoms produced on susceptible plants are very similar. Like other thiocarbamates they are active on most grass species, particularly *Avena* spp. They enter the plant through portions of the shoot or coleoptile at or below the soil surface, but not through the roots (Friesen *et al* 1962, Parker 1963, Holroyd 1964b, 1968b, Appleby *et al* 1965). Thus they differ from thiocarbamates such as EPTC, which enter the plant readily through roots and shoots (Crafts 1964). Within the plant, like many other thiocarbamates, they inhibit the formation of waxes and interfere with mitosis and cell extension (Morrison 1962, Banting 1967, 1970, Wilkinson and Smith 1973, McKercher *et al* 1975). The actual cause of death in susceptible plants is open to speculation. Corbett (1974) suggested dehydration due to the absence of cuticular wax but this seems unlikely to be the main phytotoxic effect of di-allate and tri-allate as soil treatment prevents many oat seedlings from even reaching the soil surface. Morrison (1962) soaked the dry seed of various crop species in an aqueous solution of di-allate and found similar cytological effects in all the meristematic areas of the plants. At high doses mitotis was blocked while at lower doses it continued after a temporary stoppage, but abnormally. Polyploid cells were produced in wheat and barley but, unlike the effects of propham, there was no actual breakage of the chromosomes. The crops tested in this way were, in increasing order of sensitivity: peas, flax, rye, wheat, barley and oats.

In 1970 Banting showed that the vapour of di-allate and tri-allate was more damaging (as indicated by mitotic abnormalities) to shoot than root tissues of both wheat and *A. fatua.* Wheat was damaged much less than *A. fatua.* However, shoot growth in both species was inhibited by vapour concentrations which did not affect mitosis. Banting therefore concluded that mitotic damage was of secondary importance and that the major effect was an inhibition of cell elongation and expansion. However, all tissues in the shoot do not respond similarly. Banting found that the meristematic areas at the base of the first leaf of wild oat plants were more susceptible than those at the shoot apex. This could be because the shoot apex is more protected than the base of the first leaf and therefore is less accessible to the herbicide. However, McKercher *et al* (1975) working with non-dormant seed of *A. fatua* sown into soils treated with tri-allate granules, found that after 10 days, the length of the mesocotyl of the resulting seedlings was unaffected. The major effect was on the length of the primary leaf and coleoptile. In two out of the three soils used they found that the extension of the coleoptile was stimulated by tri-allate whereas the primary leaf attained a length of only 29-54% of that on untreated plants. Nalewaja (1968) working with ^{14}C-labelled di-allate found that the pattern of uptake and translocation was similar in wheat, barley and wild oat, and although there was less translocation of ^{14}C to the roots of wild oats than to those of barley he concluded that differential uptake and translocation could not account for the differences in susceptibility.

Thus, *Avena* spp. are considerably more susceptible to direct treatments with di-allate or tri-allate than most cereals, but the reasons, although they seem to be physiological, are not obvious. As both compounds are principally soil-acting and reach the plant in the gaseous and/or the aqueous phase, their activity and selectivity is influenced by many soil factors. This is discussed later under application and formulations (see p. 187).

Symptoms

In wild oat plants which germinate from seed in treated soil the coleoptile is generally thickened and brittle and often ruptures below the tip allowing the first leaf to burst out and to form a loop (McKercher *et al* 1975). However, in many instances the coleoptile fails to reach the soil surface. Holroyd (1960b) noted that the effects were very much 'all or nothing'; if a plant was not killed early in development it grew almost normally and the proportion of small wild oat panicles produced was not influenced.

Plants of *Avena* spp. which were treated after emergence, however, showed very characteristic symptoms. Holroyd (1968b) noted that under field conditions the development of new leaves on affected plants stopped. Leaves which had already emerged ceased longitudinal growth but continued to develop in width so that larger plants formed small rosettes. Leaf colour became darker and cuticular wax failed to form. Plants often remained in this inhibited state for six weeks or more, before they either died or, in some cases, resumed growth either from the main shoot or more usually from a tiller.

The most characteristic symptom of damage in crops is de-waxing although Holroyd (1960b) noted that the effects on barley and wheat were somewhat different. Barley treated pre-emergence with too high a dose either failed to emerge or grew more or less normally with occasional chlorosis and one or two trapped leaves. The symptoms on wheat were much more marked and long lasting. Some plants failed to emerge and if excavated showed characteristically deformed, thickened and brittle shoots. Other plants which emerged were stunted with many leaves which were trapped and tubular. Damaged plants were slow to recover and matured later than undamaged plants.

Dose

Under normal conditions both di-allate and tri-allate are relatively volatile, tri-allate somewhat less than di-allate, and if applied to the soil surface as a liquid formulation losses can be high and effectiveness very much reduced. In one of the earliest published reports, Deming *et al* (1959) stated that the activity of di-allate on wild oats was increased by a factor of 4-8 when it was incorporated with the soil. Other early reports of research in North America and Great Britain by Selleck (1958, 1959b,c, 1961), Carder (1959a,c), Hannah (1959), Brown (1959), Friesen (1960b), Molberg and Banting (1960d), Holroyd (1960b), Holly (1960), Evans (1960), Friesen and Walker (1960) and Leggett (1960, summarising 34 reports), all stressed the influence of soil factors and the type of incorporation on the effectiveness and selectivity of di-allate, but found that a dose of 1.4-1.7 kg/ha would under most conditions give wild oat control of 85-99%. Subsequently Selleck and Hannah (1962) reported that tri-allate was more selective to cereals than di-allate at similar doses. Banting (1963) summarising Canadian work also concluded that tri-allate was more selective in cereals and that the optimum dose was 1.4 kg/ha. May (1973), however, working on soils of 9 and 15% organic matter found that a dose of 3 kg/ha was required to give 100 and 83% control respectively of *A. fatua*. All thsee reports relate to the use of di-allate and tri-allate emulsion either before or after drilling the crop but before emergence of the wild oats.

In 1968 Holroyd found that doses up to 2.2 kg/ha of 5% granular formulation of tri-allate controlled *A. fatua* at growth stages up to tillering without soil incorporation. Activity was only slightly less than that given by a conventional application. Subsequently, numerous workers such as Proctor and Livingston (1972) and Hodkinson (1972) in Great Britain; Gummeson (1973) in Sweden; Coutin *et al* (1971), Bouchet (1972) and Maynadier *et al* (1971, 1973) in France and Klefeld and Weiss (1970) in Israel confirmed the post-emergence effectiveness of tri-allate granules on wild oats at doses of 1.4 to 2.2 kg/ha.

Application and formulation

As already indicated in the previous section both application and formulation factors can have major effects on the activity of both di-allate and tri-allate. The formulation used in all the early work with both compounds was an emulsifiable concentrate and this required mixing with the soil relatively soon after application to be effective. The importance of the type and degree of soil mixing was highlighted by Selleck (1959c) who showed that 0.9 kg/ha of di-allate gave only 75% control of wild oats when mixed in with a single discing but 90% control with double discing. Similarly Leggett (1960), in a summary of 34 reports of Canadian work stated that, although volume rate appeared to be important, the soil needed to be in a good, workable condition; mixing to a depth of 5 cm was more effective than 10 to 15 cm, and double was better than single incorporation.

Friesen *et al* (1962), Parker (1963), Holroyd (1964b) and Molberg *et al* (1964) in pot and field experiments, investigated in more detail the various factors influencing the activity and selectivity of di-allate and tri-allate in cereals. All confirmed the need to mix the herbicides thoroughly with the soil for maximum activity on the wild oats. Holroyd (1964b) studied the initial distribution of herbicide given by using spring tine harrows, and a rotary cultivator to mix in a surface application of a fluorescent tracer and concluded that ordinary farm implements have severe limitations when used for this purpose. Most of the herbicide was concentrated in the upper layers of the cultivated soil, and distribution, both vertically and horizontally, was very uneven. A double rotary cultivation gave a deeper and more even distribution than a single. Parker (1963) in pot experiments and Holroyd (1964b) in the field showed that a specific dose mixed in deeply (10 cm) was less active on shallow than deep sown sown oats but the reverse was true when mixing was shallow (1-2.5 cm). The distribution of wild oat seed in the soil is governed to a large extent by the preceeding cultural history. In land which has been ploughed regularly after harvest, seed is distributed more or less evenly down to plough depth but in 'direct drilled' or 'minimum tilled' land, where there has been no soil inversion, seed is concentrated in the surface layers. Thus under a no-ploughing regime, where the bulk of the seed is near the surface, shallow mixing of the herbicide should be more effective than deep, and where the land is ploughed regularly the reverse should be true. One of the problems common to all herbicides which have to be mixed into the soil is that this has to be done with farm machinery which is designed to produce a seed bed. No machine is yet available commercially which has been designed specifically for the mixing of herbicides with the soil.

