PARAQUAT, PEROXIDE AND SUPEROXIDE

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Summary The reaction between paraquat radical and oxygen has been investigated by electron spin resonance and by pulse radiolysis, and rate constants for reaction between paraquat radical and both oxygen and superoxide ion ($O_2^{-\cdot}$) have been determined. Calculations based on these show that superoxide ion should be formed inside photosynthesising chloroplasts in a paraquat-treated plant, and should be stable enough to diffuse to the chloroplast envelope, which is the first site to show visible damage as a result of paraquat treatment. Superoxide ion should initiate peroxidation of unsaturated lipids in the membranes of the chloroplast and cause their partial oxidation to malondialdehyde, as observed in treated plants. It is the most likely candidate for the assumed phytotoxic product which paraquat causes to be formed in plants.

Résumé On a examiné la réaction entre le radical de paraquat et l'oxygène par RPE et par le pulse radiolysis, les constantes de taux étant determinées pour cette reaction et pour celle entre le radical de paraquat et l'ion superoxyde ($O_2^{-\cdot}$). Nos calculs fondés sur ces résultats montrent que les ions superoxydes doivent se former dans les chloroplastes de photosynthèse d'une plante traitée avec paraquat. Ces ions doivent être assez stable pour diffuser jusqu'à l'enveloppe du chloroplaste, l'endroit où on voit les premiers dégâts occasionnés par un traitement de paraquat. Les ions superoxydes doivent y initier la peroxydation des lipides insaturées de la membrane en donnant le malondialdéhyde qui se trouve dans les plantes traitées. Les ions superoxydes sont les candidats les plus probables pour les produits phytotoxiques supposés d'être générés par l'action de paraquat dans une plante verte.

INTRODUCTION

The primary events which cause paraquat to act as a herbicide are well established. (For a recent review see Corbett (1974).) The consensus is that paraquat is reduced in chloroplasts to its radical, which then reacts with oxygen and forms a phytotoxic reduction product, while the paraquat is regenerated. This paper is concerened with the nature of the phytotoxic product formed from paraquat radical and oxygen.

Paraquat radical behaves as a 1-electron reducing agent. It should therefore reduce oxygen by a series of 1-electron steps until the oxygen reaches the oxidation level of water. Allowing for the intervention of protons where necessary, the reactions result in the formation of superoxide ion ($O_2^{-\cdot}$), hydrogen peroxide and hydroxy radical as intermediates.

$$PQ^{+\cdot} + O_2 \xrightarrow{k_1} PQ^{++} + O_2^{-\cdot}$$

$$PQ^{+\cdot} + O_2^{-\cdot} \xrightarrow{k_2} PQ^{++} + O_2^{--} \xrightarrow{2H^+} H_2O_2$$

$$PQ^{+\cdot} + H_2O_2 \xrightarrow{k_3} PQ^{++} + OH^- + HO^\cdot$$

$$PQ^{+\cdot} + HO^\cdot \xrightarrow{k_4} PQ^{++} + OH^- \xrightarrow{H^+} H_2O$$

Two of these intermediates, $O_2^{-\cdot}$ and $HO^\cdot$ are highly reactive radicals, the steady-state concentration of which will depend on the rate contstants k_1 to k_4. Measuring these should allow the concentrations to be calculated. Alternatively, electron spin resonance could be used to look for the radicals.

METHOD AND MATERIALS

Electron spin resonance (ESR) spectra were recorded on a Varian E-4 EPR spectrometer fitted with a flow-through cell. Streams of liquid from two reservoirs could be mixed immediately before entering the cell, and the ESR signal observed about 1/50 sec. after mixing. The reservoirs normally contained a solution of paraquat dichloride (10^{-3}M) partially reduced with either zinc or sodium dithionite, and oxygenated water, respectively.

Rate constants were estimated by analysis of the decay curves for paraquat radical generated suddenly in a solution containing a low concentration of oxygen (3×10^{-5}M). The pulse radiolysis equipment used for this was as described by Farrington et al. (1973). The radical was generated by firing a short (< 1µ sec) pulse of high-energy electrons into the solution, which contained paraquat dichloride at 10^{-3} M and sodium formate at 10^{-1} M. Under these conditions, the formation of paraquat radical ($\sim 10^{-4}$ M) was complete within 10 µ sec. Its subsequent decay as it reacted with oxygen was monitored by its UV absorbance at 396 nm.

RESULTS

ESR experiments

Paraquat radical solution, produced by partial reduction of paraquat solution with either zinc or sodium dithionite, gave a multi-line ESR spectrum similar to that described by Johnson and Gutowsky (1975). When a small proportion of oxygenated water was mixed in with the solution before it entered the ESR cell, the intensity of the signal was reduced, but no new signal appeared. The proportion of oxygenated water was increased stepwise until the mixed solution became colourless, and beyond, but no new signal could be detected. The result was the same at pH 2 (acetic acid added, and zinc used as the reducing agent) and at pH 10 (sodium carbonate added, and sodium dithionite used as the reducing agent).

Kinetic experiments

The decay curves for the disappearance of paraquat radical produced in a solution containing oxygen were anaylsed in terms of the two consecutive reactions

$$PQ^{+\bullet} + O_2 \xrightarrow{k_1} PQ^{++} + O_2^{-\bullet}$$

$$PQ^{+\bullet} + O_2^{-\bullet} \xrightarrow{k_2} PQ^{++} + O_2^{--}$$

The best values of k_1 and k_2 were found by simulating the kinetics on a digital computer and adjusting the guessed values of k_1 and k_2 until the best fit to the experimental curves was obtained. The mean values were $k_1 = 7.4 \times 10^8\ M^{-1}\ sec^{-1}$ and $k_2 = 1.3 \times 10^9\ M^{-1}\ sec^{-1}$.

DISCUSSION

Of the three possible candidates, $O_2^{-\bullet}$, H_2O_2 and $OH^{\bullet}$, for the phytotoxic reduction product of oxygen, only H_2O_2 has previously been shown to be formed in paraquat-treated chloroplasts (see Corbett 1974). Evidence for $O_2^{-\bullet}$ and $OH^{\bullet}$, even if these are formed, would be very much harder to obtain, and the present ESR studies show that even under the most favourable conditions, neither of these two radicals can be observed in solution. However, because they are so reactive, even a very low concentration might be sufficient to cause membrane damage, which is all that is required to bring about the observed desiccation effects of paraquat in plants (Dodge 1971). To do this, however, the concentration of reactive radical must not have decayed to zero before it reaches the membrane. In case of hydroxy radical this is likely to have happened. Hydroxy radical, it is assumed , is formed by the action of paraquat radical on hydrogen peroxide. Its rate of formation is given by the rate at which paraquat reacts with H_2O_2, and this is very slow (White 1971). At the same time it disappears by reaction with more paraquat radical. By analogy with the rate constants for reaction of $PQ^{+\bullet}$ with O_2 and $O_2^{-\bullet}$, the rate constant for this disappearance is expected to be at least $10^8\ M^{-1}\ sec^{-1}$, whereas the rate constant for the formation of $HO^{\bullet}$ is $2.3 \times 10^3\ M^{-1}\ sec^{-1}$ (Thorneley 1974). The ratio of these two, multiplied by the concentration of hydrogen peroxide, gives the steady state concentration of $HO^{\bullet}$, which clearly must be very small indeed.

If the same argument is applied to superoxide ion, the steady-state concentra - tion works out at 8×10^{-5} M when the solution is saturated with air. It is therefore not surprising that no ESR signal for $O_2^{-\bullet}$ was observed, since in the time between mixing and entering the cavity of the spectrometer the concentration would have fallen, due to the very fast reaction of $O_2^{-\bullet}$ with itself (Baker <u>et al</u>. 1970), to a level below the detection limit of the instrument.

What is more relevant is the concentration of superoxide ion at the chloroplast envelope. This can be calculated assuming a steady state has been reached in which both paraquat radical and oxygen, in a molar ration of 4:1,are being generated by photosynthesis inside the chloroplast, and are diffusing outwards. The calculation shows that the concentration of paraquat radical falls off very rapidly from the point at which it encounters the oxygen, being reduced to less than 1% of its initial concentration in 3 µm. On the other hand, the concentration of superoxide ion remains almost constant, at about 1 µM, for distances of 10 µm, or more. It should therefore be able to reach the chloroplast envelope, the chloroplast being some 20 µm across, and if it can cross it, it could diffuse out as far as the tonoplast.

Accepting, then, that both superoxide ion and hydrogen peroxide can reach the membranes which are the first sites to be attacked, which is the more likely to cause the effects observed? Hydrogen peroxide is a mild oxidant and a very powerful nucleophile, but the unsaturated lipids in the membranes would not appear to offer much scope for attack. On the other hand, superoxide ion, being a reactive radical, should abstract hydrogen atoms with great ease, forming HO_2^-, the anion of hydrogen peroxide. The radicals left behind could either dimerize or could react with oxygen, resulting in peroxide formation. Both of these reactions would disrupt the molecular organization of cell membranes. They would be especially significant for unsaturated hydrocarbon chains, which occur in lipids, since the radicals formed by hydrogen abstraction are stabilized by resonance:

$$-CH_2CH{=}CH- \longrightarrow -\dot{C}H{-}CH{=}CH- \longleftrightarrow -CH{=}CH{-}\dot{C}H-$$

Paraquat is observed to cause the formation of malondialdehyde (Baldwin et al. 1968), which is one of the products of peroxidation of lipids (Tam and McCay 1970). Chemical evidence would therefore favour superoxide ion over hydrogen peroxide as the primary toxicant formed by paraquat, in line with the suggestion by Kosower and Kosower (1969) that $HO_2^{\cdot}$ (the protonated version of $O_2^{-\cdot}$) is responsible for the lysis of red blood cells by the azoester PhN=N-COOAc in the presence of oxygen.

The implication of this study is that other compounds with the same mode of action as paraquat could arise in series other than the bipyridyls if the compound were reducible to a stable free radical, could interact with an electron carrier in the electron transport chain of photosynthesis to form this radical, and if the radical could then transfer its electron to oxygen to form a significant concentration of superoxide ion. The additional requirement is that the compound must be able to get to the point where all these reactions take place. With such a list of requirements it is perhaps not surprising that as yet we have not found another such compound.

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Proceedings 1976 British Crop Protection Conference - Weeds

HERBICIDES WHICH AFFECT PROTEIN SYNTHESIS IN PLANTS

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Summary Although little is known about the precise mode of action of herbicides at the molecular level, an inhibition of the fundamental process of protein synthesis is implicated in the activity of several different groups of herbicides. In only a few cases, however, is there good evidence that protein biosynthesis is the primary target. Work with the anilinopropionamide MDMP, and to some extent with propachlor, has indicated that, with the application of the newer techniques of biochemistry, an understanding of the mode of action of herbicidal protein synthesis inhibitors can be approached.

INTRODUCTION

In this paper it is not intended to give a comprehensive catalogue of all herbicides known to inhibit plant protein synthesis. Rather, it is proposed to illustrate, with a few examples, some of the problems and challenges involved in establishing whether or not a herbicide kills a plant by blocking its ability to synthesise protein.

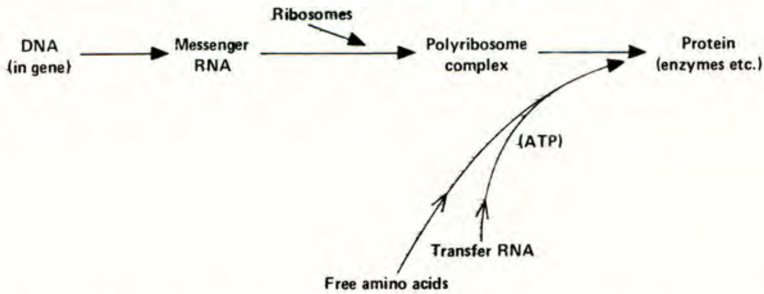
Despite the increasing use of herbicides in farming practice throughout the world, relatively little is known about how these chemicals actually work. It is true that often a herbicide is known to have drastic effects on, say, respiration or photosynthesis, but rarely is there a sound understanding of how the compound is acting at the molecular or macromolecular level. In the design of novel herbicides there is almost invariably a gulf between the biochemist, struggling to comprehend a complex of life-processes, and the synthetic chemist, wishing to know how to tailor his molecules to influence plant growth in an agronomically useful way. At this time, when the precision of the selective effect of chemicals on plant species is becoming critical, and when the environmental consequences of chemical application are so important, it is unfortunate that we remain so ignorant of the mechanisms by which our herbicides exert their effects.

PROTEIN SYNTHESIS: PROBLEMS AND MECHANISMS

There are many problems involved in elucidating the mode of action of a herbicide. For example, the compound may be modified by the plant so that the actual herbicidal chemical is not the one which was originally applied. A compound, even if not metabolised, may have several modes of action which operate simultaneously. Furthermore, one inhibitory effect may result from the inhibition of a related process, not itself directly affected by the compound. Since protein synthesis is such a central and essential process to all living organisms, the problems involved with this process are perhaps particularly difficult.

Growth and differentiation in plants, as with all living organisms, is dependent on a continual supply of the enzymes (proteins) needed to catalyse the essential processes of life. The 'blueprint' for a given enzyme is housed in the base-sequence of DNA, a nucleic acid which constitutes the substance of genes (Fig. 1). When a particular enzyme is needed, a smaller nucleic acid, whose constituent bases are complementary to those of the gene DNA, is synthesised. This 'messenger' RNA moves into

Fig. 1 Sequence of protein synthesis



a different compartment of the cell, where it combines with ribosomes to form the polyribosome complex on which the enzyme can be synthesised. Before a given amino acid can be linked to the partly-formed protein, it is combined with another species of nucleic acid, 'transfer RNA'. Each transfer RNA species is specific for one of the twenty or so amino acids found in proteins and is also able to recognise the sequence of three bases in the messenger RNA which is equivalent to the amino acid it has 'activated'. By this means, as the ribosomes move along the messenger RNA, the amino acids are linked in the order necessary to give the protein its enzyme activity. Several of the steps involved in the process depend on an input of energy, usually supplied in the form of adenosine triphosphate (ATP).

Protein synthesis in plants can be studied by incubating segments of plant tissue with a radioactively labelled amino acid, and, after a suitable period of time, measuring the amount of radioactivity in the protein isolated from the tissue. Herbicides can be added, at meaningful concentrations, and their effects examined. Mann et al. (1965), using this approach, found that four herbicides out of twenty-three tested inhibited amino acid incorporation in barley and a legume. Moreland et al. (1969) found that thirteen out of twenty-two herbicides tested against soyabean inhibited amino acid incorporation into protein. Their findings, summarised in part in Table 1, illustrate that this type of inhibition can be observed in a range of different types of herbicides, although sensitivity can vary with experimental conditions and plant species used.

Although a positive result with this kind of assay is a step towards establishing protein synthesis as the target system, a major snag, fully recognised by the authors mentioned, is that amino acid incorporation can be affected by many processes. These include amino acid uptake by the tissue, nucleic acid synthesis, respiration and photosynthesis (the last two supplying ATP) (Fig. 1).

Despite this type of problem, progress can be made, and in two particular ways. The first is by the separation of the processes in time. If process A is inhibited in a tissue before any effect on process B is observed, then it is unlikely that B is the primary site of the inhibitor. The second is through the isolation of the processes in space by the establishment of cell-free systems which comprise only part of the system under study, and on which the effect of inhibitors can be examined in the absence of dependence on other processes.

Table 1

Some herbicides which affect protein synthesis, as measured by the incorporation of radiolabelled amino acids into proteins of plant tissue segments

Herbicide		Plant species		
Group	Name	Barley[1]	Sesbania[1]	Soyabean[2]
α-Chloroacetamides	CDAA	+	+	0
	Propachlor	-	-	+
Carbamates	CIPC	+	+	+
Thiocarbamates	CDEC	0	0	+
Benzonitriles	Ioxynil	+	+	+
	Dichlobenil	0	0	+
Nitrophenols	Dinoseb	-	-	+
Amides	Propanil	0	0	+
Auxins	2,4,5-T	-	-	+
Phenylureas	Diuron	-	-	+
Miscellaneous	Fenac	-	-	+
	Endothal	0	+	-
	Pyrichlor	-	-	+
	Karsil	-	-	+

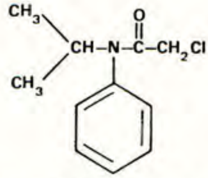
+ = Inhibition   0 = No inhibition   - = No data
[1]From Mann et al. (1965) [2]From Moreland et al. (1969)

PROPACHLOR AND MDMP

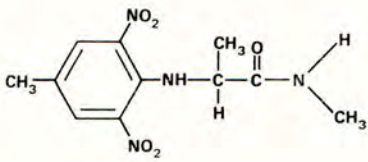
Some recently published work of Duke et al. (1975) can be used to illustrate these methods. These workers studied the effects of the α-chloro-acetamide, propachlor (Fig. 2) on various biochemical processes in the roots of cucumber seedlings. Using radiolabelled precursors and excised tissue, they were able to show that inhibition of amino acid incorporation occurred before inhibition of apparent RNA synthesis (Fig. 3). Use of cell-free preparations enabled them on one hand to eliminate ATP supply and respiration as likely target systems and on the other to narrow down the site of action to a process involved in the presentation of the amino acid to the protein chain being formed on the polyribosome.

By way of further illustration of the use of cell-free systems in the elucidation of herbicide mode of action, some aspects of the work with the experimental preemergence herbicide MDMP [2-(4-methyl-2,6-dinitroanilino)-N-methyl propionamide, WL 19511], (Yates, 1968) can be discussed. The compound (Fig. 2) does not affect respiration, ATP synthesis, photosynthesis or the amino-acid-tRNA interaction. It does inhibit the incorporation of amino acids into the protein of soyabean hypocotyl segments, an effect observed by Moreland (private communication) and confirmed by Kerr and Avery (1972). A typical inhibition/concentration curve is shown, for wheat embryos, in Fig. 4. At first it was supprising to find that polyribosomes isolated from wheat, although able to incorporate amino acids, were insensitive to MDMP (Fig. 5).

Fig. 2 Structures of propachlor and MDMP



Propachlor (2-chloro-N-isopropylacetanilide)



MDMP [2-(-4-methyl-2,6-dinitroanilino)-N-methyl propionamide]

Fig. 3 Rate of inhibition of protein and RNA synthesis in excised cucumber roots by propachlor (5 μg/ml)

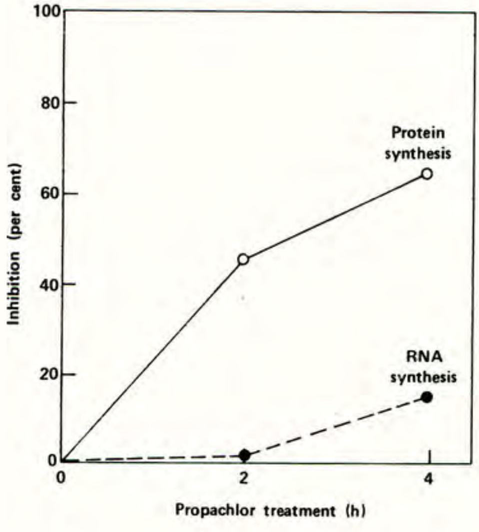


Fig. 4 Inhibition, by MDMP, of amino acid incorporation into the protein of excised wheat embryos

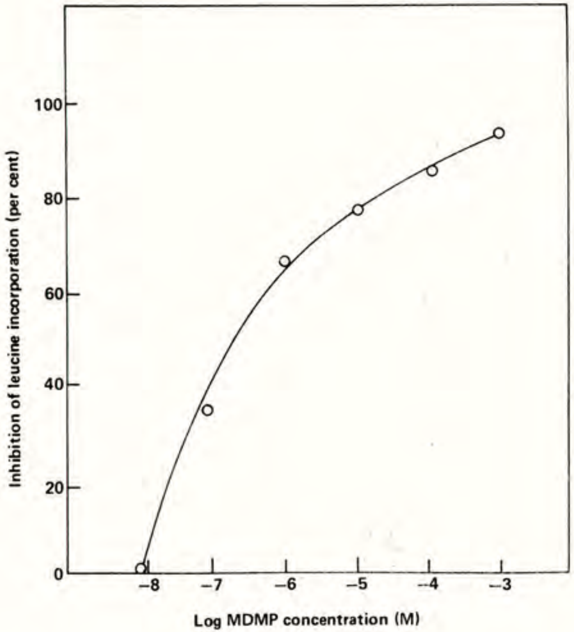
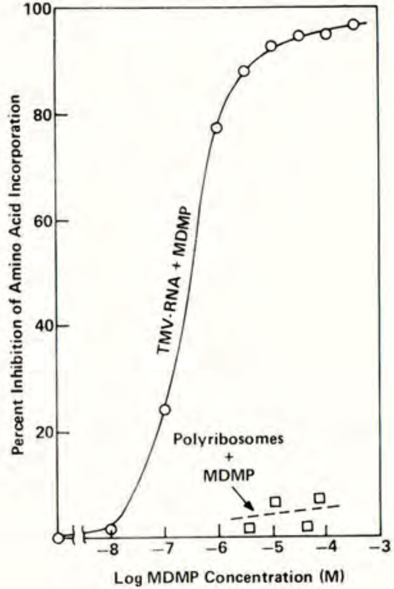


Fig. 5 Effect of MDMP on TMV-RNA-dependent and polyribosome-dependent amino acid incorporation by a cell-free preparation from wheat embryo



However, when messenger RNA (in the form of tobacco mosaic virus RNA, endogenous plant messenger RNA being impossible to isolate at the time) was added, so that the polyribosomal complex had to be formed before protein synthesis could begin, then the incorporation became sensitive to MDMP (Fig. 5). From these results it seemed that the inhibitor, although unable to prevent the incorporation of amino acids into proteins actually in the process of being formed on the polyribosomal complex, did act by preventing the initiation of new proteins.

Subsequent biochemical investigation has not only confirmed the initiation of protein synthesis to be the region of action for MDMP, but has pinpointed the stage of the stepwise formation of the polyribosome complex at which the inhibitor exerts its action (Weeks and Baxter, 1972). In all cases, the concentrations of MDMP required to achieve inhibition in vitro were of the same order as those needed to bring about pre-emergence herbicidal effects in the greenhouse. This strongly suggested that the inhibition of protein synthesis was responsible for the herbicidal action. However, it is not yet known with which component the herbicide acts, nor is the chemistry of the interaction understood.

Acknowledgements

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With respect to the MDMP work, the author wishes to acknowledge the valued contribution of colleagues at the Shell Laboratories and also the collaboration of Dr. D. P. Weeks, the Institute for Cancer Research, Philadelphia, U.S.A., and Dr. D. E. Moreland, U.S.D.A. Crop Science Department, North Carolina State University, Raleigh, U.S.A.

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EXPERIMENTS INTO THE MECHANISM OF ACTION OF THE PHOTOSYNTHETIC INHIBITOR HERBICIDE, MONURON

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Summary The sequence of events which followed the application of monuron to illuminated flax (Linum usitatissimum) cotyledons are described. After a rapid cessation of photosynthetic carbon dioxide uptake, there was a gradual decay of chloroplast pigments. It is suggested that when electron flow is inhibited, excitation energy is initially channelled from photosystem 2 to photosystem 1 and also to the carotenoids. The rapid breakdown of carotenoid pigments is suggested to result from an overloading of this protective system. The subsequent destruction of chlorophylls and the production of malondialdehyde is discussed in relation to the generation of excited singlet oxygen and the initiation of lipid peroxidation.

INTRODUCTION

It is well known that the so-called photosynthetic inhibitor herbicides, which include the ureas, triazines, uracils and hydroxybezonitriles, exert an initial effect in plants by the inhibition of chloroplast electron transport and consequently carbon dioxide incorporation. Many workers have used the Hill Reaction, the reduction of an artificial electron acceptor by isolated chloroplasts, to asses the effectiveness of herbicidal activity.

Early work by Minshall (1957) noted a greater degree of phytotoxic injury when monuron treated leaves were illuminated. This was subsequently related to light absorbed by the chloroplast pigments (Ashton 1965) and was more evident as the light intensity of treatment was increased (Van Oorshot and Van Leeuwen 1974).

The identification of the sequence of phytotoxic events which follow the herbicidal inhibition of electron transport have been studied in isolated chloroplasts (Stanger and Appleby 1972, Ridley, 1975). These authors suggested that when chloroplast electron flow was prevented, the excitation energy would instigate photodestructive changes which could not be prevented by the normal protective mechanisms.

In this investigation we have monitored some of the events which followed the application of monuron to light incubated flax cotyledons, in an attempt to identify more clearly the toxic events which accompany an inhibition of photosynthesis *in vivo*.

METHOD AND MATERIALS

Flax (Linum usitatissimum var. Noralt) seedlings were grown on vermiculite under continuous illumination. Detached seven day old cotyledons were floated on a solution of monuron (1×10^{-3}M) under light of $30W/m^2$ at $25^{o}C$.

Techniques for the isolation of chloroplasts and the measurement of ferricyanide and silicomolybdate reduction were as described by Pallett and Dodge (1976). Carbon dioxide exchange, ascorbate photo-oxidation, chlorophyll content and malondialdehyde estimations were performed as described by Harris and Dodge(1972). Carotenoid contents were measured by a method based on that of Bishop and Wong (1971).

RESULTS

Figure 1 shows the effect of monuron treatment on some photosynthetic events of flax cotyledons. CO_2 uptake was totally inhibited after 100 min. although electron flow from water to the artificial oxidants ferricyanide and silicomolybdate was shown to occur for a longer period in isolated chloroplasts. Electron flow to ferricyanide was totally inhibited after 24h treatment while silicomolybdate reduction continued for a further 24h. Ascorbate photo-oxidation, a measure of photosystem 1 activity, showed an initial rapid stimulation with an increase of almost 230% after 16h monuron treatment. This was followed by a progressive decline to a total cessation after 96h.

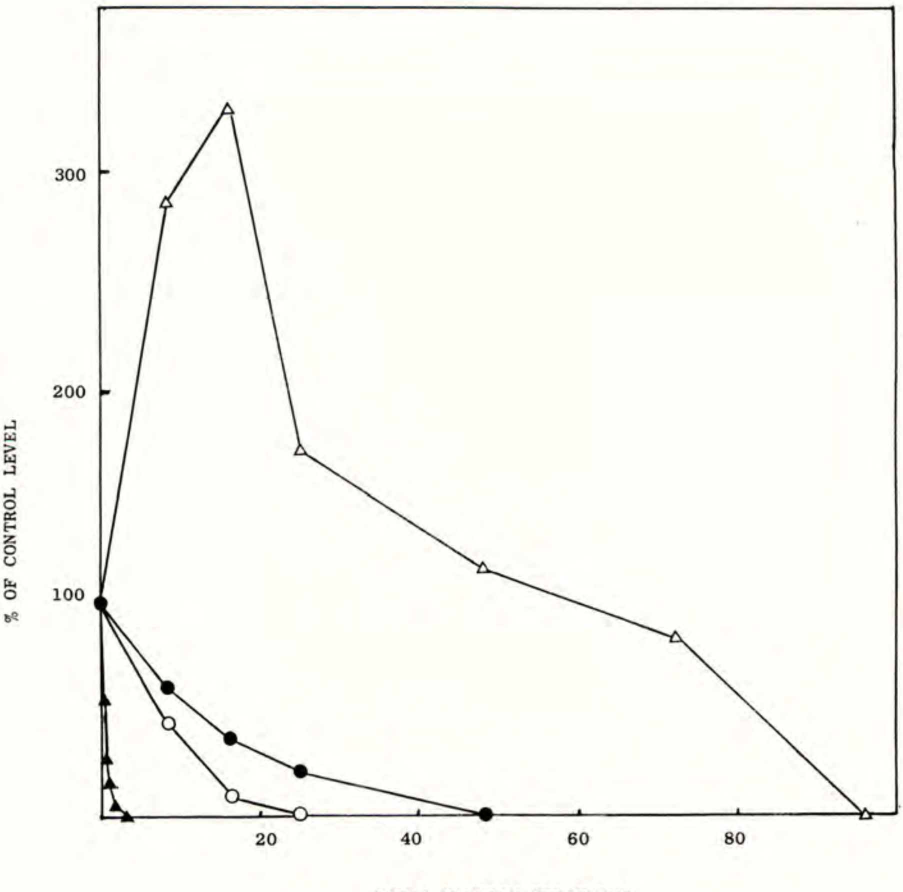
Figure 2 shows the changes in some chloroplast pigments, and in the increase in the level of malondialdehyde, a breakdown product of unsaturated fatty acid hydroperoxides. An immediate destruction of β-carotene contrasted markedly with the xanthophyll pigment lutein which showed an initial increase. This pigment however, subsequently decayed at a similar rate to β-carotene. Chlorophyll levels remained almost unchanged for 16h, and the rapid destruction of these pigments coincided with a progressive increase in the malondialdehyde level of the cotyledons

DISCUSSION

The cessation of photosynthetic CO_2 uptake was an indication of the rapid penetration of the herbicide into the cotyledons and of its interaction with chloroplast membranes. It was of interest that chloroplasts isolated from treated leaves showed Hill Reaction activity with both ferricyanide and silicomolybdate as electron acceptors, although in vivo electron flow was prevented. This could indicate the removal of monuron from the chloroplast receptor site(s) during the isolation procedure. In the case of silicomolybdate however, it is known that this oxidant is reduced at two sites, one before and one after the inhibitor site (Giaquinta and Dilley 1975). The cessation of activity with this oxidant thus gave an indication of the inactivation of the oxygen evolving system in vivo, and thus of the point at which the reduction of the primary oxidant of photosystem 2 ceased to occur. The rapid stimulation of in vitro photosystem 1 activity indicated that after the inhibition of electron transport there was energy transfer between the photosystems which might be channelled in vivo into cyclic electron flow (Ridley 1975).

FIGURE 1.

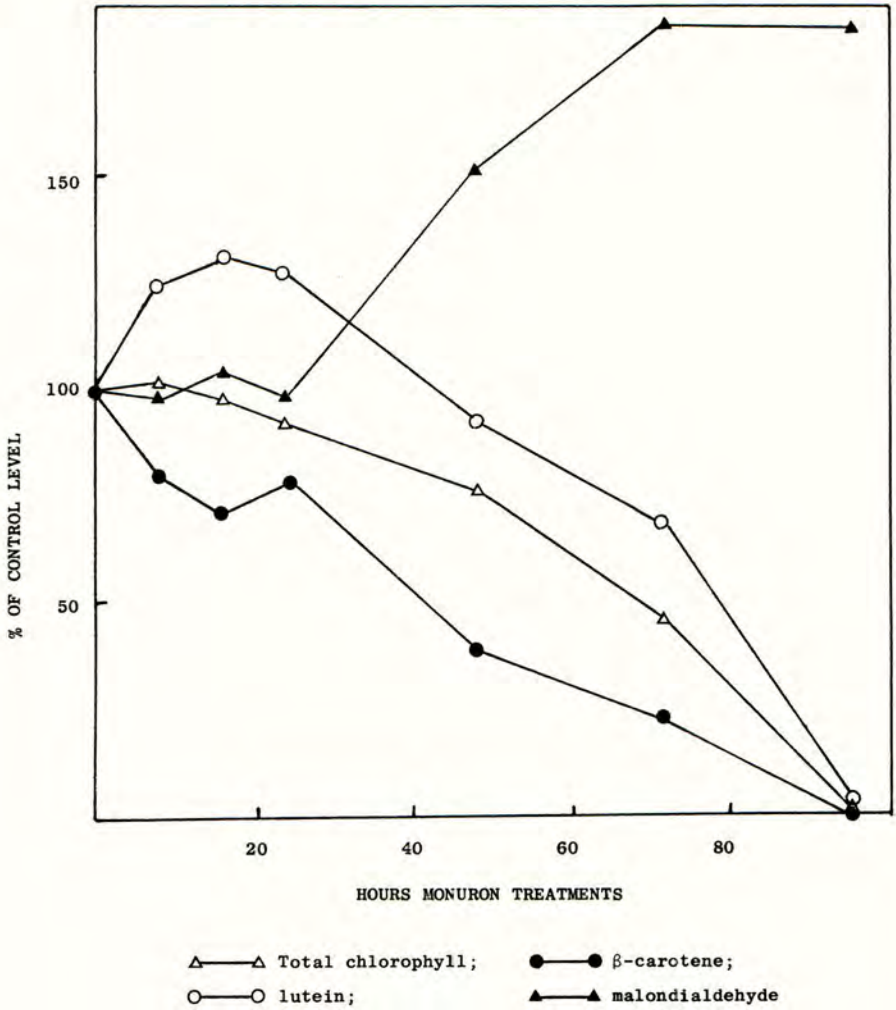
The effect of monuron treatment on flax cotyledon photosynthesis



▲—▲ Carbon dioxide uptake of intact cotyledons:
○—○ Ferricyanide reduction, ●—● silicomolybdate reduction and
△—△ ascorbate photo-oxidation of isolated chloroplasts

FIGURE 2.

The effect of monuron treatment on pigment levels and lipid peroxidation (Malondialdehyde formation) of flax cotyledons



There is considerable evidence to suggest that part of the role of carotenoid pigments within the photosystems is involved with the dissipation of excess excitation energy (Krinsky 1971). In place of a direct transfer of energy from chlorophylls to carotenoids and then dissipation by an enzyme mechanism, Foote (1968) has suggested that transfer might involve excited singlet oxygen. The rapid decay in the level of β-carotene and also of neoxanthin and violaxanthin (K.E. Pallett, unpublished experiments) prior to chlorophyll destruction, was an indication that an energy transfer from chlorophylls to carotenoids was occurring, but that the system was overloaded. The initial rise in the level of lutein might suggest that this pigment is not associated with photoprotection but only functions as an energy absorbing component of the chloroplast light-harvesting antenna protein complex (Thornber 1975). The later instigation of chlorophyll breakdown, approximately coincidental with malondialdehyde production, would indicate that chlorophyll was undergoing photo-oxidative destruction, and that the excited singlet oxygen was attacking unsaturated lipids in the chloroplast membranes. This would lead to the induction of lipid peroxide free radicals, (Anderson and Krinsky, 1973) and the destruction of cell membrane by a deteriorative chain reaction. The ultrastructural changes demonstrated after treatment of leaves with atrazine (Ashton et al 1963) would indicate that this could be a common series of events with all photosynthetic inhibitor herbicides. Further work is in progress to confirm this suggestion.