The introduction of the granular formulation of tri-allate (10% w/w on 24/28 mesh attapulgite) has increased the latitude with which tri-allate can be used. Holroyd (1968b) using a 5% granule found that even wild oats which had begun to tiller could be controlled with doses as low as 1.7 kg a.i./ac. Subsequent work (Holroyd and Bailey 1970) indicated that 5 and 10% formulations were equally effective. They found that in winter crops pre-emergence treatments were slightly more effective than post-emergence treatments, but in spring crops, treatments applied just after the wild oats had emerged were the most effective. Hodkinson (1972) summarising results from 70 experiments during 1970-1972 came to broadly similar conclusions. Gummeson (1973) in Sweden mixed in both granular and liquid formulations and found them equally effective either before or after sowing. In France, Bouchet (1972) and Maynadier *et al* (1973) working with hard and soft winter wheats found the granules to be most effective when used pre-emergence. Post-emergence treatments controlled the wild oats but did not give the same crop yield response. Bouchet (1972) found that post-emergence treatments were the more effective in spring wheat. The main advantages of the granular formulation are its ease of use and the wider range of conditions under which it can be used. Where soil conditions are suitable, the emulsifiable concentrate mixed into the soil will generally be more effective.

Environmental factors

Hannah *et al* (1960a,b) stated that the effectiveness of di-allate was little influenced by environmental factors. They reported that a dose of 1.7 kg/ha controlled wild oats on soils ranging from sandy loams to heavy clays, at temperatures ranging from 3 to 20°C and in rainfall of 6-33 cm during the growing season. The most important factor, they concluded, was thorough incorporation with the soil relatively soon after application. However, both di-allate and tri-allate are relatively volatile compounds and environmental factors at the soil surface after application and also within the soil after mixing influence activity. Hance *et al* (1973) found that 50% of a liquid tri-allate applied to wet soil (15% moisture) was lost in three days even in the still air conditions of a glasshouse. Under field conditions much more rapid loss could be expected. The amount of herbicide lost through volatilisation could be very high if mixing is delayed more than an hour or two under windy conditions, on a moist soil surface and with a strong sun. A granular formulation is much less liable to loss in this way. Hance *et al* (1973) found that 50% of the tri-allate was lost from 10% granules exposed on a wet (15%) soil surface in the glasshouse in 8.5 days (cf liquid formulation above). In the field, 50% was lost in 10 days in spite of relatively high temperatures (average daily maximum 20°C). This is one of the reasons why granules are more effective than a liquid formulation when left on the soil surface. Dry soil, however, holds tri-allate relatively strongly and 50% was lost only after 69 days, irrespective of whether the material was applied as a liquid or granular formulation. Banting (1967) showed that the control of *A. fatua* was dependent on vapour movement and increased as the soil moisture was increased from 15 to 25%. Conversely, McKercher *et al* (1975) reported that tri-allate phytotoxicity was similar at soil moisture levels of either 5% greater than wilting point or 5% less than field capacity. However, excessive moisture can reduce selectivity and increase crop damage (Molberg *et al* 1964). Holroyd (1964b) suggested that in wet soil the redistribution of di-allate and tri-allate after the initial mixing is prevented or reduced, and pockets of high and low concentration are maintained. High soil organic matter content can reduce activity and May (1973) found that approximately twice as much tri-allate was required to give satisfactory wild oat control on soils of 9 to 15% organic matter content.

Growth stage of wild oats

All the early reports indicated that di-allate and tri-allate were most effective when applied before the emergence of the wild oats. However Banting (1967) found that when he replaced the top 5 cm of soil from around *A. fatua* plants in the 1 to 1½-leaf stage with tri-allate treated soil, growth ceased almost immediately. Plants at the 2 to 2½-leaf stage were much more resistant. Holroyd (unpublished) also found that under glasshouse conditions oats became much more resistant to tri-allate granules on the soil surface when they reached the 2 to 2½-leaf stage. Under field conditions they were susceptible up to early tillering (Holroyd 1968b). In France, Maynadier *et al* (1971) and Coutin *et al* (1971) also found that wild oats up to the 2 to 3-leaf stage were susceptible to the granular formulation. After tillering the resistance of *A. fatua* increases relatively rapidly particularly under glasshouse conditions (Miller 1973).

Crop tolerance

Doses of di-allate and tri-allate which will control wild oats can be used in most broad-leaved crops without any risk of crop damage. Hannah (1959) reported that flax and sugar beet were resistant to di-allate; Banting and Molberg (1959), Carder (1959c) and Leggett (1960) found flax was resistant, and Hannah *et al* (1960a,b) that flax, peas, lentils, safflower, sugar beet, sunflower and oil seed rape were resistant to a dose of 1.7 kg/ha di-allate. The Pea Growing Research Organisation (PGRO 1970) reported that 15 cultivars of dwarf beans were not damaged by 1.7 kg/ha tri-allate applied pre-drilling. Currently in the United Kingdom di-allate is approved for use in brassica crops, sugar beet and red beet, and tri-allate in carrots, peas and beans (ACAS 1975). Cereal crops are somewhat more susceptible and Banting (1963), Parker (1963) and Holroyd (1964b) found that tri-allate was marginally more selective in these crops. Barley is more resistant than wheat but can still be damaged under adverse soil conditions or where planted shallowly into a heavily treated layer of soil (Holroyd 1960b, 1964b, Parker 1963). The selectivity in wheat can however be increased if the herbicide is mixed with the upper 2-3 cm of soil and the crop seed planted 2-3 cm below this layer, in untreated soil (Parker 1963, Friesen *et al* 1962). Adverse soil conditions, particularly excessive moisture, can however increase crop damage (Molberg *et al* (1964, Holroyd 1964b). The granular formulation was more selective than the liquid formulation but wheat could still be damaged if a dose of 2.2 kg/ha as 5 or 10% granules was mixed in before drilling, or drilling was shallow. Indications were that cultivars Maris Ranger and Joss Cambier were somewhat more susceptible than Cappelle Desparez (Holroyd and Thornton 1970). Norris and Lardelli (1972) also reported that some cultivars of wheat were more tolerant than others.

Mixtures

There is relatively little published information on the use of mixtures of either di-allate or tri-allate in any crops, but Bray (1974) reported on the successful use pre-sowing of a mixture of pyrazone and di-allate in sugar beet for the control of *A. fatua* and broad-leaved weeds. Strykers and van Himme (1973) mentioned the successful use of tri-allate with butachlor or acetochlor to control annual grasses in winter wheat (cvs. Palmaress and Leda) in their review of experiments for the year 1971-1972.

There are also very few reports of the use of di-allate or tri-allate pre-emergence influencing crop susceptibility to subsequent herbicide treatments, although Davies and Dusbabek (1973), working with peas, reported an increased uptake of ^{14}C-labelled 2,4-D, atrazine, TCA and diquat after previous exposure of the leaves to di-allate vapour.

Residues

The persistence of di-allate and tri-allate in the soil is dependent on soil characteristics and evironmental factors. Di-allate is only about half as persistent as tri-allate. Holroyd (1962b) found that the activity of di-allate persisted for 5 months and tri-allate for 10 months in a sandy loam soil at a dose of 1.4 kg/ha. Research workers have reported the persistence of residues of both compounds for varying lengths of time, Linden and Schicke (1965), using tri-allate at doses of 3.4-6.7 kg/ha, recorded 5-6 months on a loam and 6 months on a sandy soil; Desmoras *et al* (1963) and Linden (1964) more than 6 months for tri-allate at doses of 1.7 to 11.2 kg/ha; but all agree that di-allate is only about half as persistent as tri-allate. Fryer and Kirkland (1970) found that soil residues of tri-allate could be detected for 5-6 months after applying doses of 1.7 kg/ha on an annual basis. When they applied 3.4 kg/ha twice yearly residues persisted but there was no build-up over a 6 year period. They detected no residues of tri-allate in barley straw or grain grown on the treated area.