Acknowledgement

This work was supported by a Bath University Research Studentship granted to K.E.P.

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THE EFFECT OF DIFFERENT SOIL-MANAGEMENT SYSTEMS AND HERBICIDES ON THE GROWTH AND CROPPING OF RASPBERRIES

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Summary Growth and cropping of raspberries cv. Malling Jewel under various soil management systems was studied in two experiments lasting 9 and 5 years respectively. Cultivation, non-cultivation, straw mulching and the use of a residual and a contact herbicide were compared.

Where no mulch was used fruit yield was not consistently different on cultivated compared with non-cultivated treatments. Straw mulches resulted in consistently larger yields and less cane production. Taking the treatments together fruit yield appeared to be inversely correlated with cane production.

There was little difference in the response of the crop where simazine was compared with paraquat for weed control indicating no harmful effects of repeated use of the same residual herbicide.

Mulching increased leaf nitrogen levels on non-cultivated plots but there was no direct effect of soil treatment with simazine or paraquat on leaf nitrogen.

Differences in overall yield from year to year were larger than differences caused by management treatments but the results suggest that a non-cultivation system combined with careful regulation of sucker growth should lead to improved fruit yields.

INTRODUCTION

The introduction of efficient soil-acting herbicides for soft fruit in the early 1960's made it possible for crops to be grown without any cultivation. Since some of these plantations can remain for 10 years or more there was a need for information on the response of crops and soil to non-cultivation and on any undesirable effects of repeated applications of residual herbicides. Experiments to compare the effect of different soil-management treatments on raspberries have been carried out since then at a number of centres in the British Isles (Lawson and Waister, 1972; Uprichard et al, 1974; Rath and Cleary, 1974). The results have shown that this crop can vary in its response to non-cultivation.

Two experiments on raspberries were laid down at Begbroke Hill in 1962 and 1963. In the first, the effect of combinations of simazine treatment, straw mulching and alley cultivation were compared with a standard cultivation treatment. In the second the effect of a single annual cultivation was compared with non-cultivation on plots receiving either simazine or paraquat. An interim report on the first experiment has been published (Clay and Ivens, 1966). Results of studies in the first experiment on weed seed and worm populations and on soil properties are presented elsewhere (Clay and Davison, 1976).

METHOD AND MATERIALS

The experiments were carried out at Begbroke Hill, on a level site on sandy loam soil overlying calcareous gravel to a depth of 0.75-1 m. Soil organic matter content was 3% and pH 6.5 at the start of the experiment. The cultivar Malling Jewel was used in both experiments.

Experiment 1. Details of the soil-management treatments are given below:

Treatment code	Rows	Alleys
H/C	Handweeded	Cultivated
S/C	Simazine	Cultivated
SM/C	Simazine + mulch	Cultivated
HM	Mulch (+ handweeding)	
SM	Mulch + simazine	
S	Simazine	

A randomized block design was used for the experiment with six replicates. Each plot consisted of a 7.3 m long row of canes separated from adjacent treatments by a guard row; the rows were 1.95 m apart. Simazine and mulch treatments were applied to the whole of the area between treated and guard rows where appropriate.

Canes were planted at 0.45 m spacing in the row in February 1962. They were cut back to 10 cm after planting and, as the first years growth was sparse, cut back again the following winter. Sucker growth in the alleys was controlled by mowing two to three times each year from May onwards. An alley width of 1.1 m was maintained until 1968 season when it was increased to 1.5 m. Canes were allowed to grow along the length of the row to form a hedge. From 1964 to 1967 suckers were removed in June from the outer 20 cm of each side of each row. Thinning of the canes was carried out in winter to leave 10 to 12 canes per metre. Fruiting canes were generally tipped each year at a height of 1.4 m.

Where alleys were cultivated a rotary cultivator 1.1 m wide was used working to a depth of 7.5 to 10 cm. Four or five cultivations were carried out annually on these treatments when weed growth in the alleys of the handweeded/cultivated treatment was 5-7.5 cm high. Handweeding consisted of hand-pulling and shallow hand-hoeing.

Simazine (50% w.p.) was applied as a spray in March each year at a dose of 2.2 kg/ha a.i. Applications were made with an Oxford Precision sprayer at a volume rate of 550 l/ha. A mulch of 6.7 t/ha barley straw was applied to appropriate treatments each spring shortly after the simazine treatment. On hand-weeded mulched plots paraquat was applied to control volunteer cereals.

Compound fertilizer (N.P.K. 16:9:9) was applied each spring to all plots at a rate of 340 kg/ha; an additional 170 kg/ha of ammonium sulphate was applied to all mulched areas. Routine application of pesticides were made throughout the growing season.

Weeds were generally well-controlled by simazine. In late winter any emerged weeds on simazine-treated areas and on the mulched plots not receiving simazine were treated with paraquat.

The number and height of canes removed and the total fruit yield was recorded. On some treatments leaf samples were taken from well-grown suckers on 29.7.66 for nitrogen determination. 36 canes per plot were sampled, one leaf being removed from the middle region of each cane; leaves were then dried at 80°C for 12 hours before analysis.

Experiment 2. The following soil-management treatments were compared using a split-plot design:

Main-plots
1. Bare soil; no cultivation (code NC)
2. Bare soil; annual alley cultivation (AC)
3. Mulched row; annual alley cultivation (AC/M)

Sub-plots
A. Annual simazine treatment (S)
B. Paraquat treatment as necessary (P)

A randomized block design was used with four replicates. Each main plot consisted of two rows of canes, 7.3 m long, separated from adjacent main-plot treatments by a guard row; the rows were 1.95 m apart. Sub-plots consisted of two rows, 3.4 m long with 50 cm discard between the two treatments. Cultivated alleys were 1.5 m wide.

Canes were planted at 0.45 cm spacing in the row in November 1962 and then cut back to leave three buds. Sucker growth in the alleys was controlled by paraquat treatment and by mowing as necessary. Only suckers arising from stools at the initial planting position were retained for fruiting. Other cultural and treatment methods were the same as in Experiment 1.

Simazine (50% w.p.) was sprayed at 2.2 kg/ha a.i. in March each year. Paraquat (20% a.c.) was applied as a spray at 1.1 or 2.2 kg/ha a.i. at the same time and at three or four other dates during the year, when most of the weeds were at the seedling stage. The dose of paraquat was determined by density of weed growth and season. Paraquat treatments were applied overall in the dormant season but only to the alley in the growing season; the applications were extended to the simazine treated plots in late spring/early summer to control suckers. Cultivation and mulch treatments were not commenced until the 1965 season and these were then carried out, prior to the simazine application in March each year.

The same assessments were carried out as in Experiment 1.

RESULTS

Experiment 1. Records of fruit yield (Table 1) show that although there was considerable variation from year to year the overall straw mulch treatments consistently outyielded the other treatments. Yields from the treatment with mulched rows were variable but overall no different from non-mulched plots. In the non-mulched treatments there were no significant differences between yields on cultivated and non-cultivated plots.

Records of cane production are given in Table 2 and represent total production on the plot rows (canes pruned in summer and autumn plus cane retained for fruiting but measured prior to tipping). Cane number was generally considerably lower on the mulch treatments compared with the standard cultivated/handweeding treatment whereas the non-mulched, simazine-treated plots produced consistently more canes. Measurements of cane length per plot showed a similar pattern.

Experiment 2. There were large differences in yield from year to year (Table 3). Mulched rows produced slightly higher yields than non-mulched in each year. With the non-mulched treatments there was no difference in yield between the cultivated and non-cultivated treatments. Plots treated with simazine generally gave slightly larger yields than those receiving paraquat.

Cane numbers and length were consistently less on plots with mulched rows compared with non-mulched (Table 4). There was slightly more cane growth on bare-soil plots receiving an annual cultivation compared with that on non-cultivated plots. Cane numbers and length were generally greater on plots treated with simazine compared with paraquat.

Measurements of leaf-nitrogen content (Table 5) showed that levels on mulched plots were higher than on non-mulched but with the latter treatments there was no significant effect resulting from the use of simazine.

Table 1

Fruit yields with different soil management treatments (Expt 1)

Treatment code† Row/Alley	Total fruit yield as % handweeded/cultivated treatment (H/C) 1964	1965	1966	1967	1968	1969	1970	Mean 1964-1970
H/C (yield,t/ha)	100 (8.1)	100 (14.2)	100 (9.3)	100 (7.0)	100 (15.5)	100 (8.4)	100 (9.4)	100 (10.3)
S/C	85	96	98	89	97	109	106	98
SM/C	124*	83*	123***	92	104	94	111	103
HM	125*	102	138***	106	106	111*	117*	114**
SM	114	114	130***	107	106	120**	127*	116***
S	93	99	113	85	98	108	112	101
SE ±	8.2	5.2	3.4	5.2	2.6	3.3	4.8	2.7

*, **, *** indicate treatments significantly different from standard at 5, 1 and 0.1%; † treatment code: H, handweeding (row); C, cultivation (alley); S, simazine; M, mulch

Table 2

Cane numbers and length with different soil management treatments (Expt 1)

Treatment code† Row/Alley	Values as % handweeded/cultivated treatment (H/C) Cane number 1963	1964	1965	1966	1967	1968	1969	1970	1963/70	Cane length 1963/70
H/C (no/plot)	100 (365)	100 (260)	100 (323)	100 (317)	100 (318)	100 (322)	100 (298)	100 (222)	100 (2425)	100 (2548 m/plot)
S/C	108	110	124	115**	126***	118**	107	105	115***	108**
SM/C	61***	73**	94	95	93	88*	77*	58***	81***	75***
HM	53***	55***	79*	91	105	96	84*	88*	81***	78***
SM	42***	54***	89	85**	105	90	82*	85**	79***	74***
S	107	108	112	118**	134***	113*	105	101	113***	104
SE ±	6.0	5.7	6.5	3.6	3.4	3.8	5.5	3.8	2.0	2.0

*, **, *** indicate treatments significantly different from standard at 5, 1 and 0.1%
† treatment code: H, handweeding (row); C,cultivation (alley); S, simazine; M, mulch.

Table 3

Fruit yield (t/ha) with different soil management treatments (Expt 2)

Treatment code† Main-plots	Sub-plots	1965	1966	1967	1968	1965-1968 mean
NC	S	14.6	9.8	3.9	16.9	11.3
	P	14.2	9.5	4.2	16.1	11.0
	Mean	14.4	9.7	4.1	16.6	11.2
AC	S	14.8	9.5	4.5	15.9	11.2
	P	14.4	10.0	4.0	15.6	11.0
	Mean	14.6	9.8	4.3	15.8	11.1
AC/M	S	15.8	10.7	5.5	17.4	12.4
	P	13.9	10.1	6.1	16.1	11.5
	Mean	14.9	10.4	5.8	16.7	11.9
Sub-plot means	S	15.1	10.0	4.7	16.8	11.6
	P	14.2	9.9	4.8	15.9	11.2
SE ± Main-plots		0.45	0.43	0.22	0.47	0.17
SE ± Sub-plots		0.49	0.31	0.11	0.21	0.20
SE ± Interaction		0.76	0.57	0.26	0.53	0.29

† Treatment code: NC, no cultivation; AC, annual cultivation; M, straw mulch (rows); S, simazine; P, paraquat

Table 4

Cane numbers and mean length with different soil management treatments (Expt 2)

Treatment code† Main-plots	Sub-plots	Cane numbers/plot 1965	1966	1967	1968	1965-68	Length/cane (m) 1965-68
NC	S	67	249	329	301	236	1.42
	P	79	226	302	253	215	1.37
	Mean	73	237	315	277	226	1.39
AC	S	77	266	329	296	242	1.38
	P	78	227	314	291	228	1.42
	Mean	78	246	321	294	235	1.40
AC/M	S	75	191	259	243	192	1.45
	P	71	188	259	237	189	1.41
	Mean	73	189	259	240	190	1.43
Sub-plot means	S	73	235	306	280	224	1.41
	P	76	214	292	260	210	1.40
SE ± Main-plots		1.2	7.7	9.2	17.0	6.0	0.012
SE ± Sub-plots		0.4	6.7	3.6	6.4	3.5	0.011
SE ± Interaction		1.3	11.3	10.3	18.7	7.4	0.019

† Treatment code: NC, no cultivation; AC, annual cultivation; M, mulch (rows); S, simazine; P, paraquat

Table 5

Leaf nitrogen content (% leaf dry weight) of plants grown under different soil management treatments. Sampled 29.7.66

Experiment 1		Experiment 2	
Rows handweeded cultivated alleys (H/C)	3.28	Bare soil/simazine, no cultivation (NC.S)	3.24
Overall mulch (HM)	3.45	Bare soil/paraquat, no cultivation (NC.P)	3.18
Overall mulch/ simazine (SM)	3.48	SE $\pm$	0.050
Bare soil/simazine no cultivation (S)	3.31		
SE $\pm$	0.041		

DISCUSSION

The absence of consistent differences in fruit yield between cultivated and non-cultivated treatments (Table 1) agrees with results in N Ireland (Uprichard et al, 1974). Cane production was lower where the rows were hand weeded (Table 2); this was probably an effect of hoeing on emerging suckers since where the rows were treated with simazine and the alleys cultivated cane production was similar to the non-cultivated treatment. In Experiment 2 there were only small differences in fruit yield and in cane growth (Tables 3, 4) between non-cultivated plots and those receiving an annual cultivation in spring. This confirms that shallow alley cultivations probably do not damage root growth in raspberries in the way that they do in fruit crops such as blackcurrants with more root near the soil surface (Robinson, 1963).

In both experiments straw mulch treatments increased fruit yield and depressed sucker growth compared with all unmulched treatments. While the increased soil moisture in summer under mulch and the higher nitrogen fertilizer rate may have contributed to the larger yield, the biggest factor would appear to be the reduced competition from suckers for moisture and nutrients in the growing season.

The response of the crop to the mulched row/cultivated alley treatments was variable. In experiment 2 effects on yield and cane growth were consistent relative to other treatments but in Experiment 1 they varied considerably although there was a steady decline in cane production as the experiment progressed. There was no clear reason for this variation; it could be linked with the difficulty of maintaining a uniform thickness of straw along the rows where frequent alley cultivations were carried out.

The cause of the depression of sucker growth on mulched plots is not clear. Lower soil temperatures in spring and pathogen attack on emerging suckers have been suggested as possible reasons (Clay and Ivens, 1966); toxic exudates from the straw could also be involved (McCalla and Haskins, 1964; Barber et al, 1976).

The data on leaf nitrogen (Table 5) show that the only definite difference in levels was between mulched and unmulched plots. There have been reports that better growth of simazine-treated crops results from a direct stimulatory effect of the herbicide on the plants (Ries et al, 1963; Gast and Grob, 1964). Higher leaf nitrogen levels in simazine-treated crops have been reported by Robinson (1964) in raspberries and Hughes (1972) in gooseberries. The absence of any difference between leaf nitrogen levels in non-cultivated plots treated with paraquat compared with simazine and on mulched plots with and without simazine suggests that the reported increases could be an effect of the growing system rather than a direct effect of the herbicide.

When the experiments were commenced there was concern that repeated use of residual herbicides might lead to a build-up of herbicide in the soil that would adversely affect the crop. No such effect of simazine was shown in Experiment 1 where yields on the simazine-treated mulched plot were somewhat greater than on unmulched plots. In Experiment 2 yields from the simazine treated plots were slightly higher than where paraquat was used, probably because of competition from the small amount of weed inevitable on plots weeded with a contact herbicide. The absence of any build up of simazine activity in the soil over the first 4 years of Experiment 1 was reported by Clay and Ivens (1966) and this has been confirmed by subsequent analyses (Clay, unpublished data).

The results of these experiments indicate that overall straw mulches can lead to appreciable improvement in yield. They may be expected to give better results in drier parts of the country and be useful in reducing erosion. Their general use may be limited, however, because of the possibilities of increased frost damage (Robinson, 1974) and the risk of cane injury after heavy rain in the growing season. Mulches of well-rotted farmyard manure are a possible alternative, the risk of frost injury being less than with straw (Robinson, 1964), but use of these has not led to yield increases (Uprichard et al, 1974; Rath and Cleary, 1974) possibly because of difficulties in controlling weeds (Hughes, 1972).

If the main effect of the mulches has been to reduce sucker growth this can be achieved in other ways. Sucker removal is part of the traditional cultural system in Scotland (Lawson and Waister, 1972). Lawson and Wiseman (1975) have shown that, with a vigorous cultivar, removal of early sucker growth from stools can lead to considerable yield increases. This reduction in sucker production is now being achieved with applications of dinoseb along the rows and can be expected to improve yields particularly in dry seasons as well as making harvesting easier.

While the variation in yield from year to year resulting from other causes is larger than that induced by soil-management treatments the fact that some non-cultivation systems have consistently outyielded cultivated treatments suggests that effective control of weeds combined with regulation of sucker growth should play a useful part in increasing fruit production.

Acknowledgements

The help of ADAS Soil Science Department, Coley Park, Reading in carrying out leaf nitrogen analyses is acknowledged. The experiments reported in this paper were initiated by Dr G W Ivens when at WRO.

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THE EFFECT OF 8 YEARS OF DIFFERENT SOIL-MANAGEMENT TREATMENTS IN RASPBERRIES ON WEED SEED AND WORM POPULATIONS, SOIL MICROFLORA AND ON CHEMICAL AND PHYSICAL PROPERTIES OF THE SOIL

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Summary The effect of 8 years of different soil management treatments in raspberries on a number of soil properties was examined. Cultivation, non-cultivation, straw mulching and the use of simazine were compared. Viable weed seed populations increased more than 10-fold over 8 years on cultivated plots but there was no increase on simazine-treated unmulched plots. Fruit seeds (mainly raspberry) formed from 25-50% of the population on non-cultivated treatments at the end of the experiment with a large proportion found below 7.5 cm.

Earthworm populations were much lower on non-cultivated bare soil plots, probably due to reduction in food material.

CO_2 evolution and total mineral nitrogen levels were not affected by the use of simazine on mulched plots.

pH levels fell in the surface soil of non-cultivated plots particularly where mulch was used. Organic matter contents were greatest at the surface of non-cultivated plots.

Soil magnesium, nitrogen and potassium levels at different depths were not greatly affected by treatments but there was a concentration of phosphorus in the surface 6 cm of non-cultivated soil.

Bulk density and soil strength were greater in the surface layers of non-cultivated soil but this had no adverse effect on crop performance.

INTRODUCTION

Soft fruit crops including raspberries have been grown for some years without any cultivations, using herbicides to control weeds. When herbicides were coming into use in these perennial crops concern was expressed about effects on soil conditions, mainly because of the lack of information on the direct effects of herbicides on soil organisms and on the results of leaving plantation soil uncultivated for many years (Russell, 1966). Reports of experiments and of commercial experience to date suggest that very few problems have arisen (Buckley, 1973; Robinson, 1974) the main adverse effect being due to a reduction in pH levels on some soils.

An experiment to test the effects of soil-management treatments on growth and cropping of raspberries was carried out at Begbroke Hill from 1962-1971 and during its course various soil properties were examined. Soil pH, organic matter and nutrient levels were measured in 1966 and in January 1971. At the end of the experiment estimates of weed seed and worm populations were obtained and microbial activity and soil compaction measured. The results of these assessments are presented in this paper. The effects of the treatments on growth and yield and on simazine residues in the soil have been reported elsewhere (Clay and Ivens, 1966; Clay and Davison, 1976).

METHOD AND MATERIALS

The experiment was carried out on a sandy loam soil of the Badsey/Sutton series overlying calcareous gravel to a depth of 0.7-1.0 m. The following mechanical analysis was obtained at the start of the experiment:-

stones, 2.4%; coarse sand, 46.5%; fine sand, 23.8%; silt, 7.0%; clay, 16.3%

Details of the location, lay-out and cultural treatments in the experiment have been given (Clay and Davison, 1976 - Experiment 1).

This report is concerned with the four alley treatments which were:-

cultivation (no simazine, handweeded rows)
simazine (no cultivation; no mulch)
mulch (no cultivation; no simazine)
simazine + mulch (no cultivation)

The cultivation treatment involved rotary cultivation of the alleys four or five times a year to a depth of 7.5 to 10 cm; the first cultivation was in early April and the final one in late September each year. Simazine was applied at 2.2 kg/ha in March each year; a mulch of 6.7 t/ha barley straw was put on following the simazine treatment.

Details of the various assessments are given below, samples being taken from each replicate except where specified. Positions selected were between the wheel tracks of machinery used in the plantation. On mulched plots loose straw was removed from the sampling positions before extraction.

Weed seeds A preliminary assessment of the viable weed seed population of the soil was made at the start of the experiment. Nine 2.5 cm diam. cores from 0-15 cm depth were taken on 2.3.62. Samples were placed in shallow earthenware pans and kept moist in an unheated glasshouse; weed seedlings were identified and removed soon after emergence. The soil was thoroughly disturbed three or four times a year. Assessments were continued for 18 months.

A final sampling to assess weed seed populations was made on 20.1.71. Sixteen 2.5 cm diam. cores were taken from 0-7.5 and 7.5-15 cm depths on each plot. The same method of assessment was used as for the earlier sampling.

Earthworms Worms were extracted with dilute formalin solution on 10.12.70 by the method described by Raw (1959). Two 0.75 m square quadrats were used on each plot the quadrats consisting of 5 cm deep metal frames pushed slightly into the soil surface to prevent leakage of solution and escape of worms. The numbers of earthworms coming to the surface after treatment were counted, Lumbricus terrestris was recorded separately from other species.

Soil microflora Soil samples were taken from the two overall mulch treatments on 29.1.71 and 5.5.71 for measurement of CO_2 evolution and ammonia and nitrate nitrogen content. Four 2.5 cm diam. cores were taken to a depth of 5 cm on each plot; only three replicates were used for the second sampling. CO_2 evolution was measured by the method involving Kilner jars described by Grossbard and Marsh (1974) who also give the method used for the nitrogen determination.

Chemical properties Soil samples were taken from positions 45 cm from the row centre on 18.7.66; four cores were taken from 0-5 and 5-10 cm depths on each plot with a 5 cm diam. tube. The samples were analysed for pH, organic matter, P and K levels by the ADAS Soil Science Department, Reading, using standard methods (MAFF, 1973).

Further samples were taken on 18.1.71 from positions 60 cm from the row. The depths sampled are shown in Table 4. Six samples were taken per plot, those from the surface layers were obtained with a small trowel, deeper samples with a 2.5 cm diam. tube. The moss present on the overall herbicide bare soil plot was included in the 0-1 cm sample, there being no clear boundary between moss and soil. Samples were analysed as above but total N and Mg levels were also determined.

Physical properties Bulk density - soil cores were obtained from 0-5 and 5-10 cm depths in two positions in the alleys on each plot using 12.5 cm diam. metal cylinders and the apparent specific gravity was determined. Soil strength - soil strength was assessed using a cone penetrometer with a 30° cone of 1.27 cm diam. (Soane et al, 1971). Measurements were made to a depth of 50 cm in six positions in the alleys of each plot, using three replicates of the experiment.

RESULTS

Weed growth and seed populations The soil samples taken at the start of the experiment gave an estimated seed population of 1290 per m^2 (SE $\pm$ 106). The proportions of different species groups present were:- annual broad-leaved weeds, 39% - mainly Cerastium vulgatum; perennial broad-leaved weeds, 12%; Poa annua, 9% and, other grasses, 40%.

Throughout the course of the experiment weed growth on the cultivated plots was vigorous, the main species were Capsella bursa-pastoris, Stellaria media and Poa annua. These frequently seeded between cultivations. The simazine treatments resulted in weed-free plots until late-autumn each year when a few annual weeds, mainly Senecio vulgaris developed. Weed growth on mulched-handweeded plots was sparse apart from a flush of volunteer barley each spring which was killed with paraquat when about 10 cm high.

Table 1 shows there was a large increase in the number of seeds of annual weeds in cultivated plots during the course of the experiment. Mulched plots showed a smaller increase and bare soil/non-cultivated plots little change. The proportion of seeds in the 7.5-15 cm layer compared with the surface layer was very much lower on the cultivated plots compared with non-cultivated. By the end of the experiment perennial dicotyledonous weeds were only found on the non-cultivated plots and these mainly in the deeper soil-layer. The largest numbers of fruit seeds (mainly raspberry) were found on the mulched plots with 25-30% of them in the 7.5-15 cm layer.

Earthworms There were 60% fewer earthworms recovered from the non-cultivated, bare-soil plots than from the cultivated plots (Table 2). Both Lumbricus terrestris and the other species were affected. Numbers recovered from the no-herbicide mulched plots were similar to those on cultivated plots; there was some reduction in numbers on the simazine-treated mulched plots, particularly of L.terrestris.

Soil microflora There was no effect of previous simazine treatment on CO_2

evolution or on total mineral nitrogen levels in soil taken from the mulched plots at either sampling date (Table 3).

Table 1

Estimated viable weed seed population in soil samples from different soil management treatments: sampled 22.1.71

Transformed values; $\log_{10}(10x + 1)$ transformation (actual values per m^2, in parentheses)

Species group	Sample depth (cm)	Cultivation	Simazine	Mulch	Mulch + Simazine	SE ±
Annual grasses	0-7.5	2.43 (3890)	0.39 (70)	1.34 (440)	1.53 (550)	0.230
	7.5-15	1.63 (630)	0.77 (130)	0.85 (200)	0.84 (170)	
	Total ø	2.03 (4520)	0.58 (200)	1.10 (640)	1.19 (720)	0.168
Agrostis stolonifera	0-7.5	0.35 (40)	0^x (0)	1.25 (260)	1.40 (370)	0.198
	7.5-15	0.25 (70)	1.06 (220)	0.96 (260)	0.52 (70)	
	Total	0.30 (110)	0.53 (220)	1.10 (520)	0.96 (440)	0.147
Annual dicotyledons	0-7.5	2.73 (7650)	0.62 (460)	1.80 (920)	1.74 (790)	0.192
	7.5-15	2.02 (1510)	1.04 (200)	1.62 (890)	1.23 (240)	
	Total	2.38 (9160)	0.83 (660)	1.71 (1810)	1.48 (1030)	0.147
Perennial dicotyledons (weeds)	0-7.5	0^x (0)	0 (0)	0 (0)	0.39 (70)	0.170
	7.5-15	0 (0)	0.79 (130)	1.19 (220)	0.72 (220)	
	Total	0 (0)	0.39 (130)	0.60 (220)	0.56 (290)	0.149
Fruit species	0-7.5	1.74 (760)	1.42 (370)	2.02 (1750)	2.13 (2030)	0.157
	7.5-15	0.74 (110)	0.22 (40)	1.64 (740)	1.40 (590)	
	Total	1.24 (870)	0.82 (410)	1.83 (2490)	1.76 (2620)	0.109
All species	0-7.5	1.96 (12340)	0.69 (900)	1.38 (3370)	1.43 (3810)	0.087
	7.5-15	1.21 (2320)	0.68 (720)	1.20 (2310)	0.95 (1290)	
	Total	1.59 (14660)	0.69 (1620)	1.29 (5680)	1.19 (5100)	0.065

^{x}SE's not applicable to zero values. ø transformed values are mean of the 2 depths.

Table 2

Estimated worm population (no/m^2) in the alleys of different soil management treatments: assessed 10.12.70

Treatment	*Lumbricus terrestris*	Other spp.	Total
Cultivated	38	13	51
Simazine	17	4	21
Mulch	33	13	46
Mulch + simazine	22	11	33
SE ±	6.2	2.5	7.1

Table 3

The effect of simazine on CO_2 evolution and total mineral nitrogen levels in soil from mulched plots sampled 5.5.71

	No simazine	Overall simazine	SE
CO_2 evolution (ppm)	189	200	± 25.9
Mineral N (µg/g)	14.3	13.9	± 1.69

Table 4

The effect of different soil-management treatments on pH, organic matter, total N, P, K and Mg levels in soil from alleys at several depths and at two sampling dates

Treatments / Depths (cm)	1966 0-5	1966 5-10	1966 0-10	1971 0-1	1971 1-3	1971 3-6	1971 6-12	1971 12-24	1971 0-24
Soil pH									
Cultivation	5.5	6.1	5.8	6.3	6.2	6.0	6.1	6.6	6.4
Simazine	5.3	6.2	5.7	6.1	5.2	5.0	5.8	6.5	6.0
Mulch	4.5	5.3	4.9	4.8	4.6	4.4	5.1	6.4	5.6
Mulch + Simazine	4.5	5.2	4.8	4.7	4.5	4.4	5.2	6.3	5.6
SE ±		0.14					0.11		
Organic matter (%)									
Cultivation	3.5	3.3	3.4	3.9	3.5	3.7	3.5	3.4	3.5
Simazine	3.0	3.2	3.1	7.0	3.6	2.9	3.1	3.5	3.5
Mulch	3.5	3.4	3.4	8.8	4.7	3.3	3.4	3.5	3.8
Mulch + Simazine	3.3	3.2	3.2	8.2	5.4	3.4	3.5	3.6	3.9
SE ±		0.14					0.25		
P (ppm)									
Cultivation	7.3	3.5	5.4	37	40	39	27	19	26
Simazine	6.6	3.9	5.2	46	79	54	22	23	32
Mulch	7.5	4.1	5.8	83	96	56	32	25	39
Mulch + Simazine	8.2	3.1	5.6	82	93	59	33	25	39
SE ±		0.66					3.3		
K (ppm)									
Cultivation	485	373	430	530	485	437	318	172	283
Simazine	473	378	425	327	362	307	267	215	256
Mulch	389	391	390	370	377	367	302	288	312
Mulch + Simazine	353	362	358	327	317	317	285	273	287
SE ±		17.9					15.8		

Treatments / Depths (cm)	1971 0-1	1971 1-3	1971 3-6	1971 6-12	1971 12-24	1971 0-24
Total N (%)						
Cultivation	0.22	0.24	0.25	0.23	0.29	0.26
Simazine	0.36	0.21	0.19	0.20	0.22	0.22
Mulch	0.37	0.26	0.19	0.20	0.21	0.22
Mulch + Simazine	0.32	0.29	0.21	0.21	0.21	0.22
SE ±			0.029			
Mg (ppm)						
Cultivation	56	49	45	47	59	53
Simazine	55	41	33	46	62	52
Mulch	44	37	21	35	55	44
Mulch + Simazine	45	33	25	39	50	43
SE ±			3.2			

NB. Methods of extraction for P and K changed between 1966 and 1971; see MAFF (1973) pH and organic matter content. At depths down to 12 cm the soil was more acid on the non-cultivated treatments compared with the cultivated, especially under straw mulch, but there was little change in levels between 1966 and 1971 (Table 4). There was little difference in the organic matter content of the different depths on unmulched plots or change between 1966 and 1971 except for a large amount in the 0-1 cm level of the non-mulched, simazine plot at the second sampling (Table 4). On mulched plots organic matter levels in the 0-6 cm layer rose by 25-30% between 1966 and 1971 compared with the cultivated treatment; below 6 cm there was no change and levels were similar to those on unmulched plots.

Soil nutrients The soil nutrient levels recorded in 1966 and 1971 are shown in Table 4. At the later sampling date there was a much higher amount of phosphorus in the 0-6 cm layer of the non-cultivated treatments compared with the cultivated plots, but no appreciable differences below 6cm. There was more potassium in the 0-6 cm layer of the cultivated treatment but less below 12 cm compared with other treatments. There was little difference in total nitrogen levels except for an increase in the surface layer of non-cultivated compared with cultivated plots. Magnesium levels were lowest in the mulched treatments in the 0-12 cm layer and highest on the cultivated plots.

Table 5

Dry bulk density of soil taken from the alleys of different soil management treatments: samples taken 20.1.71

Sample depth (cm)	0 - 5	5 - 10	Mean
Cultivated	1.21	1.23	1.22
Simazine	1.35	1.28	1.31
Mulch	1.25	1.26	1.25
Mulch + simazine	1.28	1.23	1.25
SE ±	0.042		0.026

Table 6

Penetrometer measurements in soil in alleys under different soil management treatments, recorded 19.1.71

Depth (cm)	Penetrometer index values: Cultivation no simazine	No cultivation + simazine	Mulch No simazine	Mulch + simazine
3.75	37	67	102	100
7.50	59	87	125	126
11.25	87	87	125	147
15.00	95	89	110	106
18.75	92	92	95	96
22.50	99	99	88	97
26.25	117	99	96	105
30.00	135	116	95	112
33.75	152	132	114	121
37.50	176	142	149	147
41.25	177	158	157	157
45.00	200	165	153	169
48.75	208	198	170	181
52.50	202	207	193	179

SE (treatments x depths) ± 10.9

Bulk density There was a small increase in bulk density on all the non-cultivated treatments compared with the cultivated, particularly in the upper layer sampled (Table 5). Bulk density was greatest on the non-mulched treatment.

Soil strength The measurements on the non-mulched plots showed that the cultivated treatment was much less resistant to penetration by a mechanical probe in the soil surface layer (Table 6). From 10-25 cm there was no difference from the non-cultivated treatment but between 25 and 50 cm the cultivated treatment was slightly more resistant. The mulched treatments were the most resistant down to 15 cm but similar to the non-mulched non-cultivated treatment below this.

DISCUSSION

Weed seed populations For many years prior to its use for this experiment the site was a grassed-down paddock. The initial weed seed population was very low compared to the average reported for arable soils (Roberts, 1970) but this increased about 10-fold on the cultivated plots by the end of the experiment (Table 1). By contrast there was no increase in numbers on the non-cultivated unmulched plots although the species composition changed. Seeds of fruit species (mainly raspberry with occasional blackcurrant and strawberry) formed about 25% of the population in the bare soil treatment. In a comparable experiment in N.Ireland, Allott, (1970) found a similar difference in seed numbers between cultivated and non-cultivated treatments. Total seed populations on mulched plots (Table 1) were about 30% of the cultivated treatment - a much higher proportion than in the N.Ireland experiment. The species present consisted largely of imported seed - fruit species (50%) and species brought in with the straw but there was little difference in populations or species composition between simazine-treated and non-treated plots.

There was a much greater proportion of seeds in the deeper soil layer on non-cultivated compared with cultivated treatments - as was found by Allott (1970). The deeper seeds included a large proportion of fruit seeds - species not found in the initial sampling. This suggests such seeds were taken down below 7.5 cm by infiltrating rain through worm channels or cracks or by the activity of soil animals.