Smith (1970) studied the degradation of di-allate and tri-allate in prairie soils and found that at doses equivalent to 2.5-2.8 kg/ha di-allate residues were reduced by 50% in four weeks at moisture levels above wilting point. Below wilting point he found little degradation. Anderson and Domsch (1974) found that the degradation was largely microbiological and that whereas a concentration of 2.5 ppm of di-allate in non-sterile soil disappeared within 4 weeks, less than 50% had disappeared from sterile soil after 20 weeks. However, in contrast, McKercher *et al* (1975) incubated soil containing tri-allate granules for 20 weeks at constant temperatures of 10 and 20°C at soil moistures of 5% above wilting point and 5% less than field capacity, and found no effect on phytotoxicity.

CYCLOATE

Mode of action

Cycloate, a thiocarbamate herbicide, is active against young germinating seedlings. It is thought to be taken up by the young plants, killing them just before or just after emergence. As it is a fairly volatile herbicide, thorough incorporation is required for high activity.

Wild oat control

Schweizer and Weatherspoon (1967) achieved 81, 91 and 97% control of wild oats with 2.2, 4.5 and 6.7 kg/ha, respectively, when incorporated to a depth of 4 cm. Knife injection was less effective than power incorporation. In three experiments carried out in France the response of wild oats to cycloate was rather variable, 2.9-4.3 kg/ha giving between 58 and 97% control, with no clear dose response (Lhoste *et al* 1970). Similar doses of cycloate mixed with lenacil or pyrazon achieved good control in a number of trials (Durgeat *et al* 1970a,b).

Environmental factors

Soil type has been shown to affect cycloate activity, lower doses being required on light soils than on heavy (Koren *et al* 1968). It is recommended that a dose of 2 kg/ha is used on very light soil and one of 4 kg/ha on heavy (Farm Protection 1973).

Crop tolerance (sugar beet)

In a number of experiments sugar beet was not damaged by doses as high as 5 kg/ha, even when planted immediately after the herbicide application (Evans and Watts 1973, Schweizer 1974, Lee *et al* 1969, Durgeat *et al* 1970b). At doses higher than 5 kg/ha, cycloate was found to cause some damage (Lhoste *et al* 1970, Schweizer and Weatherspoon 1967). However, Wicks and Anderson (1969) and Dawson (1971) showed that incorporated treatments of 3.4 kg/ha reduced the stands of sugar beet plants. Dawson also found that cycloate affected the cotyledons of the sugar beet plants, reducing their size, and making them a darker green.

Mixtures

In practice cycloate is applied with one of several other soil-applied herbicides to widen its weed control spectrum. Mixtures with lenacil (0.4-0.8 kg/ha) and pyrazon did not affect cycloate's toxicity to wild oats (Durgeat *et al* 1970a,b).

UREAS

The substituted ureas are phytotoxic to both dicotyledonous and monocotyledonous species. In general they have a greater effect on the seedlings of smaller seeded weeds and annual grass weeds in particular. Several compounds have been developed and marketed primarily for the control of annual grass weeds such as *Alopecurus myosuroides* (blackgrass) in winter cereals but their activity on *Avena* spp. is often relatively high, although unpredictable.

Mode of action

The substituted ureas as a general rule inhibit photosynthesis by interfering with the electron transfer during the Hill reaction (Corbett 1974). The actual mechanism of selectivity between graminaceous species is unknown but is almost certainly related to seed size, depth of seeding and rate of uptake from the soil. The difference in the susceptibility of varieties of winter wheat to some of the compounds, however, suggests that more subtle physiological differences are also implicated. Recent work has indicated that these differences are inherited (Tottman *et al* 1975).

Symptoms

The toxic symptoms produced by the substituted ureas are characteristic of their mode of action in that, where uptake is through the plant roots, leaves become progressively more chlorotic and then necrotic until the plant finally dies. The speed of action is dependent on the solubility of the compound and soil and climatic conditions. In general the more soluble compounds have the greater foliar activity, and this is characterised by a relatively rapid 'contact' effect in which the treated leaves collapse and become necrotic.

LINURON, MONOLINURON AND METHABENZTHIAZURON

Linuron (Chesalin and Kovaleva 1965), monolinuron (Conturier 1963) and methabenzthiazuron (Mulder 1970) have all been found capable of controlling *Avena* spp. selectively in wheat, but none is generally recommended for this purpose because of their unreliable selectivity and/or effectiveness (Gill and Brav 1972, Russel 1968). However Wilson and Hutchinson (1970) found that a mixture of linuron and oxadiazon was safe pre-emergence to potatoes on a range of soils and was effective on *Avena fatua*.

METOXURON

Mode of action

Uptake can occur through both the foliage and the roots. The mode of action is the same as that for other substituted ureas (see above).

Symptoms

The symptoms are typical of a photosynthetic inhibitor–(see above).

Dose

In winter wheat and winter barley doses of 2.4 to 4.8 kg/ha have given fair to good control (50-95%) of *A. fatua* and *A. ludoviciana* with consequent increases in yield. However, control has not generally been improved by increasing the dose above 4.8 kg/ha and on occasions doses of 6.4 kg/ha have failed to control wild oats (Maynadier *et al* 1973, Maynadier *et al* 1971, Catizone 1974, Griffiths 1970, North and Livingston 1970, Bouchet and Faivre Dupaigre 1968, Holroyd and Bailey 1970, Malbrunot 1969, Bouchet *et al* 1969, Griffiths and Ummel 1970a, Proctor and Livingston 1972, Guillemenet 1971b, Bouchet 1969a, and Henaver and Ummel 1972). Similar doses to those used in cereals are used selectively in carrots but although the control of many annual weeds is adequate that of wild oats is variable.

Application factors and formulation

The two standard formulations are wettable powders, one 'flowable', and there appear to be no particular application factors of importance. A microgranule formulation which was tested by Ummel *et al* (1974) showed a similar level of activity to the wettable powder. There was a lack of direct effect on the foliage which was assumed to be compensated for by the increased amount of compound which reached the soil surface. However, although it was less toxic to sensitive cereal varieties it was less reliable.

Environmental factors

Metoxuron has been found to be most effective on the wetter mineral soils (Proctor and Armsby 1974, Griffiths and Ummel 1970a). Activity is low on soils of high organic matter content. However soil pH or calcium ion content has also been found to be important and toxicity has generally been increased on acid soils by the addition of lime (Banting *et al* 1976).

Growth stage of wild oats

Post-emergence treatments have generally been found to be more effective than pre-emergence (North and Livingston 1970, Proctor and Livingston 1972). The best control of *A. fatua* has been achieved at the 2 to 3-leaf stage and of *A. ludoviciana* at the beginning of tillering (Henaver and Ummel 1972, Malbrunot 1969).

Crop tolerance

Many varieties of winter wheat and barley will tolerate metoxuron at doses up to 4.8 kg/ha (Bouchet and Faivre Dupaigre 1968, Griffiths 1970) but some varieties such as Chalk, Heima Desprez, Maris Huntsman, Maris Nimrod, Maris Templar, Mildress etc are sensitive and are not normally treated (Griffiths and Ummel 1970b). The tolerance of spring wheat and barley appears to be variable (Frost 1972) but greater during tillering (Malbrunot 1969, Dufour and de Gournay 1971). The sensitivity and the recovery of susceptible varieties are influenced by soil and environmental conditions and in some instances where weed populations have been high, even susceptible varieties have responded to the removal of weed competition and given satisfactory yields (Malbrunot 1969, Hubbard and Livingston 1974).

Mixtures

A commercially available mixture with simazine has a similar range of susceptible crop varieties and level of activity on wild oats (Ayres *et al* 1972).

Residues

Residues seem to present little problem to succeeding crops when use is at normal doses. A dose of 6 kg/ha has a half life in soil of 10 to 30 days (Martin 1974).

CHLORTOLURON

Mode of action

See above (p. 192) but it is less soluble than metoxuron and entry into the plant is mainly through the roots.

Symptoms

These are typical of a substituted urea (see above).

Dose

Doses of 2.4 to 3.6 kg/ha applied either pre- or early post-emergence have given good control of *A. fatua* and *A. ludoviciana* in winter wheat (Proctor and Livingston 1972, North and Livingston 1970, Proctor and Armsby 1974, Guillemenet 1971, Hubbard and Livingston 1974, Tysoe 1974, Green 1970, L'Hermite *et al* 1969, Smith and Tyson 1970) and increased yields (Maynadier *et al* 1973, Degez *et al* 1971, Maynadier *et al* 1971), but control has not always been reliable (Catizone 1974, Holroyd and Bailey 1970).

Application factors and formulation

The standard formulation is a wettable powder and application factors do not appear to be of particular importance provided that distribution is adequate.

Environmental factors

Like metoxuron it is most effective on the wetter mineral soils (Proctor and Armsby 1974) but heavy rain after application can increase the toxicity to the crop (Smith and Tyson 1970). Soil pH or calcium ion content of the soil has relatively little influence on activity, but the higher the soil organic matter content the lower the activity.

Growth stages of wild oats

Chlortoluron is most effective pre- and early post-emergence up to the 3-leaf stage (Degez *et al* 1971, L'Hermite *et al* 1969, Guillemenet 1973, 1971, Proctor and Armsby 1974, Proctor and Livingston 1972, Maynadier *et al* 1973).

Crop tolerance

Many winter wheat varieties tolerate up to 4.8 kg/ha (Smith and Tyson 1970, van Hiele *et al* 1970) but safety margins decrease after mid-tillering (L'Hermite *et al* 1969, Degez *et al* 1971, Maynadier *et al* 1973). As with metoxuron, some varieties of winter wheat are susceptible and are not normally treated (Smith and Tyson 1970, Van Hiele *et al* 1970, Degez *et al* 1971). However the susceptibility of the particular wheat crop, and its ability to recover, is influenced by the soil and environmental conditions and if heavy weed competition is prevented by the herbicide treatment, yields of even susceptible varieties can be satisfactory (Hubbard and Livingston 1974).

Mixtures

Lhoste *et al* (1971) found that the addition of mecoprop increased the number of broad-leaved weed species controlled.

Residues

There are no references in the literature to residue problems at normal doses and 6 kg/ha is reported to have a half life in soil of 30 to 40 days (Martin 1974).

ISOPROTURON

Mode of action

As for other substituted ureas (see above). Uptake is through both foliage and roots.

Symptoms

Typically those of substituted ureas (see above).

Dose

Isoproturon at 2.5 kg/ha has given moderate to good control (60-100%) when applied pre-emergence to *A. fatua* and *A. ludoviciana* in winter wheat. A lower dose of 2.0 kg/ha has given equally good control when applied post-emergence at up to up to 2 leaves on the wild oats (Proctor and Armsby 1974, Rognon *et al* 1972, Guillemenet 1973). However, selectivity in spring barley was inadequate (Baldwin and Finch 1974).

Application factors and formulation

The formulation most generally used has been a wettable powder and no particular application factors have been reported as important.

Environmental factors

Although there is some activity through the foliage, uptake through the plant roots is the most important and both Proctor and Armsby (1974) and Baldwin and Finch (1974) report that 'adequate' moisture is necessary for a high level of activity. It is also likely that activity will be greater on the lighter rather than the heavier and more organic soils although there are no reports as yet that soil acidity is important as with metoxuron.

Growth stages of wild oats

Like metoxuron, isoproturon has a higher level of activity when applied post-emergence although it seems that the wild oats become more resistant beyond the two to three-leaf stage (Proctor and Armsby 1974, Rognon *et al* 1972).

Crop tolerance

Unlike chlortoluron and metoxuron, isoproturon seems to be tolerated equally by most varieties of winter wheat (Hewson 1974, Hubbard and Livingston 1974, Tottman *et al* 1975). However, Proctor and Armsby (1974) found this tolerance to be somewhat variable, with doses as low as 2 kg/ha reducing the yields in some experiments, particularly in December. Hewson (1974) in contrast found that all the winter cereal varieties being grown in the United Kingdom were unaffected by double the 'normal' doses (5.0 kg/ha pre-emergence and 4.2 kg/ha post-emergence).

Mixtures

No references to the testing of mixtures have been noted in the literature.

Residues

There are no references to residues. These, in any case, are unlikely to be a problem at normal rates.

TRIAZINES

A large number of substituted triazines have been developed as herbicides following the original discovery of simazine (Gast, Knusli and Gysin 1955). They all appear to interfere with photosynthesis, possibly due to inhibition of the Hill reaction (Gysin and Knusli 1958) following uptake by the plant roots. Compounds with a higher solubility in water such as atrazine (70 ppm) can also enter through the foliage.

Of the triazines which have been studied for their potential as selective wild oat herbicides, atrazine and simazine are amongst the most effective, although they are selective in only a few crops. They are similar in mode of action and in the symptoms produced.

Mode of action

Simazine and atrazine interfere with photosynthesis in many species of plants. Gysin and Knusli (1956) observed that seed germination was almost unaffected by the 2-chloro-4,6-(alkylamino)-triazines (which includes simazine and atrazine). Ashton (1965) showed that light was necessary for the herbicidal action of atrazine and the degree of injury was proportional to light intensity. Van Oorshot (1965) established that simazine was tolerated by maize because of its breakdown in the plant and Shimabukuro *et al* (1971) identified the presence of an enzyme in maize which destroyed atrazine. However other crops are marginally more resistant than maize and 'depth protection' (ie the physical separation of the herbicide on the soil surface from the roots of deeper sown plants) can help to maintain or increase any selectivity shown by the relatively insoluble simazine (5 ppm in water). Atrazine is more soluble and, in addition to having more foliar action, is less influenced by 'depth protection'.

Symptoms

Typical symptoms in damaged plants are chlorosis and/or necrosis. Partially affected plants, however, often recover and show a darker green and apparently more vigorous regrowth. Ries, Pulver and Bush (1974) showed that sub-lethal doses of simazine increased the growth and protein content of barley seedlings grown in nutrient solution.

SIMAZINE

Dose

The dose of simazine which will control wild oats under field conditions has been found to be extremely variable. In the United Kingdom, Hayward (1960) reported complete control with 1.7 to 2.2 kg/ha. Gregory (1960) found that 2.2 kg/ha applied pre-emergence in the early winter in a series of trials, gave 79-100% control of *A. fatua* but that treatments applied post-emergence were ineffective. Wilson and Cussans (1970) working in spring and winter beans found that 0.8 kg/ha gave good control in two trials but that in other trials 2.2 kg/ha was only moderately effective. Elliott (1959) and Bradford (1968) in general surveys of usage reported moderate and disappointing degrees of control with 1.0 to 2.2 kg/ha. In France, Longchamp *et al* (1961) and Rognon *et al* (1963) also had variable results.

In North America, Lee (1957) as summariser of fourteen research reports stated that 3.8 kg/ha gave 95% control of *A. fatua*. Other workers (Friesen 1958, Furtick 1958) also confirmed that doses of 2-4 kg/ha were effective. However, Lee (1958) and Sexsmith (1959d) found that activity was increased considerably by incorporation, 1 kg/ha giving excellent wild oat control. However, selectivity in marginally resistant crops was reduced.

Boiko and Petelko (1966) reported that fertilisers increased the susceptibility of *A. fatua* by about 10%. There is no doubt that the dose of simazine which will control wild oats effectively is influenced by a number of environmental factors such as soil moisture, soil organic matter and the depth in the soil from which the wild oats are growing. Unfortunately, any measures which are taken to increase its effectiveness and reliability on wild oats, for example, soil incorporation, tend to reduce its selectivity in crops which are marginally resistant.

Application factors and formulation

The most commonly available formulation of simazine is a wettable powder which is mainly active through the soil. Application factors, apart from a relatively even coverage, tend to be unimportant. Mixing with the soil and soil conditions at the time of treatment can however influence activity as indicated above. Weed control is reputed to be better if application is made to soils with a fine tilth (Fisons 1973d).

Environmental factors

Many authors have reported on the necessity of soil moisture for simazine to be effective. Soil type is also important with activity being reduced on soils of higher organic matter. Gregory (1960) noted that the control of wild oats was best on chalky soils and worst on heavy clay soils.

Growth stage of wild oats

There is a fairly general consensus that pre-emergence or pre-sowing treatments are more effective than those applied post-emergence (Lee 1958, 1957, Friesen 1958, Gregory 1960, Bullen and Hughes 1960), and that plants which have emerged become progressively more resistant.