While final seed numbers were relatively small on non-cultivated plots, weeds were still emerging in the final years of the experiments on the treatment where simazine was not used and, in the autumn on the simazine treatments. This suggests that it might be false economy to reduce the doses of residual herbicides after some years of non-cultivation as has been suggested (Allott,1970) and that changes in weed species may require different herbicides.

Earthworms The reduction in the number of earthworms recovered from the bare soil, non-cultivated treatment compared with the other treatments (Table 2) corresponds to the results of Stringer et al (1971) under apples. The reduction in food sources-surface vegetation, on such plots is the probable reason. By contrast in cereal crops earthworm numbers have been found to be appreciably larger in non-cultivated compared with ploughed plots (Edwards, 1975). The slight reduction in numbers where mulched plots were treated with simazine may have been due to the virtual absence of weed growth on these plots compared with the untreated plots. No direct effects of simazine on earthworms have been reported where the herbicide has been used at recommended rates for fruit crops (Edwards,1970). No fungicides of the benomyl type, known to be toxic to worms (Stringer and Wright, 1973), were used in the experiment. Earthworms may be particularly important in maintaining soil structure and fertility on non-cultivated land (Edwards,1975).

Microflora Measurements of CO_2 evolution and total mineral nitrogen in soil are frequently used as indicators of any effects of a herbicide on general microbial activity and on mineralization of nitrogen (Greaves et al,1976). The absence of any significant effects of simazine in this experiment agrees with results from experiments in arable crops and tests where large doses of simazine were applied to soil (Grossbard,1971). Robinson (1966) reported consistently lower nitrate nitrogen levels under straw mulch than on non-mulched plots. In this experiment tests were not made on non-mulched plots as the amount of weed growth occurring on the cultivated treatment would invalidate any comparison of the effects of simazine (Grossbard, 1971).

pH and organic matter content pH levels of soil have been found to fall in non-cultivation growing systems in fruit (Jordan and Bailey,1968; Banwell,1972). This change may only affect the surface layer of the soil (Table 4) and has not been shown to have deleterious effects in soft fruit. The lowest pH levels were found under the mulch and may have resulted from the application of ammonium sulphate to these plots. Organic matter levels appeared to vary little under different treatments where no mulch was applied apart from a large increase in the 0-1 cm layer on the non-cultivated plots due to moss (Table 4). On the mulched plots levels were similar to other treatments in 1966 but there was an appreciable increase in the amount in the 0-3 cm layer in 1971. Other reports do not show any consistent differences between cultivated and non-cultivated treatments (Robinson,1974); where an organic mulch or moss is present there is difficulty in establishing where the true level of the soil surface lies.

Soil nutrients The data on soil nutrients (Table 4) show some differences in treatments and changes during the course of the experiment but generally nutrient levels would be regarded as satisfactory for the growth of this crop (MAFF,1973). Magnesium levels were low, particularly on mulched plots. The higher phosphorus levels in the surface 6 cm of non-cultivated plots reflect the insolubility of this element but amounts below this were similar to those on the cultivated treatment. Compared with the unmulched, non-cultivated treatment in this experiment, Drew and Saker (1976), working with direct-drilled barley on a clay loam soil report a similar gradient in potassium concentration but a more extreme fall in phosphorus levels with increasing depth.

Bulk density and soil strength The slight increase in bulk density found in the surface of non-cultivated compared with cultivated soil (Table 5) agrees with the results of similar experiments in Ireland (Robinson,1974). The increase in compaction is also shown by the penetrometer measurements (Table 6). Increases of bulk density of this order have been shown to reduce pore space of the surface soil (Bulfin and Gleeson,1967; Soane et al,1975), but this effect has not generally been linked with reduction in water infiltration rates (Robinson,1974) nor has it adversely affected crop growth, possibly because of the more continuous nature of channels in non-cultivated soil. The greater strength of non-cultivated soil may have advantages in avoiding the severe compaction due to wheel tracks that can be found on cultivated soil (Soane et al,1975). Penetrometer index values in the surface 12cm of the mulch treatments were appreciably higher than on the unmulched treatments. This contrasts with the relative effects on bulk density of the surface soil and with penetrometer results reported by Bulfin and Gleeson (1967) where a manure mulch had been used.

The results reported on soil conditions under different management systems show that the non-cultivated treatments have had no obvious deleterious effects. Crop growth and yield with all treatments were satisfactory for the duration of the experiment (Clay and Davison, 1976) but there are some aspects that could give rise to problems on other soils. The long-term consequence of the reduction in earthworm numbers in non-cultivated bare soil is unknown. The higher concentrations of phosphorus found near the surface of the undisturbed soil suggest that poor distribution of this element could be a problem in some soils if crop roots do not exploit the surface soil. The fall in pH values of the surface 12 cm of soil in the non-cultivated treatments had no harmful effect, in this instance. In apples such changes have led to manganese toxicity on some soils (Banwell, 1972) but the condition can be readily corrected by liming.

Acknowledgements

Thanks are due to the Soil Science Department, ADAS. Reading for soil analyses, to the WRO Botany Group for the preliminary estimate of weed seed populations, to the WRO Microbiology Group for the CO_2 and nitrogen determinations and to colleagues at WRO and other ARC institutes for advice on techniques.

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THE CONTROL OF ANNUAL WEEDS IN NEWLY-PLANTED AND ESTABLISHED STRAWBERRIES

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Summary A number of herbicides were compared for the control of seedling weeds in newly planted and established strawberries. Lenacil and simazine gave good control of seedling weeds in newly planted strawberries. A trietazine and simazine mixture also gave good control but caused damage in some trials. Trifluralin and pyrazone gave inadequate weed control and also caused plant damage. A double application of the post-emergence herbicide, phenmedipham, gave good control of established annual weeds. A single application of phenmedipham and Actipron and of trietazine and simazine also gave some control of established annual weeds.

INTRODUCTION

Satisfactory control of annual weeds can usually be obtained in strawberry plantations with the residual herbicides simazine and lenacil. However, in the first year of a strawberry plantation, weed control is sometimes inadequate. The problem can be particularly severe where spring planting is followed by a period of dry weather. While phenmedipham will control the emerged seedlings of many weed species it is less effective when these have become established. There is a need for a residual herbicide less affected by soil moisture conditions than simazine and lenacil, for use on strawberries. There is also a need for a contact herbicide effective at a later stage of weed growth and against a wider range of weeds than phenmedipham. Lawson and Wiseman (1972) reported good results with trifluralin incorporated pre-planting. Clay (1972) found pyrazone promising. Ellis (1973) reported promising results with a mixture of trietazine and simazine when used in a series of grower trials on established strawberry plantations. A number of trials were laid down at Clonroche to ascertain the usefulness of these herbicides under Irish conditions.

MATERIALS AND METHODS

Experiment 1

Strawberry runners, cv. Cambridge Vigour, were planted 0.45 m apart in rows 0.9 m apart on 13 April, 1973. The post-planting treatments listed in Table 1 were applied on 1 May 1973, while the pre-planting treatments of trifluralin were applied and incorporated by shallow rotary cultivation on 11 April 1973. The trial had a randomised block design with four replicates. Plots contained two rows of 25 plants.

Table 1

Herbicides for the control of annual weeds in strawberries

Herbicide	Method of application	dose kg/ha
Trifluralin	incorporated pre-planting	1
Trifluralin	incorporated pre-planting	2
Pyrazone	overall	2.5
Pyrazone	overall	5
Lenacil	overall	2
Lenacil +	0.3 m band over row	2
Simazine	0.6 m band to alley	2
Simazine	overall*	2

*Given root dip in 30% charcoal slurry before planting.

Experiment 2

A trial similar to Experiment 1 was laid down in 1974. Strawberry runners, cv. Cambridge Favourite were planted 0.4 m apart in rows 0.86 m apart on 16 May 1974. The post-planting treatments listed in Table 2 were applied on 24 May 1974. The trifluralin had been incorporated lightly by shallow rotary cultivation on 13 May 1974. The trial area was maintained weed free during the remainder of 1974 and 1975 by routine treatments with simazine and paraquat. The post-planting herbicide treatments were again applied to the same plots on 19 January 1976.

Experiment 3

Strawberries, cv. Cambridge Vigour were planted on 12 May 1975. The plants were spaced 0.5 m apart on ridges 0.9 m apart. The plantation received lenacil treatments for weed control during summer 1975. By early October this area was uniformly infested with *Viola arvensis*, which was 7 to 10 cm high. This area was also lightly infested with *Chrysanthemum segetum* and *Poa annua*. On 16 October 1975 these plots were sprayed with the treatments listed in Table 3.

Experiment 4

An area of strawberries, cv. Cambridge Favourite was planted on 15 May 1975. The plants were spaced 0.4 m apart on ridges 0.9 m apart. During winter 1975-1976 this area became infested with *V. arvensis* seedlings. On 30 April 1976 the treatments listed in Table 4 were applied. The first dose of the double application of phenmedipham was applied on 28 April 1976. At the time of spraying the *V. arvensis* plants were 5 to 7 cm high. Plot size was 2 rows 10 m long. The trial had a randomised block design with 4 replicates.

Experiment 5

This trial was laid down to compare the effect of applying a proprietary mixture of trietazine and simazine * at monthly intervals after planting strawberries. Strawberries, cv. Cambridge Vigour, were planted on 20 November, 1975. The plants were spaced 0.5 m apart on ridges 0.9 m apart. The mixture was applied at 1.68 kg/ha to different plots in mid-December, mid-January, mid-February, mid-March, mid-April, and mid-May. Plot size was 2 rows 12.5 m long. The trial had a randomised block design with 4 replicates.
*Applied as product Remtal, dose given as total a.i.

Experiment 6

An area of strawberries, cv. Cambridge Vigour was planted up on a growers holding in October 1975. The plants were spaced 0.5 m apart on ridges 0.9 m apart.

During winter 1975-76 the plantation became badly infested with Holcus mollis and lightly infested with Poa annua. On 4 March 1976 diphenamid was applied at 5 and 10 kg/ha. Treatments consisting of hand weeding plus trietazine and simazine mixture at 1.5 kg/ha and no weed control were also included.

RESULTS

Experiment 1

Trifluralin incorporated pre-planting caused stunting of the plants and reddening of the foliage during May 1973. This stunting persisted during June. Later in the summer the plants recovered well and by the end of the growing season were similar in size to plants receiving the other treatments. Pyrazone at 2.5 kg/ha and 5.0 kg/ha caused marginal scorching of the leaves of treated plants during May. The scorching was very severe on some plants and during June these plants died back completely. At the end of the growing season 23% and 37% of the plants had died on the plots treated with pyrazone at 2.5 and 5.0 kg/ha respectively. The less severely damaged plants recovered almost completely during late summer and autumn 1973. The lenacil and simazine treatments did not have any apparent effect on plant growth.

The principal weeds in the trial area were V. arvensis, Atriplex hastata, Spergula arvensis, Fumaria officinalis, Trifolium repens, Anagallis arvensis, P. annua and Alchemilla arvensis. Simazine gave best control of all species except A. hastata, which was best controlled by trifluralin at 2 kg/ha. Lenacil gave good control of all weeds except V. arvensis and Anagallis arvensis. Trifluralin gave adequate control of A. hastata and Anagallis arvensis only, while pyrazone did not adequately control any of the weeds present.

Experiment 2

Weather at Clonroche following planting was warm and dry. Plant establishment was poor and in early July approximately 23% of the plants had failed to establish or established only poorly in the trial area. Because of the drought, symptoms of herbicide damage did not show up clearly on the foliage of any plants. However, approximately 57% of the plants treated with pyrazone at 5.0 kg/ha either failed to establish or established only poorly.

The principal weeds present in the trial area were F. officinalis and A. hastata. The trifluralin and pyrazone treatments gave poorer control of the species than did the lenacil, simazine or trietazine and simazine treatments. During autumn 1974 matted rows were established in the trial area. No symptoms of herbicide damage occurred in 1975 or 1976.

Crop yield was not significantly affected by herbicide treatment in 1975, although there was a tendency for yield to be reduced by the simazine treatment (Table 2). In 1976 crop yield was significantly reduced by the simazine treatment.

Table 2

Effect of residual herbicides on crop yield of strawberries

Herbicide	Method of application	Dose kg/ha	Crop yield (tonnes/ha) 1975	1976
Trifluralin	incorporated pre-planting	1.0	11.8	20.3
Trifluralin	incorporated pre-planting	2.0	11.6	17.2
Pyrazone	overall	2.5	9.6	17.1
Pyrazone	overall	5.0	9.7	15.8
Lenacil	overall	2.0	10.1	18.0
Lenacil + simazine	0.3 m band over row +0.6 m band to alley	2.0 2.0	11.1	19.00
Simazine ++	overall	2.0	8.6	13.3
Trietazine + simazine*	overall	0.75	10.2	18.5
Trietazine + simazine*	overall	1.50	10.6	19.0
F test			N.S.	**
S.E. (df = 24)			0.83	0.87

*Applied as product Remtal, dose given in total a.i.
++Given root dip in 30% charcoal slurry before planting.

Experiment 3

All phenmedipham treatments caused only slight yellowing of the leaf margins, of the strawberry plants. All treatments caused severe stunting of the *V. arvensis* plants. This stunting persisted throughout the winter of 1975-1976. Later on the weeds recovered so that a hand weeding was required in April 1976. There was no obvious difference in effectiveness between the phenmedipham treatments. Crop yield was not affected by the treatments in 1976 (Table 3).

Table 3

Effect of phenmedipham on crop yield of strawberries

Herbicide	Dose	Crop yield (tonnes/ha)
-	-	12.5
Phenmedipham	1.1 kg/ha	10.8
Phenmedipham + Actipron	1.1 kg/ha 5.6 l/ha	13.3
Phenmedipham + Actipron	1.6 kg/ha 5.6 l/ha	13.8
F test		N.S.
S.E. (df = 6)		1.31

Experiment 4

All *V. arvensis* plants treated with herbicide were severely scorched during early May 1976. By the end of May almost all *V. arvensis* plants treated with phenmedipham alone or trietazine + simazine had completely recovered. About 50% of the *V. arvensis* plants treated with phenmedipham + Actipron and phenmedipham + trietazine + simazine had been killed while the remainder recovered. The *V. arvensis* plants were completely eradicated from the plots receiving the double dose of phenmedipham.

Table 4

Effect of herbicides on crop yield of strawberries cv. Cambridge Favourite - April 1976

Herbicide	date applied	dose	Crop yield (tonnes/ha)
Control	-	-	10.2
Phenmedipham	30/4/76	1.15 kg/ha	7.8
Phenmedipham +	30/4/76	1.15 kg/ha	
Actipron	30/4/76	6 l/ha	8.4
Phenmedipham +	28/4/76	1.15 kg/ha	
phenmedipham	30/4/76	1.15 kg/ha	9.5
Trietazine + simazine*	30/4/76	1.50 kg/ha	8.2
Phenmedipham +	30/4/76	1.15 kg/ha	
trietazine + simazine*	30/4/76	1.50 kg/ha	7.3
F test			N.S.
S.E. (df = 15)			1.00

*Applied as product Remtal. Dose given in total a.i.

Experiment 5

During late April and early May symptoms of herbicide damage occurred on some plants in all previously sprayed plots. This damage became more severe during May and by early June several plants had been killed. The damage was particularly severe on February, January and December sprayed plants (Table 5). Only slight marginal yellowing of the foliage occurred on the plants sprayed during May. During June and July the less severely damaged plants made a good recovery and in early August differed little in size from undamaged plants.

Table 5

Effect of trietazine + simazine applied at intervals to newly planted strawberries

Date of application	% plants surviving August 1976	% strong plants	mm rain in following 4 weeks
19/12/75	83	72	45
20/1/76	75	62	77
25/2/76	60	53	91
23/3/76	88	84	39
21/4/76	94	87	41
21/5/76	98	96	37

The damage to the plants appeared to be connected with rainfall in the four weeks following spraying.

Experiment 6

Both diphenamid treatments caused severe scorching of the strawberry foliage during April. During May many of the plants receiving the higher dose died. Later in the summer the less severely damaged plants receiving the higher dose and all plants receiving the lower dose recovered well. In early August 33% of the plants receiving the higher dose had been killed while a further 33% were severely stunted. In early August the plants which had received diphenamid at 5 kg/ha had completely recovered. The plants were completely unaffected by trietazine + simazine treatment.

Both doses of diphenamid controlled P. annua completely. The diphenamid treatments also caused severe scorching of the H. mollis foliage but during late May this weed made a good recovery. The trietazine + simazine treatment suppressed the germination of P. annua but failed to control H. mollis.

DISCUSSION

In Experiment 1 and 2 pyrazone was too harmful to newly-planted strawberries for use under Irish conditions. Although trifluralin caused temporary damage from which the plants later recovered, subsequent cropping was not affected. However, weed control was unsatisfactory on the range of weeds occurring in both trials. Trifluralin could be useful against certain weeds resistant to simazine and lenacil and succeptible to it, or more commonly to overcome the problem of dry soil conditions after planting. However, the usual practice in Ireland of planting on ridges would make shallow incorporation of trifluralin very difficult. The mixture of trietazine + simazine gave variable results. It gave excellent control of seedling weeds under dry soil conditions. In Experiment 5 the trietazine + simazine caused severe plant damage on some dates of application. The degree of damage appeared to be associated with rainfall in the four weeks following herbicide application. The damage in Experiment 5 was probably also increased by the fact that the top of the planting ridge consisted of 48% finely broken shale fragments. In Experiment 2, where only slight damage was caused by the trietazine + simazine mixture, soil type was heavier and the rainfall was low in the period following spraying.