Crop tolerance

Maize is the only cereal grown under temperate conditions which is almost completely resistant. Vossen (1961) found that 5 kg/ha did not reduce yields and Lee (1957), Friesen (1958), that doses between 2 and 4 kg/ha had no effect. Other cereals such as barley and wheat were generally severely damaged by doses which affected wild oats (Longchamp *et al* 1961, Vossen 1961, Rognon *et al* 1963). Lee (1958) reported that wheat, barley and oats were damaged when sown 10 to 20 days after the application of 2.2 kg/ha of simazine. In the United Kingdom the main crops in which simazine is used are field and broad beans. Doses of 0.5 to 1.0 kg/ha are used, the higher dose on heavier soils. It is also used in horticultural crops such as asparagus, strawberries and top fruit at doses up to 2.2 kg/ha (Fisons 1973d). Potatoes also show some tolerance but this has proved to be to marginal in practice.

Mixtures

Simazine is frequently added to other less persistent herbicides to help to maintain a control of germinating annual weeds but few if any of these mixtures have been directed specifically at wild oats.

Residues

Fryer and Kirkland (1970) in a long-term experiment found that simazine, applied at a dose of 1.7 kg/ha to maize, declined in the soil rapidly during the first 6 weeks; after this period 20-25% of the applied dose could be recovered. These remaining residues declined slowly and 0.07 to 0.14 kg/ha could be detected 23-50 weeks after application. However, under dry conditions residues can persist at relatively high levels and the manufacturers do not recommend sowing oats in the autumn following a spring application to maize (Fisons 1973).

ATRAZINE

Dose

Many reports from several countries state that 1.0 to 2.2 kg/ha will give excellent control of wild oats when applied pre-sowing or pre-emergence (Chesneau and Laborde 1961, Kampe 1967a,b, Chesalin 1962, Sexsmith 1960e). Incorporation of the atrazine pre-sowing seemed to increase its effectiveness (Kampe 1967a,b, Hiebel 1968). Treatments applied post-emergence were less effective and Hiebel (1968) found that doses of 2 to 2.5 kg/ha were required for control at the 2 to 4-leaf stage and 3 to 3.5 kg/ha when the oats were tillering. It is generally recognised that atrazine is more predictable than simazine, particularly under drier soil conditions.

Application factors and formulation

As with simazine, application factors appear to be relatively unimportant as most of its activity is through the soil. However Laborde *et al* (1969) found that a dose of 1 kg/ha + 5 litres/ha of 'oil' increased post-emergence effectiveness so that control of wild oats was satisfactory. Non herbicidal oils have been used commercially in North America to increase the post-emergence activity of atrazine in maize particularly against perennial grasses but few reports refer to control of wild oats.

Environmental factors

Environmental factors, as indicated previously, influence the activity of atrazine somewhat less than that of simazine but its effectiveness can still be considerably reduced in dry soil or on soils of high organic matter content (Fryer and Makepeace 1972).

Growth stage of wild oats

Pre-sowing or pre-emergence treatments have been found to be more effective than post-emergence. Post-emergence resistance increases with age (Hiebel 1968) see above.

Crop tolerance

Most arable crops grown in temperate conditions, with the exception of maize, have little or no resistance to atrazine.

Mixtures

Mixtures of atrazine with other herbicides such as aminotriazole and 2,4-D are used in non-crop situations to increase the effect on perennial grasses but none has been developed specifically for wild oat control. As mentioned above, non-herbicidal oils are used to increase post-emergence activity.

Residues

The problem of residues is indicated by the current recommendation that no crop other than maize or sweet corn should be grown for 18 months after applying a pre-sowing treatment of 4.48 kg/ha; after pre-emergence treatments of 1.12-1.68 kg/ha in spring, wheat, barley or beans, but not oats, may be sown in the following autumn (Fryer and Makepeace 1972).

MISCELLANEOUS

DIFENZOQUAT

Mode of action

Very little published work is available on the mode of action of this herbicide. At present the indications are that it moves along the leaf axil of the wild oat plant, where it is absorbed and passes to the site of meristematic activity at the base of the leaf. However, it is also absorbed by the leaf and is translocated to the meristem. Here, cell division is disrupted and elongation and growth cease (Cyanamid International, technical information 1975). The absorption and movement has been demonstrated with the C^{14} labelled compound (Shafer 1974).

Symptoms

Most authors agree that visible symptoms are not seen on the shoot for several days although they can develop more rapidly in warmer conditions (Cyanamid International, technical information 1975). Inhibition of the leaves and shoots is then seen and later yellowing, chlorosis, necrosis and death occurs (Cyanamid International, technical information 1975, Winfield and Caldicott 1975, Shafer 1974, Richardson and Dean 1974, Friesen and Dew 1972). The growth inhibition is often accompanied by a deeper green coloration of the leaves (Shafer 1974, Richardson and Dean 1974). The latter authors reported an increase in the number of tillers but the development of these was usually arrested. Sometimes these tillers can escape (Friesen and Dew 1972) but generally do not mature by the time the crop is harvested (Gummeson 1975). This last author has also examined the seeds from plants surviving treatment, noting reductions in their size and germination capacity.

A transient yellowing and/or scorch on wheat and barley has also been reported by various authors but these symptoms usually disappear after two weeks (Feeny and Tafuro 1975a,b, Winfield and Caldicott 1975, Vanden Born and Schraa 1974, Cutting 1974, Skorda 1974). Winfield (1974) reported minor height reductions on certain varieties while Richardson and Dean (1974) noted this on spring wheat sometimes accompanied by increased tillering.

Dose

From the available sources it appears that doses of 0.75 to 1.4 kg/ha are optimum for control of wild oats. However, doses as low as 0.56 kg/ha gave useful suppression or even control of the weed (Zimdahl and Foster 1974, Friesen and Dew 1972) while Richardson and Dean (1974) found some effects with doses of 0.125 and 0.33 kg/ha in glasshouse tests. The current recommendation for trials in Britain is 1.0 kg/ha (MAFF STL 1975). Gummeson (1975) reported reductions in plant numbers of 60-96% with doses between 0.8 and 1.2 kg/ha in Swedish field trials. Doses of 0.84 to 1.12 kg/ha caused an 84% reduction in the number of shoots in North America (Strand and Smith 1974).

Several authors, as well as reporting good wild oat control, have also recorded effects on the production of seeds by the wild oat (Baldwin 1973, Winfield 1974, Winfield and Caldicott 1975, Proctor and Armsby 1974, Baldwin and Finch 1974, Gummeson 1975, Gyllensten 1974, Skorda 1974). Assessment of control by counting panicles was found to give very similar results to panicle weights for difenzoquat (Baldwin 1973). Results of several field trials in 1973 and 1974 showed that 0.75 kg/ha reduced *A. fatua* spikelets by 79 to 99%, while 1.0 kg/ha caused 86-100% reductions (Winfield 1974). Earlier trials in four crops in 1972 showed that doses of 0.6 and 0.9 kg/ha reduced the number of spikelets by 71 and 88% respectively. Baldwin and Finch (1974) reported a reduction in panicle dry weight of 98, 93 and 86% respectively after application of 0.75 kg/ha at three successive dates in 1973 and 88 and 93% at 1.12 kg/ha in 1974 in trials in spring barley at various sites. Proctor and Armsby (1974) reported a similar level of effect with 1.0 kg/ha in winter wheat trials. In Sweden, Gyllensten (1974) found that surviving plants developed small and weak panicles with only a few, small seeds. The number of seeds in the panicles was reduced by more than 85% with doses of 0.8 to 1.2 kg/ha. Gummeson (1975) found a similar level of effect. Skorda (1974) also showed that return of viable seed to the soil was greatly reduced.

Application factors and formulation

Difenzoquat can be applied in a wide range of volumes. Good wild oat control in volumes as high as 400 or 500 l/ha applied by ground sprayer and as low as 25 to 50 l/ha applied from aircraft have been reported (Shafer 1974, Gruenholtz *et al* 1974). Feeny and Tafuro (1975a,b) obtained equally good performance with ground application of 47 to 187 l/ha or with application from aircraft at 19 to 94 l/ha. Where the effect of different volumes has been compared, most authors agree that this factor is not critical (Behrens and Elakkad 1974a, Taylor *et al* 1974, Winfield and Caldicott 1975). Behrens and Elakkad (1974a) found no differences in wild oat control when the same dose was applied in 103 or 206 l/ha or when the nozzle was used vertically or at an angle of 45°. Taylor *et al* (1974) found little difference in control of wild oat in volumes of 50, 150 and 450 l/ha while the pressure of application within each of these volumes was not a critical factor. Winfield and Caldicott (1975) found slightly less wild oat control at 100 l/ha than at

200 or 400 l/ha and no effect of pressure at any of these volumes in their field trials in spring and winter wheat. In grower trials however, two pressures of application were compared, when it was found that a pressure range lower than 1.34 bars gave less effective control than a pressure higher than this.

Most of the work to date has been carried out with difenzoquat formulated as an aqueous concentrate containing either 200, 250 or 400 grams active ingredient per litre, but soluble powder formulations have also been tested (Behrens *et al* 1973, Shafer 1974). Application with an ionic surfactant is essential (Shafer 1974) and several of these have been used at varying concentrations by many workers. Shafer (1974) found little difference between 'Agral' 90 and 'Tergitol' TMN surfactants but stated that, with each, wild oat control was better with increasing concentrations. Blank and Behrens (1973, 1974) have studied the effects of difenzoquat with different adjuvants on wild oat control in spring wheat. In the glasshouse, wild oat control was reduced significantly where Surfel was used but injury to wheat was increased significantly by 'Triton' X-100. In the field, control was again significantly reduced by Surfel while both adjuvants caused similar degrees of injury to the spring wheat (Blank and Behrens 1974). When, later, the adjuvants PM-4884, 'Tergitol' NPX, 'Tween' 20 and 'Triton' X-100 were compared, PM-4884 was found to be less effective than the other three. The best results occurred with 'Triton' X-100 (0.5% v/v). Spring wheat injury was similar with all of the surfactants. Amen (1974) found that 'Triton' X-100, 'Tergitol' NPX and X-77 were all adequate as wetters with optimum rates at 0.5 to 0.75% v/v. A concentration of 0.5% v/v 'Triton' X-100 has been used satisfactorily in other work (Behrens and Elakkad 1974a, Lee and Alley 1974, Miller and Nalewaja 1974c,e). The problem of foaming may occur with the use of surfactants and it is claimed that this can be overcome by adding a silicone based anti-foaming agent to the spray mixture at a concentration of 0.005% (Cyanamid International Corporation, technical information 1975).

Environmental factors

Phytotoxicity to wild oat develops more rapidly at high than at low temperatures (Cyanamid International Corporation, technical information, 1975). Gruenholtz *et al* (1974) found temporary crop sensitivity to frost or low temperatures at application. The same authors have reported that rain within five hours of spraying reduces efficacy but that morning dew does not influence the treatment unfavourably. Gyllensten (1974) sugggested that four hours without rain should follow the spraying.

Anderson (1975) found no influence of soil type on activity in extensive field trials in Sweden, but pointed out that this is not surprising as difenzoquat is a foliar acting herbicide. Zimdahl and Foster (1974) found little difference in wild oat control on two different soils, one a clay loam and the other a sandy loam.

Growth stage of wild oats

Control of wild oats over a wide range of growth stages has been found, from the 2-leaf stage to the beginning of shooting (Cyanamid International

Corporation, technical information 1975), from the 1-leaf stage up to tillering (Winfield and Caldicott, 1975) or from the 2 to 6-leaf stages (Shafer 1974). The last author suggested that the optimum stage of growth for treatment was between the 3 and 6-leaf stages and where treatment has been carried out at these stages, control was generally successful (Amen 1974, Baldwin and Finch 1974, Gruenholtz *et al* 1974, Proctor and Armsby 1974, Richardson and Dean 1974, Skorda 1974, Zimdahl and Foster 1974).

Several authors have made direct comparisons of effectiveness at varying stages of growth of the wild oat. Thus Friesen (1972) found that control improved as plants approached the 5-leaf stage, while in early applications developing tillers escaped (Friesen and Dew 1972). Lee and Alley (1974) found greater activity in the 4 to 5-leaf stage rather than the 2-leaf stage. Behrens *et al* (1974) found more effect at the 4-leaf stage than with earlier or later applications, lending support to their previous work (Behrens *et al* 1973) where better control was found at later (2-6 leaves) rather than earlier (1-3 leaves) applications. Catizone (1974) found poorer control of *A. ludoviciana* with early applications than at the recommended 3 to 5-leaf stage. Gyllensten (1974) found that this was the most effective time of spraying in 28 Swedish trials while Gummeson (1974) noted that some recovery of wild oat can occur if sprayed too early.

Feeny and Tafuro (1975a,b) have related optimum treatment levels not only to the growth stage of wild oat but also to their density and the degree of competition offered by the crop. Amen (1974) also said that control was proportional to the degree of wild oat infestation.

Crop tolerance

Considerable work has been done on crop tolerance in barley and wheat (Amen 1974, Anderson 1975, Behrens *et al* 1973, Behrens *et al* 1974, Behrens and Elakkad 1974a, Friesen 1972, Friesen and Dew 1972, Gruenholtz *et al* 1974, Gyllensten 1974, Miller and Nalewaja 1973a,b,c, Miller and Nalewaja 1975, Schafer 1974, Skorda 1974, Winfield 1974, Winfield and Caldicott 1975); spring barley and spring wheat (Richardson and Dean 1974, Taylor *et al* 1974, Anderson 1974, Feeny and Tafuro 1975b, Lee and Alley 1974, Lee *et al* 1974, Strand and Smith 1974, Zimdahl and Foster 1974, Baldwin and Finch 1974, Arnold and O'Neal 1973, Hunter 1974a, Vanden Born and Schraa 1974, Blank and Behrens 1973, 1974, Feeny and Tafuro 1975a, Miller and Nalewaja 1974c); winter wheat (Baldwin 1973, Baldwin and Armsby 1973, Catizone 1974, Livingston and Baldwin 1973, Proctor and Armsby 1974).

It is generally agreed that greater tolerance is found in barley than in wheat (Behrens *et al* 1974, Behrens and Elakkad 1974a, Friesen 1972, Friesen and Dew 1972, Schafer 1974, Winfield and Caldicott 1974, Richardson and Dean 1974, Taylor *et al* 1974). Furthermore there is some evidence that winter wheat is more tolerant than spring wheat (Feeny and Tafuro 1975a, Shafer 1974, Winfield 1974, Winfield and Caldicott 1975) although there are exceptions in certain varieties. Miller and Nalewaja (1975) also point out that large differences in susceptibility among cultivars within a crop (wheat and barley) can occur. Current recommendations in Britain are for spring and winter barley and winter wheat, applying treatments between early tillering and just before jointing commences (MAFF STL 1975).

The possible use of difenzoquat in other crops has also been investigated. Schafer (1974) reported that some varieties of rape, flax and vetch were tolerant but sugar beet was sensitive. Miller and Nalewaja (1974e)found flax resistant, while Behrens and Elakkad (1974b) reported some injury. Oswald and Haggar (1974) found tolerance to difenzoquat in certain varieties of perennial and Italian ryegrass and cocksfoot at 1.0 kg/ha. All were checked at 3.0 kg/ha, however, as was timothy at 1.0 kg/ha. Good tolerance of meadow fescue as well as perennial ryegrass has also been found (Mead *et al* 1973). Darwent (1974) reported tolerance of forage grasses in North American trials. Friesen (1972) found fair to good tolerance of Polish rape but Argentine rape (*B. napus*) was highly sensitive. Bowren (1974) has summarised the work of several authors in rape, several cases of crop damage being recorded.

Mixtures

The possibility of mixing difenzoquat with other herbicides, mainly those used for broad-leaved weed control, has received considerable attention. The manufacturers state that it is compatible with esters of 2,4-D, 2,4,5-T, MCPA, dichlorprop, bromoxynil and ioxynil. Tank mixes of the sodium, potassium or amine salts of these have given reduced wild oat control in some cases, although broad-leaved weed control has been unaffected. A few trials have indicated that control of wild oats is not affected if a minimum interval of one day is allowed between applications of difenzoquat and the broad-leaved herbicides (Cyanamid International Corporation, technical information 1975). Some support for compatibility witb the ester formulations is shown in the work of Gruenholtz (1974), who found that difenzoquat gave good wild oat control when mixed with 2,4-D or MCPA esters. Also, Arnold and O'Neal (1973) obtained decreased effects with the amine salts but esters had no influence on wild oat control.