The double application of phenmedipham showed very good promise for the control of established broadleaved weeds. The additive, Actipron, also gave an increase in the effectiveness of phenmedipham.

Acknowledgements

The help of the companies who supplied the herbicides used in these experiments is gratefully acknowledged. The authors also wish to thank Mr. J.J. Doyle for technical assistance.

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THE RESPONSE OF STRAWBERRY CULTIVARS TO MIXTURES OF PHENMEDIPHAM WITH OTHER HERBICIDES AND WITH MINERAL OILS

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Summary Mixtures of phenmedipham with residual herbicides, two mineral oils or barban were applied to different cultivars of strawberry in a series of pot and field experiments.

The addition of lenacil (2.0 kg/ha) or simazine (1.0 kg/ha) did not increase the phytotoxicity of phenmedipham (1.0 kg/ha).

Applications of phenmedipham with mineral oils were slightly more phytotoxic than the standard treatment but generally caused less injury to sprayed leaves than two applications of phenmedipham (each of 1.1 kg/ha) applied with a 48 hour interval. The effects of all treatments on leaves were soon outgrown. In field experiments mixtures of phenmedipham with a mineral oil had no lasting effect on growth but fruit yield was slightly reduced when treatments were applied just prior to flowering.

Barban (0.7 kg/ha) mixed with phenmedipham (1.1 kg/ha) produced very rapid effects on sprayed leaves but these were soon outgrown and final growth was similar to that with the phenmedipham/oil treatments.

cv.Cambridge Prizewinner, Domanil and Senga Gigana showed more leaf effects than the other cultivars; the effect on plant growth was only slight but the extreme chlorosis of sprayed leaves of Domanil remained conspicuous. Redgauntlet was the most tolerant of the 17 cultivars tested.

INTRODUCTION

Phenmedipham has become one of the most useful herbicides for weed control in strawberries in the UK since its introduction for this crop in 1972. While applications may cause transient yellowing of leaves, growth and yield are not affected (Clay et al.1974). The limitations of the treatment are the range of weeds controlled, grasses and mayweeds being unaffected, and the short period of weed growth at which the recommended dose is effective. In sugar beet, the crop in which the herbicide was originally recommended, larger weeds have been controlled by modifying the treatment in two ways; either by mixing the herbicide with mineral oil (MAFF,1975) or mixing with barban. The latter combination is particularly effective against Polygonaceous weeds, eg Polygonum aviculare (Griffiths, 1976).

A further technique for controlling larger weeds in strawberries is to apply the herbicide twice with an interval of 48 hours between doses; this method has been successfully used by growers in South East England in recent years. Although there have been no reports of serious crop damage from phenmedipham on strawberries, in practice some cultivars appear to show more leaf effects, in particular the cultivar Domanil (Buttfield, 1976).

A series of pot and field experiments were carried out at Begbroke and Loughgall to examine the effect on strawberries of applying mixtures of phenmedipham and various additives and to test for differences in cultivar response. The response of 17 cultivars was compared and also the tolerance of the crop to mixtures of phenmedipham with lenacil and simazine.

Table 1

Experimental details - replication, crop age, herbicide application dates and maximum air temperatures around the treatment dates.

Expt. No.	Type	Replicates	Crop age at 1st spraying (months)	Application dates	Daily maximum air temp. (°C) Week before spraying (mean)	Day of spraying	Week after spraying (mean)
1	Pot	3	1.5	14.8.73	23	28	24
2	Pot	3	1.5	14.8.74	21	21	23
3	Field	4	9	15.4.75	10	12	15
				25.4.75	16	19	16
				8.5.75	15	17	13
				19.5.75	12	18	15
4	Field	3	9	13.5.75	13	15	16
5	Pot	4	2.5	10.6.75	21	23	22
				(12.6.75)*	24	26	21
6	Pot	4	2.5	16.6.76	23	14	21
				(18.6.76)*	21	23	24

* repeat application to one treatment

METHOD AND MATERIALS

Details of soil, replication, crop age and dates of herbicide application are given in Table 1. Experiment 4 was carried out at Loughgall, all the others at Begbroke. For the pot experiments, runners were planted in 17.5 cm diam. plastic pots in loam-based compost and grown outside. Treatments were applied with a laboratory pot sprayer fitted with a Spraying System Teejet 8001, giving a spray volume of 225 l/ha. Following spraying, plants were grown on outside but protected from rain; subsequent watering avoided wetting leaves.

In the field experiment at Begbroke metre square plots were used each with three rows of three plants set out equidistantly. A randomised block design was employed. Lenacil at 2.2 kg/ha was applied to all plots one week after planting. Runners were removed at intervals in the summer after planting out. In the second year they were allowed to root in the plot but those extending outside the plot were removed at intervals and weighed. Experimental treatments were applied with an Oxford Precision Sprayer used in conjunction with a screened spraying frame. Spray jet type and volume rate were the same as in the pot experiments.

The Loughgall experiment (Expt.4) was laid out using a randomised block design with a plot size of 12.5 m x 0.9 m. The plots consisted of a single row of plants;

those receiving phenmedipham + adjuvant oil A were divided into three to allow three rates of phenmedipham to be applied. Treatments were applied with an Oxford Precision Sprayer at a volume rate of 560 l/ha.

The following herbicide formulations were used:-

phenmedipham, 11.4% ec; simazine, 50% wp; lenacil, 80% wp; barban, 12.5% ec.
adjuvant oil A: 97% emulsifiable paraffinic oil as BP 'Actipron'
adjuvant oil B: 99% emulsifiable paraffinic oil as Fisons 'Fyzol 11E'.

Doses of herbicide are expressed in terms of active ingredient while the doses of oils are given as the quantity of product used. Details of the herbicide treatments in each experiment are given in Tables 2-7.

The cultivar Cambridge Favourite was used in all the experiments at Begbroke. The cultivars involved in the tests of cultivar tolerance are shown in Tables 6 and 7. In the experiment at Loughgall the cultivars used were Cambridge Favourite and Cambridge Vigour.

Standard pesticide spray programmes were carried out in all experiments but no sprays were applied in the week before or after experimental treatments.

Assessments of crop response were made in all experiments in the weeks following spraying, scoring the plants visually for leaf damage using the following 0-9 scale.

0 = plant dead;	1 = plant moribund, no green leaf;
3 = plant very stunted, some growth;	5 = 50% growth inhibition;
7 = distinguishable growth inhibition;	9 = plant healthy, as control.

Leaf fresh weight was determined at the end of all the pot experiments. In the field experiments fruit yield, runner number and weight and plant crown numbers were recorded, as shown in Tables 4 and 5.

RESULTS

Maximum temperature levels around the time of spraying are shown in Table 1.

Experiment 1. All the treatments caused chlorotic patches to develop on sprayed leaves within a week of treatment (Table 2). Symptoms were slightly more severe with 4 kg/ha phenmedipham but with all treatments injury was soon outgrown and the only significant difference from control plants when the final assessment was made after 2 months was with the phenmedipham + simazine treatment where leaf weight was reduced by 6%.

Experiment 2. The addition of the oil to phenmedipham slightly increased the amount of foliar injury and, where the phenmedipham rate was 1.1 kg/ha or more, depressed leaf fresh weight slightly when assessed after 2 months (Table 3). With phenmedipham at 1.1 kg/ha there was a slightly greater effect on final leaf weight with the addition of 2.8 l/ha than 5.6 l/ha oil. The type of injury was similar to that caused by phenmedipham alone. Sprays of the oil alone had no apparent effect.

Experiment 3. There was slightly more leaf damage where the oil was added to phenmedipham and, with two of the four application dates, significant reductions in fruit yield (Table 4). There was no difference between any of the treatments in subsequent runner production or crown number the following winter.

Experiment 4. With Cambridge Vigour there was a slight increase in the amount of leaf injury caused by the addition of the adjuvant oil to phenmedipham but none with C.Favourite (Table 5). There were no significant differences in subsequent runner production between the treatments. (As the plots treated with the three phenmedipham + oil treatments were one-third of the size of the plots receiving the other treatments results from the former have been pooled for the purposes of analysis).

Table 2

The effect of phenmedipham ± lenacil or simazine applied on 14.8.73 on growth of strawberries (Expt.1).

Treatment		Dose (kg/ha)	Damage score (0-9) 22.8.73	12.10.73	Fresh wt. leaves (% control) 15.10.73
Phenmedipham		1	8.0***	9.0	108
"		2	7.7***	8.7	114
"		4	7.0***	8.3	106
"	+ lenacil	1 + 2	8.0***	9.0	106
"	+ simazine	1 + 1	8.0***	8.2	94*
Untreated control (actual values)			9.0	9.0	46.7 g
SE ±			0.13	0.45	8.0%

***, **, *: indicates significant differences from controls at p=0.001, 0.01, 0.05

Table 3

The effect of phenmedipham ± adjuvant oil A applied on 14.8.74 on growth of strawberries (Expt.2).

Treatment		Dose (kg/ha)	Damage score (0-9) 21.8.74	7.10.74	Fresh wt. leaves (% control) 10.10.74
Phenmedipham		0.8	7.3***	9.0	106
"		1.1	7.7***	9.0	89
"		2.2	7.0***	9.0	86
"	+ oil A	0.8+5.6	7.7***	9.0	101
"	"	1.1+2.8	7.7***	8.7	75*
"	"	1.1+5.6	6.7***	9.0	87
"	"	2.2+11.2	5.3***	8.3	71**
Oil A		2.8	9.0	9.0	99
"		5.6	9.0	8.3	99
"		11.2	9.0	9.0	107
Untreated control (actual value)			9.0	9.0	69.0g
SE ±			0.21	0.73	8.7%

***, **, *: indicates significant difference from control at p=0.001, 0.01, 0.05

Experiment 5. For the cultivars as a whole the treatments affected leaf condition and final leaf fresh weight in the following order of toxicity:- phenmedipham 2 x 1.1 kg/ha (most toxic), 2.2 kg/ha single dose, 1.1 kg/ha + oil, 1.1 kg/ha alone (least toxic), (Table 6). Senga Gigana was consistently more susceptible to the phenmedipham treatments than the other cultivars but all plants had recovered by the end of the experiment. No cultivar was more tolerant than C.Favourite.

Experiment 6 Injury symptoms showed up after one day with the phenmedipham + barban treatment, the surface of sprayed leaves becoming blackened. Necrosis of part or the whole of the sprayed leaves developed later on most cultivars but the plants rapidly recovered. Symptoms from the other treatments developed more slowly consisting of chlorotic and/or necrotic patches on sprayed leaves. Chlorosis was much more obvious on a few cultivars particularly Domanil, extensive yellow/white patches developing on sprayed leaves. There was more chlorosis on the plants sprayed with the mixtures or the double phenmedipham dose compared with the single application. Symptoms were masked after 2 weeks by the growth of new leaves.

The assessment of crop condition after 2 weeks showed that there was least leaf injury with the single phenmedipham dose. There was no consistent difference between the other treatments although Domanil, Redgauntlet and Senga Gigana were more damaged by the repeated treatment than by the mixtures.

Table 4

The effect of phenmedipham (1.1 kg/ha) ± adjuvant oil A (5.6 l/ha) applied at four dates on growth and yield of strawberries (Expt.3)

Treatment dates	Damage score (0-9) 30.5.75		Fruit yield°		Runner wt.° (July-Oct.)		Crown No.° 9.12.75	
	P+	P+A+	P	P+A	P	P+A	P	P+A
A 15.4.75	9.0	9.0	108	100	109	97	111	101
B 25.4.75	9.0	8.0***	109	83*	111	123	100	105
C 8.5.75	8.5	7.0***	106	87	108	111	105	106
D 19.5.75	7.0***	6.5***	94	86*	103	119	102	102
Lenacil standard	9.0		14.8 t/ha		1900 g/plot		60/plot	
SE ±	0.20		6.2%		11.5%		5.8%	

° given as percentage of lenacil standard. +P=phenmedipham, A=adjuvant oil A.
***, **, * indicates values significantly different from lenacil standard at p = 0.001, 0.01, 0.05

Table 5

The effect of phenmedipham ± adjuvant oil A (5.6 l/ha) applied on 13.5.75 on the growth of Cambridge Favourite and Cambridge Vigour strawberries (Expt.4)

Treatments	Cv.	Damage score (0-9) 27.5.75		Runner Number/plot+		Runner wt. Kg/plot+	
Small plot treatments							
Phenmedipham 0.8 kg/ha	C.Fav.	8.0		433		8.3	
+ adjuvant oil A	C.Vig	7.0		215		3.6	
	Mean		7.5		648		11.9
Phenmedipham 1.0 kg/ha	C.Fav.	8.0		427		9.3	
+ adjuvant oil A	C.Vig.	6.7		275		5.5	
	Mean		7.3		702		14.8
Phenmedipham 1.1 kg/ha	C.Fav.	7.7		433		9.5	
+ adjuvant oil A	C.Vig.	6.0		243		4.2	
	Mean		6.8		676		13.7
Large plot treatments							
Phenmedipham *	C.Fav.	7.9		1293		27.1	
+ adjuvant oil A	C.Vig.	6.6		733		13.4	
	Mean		7.2		2026		40.5
Phenmedipham 1.1 kg/ha	C.Fav.	7.7		1458		28.2	
	C.Vig.	7.7		742		13.7	
	Mean		7.7		2200		41.9
Lenacil 2.0 kg/ha	C.Fav.	8.0		1368		27.3	
	C.Vig.	8.7		775		13.2	
	Mean		8.3		2143		40.5
SE treatments ±		0.17		110.2		2.50	
SE cultivars ±		0.14		90.0		2.05	
SE treat's x cv. ±		0.24		115.9		3.55	

* Mean or pooled values of the 3 phenmedipham + oil treatments +assessed 18.9.75

The most susceptible cultivars appeared to be Cambridge Prizewinner, Domanil, Senga Gigana and S.Precosana. Redgauntlet was more tolerant than any other cultivar.

Final weights were generally greater on the 1.1 kg/ha phenmedipham treatment than the others but the differences from the control plants were relatively small and not consistently correlated with the damage scores.

DISCUSSION

There appeared to be no increase in the toxicity of phenmedipham when applied in mixture with lenacil or simazine (Table 2). A similar result was found by van Himme and Stryckers (1975). Such mixtures could be useful if susceptible weeds are already present when the residual herbicides need to be applied.

Table 6

The effects of phenmedipham ± adjuvant oil A applied on 10.6.75 on seven cultivars of strawberry (Expt.5)

Cultivar	P^x	$2P^x$	$P+P^x$	$P+A^x$	Control	SE±
	Damage score (0-9) on 20.6.75					
Litessa	7.2***	6.5***	6.5***	6.8***	9.0	
Tamella	8.0**	6.8***	6.5***	6.5***	9.0	
Tioga	7.5***	6.5***	6.3***	6.8***	9.0	
C.Favourite	7.8***	7.0***	6.5***	7.3***	9.0	0.21
Elista	7.3***	5.8***	5.5***	6.5***	9.0	
Montrose	8.0**	6.8***	6.3***	7.3***	9.0	
Senga Gigana	6.5***	5.5***	5.0***	5.8***	9.0	
Treatment mean	7.5***	6.4***	6.1***	6.7***	9.0	0.08
	leaf fresh weight (as % control), 1.8.75					
Litessa	90	85*	78**	89	73.0+	4.4%
Tamella	107	91	83	92	65.1	5.0
Tioga	99	89	87	79**	62.7	5.2
C.Favourite	85	100	93	103	56.8	5.7
Elista	103	81*	85	80*	51.5	6.3
Montrose	112	111	92	100	61.4	5.3
Senga Gigana	86**	85*	89*	83*	66.7	4.8
Treatment mean	96	91	85**	88*	62.4	2.0

x P = phenmedipham 1.1 kg/ha; 2P = phenmedipham 2.2 kg/ha; P+P = two applications of phenmedipham with 48 hr interval; P+A = phenmedipham 1.1 kg/ha + adjuvant oil A 5.6 l/ha.