Some evidence to the contrary however is seen in the work of Miller and Nalewaja (1973a) who reported that dimethylamine salts of MCPA and 2,4-D did not reduce wild oat control, the mixture with 2,4-D even giving some increased effect, while ester formulations of these gave variable control. Several authors have used mixtures of difenzoquat and MCPA or 2,4-D with varying results (Blank and Behrens 1973, 1974, Behrens *et al* 1973, 1974, Anderson 1974, Lee and Alley 1974, Amen 1974, Feeny and Tafuro 1975a,b, Friesen and Dew 1972). Friesen and Dew (1972) found that a 3-way mixture with MCPA and bromoxynil was physically compatible without serious loss of efficiency for wild oat control. Feeny and Tafuro (1975a,b) found that this mixture was compatible giving good selective wild oat and broad-leaved weed control, as did a binary mixture with the bromoxynil. Behrens *et al* (1974) found that a binary mixture with bromoxynil did not reduce wild oat control. A 3-way mixture with MCPA + dalapon worked successfully (Miller and Nalewaja 1974e). Anderson (1974) working with a 4-way mixture consisting of dicamba, mecoprop and 2,4-D found an increased yield of barley and a better weed control rating than with the proprietary mixture of the 3 broad-leaved weed herbicides alone ('Kilmor') in a situation consisting mainly of broad-leaved weeds but with no wild oats present.

Mixtures of barban and difenzoquat have been investigated in North America. Behrens *et al* (1974) reported that addition of barban did not increase wild oat control. Banting (1974) summarised several reports where synergism had occurred. Miller and Nalewaja (1973c) found that barban and difenzoquat combinations applied at the 4-leaf stage or as a split application (of barban at the 2-leaf and difenzoquat at the 4-leaf stages) gave good control at one location but was variable at another. A 3-way combination of difenzoquat, barban and benzoylprop-ethyl generally gave good control of wild oats, but both barley and wheat were injured. Crop tolerance studies of a binary mixture with barban have also been carried out. Hunter (1974a) found greater yields of wheat grain with this mixture than with difenzoquat alone, while Vanden Born and Schraa (1974) reported no significant differences in the yield of five wheat varieties when treated with difenzoquat alone or mixed with barban.

Gruenholtz *et al* (1974) reported that difenzoquat was compatible with the insecticides malathion and dimethoate and also with chlormequat and foliar fertilisers.

Residue risks

Difenzoquat is not metabolised in plant or soil, therefore analytical methods for residues only detect the parent compound. Residues in wheat and barley grains at harvest, following application at the recommended time, are usually below the sensitivity of the method (0.05 ppm). Residues in wheat and barley straw at harvest range from 0.5 to 0.1 ppm (Cyanamid International Corporation, technical information 1975). In residue tests in Sweden, the levels detected in grain were less than 0.05 ppm (Gyllensten 1974).

In the soil, it is not degraded by microflora nor does its presence have any apparent effect on soil micro-organisms. However, it is photodegradable and this accounts for its disappearance from the soil under field conditions. Rate of disappearance studies in soil showed that following application in 5 field experiments in the USA, 50% or more had been degraded within 3 months. No significant amounts were found in the layer 7.5 to 15 cm deep. After 6 months, surface layer residues were not detected in 2 trials and were low in the other 3, the maximum being 0.3 ppm (Cyanamid International Corporation, technical information 1975).

Control of other Avena *species*

Avena ludoviciana, A. sterilis, A. barbata and *A. macrocarpa* are said to be sensitive, as well as *A. fatua* (Cyanamid International Corporation, technical information 1975). Shafer (1974) reported control of *A. fatua, A. sterilis* and *A. ludoviciana* at doses between 0.6 and 1.2 kg/ha. Catizone (1974) found artificially seeded *A. ludoviciana* to be well controlled.

Jorgenson *et al* (1974) found that difenzoquat gave equally good control of wild oat plants raised from seeds which had been categorised according to colour (grey, brown, light brown and white).

EFFECTS OF CHEMICALS ON SEEDS

Herbicides and plant growth-regulators may affect seed production and seed behaviour. The effects on seed production have been difficult to delimit satisfactorily. Thus, herbicides, which are designed to kill the weed, must inevitably prevent or reduce seeding. Only those instances where chemicals do not necessarily kill the weed, yet do affect seed production have been included. It is remarkable that, although so much has been published on the effects of chemicals on plants, very little has been written about their effects on the seeds produced by the surviving plants. On the other hand, the testing of plant growth-regulators on germination, dormancy and even longevity of weed seeds, which has also a limited literature, is only a recent development and one that may yet prove to be extremely useful in weed control.

The review also embraces the herbicide glove with which chemicals are applied directly to the flowering panicles, with the sole object of preventing the production of viable seed, either by preventing seed formation or rendering any seed produced non-viable.

The more recent literature makes only limited reference to the effect of the newer herbicides such as benzoylprop-ethyl on the dormancy of wild oat seed produced (see under the chemicals concerned). It is difficult on occasion to determine from publications whether seeds have been killed or merely rendered dormant by the treatment given; similarly whether the author has equated viability and germination (see Glossary). When in doubt, the original terminology has been used.

The effects on seeds of herbicides and of plant-growth regulators other than gibberellic acid are reviewed below. The effects of other chemicals, including gibberellic acid, are reviewed in Chapter 3, Seed Behaviour. A total of 30 publications have been referred to in this section. There have been no previous reviews on this aspect.

EFFECTS OF HERBICIDES AND PLANT GROWTH REGULATORS ON SEED PRODUCTION

Knowles (1953) was the first to report reduced seed production of wild oat plants after treatment with a selective herbicide. Almost complete sterility was produced in various cereal crops and wild oats (*Avena fatua*) by spraying with maleic hydrazide at 1.12 kg/ha before the heads had emerged. However, the same dose, applied when wheat and barley had been 'in head' six days and wild oats and cultivated oats were in the 'shot blade' stage, had no effect on wheat grain yields and yet rendered both oat species more or less sterile. Flax was intermediate with 40% of the heads sterile. Seed from treated plants was subsequently tested for viability and, whereas flax and barley were unaffected, wheat germination was reduced from 92 to 9%. These results suggested that useful selectivity might be obtained in barley. Further experiments were carried out by others with somewhat similar results, but wild oats produced some seed and there was uncertainty as to whether these were dead or merely dormant (Helgeson 1955). In Britain, attempts with maleic hydrazide to induce sterility selectively in wild oats in barley caused crop damage at concentrations which reduced the viability of wild oats to less than 50% (Thurston 1956b). One of the problems has proved to be the extended period over which wild oat panicles can emerge, particularly if the growth of the main shoot is checked, and the relatively short period during which individual panicles are susceptible (Holroyd, unpublished).

Dalapon at 4.48-6.72 kg/ha was also found to affect seed production. Treatments applied at growth stages up to 'fully tillered' reduced heading, but applications at the 'boot' stage allowed viable seed to form (Andersen and Helgeson 1954, Helgeson 1955). Later work in which doses of 0.56, 2.24 and 6.72 kg/ha of dalapon were applied at growth stages between 'late jointing' and 'early dough' showed that the seeds produced by treated plants generally gave rise to seedlings, but these did not survive long. Two to eight per cent of the seedlings from plants treated with 6.72 kg/ha survived 5-6 weeks (Andersen and Helgeson 1958). This confirmed an observation made by Southwick (1955). (Further reference is made to this on p. 148).

A number of compounds such as fluoro-phenoxyacetic acid salts and cacodyllic acid have been found to prevent seed formation in the flowering heads of grasses (Andersen and McLane 1958). However, the small amount of work which has been done with wild oats suggested that although seed formation could be prevented, timing of the application was very critical. For maximum effect the fluoro-phenoxyacetic acids had to be applied just after jointing and cacodyllic acid at anthesis. Wheat and barley were similarly affected and there was little or no selectivity (Holroyd, unpublished). Stevens (1966) also found that seed production by many plants could be reduced by dimethyl-arsenic acid (cacodyllic acid) and suggested that this was due to sterilisation of the pollen or the ovum.