***,**,* indicates values significantly different from controls at p=0.001, 0.01, 0.05

+ = actual values, g/plant

The absence of severe effects from doses of phenmedipham up to 4 kg/ha (Table 2) or to repeated applications of 1.1 kg/ha, (Tables 6 and 7) confirm the considerable tolerance of the herbicide by strawberries indicated by earlier experimental work and commercial practice. The pot experiments were carried out during periods of hot weather to ensure phytotoxicity occurred but even the most damaging treatments appear to have had no permanent effect on growth. In sugar beet, applications late in the day are recommended in hot weather to reduce chances of injury (MAFF, 1975) but in Experiment 1 where an early morning application of phenmedipham was compared with a late afternoon treatment there was no difference in response. Confirmation of the considerable resistance the crop can show to the herbicide has been provided by use by growers. Repeated applications of phenmedipham at 1.1 kg/ha + oil have

Table 7

The effects of phenmedipham ± additives applied on 16.6.76 on a range of strawberry cultivars (Expt.6)

	Cultivar	Damage score (0-9) 2.7.76							Fresh weight of leaves/pot 7.7.76 as % control						
		P^x	P+P	P+A	P+B	P+C	Control	SE ±	P	P+P	P+A	P+B	P+C	Control+	SE ± %
1.	C.Favourite	7.0	6.0	5.8	6.0	6.0	9.0		111	104	108	99	109	89.5	8.2*
2.	C.Vigour	7.5	6.8	6.8	6.5	6.5	8.6		99	92	97	105	91	104.8	7.0
3.	Domanil	6.3	5.3	5.8	6.0	5.5	9.0	0.29*	111	105	106	99	101	104.7	7.0
4.	Gorella	7.0	6.5	6.3	6.5	6.3	9.0		103	87	96	96	92	99.6	7.3
5.	Redgauntlet	8.0	7.0	7.8	7.5	7.3	9.0		113	102	104	115	109	87.2	8.4
6.	Senga Gigana	6.0	5.5	5.8	6.0	6.0	9.0		95	89	93	97	88	110.9	6.6
7.	Senga Precosana	6.3	5.8				9.0		108	93				97.7	5.5
8.	Royal Sovereign	6.8	6.0				9.0		107	90				87.0	6.2
9.	C.Prizewinner	6.5	4.8				9.0		107	92				77.9	7.0
10.	C.Premier	7.3	6.0				9.0	0.22*	114	110				80.9	6.7
11.	Elista	7.3	6.0				9.0		100	85				83.3	6.5
12.	Montrose	7.0	6.0				9.0		107	95				100.8	5.4
13.	Marmion	7.0	5.8				9.0		117	99				84.1	6.4
14.	Tamella	6.8	5.5				9.0		104	83				95.8	5.7
15.	Pantagruella	7.3	6.0				9.0		106	112				76.8	7.1
	Tr.Mean (all cv.)	6.9	5.9				8.9	0.05°	107	96				92.0	1.2°
	" (cv.1-6)	7.0	6.2	6.3	6.4	6.3	9.0	0.10°	105	96	100	102	98	99.4	2.7°

P^x, phenmedipham 1.1 kg/ha; P+P, phenmedipham 1.1 kg/ha (two applications); P+A, phenmedipham 1.1 kg/ha + oil A 5.6kg/ha; P+B, phenmedipham 1.1 kg/ha + oil B 5.0 l/ha; P+C, phenmedipham 1.1 kg/ha + barban 0.7 kg/ha.

*SED; standard error for comparisons of treatment means with controls for each cv; °SED for all cultivars

+Actual values, g/plot

been made to control large weeds without noticeable crop injury (Buttfield, 1976). These applications were carried out in early spring.

The addition of mineral oil to phenmedipham, which enables larger weeds to be controlled (MAFF, 1975) did not give much greater injury in pot or field experimen and no effects on subsequent growth. The small yield reductions recorded with th mixture in Experiment 3 (Table 4) suggests applications just prior to flowering are better avoided. The treatment with added oil has been successfully used commercially (Buttfield, 1976). There was no apparent difference in the effect o the two oils used in Experiment 6; both are in use in sugar beet (MAFF, 1975; Griffiths, 1976). The effect of the phenmedipham/barban mixture appeared more severe initially but the plants recovered quickly (Table 7). There are no report of tests with this mixture on strawberries but promising results have been obtain in an experiment at Kirton EHS (Garner, 1976). As well as controlling larger weed than the standard phenmedipham treatment, the range of weed species controlled is extended (MAFF, 1975).

There appear to be some differences in varietal tolerance to phenmedipham although the extreme chlorosis found with Domanil may give the appearance of more severe injury than in fact occurs. Cambridge Prizewinner, Domanil and Senga Giga were appreciably more injured than the other cultivars; this result agrees with commercial experience with the last two cultivars (Buttfield, 1976). Redgauntlet showed very minor leaf symptoms with all treatments. In field experiments with t most widely-grown cultivars in the UK only small differences in leaf effects hav been found and no differences in growth or yield (Uprichard, 1972; Clay *et al*, 19 The results of this work indicate that the various means used to increase the activity of phenmedipham on emerged weeds should not lead to severe crop injury w used on strawberries. When faced with the problem of extensive weed growth growe are prepared to accept the leaf injury that may occur. Differences in varietal t ance do exist and phenmedipham treatments may need to be modified on more suscept cultivars when spraying in conditions conducive to damage.

Acknowledgements

Thanks are due to the chemical manufacturers for the supply of herbicides/oi used in these experiments.

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THE RESPONSE OF FOUR VARIETIES OF STRAWBERRY TO 2,4-D APPLIED ON FIVE DATES IN THE YEAR OF PLANTING

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Summary 2,4-D at 1, 2 and 4 kg/ha was applied on five dates between May and October to four varieties of strawberry, Cambridge Favourite, Cambridge Vigour, Redgauntlet and Gorella. Treatments were applied in the year of planting. The effect on the total number of crowns and yield of the parent and daughter plants is described.

Date of application of 2,4-D was the main factor determining the number of crowns produced. There was no mortality of treated plants but total crown numbers were reduced by July and August applications, particularly at the higher doses. There was no dose response in the safest months which were May and June. There were no major differences between the four varieties.

The yield of Cambridge Favourite reflected the reduction in crown numbers but Redgauntlet was affected less because of greater yield of fruit from surviving crowns at the earlier application dates. Abnormal fruits were confined to plants treated in October but occurred on all four varieties.

It is concluded that 2,4-D is a promising treatment for the control of perennial broad-leaved weeds in newly planted strawberries but treatment should be confined to weedy areas.

INTRODUCTION

The most serious problem weeds in strawberries at present are, in order of importance, Cirsium arvense (Creeping Thistle), Convolvulus arvensis (Field Bindweed) and Agropyron repens (Common Couch) (Clay, 1975). Propyzamide and terbacil are recommended for the control of A.repens in strawberries but there are no recommendations for the control of C.arvense and C.arvensis, even though both of these weeds are controlled by several growth-regulator herbicides (Fryer and Makepeace, 1972). However there is a growers risk recommendation for spot treatments with 2,4-D at 1 kg/ha after fruiting (MAFF, 1973).

2,4-D has been found to be the safest of several growth-regulator herbicides that have been applied to strawberries (Roach, 1957; Davison, 1972). When damage has occurred it was related to the date of application (Loughgall 1960, 61, 62; Davison, 1972) and the crop variety (Hemphill, 1959).

The present work was designed to determine the response of four widely grown varieties of strawberries to 2,4-D applied in the year of planting.

METHOD AND MATERIALS

Four varieties, Cambridge Favourite, Cambridge Vigour, Redgauntlet and Gorella, were planted 1.5 x 1.2 m apart on 21 March 1974 in a sandy loam soil at Begbroke. Each plot consisted of the parent plant and all its daughter plants. These were confined to an area of 1 m diameter by training the runners around the parent plant. Flower trusses were removed in the year of planting.

Annual weeds were controlled with herbicides that are used in commercial crops. Lenacil at 2 kg/ha and phenmedipham at 1.5 kg/ha were applied four days after planting. A mixture of chloroxuron at 3.5 kg/ha and lenacil at 1.25 kg/ha was applied two months later and weed control was maintained throughout the second year by applying simazine at 1 kg/ha in the winter. Insecticides and fungicides were applied when required to control foliar pests and diseases. A drench of 200 ml of 0.2% benomyl was applied to each plant the day after planting to check verticillium wilt (Verticillium dahliae).

The experimental treatments, 2,4-D amine at 1, 2 and 4 kg/ha, were applied with an Oxford Precision Sprayer fitted with two Teejet 8003 fan nozzles. The pressure was 1.6 bars and the volume rate was 533 l/ha. Drift was prevented with a windshield which surrounded the plot. The treatments were replicated four times and a randomised block design was used. The stage of growth of one of the four varieties, Cambridge Favourite, at each of the application dates, is given in Table 1. Variations in development of the four varieties are mentioned in the results section. At each application date similar plants were dissected to enable the leaves, crowns, runners and daughter plants to be counted. Microscopic dissection of the crowns of parent and daughter plants provided information on the onset of runner production and the initiation and development of flower trusses.

The amount of spray retained was determined from plants that were sprayed with tartrazine which was recovered by washing the aerial parts in water after they had been cut at ground level. The amount was determined colorimetrically as described by Blackman et al (1958).

Observations on the type and severity of the symptoms were made one or two weeks after each treatment. The main assessments were the total number of crowns per plot in May of the year after application and the yield of fruit. Where differences are stated to be significant, $p = 0.05$.

RESULTS

The stage of growth of Cambridge Favourite at each of the five dates of application is presented in Table 1. Gorella was smaller and produced runners slightly later than the other three varieties. Cambridge Favourite and Redgauntlet produced slightly more runners and considerably more daughter plants than both Cambridge Vigour and Gorella. Redgauntlet initiated flower trusses in the daughter plants later than the other three varieties.

There were no differences in the amount of spray retained by the different varieties at the May and August applications, but Cambridge Vigour retained significantly more spray per unit dry weight than the other varieties at the June application (Table 2). Both Cambridge Vigour and Gorella retained significantly more than the other varieties in July. Although the total amount of spray retained by each variety increased with successive application dates, the amount of spray retained per unit of dry weight decreased, except for Cambridge Vigour in which retention was greater in June than in May.

Table 1

The stage of growth of Cambridge Favourite at each date of application

Date of application 1974	Numbers per parent plant: Green leaves	Runners	Daughter plants	% of daughter plants with initiated flower trusses
May 7	4.1	0	0	0
June 11	6.6	1.6	0	0
July 19	14.5	6.5	16.3	0
August 19	25.0	16.8	71.5	0
October 9	23.0	20.8	107.5	67.0

Table 2

The amount of spray (µl) retained per g dry weight

Date of application 1974	Cambridge Favourite	Red-gauntlet	Cambridge Vigour	Gorella
May 7	181	183	166	166
June 11	147	117	209	152
July 19	83	78	123	137
August 19	60	65	69	87
		SE ± 16		

All treatments caused epinasty of the petioles and runners of all varieties. This gave the plants a prostrate appearance. In addition some petioles and runners became red. Leaf formative effects were seen on the two or three leaves expanding after treatment but subsequent growth was normal and there were no leaf formative effects in the year following application.

The appearance of the fruit was unaffected by 2,4-D with the exception of the October application which resulted in crescent-shaped and fused fruits. The amount of deformed fruit was similar on all varieties and at all doses. There was an average of 7% deformed fruit but this was as high as 25% on some plants.

The number of crowns for each treatment are presented in Table 3. There were no significant reductions in the number of crowns with any variety from the May, June or October applications. The combined effect of the doses showed that the July application reduced the number of crowns significantly on all four varieties but the reduction from the August application was only significant for Cambridge Favourite and Gorella.

The values for individual doses show that, with the July application, 2 and 4 kg/ha caused significant reductions on all four varieties and, with all but Gorella, 1 kg/ha gave an appreciable reduction in crown numbers. With the August application there were significant reductions with 2 and 4 kg/ha on Cambridge Favourite and with 4 kg/ha on Gorella. The reductions with 2 kg/ha were also considerable although not significant on both Redgauntlet and Gorella.

The yields of strawberries of varieties Cambridge Favourite and Redgauntlet given in Table 4. Yields of Cambridge Favourite reflected the crown numbers. Th greatest reductions were caused by the July and August applications but they were significant for July only. There was less effect on the yield of Redgauntlet particularly with the May, June and July applications.

Table 3

Number of crowns per plant in May of the year following application

Results transformed to Log (10x + 1) for analysis: detransformed means expressed as a % of the untreated and are in parentheses.

Variety	2,4-D kg/ha	Dates of Application May	June	July	August	October
Cambridge Favourite	1	6.01(101)	6.21(118)	5.77(70)	5.84(89)	6.09(112)
	2	5.73(74)	6.03(100)	5.08(39)	5.25(50)	6.02(104)
	4	5.92(96)	5.97(93)	3.93(11)	5.29(56)	6.09(106)
	Untreated	5.90 (100) 100% = 42.3 crowns				
Redgauntlet	1	5.90(76)	6.13(90)	5.78(65)	6.11(91)	6.10(85)
	2	6.29(100)	6.18(89)	5.46(45)	6.01(80)	5.82(69)
	4	6.16(89)	5.87(66)	5.15(37)	5.65(62)	5.84(72)
	Untreated	6.22 (100) 100% = 53.9 crowns				
Cambridge Vigour	1	5.57(131)	5.84(171)	4.98(67)	5.14(80)	5.53(128
	2	5.75(147)	5.46(115)	4.31(43)	5.39(103)	5.22(92)
	4	5.33(97)	5.26(91)	4.29(35)	4.83(60)	4.73(60)
	Untreated	5.31 (100) 100% = 22.0 crowns				
Gorella	1	5.46(139)	5.47(126)	5.15(110)	5.15(87)	5.57(137
	2	5.25(99)	5.61(142)	4.50(46)	4.88(74)	5.14(91)
	4	5.37(110)	5.32(107)	3.41(17)	4.45(44)	5.43(118
	Untreated	5.20 (100) 100% = 20.3 crowns				

SE $\pm$ 0.223

Table 4

Yield of strawberries in the year following application

Results transformed to Log (10x + 1) for analysis; detransformed means expressed as a % of the untreated and are in parentheses.

Variety	2,4-D kg/ha	Date of Application May	June	July	August	October
Cambridge Favourite	1	9.03(78)	9.46(112)	9.41(92)	8.68(44)	9.25(92)
	2	8.84(50)	9.30(85)	8.10(27)	8.17(26)	9.12(74)
	4	9.24(85)	9.16(75)	6.81(7)	8.10(30)	9.04(62)
	Untreated	9.21 (100)	100% = 1368 g/plant		SE ± 0.400	
Redgauntlet	1	9.01(70)	9.15(82)	9.08(84)	9.11(71)	9.32(91)
	2	9.55(111)	9.58(113)	9.16(80)	8.86(58)	8.46(46)
	4	9.50(105)	9.42(99)	8.93(67)	7.87(35)	8.88(66)
	Untreated	9.34 (100)	100% = 1285 g/plant		SE ± 0.400	

Table 5

Yield of fruit per crown expressed as % of untreated

Variety	2,4-D kg/ha	Date of Application May	June	July	August	October
Cambridge Favourite	1	36	88	128	68	78
	2	67	82	70	58	70
	4	83	78	69	62	70
		Untreated:	100% = 33.9 g/crown			SE ± 19%
Redgauntlet	1	95	87	122	94	110
	2	107	122	178	71	69
	4	117	145	167	72	105
		Untreated:	100% = 24.6 g/crown			SE ± 20%

Although the yields of Cambridge Vigour and Gorella are not presented because both varieties were affected by Verticillium wilt, the overall response of both varieties seemed to be similar to that of Cambridge Favourite.

2,4-D caused an almost consistent but non-significant reduction in the yield of fruit per crown of Cambridge Favourite (Table 5). Redgauntlet responded differently and tended to produce more fruit per crown when 2,4-D was applied in May, June and July but not at the later dates. The yield increases with 2 and 4 kg/ha in July were significant.

DISCUSSION

The most striking feature was the overall tolerance of spring planted strawberries to 2,4-D in the seven months after planting. Despite the fact that 240 plants were treated, one-third of them with 4 kg/ha, there were no fatalities with any variety.

The management of the crop in this experiment may have exaggerated the effect of 2,4-D on yield. In commercial crops the planting density is greater, fewer daughter plants are retained and they account for a smaller proportion of the yield. Thus the effect of the July and August applications would probably have been less.

The standard errors are large, probably due to the small number of replicates of plots consisting of a single parent and all its daughter plants. Consequently only very large differences are statistically significant. Trends in the results that were not significant are probably of considerable practical importance to growers and advisers faced with the problem of 2,4-D sensitive weeds in strawberries.

The response of the four varieties was similar in terms of crown numbers which influence potential yield. There was an indication of varietal difference with Redgauntlet which produced more fruit per crown when 2,4-D had reduced the number of crowns. It occurred with the earlier applications and was greatest in July when it largely overcame the reduction in yield anticipated from the reduction in crown numbers. The lack of compensation from the August and October applications is thought to be because there was insufficient time for the plants to recover before the end of the season.

There were indications of a dose response, mainly from the July and August applications. 2,4-D at 4 kg/ha in July was particularly damaging to Cambridge Favourite and Gorella. The practical importance of the greater damage caused by high doses has to be considered in relation to the consequence of not controlling the weed and any improvement in weed control by increasing the dose. For instance, it has been shown that the long term control of Convolvulus arvensis (Field Bindweed) is greatly improved by increasing the dose of 2,4-D from 1 to 2 kg/ha (Davison and Bailey, 1974).

The major factor determining response in this experiment was the date of application; May and June being the safest months, taking into account the malformed fruit produced by the October application. The reduction in yield from the July and August applications coincided with development and establishment of daughter plants. In earlier experiments applications at this time to long established fruiting crops (Loughgall, 1962) and even to crops planted the previous autumn (Davison, 1972) have been relatively safe. This apparent discrepancy should be resolved. It is particularly desirable to find out the tolerance of fruiting crops to 2,4-D in July and August since this is a convenient period for application because the crop has been harvested and perennial broad-leaved weeds are still susceptible to 2,4-D.