Herbicides used for the control of wild oats may prevent seed production by killing the plants or the seedlings as they emerge, but some like barban exert their control by checking and stunting growth. This check may be only temporary and in the absence of crop competition affected plants can survive and recover to produce seed. Good control and reduction of seed production therefore depend largely upon a high degree of crop competition. This aspect is discussed in detail in Chapter 7, Cultural Control, and under individual chemicals in the present chapter.

Treatments of 2,4-D, MCPA and 2,4,5-T at doses of 1.12-5.6 kg/ha have resulted in seed production varying between 36 and 147% of control (Aamisepp 1959), but this is probably not significant.

DNOC has been found to increase mean wild oat seed production by 20% above untreated controls when used in cereals (Mullverstadt 1966), but even this may have been due to the elimination of competition by dicotyledonous weeds.

HERBICIDE GLOVE

The recent development of the herbicide glove (Holroyd 1973a,b) allows the localised application of a non-selective herbicide to the flowering heads of wild oat plants as soon as these can be distinguished in the crop and are tall enough to be treated easily.

The technique is to grasp the flowering shoot of the wild oat plant with the glove, thereby transferring herbicide from the absorbent pad on the palm of the glove to the wild oat. A dye helps the operator to distinguish the treated plants. The amount of liquid applied is relatively small (between 0.25 and 0.75 ml per panicle (Holroyd 1972b) but, according to the herbicide used, either the whole plant is killed or any seed produced is non-viable. As a general rule, the earlier treatments are applied, the fewer seeds are produced. Highly active phytotoxic compounds, which kill the whole plant, will, applied before the 'milk stage', generally prevent any seed production. With this technique, contamination of any surrounding crop is minimal.

Compounds which have been tested for their effects on seed formation and viability include dalapon (sodium), dalapon (ester), activated aminotriazole, TCA, sodium cacodyllate, paraquat, diquat, sodium chlorate, chlorpropham, propham, propyzamide, nitrofen, tri-allate, trifluralin, chlorfenprop-methyl, EPTC, maleic hydrazide, propionic acid, 2,4-D (iso-octyl ester), carbetamide, ethrel, fluorodifen, MSMA, DSMA, alachlor, chlorthiamid, cyanazine, ethofumesate, sodium 2,2,3,3–tetrafluoroproprop ionate and glyphosate (Holroyd 1972a,b, May 1972).

Allowing for possible toxic hazards to the operator, the most satisfactory proved to be glyphosate and dalapon (sodium). Treatment of panicles at the milk, soft or hard dough stage with 10% w/v glyphosate in water was found to prevent the formation of any seed capable of producing healthy plants. Dalapon (10 and 15% w/v) was slightly less effective, mainly because of viable seeds produced by secondary untreated panicles.

EFFECTS OF HERBICIDES AND PLANT GROWTH REGULATORS ON SEED VIABILITY, DORMANCY AND GERMINATION

In most tests with maleic hydrazide, the chemical was applied when the seeds were at the milk stage. A variety of doses were used and the results were inconsistent, seed kill varying from partial to complete. Shebeski (1954) reported that germination of *A. fatua* was prevented and Friesen (1955a) that the seed was rendered sterile if sprayed with maleic hydrazide. Doses of 0.56, 0.84 and 1.12 kg/ha used by Leggett (1955a,b) gave reduction in germination of wild oats. Carder (1955, 1959d) found 0.56 kg/ha reduced viability by 98 and 95%. Hay (1955) reported that, although there was 97 and 98% reduction of germination by 0.56 and 1.12 kg/ha, only 65% reduction was obtained with 0.28 kg/ha. In Britain only 45% reduction in viability was produced by 1.68 kg/ha and 17% by 0.84 kg/ha (Thurston 1956b).

Most applications were made at the milk stage (Carder 1955, 1959, Friesen 1955, Hay 1955, Leggett 1955). Thurston (1956) showed for both *A. fatua* and *A ludoviciana* that, when fully opened panicles were sprayed, the number of viable seeds produced was less than one third of the controls. However, it is emphasised by Dunham (1955) that the critical stage for application is only 4-7 days long–between the 'milk' and 'early dough' stages–and this, combined with its doubtful selectivity, makes it impracticable.

Dalapon, when it does not kill the plant, frequently allows seed production. The seed often appears normal and viable (Dunham 1955, Southwick 1955, Andersen and Helgeson 1958, Raynor 1958); but the seedlings are very frequently retarded and deformed and do not develop beyond the coleoptile stage (Andersen and Helgeson 1955, Dunham 1955, Southwick 1955, Raynor 1958). Unlike maleic hydrazide the timing of application of dalapon for its effects upon seeds and seedlings is not at all critical (Raynor 1958); but in most instances the chemical has been applied between the jointing and early dough stages (Dunham 1955, Southwick 1955, Andersen and Helgeson 1958). The minimum dose necessary to cause seedling deformities appears to be about 2.24 kg/ha (Raynor 1958) and above (Dunham 1955). At 0.56 kg/ha no seedling deformity was found (Andersen and Helgeson 1958).

The effects of barban upon seed dormancy, viability and germination have been virtually unstudied, although it is one of the most widely-used chemicals for wild oat control. One investigation has shown that labelled barban applied to the axils of the first leaves of seedlings did not persist as residues in the seeds formed by the treated plants (Foy 1961). Whether dormancy or viability was affected is not known.

Although 2,4-D, MCPA and other similar compounds have relatively little effect upon wild oat plants, Loomis (1954) reported a 20-30% reduction of seedling emergence by 5.6 kg/ha of 2,4-D, MCPA and 3,5-D sprayed onto seeds in boxes of soil. 2,4,5-T at the same dose had little effect. 2,4-D and MCPA inhibited growth of the seminal roots, but not of the later developing crown roots, so that most of the seedlings survived. With 2,4-D all the roots were inhibited and no seedling developed beyond the 1-leaf stage. Aamisepp (1959) found that 2.8 kg/ha of 2,4-D, MCPA and 2,4,5-T applied to *A. fatua* seeds in petri dishes had little effect upon germination, but that 5.6 kg/ha increased germination to various degrees. Whether these conflicting reports indicate toxic effects in one instance and dormancy breaking in the other is not known.

Propham at 10 kg/ha has been found to reduce greatly the germination of non-dormant seed, but has little effect upon dormant seed (Hahlin 1959). Rydrych and Seely (1964) testing propham at doses between 2.24 and 6.7 kg/ha, found that only at 3.36 kg/ha did the chemical differentiate between 'resistant' and 'susceptible' strains of *A. fatua*. Resistance apparently varied with time of year. Strains with mostly dormant seed were more susceptible than mainly non-dormant ones (cf Hahlin 1959) which the authors suggest removes the risk of selecting a more resistant strain by repeated treatment.

Seeds of wild oats subjected to di-allate vapour had their germination progressively reduced by increasing length of exposure between 2 and 6 days (Friesen and Henn 1962). The effect was not diminished by storing the seed for up to 13 weeks before sowing and the authors conclude that this indicates that the vapour can affect dormant seed. This was presumably enforced dormancy.

A report by Koopman and Daams (1960) states that dichlobenil inhibits seed of *A. fatua* at doses between 0.5 and 4 kg/ha, although whether this was kill or induced dormancy is not clear.

Indole-3-acetic acid (IAA) has been tested on ripe seeds in petri dishes and found possibly to decrease germination slightly at 10 and 100 ppm (Chancellor and Parker 1972). Naphthyl acetic acid (NAA) and potassium gibberellate, applied to the base of spikelets, slightly to greatly retarded abscission of the spikelets (Helgeson and Green 1957), but no investigation of their effects upon the seed was made.

Kinetin (6-furfurylaminopurine) at 1, 10 and 100 ppm has increased germination of wild oats slightly (from 5% to 13-18%), but a number of other growth-regulatory compounds showed no obvious inhibition or stimulation of germination (Chancellor and Parker 1972). Ethephon (2-chloroethylphosphonic acid), which has increased the germination of several other weeds with large proportions of their seeds dormant, has proved completely ineffective on wild oats at 1-100 ppm (Chancellor *et al* 1971).

Reports of the stimulatory action of gibberellic acid on the germination of wild oat seed have been reviewed in Chapter 3.