The tolerance of newly planted strawberries to 2,4-D, which has also been reported in North America (Hill, 1958), increases the opportunity to control perennial broad-leaved weeds before cropping commences.

The results of this and the earlier work clearly show that 2,4-D can damage strawberries, even during the relatively safe periods so far established. Therefore 2,4-D should only be used as a selective treatment when there is no satisfactory alternative. Perennial broad-leaved weeds frequently affect only a relatively small proportion of a given crop. This means it should often be possible to confine the 2,4-D to these areas by spot treatment with either hand applicators or tractor-mounted sprayers. In this way the minimum amount of crop is put at risk. The results also indicate that at the doses needed for long-term weed control the risk to the crop is reduced more by application at the correct time than by reducing the dose.

Acknowledgements

Thanks are due to Miss J P Crabtree and Mr J I Green for assisting with the experimental work and to Mr B O Bartlet and Mr C Marshall for the statistical analyses.

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Proceedings 1976 British Crop Protection Conference - Weeds

EXPERIMENTS ON THE LIMITATION OF CANE GROWTH IN RASPBERRY ROWS

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Summary. Techniques were examined for reducing excessive cane vigour in raspberry rows by treatment of young canes in spring. Temporary retardation of growth with propyzamide or with low rates of an NAA/aliphatic oil mixture ('Tip-off') showed promise. Defoliation with paraquat, diquat or low rates of dinoseb in oil was not found practicable since, although most canes recovered, cane quality often was impaired. Complete removal of the first flush of young canes proved an effective technique. The most promising chemical for this purpose was dinoseb in oil applied at a rate of 2.7 kg a.i. in 1000 l water, sprayed to run-off. This gave 100% knock-down without affecting subsequent emergence and growth of replacement canes. Paraquat and 'Tip-off' were less effective than dinoseb, while glyphosate severely injured the crop. While none of the experiments established the optimum treatment for individual plantations, the results showed that there is scope for substantial reduction of cane vigour in cv. Glen Clova and that it may be possible to devise techniques beneficial to the less vigorous cv. Malling Jewel.

INTRODUCTION

Tall young raspberry canes restrict access, obscure fruit during harvest and require considerable tipping when they themselves are tied-in for fruiting. Numbers well in excess of those required for future fruit production also cause obstruction and increase the costs of cane handling operations during the winter. This problem is well known in the main raspberry production areas of the north west of the United States, where some raspberry cultivars regularly produce canes over 4 m tall, but has only recently attracted attention in the United Kingdom, where the major cultivar, Malling Jewel, is not particularly vigorous. However, several of the high-yielding cultivars recently released by British plant breeders have been selected for increased cane vigour. In particular cv. Glen Clova, which has been extensively planted in Scotland in the last few years, is proving difficult to manage in mature plantations because of excessive growth of young canes.

METHOD AND MATERIALS

Experiments were carried out at Invergowrie between 1973 and 1975 on mature raspberry plantations managed on the stool system. Plots consisted of single rows of equal numbers of stools laid out in randomised blocks. Rows were 185 cm apart, with canes planted 60-70 cm apart in the row. Directed spray treatments were applied to a band 30 cm on each side of the centre of the row by Oxford Precision Sprayer, using a single angled coarse nozzle delivering 1123 l water per treated hectare. In one experiment spray volume was adjusted to ensure complete coverage of different heights of foliage. Rates and dates of application of herbicide treatments are given in the appropriate tables. All rates are quoted in terms of active ingredient per treated hectare, unless stated. Treatments were applied in one year only.

Results are presented after covariance on uniformity assessments taken before experi -mental treatments were applied.

RESULTS

Expt I Glyphosate, propyzamide and paraquat were applied along rows of cv. Malling Jewel on 24 May when young canes averaged 15 cm high. The plantation was in a sheltered position adjacent to a wind-break and regularly produced tall canes. Plots consisted of single rows of 12 stools, 7.3 m long. Each herbicide treatment was replicated four times, with three untreated control plots per replicate. Glyphosate severely stunted and distorted young canes and eventually killed most of them. Within a few days similar injury symptoms were found in laterals at the top of the fruiting canes. This injury spread as the season progressed and several fruiting canes died prematurely, but most canes produced fruit on unaffected laterals. During July, apparently normal young canes emerged and grew rapidly, but these canes went into the winter unripened. Propyzamide caused leaf curling and temporary stunting of treated young canes, while paraquat killed a proportion of the foliage and some of the growing points, but recovery was rapid. Fruiting canes apparently were unaffected by either herbicide. Untreated canes obstructed fruit picking, but herbicide treatment made access much easier. Yield of fruit (Table 1) was higher on all treated than on untreated plots, significantly so in the case of glyphosate despite its adverse effects on fruiting canes. Berry numbers were significantly higher on plots treated with glyphosate and paraquat than on untreated plots. The plantation was retained for further cropping and both numbers and heights of new canes on untreated plots were well in excess of requirement, only 53% of total production being required to give an average of 7 good canes per stool. Only half as much cane length was tied-in on plots treated with glyphosate as on untreated plots (Table 1). Quality was poor, due to short, spindly and unripened canes. Propyzamide did not significantly reduce total cane numbers, but those reaching tipping height (155 cm) were far fewer and cane length retained was 31% less than that on untreated plots. Paraquat had no adverse effect on numbers or heights of canes produced or on the length retained, although more branched canes were present than on other plots. Mean height (before tipping) of canes tied-in for subsequent fruiting was 13% and 16% less on plots treated with glyphosate and propyzamide respectively than on untreated plots.

Expt II The above treatments, together with diquat and dinoseb in oil were applied along rows of cv. Malling Jewel on 6 May when young canes averaged 10 cm high. The plantation was on an exposed site and tipping height was only 135 cm. Plots consist -ed of single rows of 6 stools, 3.66 m long, with 4 replicates of each treatment. Propyzamide was less severe on young canes than in the previous experiment but paraquat gave slightly better initial burn of these smaller canes. Diquat was slightly less and dinoseb considerably more effective than paraquat. Treated canes recovered on all these plots and mean cane height averaged 15% less than on untreated plots at the beginning of fruit picking. Glyphosate again killed young canes and injured fruiting canes, although most of them fruited. However, no herbicide treatment had any significant effect on fruit yield or its components in compari -son with the untreated control. Numbers and heights of new canes in November were below average, even on untreated plots (Table 2), due possibly to severe moisture stress during late spring and summer. The plantation was retained for further fruiting, but the objective of tying-in 7 canes/stool, all reaching tipping height, would have needed 9.5 m of cane per stool. Untreated plots achieved only 60% of this, with more than one-third of the canes being rejected and few canes requiring to be tipped. With glyphosate, the final length of cane retained was only 61% of that on untreated plots, but none of the other four treatments significantly reduced the cane length retained, although total numbers produced on plots treated with dinoseb were significantly lower. In several cases a higher percentage of the available length was retained than on untreated plots. Mean height of tied-in cane was significantly lower only on plots treated with glyphosate.

Table 1

Expt I - Fruit and cane production

Treatment of new canes	Fruiting cane records			New cane records/stool			
	Yield t/ha	Berries /cane	Mean wt g/100 berries	No. produced (Nov.) Total	No. produced (Nov.) >155cm	Cane length retained (m) (Jan.)[+]	Mean cane ht. (cm) (Jan.)[++]
Herbicide kg/ha							
Untreated	6.73	25.3	392	12.1	8.4	10.8	187
S.E. mean ±	0.241	1.11	7.4	0.44	0.43	0.59	3.5
Glyphosate 2.2	7.95*	31.2*	378	8.3***	2.7***	5.4***	156***
Propyzamide 2.2	7.09	25.9	411	10.8	4.6***	7.5*	162**
Paraquat 1.1	7.47	30.5*	368	11.8	7.3	11.7	192
S.E. mean ±	0.417	1.92	12.8	0.77	0.74	1.02	6.0

Table 2

Expt II - Fruit and cane production

Treatment of new canes	Fruiting cane records			New cane records/stool			
	Yield t/ha	Berries /cane	Mean wt g/100 berries	No. produced (Nov.) Total	No. produced (Nov.) >135cm	Cane length retained (m) (Jan.)[+]	Mean cane ht. (cm) (Jan.)[++]
Herbicide kg/ha							
Untreated	10.25	93.9	292	8.2	3.9	5.7	135
Glyphosate 2.2	9.18	75.1	307	6.6	2.4***	3.5***	108***
Propyzamide 2.2	11.19	94.2	304	8.1	3.8	5.1	125
Paraquat 1.1	11.47	102.5	312	6.8	3.3	5.4	134
Diquat 1.1	8.92	78.0	312	7.3	3.5	5.5	131
Dinoseb 1.0	8.75	76.6	309	5.8**	3.5	4.8	128
S.E. mean ±	0.865	9.65	14.5	0.55	0.23	0.36	3.6

*,**,*** Significantly different from Untreated at 5%, 1%, 0.1% level
[+] after tipping [++] before tipping

Expt III Dinoseb in oil at 2.0 kg/ha and paraquat at 2.2 kg/ha were compared at different stages of growth of young canes in a vigorous plantation of cv. Malling Jewel, next to a wind break. Plots consisted of single rows of 6 stools, 3.66 m long. A treatment involving regular cutting of all young canes was also included. There were four replicates of each cane removal treatment and three untreated control plots per replicate. Dates of application were 22 May (10 cm) and 31 May (20 cm) with a repeat application on 12 June (10 cm) to plots earlier sprayed at that stage. Speed of initial burn was much better with dinoseb than with paraquat at all dates, but the final effects of the two herbicides was very similar at all heights

Table 3

Expt III - Fruit and cane production

Treatment of new canes: Height	Herbicide	Fruiting cane records: Yield t/ha	Berries /cane	Mean wt g/100 berries	New cane records/stool (Nov.: Total length (m)	No. of canes >90cm	>155cm	Mean cane h (cm) >155
Untreated		10.91	53.8	360	24.5	14.2	7.5	187
S.E. mean ±		0.464	2.25	7.2	1.24	0.82	0.44	1.7
10cm	Dinoseb	11.26	49.9	391*	17.9*	9.6**	6.2	194
	Paraquat	10.25	46.1	376	18.5*	10.2*	5.7	188
20cm	Dinoseb	10.02	48.4	360	17.6*	9.8*	5.0**	186
	Paraquat	9.96	50.3	364	18.8*	10.6*	5.0**	184
10cm twice	Dinoseb	11.28	52.8	381	12.6***	7.3***	4.1***	183
	Paraquat	10.66	48.5	389	13.9***	8.1**	3.9***	182
Cut regularly		13.07*	51.9	437***	-	-	-	-
S.E. mean ±		0.803	3.89	12.4	2.16	1.41	0.77	3.0
All 10 cm		10.76	48.0	384*	18.2**	9.9**	6.0*	191
All 20 cm		9.99	49.4	363	18.2**	10.2**	5.0**	185
All 10 cm twice		10.97	50.7	385*	13.3***	7.7***	4.0***	183
S.E. mean ±		0.568	2.75	8.8	1.52	1.00	0.54	2.2
All Dinoseb		10.85	50.4	377	16.1***	8.9***	5.1***	188
All Paraquat		10.29	48.3	376	17.1***	9.6***	4.9***	185
S.E. mean ±		0.464	2.25	7.2	1.24	0.82	0.44	1.7

*,**,*** Significantly different from Untreated at 5%, 1%, 0.1% level

of treatment. At 10 cm about 80% of treated foliage was killed and a proportion the stem growth of young canes, but survivors produced new growing points. Treat ment at 20 cm removed some 70% of treated foliage but was relatively ineffective cane stems, most of which recovered quite quickly. Emergence of new canes was le than with the earlier treatment. The second application at 10 cm had similar eff on young canes to those of the original treatment and killed some of the less vig ous survivors. Further emergence of normal canes took place on all plots. All herbicide treatments considerably reduced obstruction by young canes at fruit harvest. However,they had no significant effect on fruit yield (Table 3). Regul cutting increased fruit yield by 20% due to increased berry size. The plantation was not kept for further cropping, but records of numbers of canes at least tall enough to tie in to the bottom wire (>90cm) and of those reaching tipping height (>155cm) showed that on untreated plots there was every likelihood of retaining a average of 7 good canes/stool. All herbicide treatments significantly reduced to cane production and numbers of canes reaching tipping height were inadequate for future requirements. No significant differences were found between dinoseb and paraquat or between treatment at 10 cm and at 20 cm. However, treatment twice at 10 cm reduced total cane length by 26% compared with the single treatment dates. There were no significant differences between treatments in mean height of canes over 155 cm tall, but all herbicide-treated plots, particularly those treated wit paraquat and/or at 20 cm, contained a proportion of spindly, brittle or malformed canes, as a result of incomplete chemical control. These canes had also been attacked by Botrytis cinerea and would have had to be discarded, regardless of height.

Expt IV Dinoseb in oil, propyzamide and 'Tip-off' (an NAA aliphatic oil mixture) were applied at a range of dosages along rows of a very vigorous plantation of cv. Glen Clova when the young canes were 10 cm high (24 April) and compared with cutting once at this stage or cutting regularly. Dosages and treatments are given in Table 4. Plots were single rows of 8 stools, 6.1 m long, with 3 replicates of each cane removal treatment and two untreated control plots per replicate.

Table 4

Expt IV - Fruit and cane production

Treatment of new canes		Fruiting cane records			New cane records/stool (Nov.)			
		Yield t/ha	Berries /cane	Mean wt g/100 berries	Total length (m)	No. of canes >90cm	No. of canes >155cm	Mean cane ht. (cm) >155
Herbicide	kg/ha							
Untreated		9.66	51.3	329	30.9	17.4	9.1	193
S.E. mean ±		0.527	3.59	7.5	1.68	1.14	0.85	3.4
Cut once		11.69*	69.0	347	27.9	16.8	8.6	190
Dinoseb	2.0	9.29	57.5	330	30.2	17.8	8.6	196
Dinoseb	3.0	12.01*	76.7*	343	30.2	17.9	8.0	192
Dinoseb	4.0	10.51	63.6	342	24.0	14.2	6.0	195
Dinoseb	5.0	11.60*	70.6	337	32.1	17.9	8.4	190
Propyzamide	1.1	9.63	52.7	327	34.9	20.4	10.8	185
Propyzamide	2.2	9.88	60.2	340	31.1	18.8	7.7	191
Propyzamide	3.3	9.13	54.5	343	35.2	21.4	10.4	189
Propyzamide	4.4	10.28	62.5	348	32.7	18.2	11.0	196
	l/ha							
'Tip-off'	5.6	8.83	54.9	336	27.8	15.9	9.3	189
'Tip-off'	11.2	9.14	54.5	343	31.7	18.8	9.5	186
'Tip-off'	16.8	12.18**	72.4	349	27.2	16.1	8.0	187
'Tip-off'	22.4	11.20	72.1	334	25.8	14.7	6.5	191
Cut regularly		15.00***	83.2**	370**	-	-	-	-
S.E. Mean ±		0.746	5.07	10.5	2.41	1.64	1.22	4.9

*,**,*** Significantly different from Untreated at 5%, 1%, 0.1% level

Propyzamide delayed growth only very slightly, regardless of dosage and no new canes emerged on these plots. Dinoseb at 2 kg/ha was 80% effective in killing young canes, while 3, 4 and 5 kg/ha gave 90%, 95% and 100% kill respectively, the speed of knock-down increasing with dosage. Surviving canes produced recovery growth of poor quality, but healthy new canes soon emerged, although a little more slowly than on cut plots. All rates of 'Tip-off' caused some distortion of treated canes. At the two lower rates they recovered within a few days and grew normally thereafter. At the higher rates the check to growth lasted longer, but the great majority of canes recovered. Little further cane emergence occurred even at the highest dosage, since canes which failed to recover remained stunted for many weeks. Despite these early differences between treatments, young canes severely obstructed picking on all plots except those cut regularly. These last plots, in response to the removal of competition by young canes, yielded 55% more fruit than untreated plots, with significant increases in both size and number of berries (Table 4). Plots cut once and those treated with 'Tip-off' at 16.8 l/ha and dinoseb at 3 and 5 kg/ha outyielded untreated plots by over 20%. Dinoseb at 2 kg/ha and 'Tip-off' at 5.6 and 11.2 l/ha gave yields significantly lower than that on plots cut once at the same date. Propyzamide had no beneficial effect on fruit yield.

Total length of cane present at the end of the season was greatly in excess of future requirements and there were no significant differences between treatments in numbers or heights present at the end of the season. Fruit pickers caused a moderate amount of random injury to tall young canes on all plots, thereby increasing the variability of cane records. Treatment once at 10 cm, regardless of method, was nevertheless not sufficiently severe to reduce either heights or numbers to manageable proportions.

Table 5

Expt V - Fruit and cane production

Treatment of new canes		Fruiting cane records			New cane records/stool (Nov.)			
		Yield t/ha	Berries /cane	Mean wt g/100 berries	Total length (m)	No. of canes		Mean cane ht (cm) >135
Height	Method					>90cm	>135cm	
Untreated		5.00	34.4	360	24.1	16.0	10.0	157
5cm	Cut	5.30	32.9	373	24.4	16.2	9.6	157
	Dinoseb	4.82	33.6	359	24.9	15.8	10.4	163
	'Tip-off'	5.07	36.1	370	20.8	14.2	9.5	167
10cm	Cut	6.08	45.4	349	22.8	15.1	8.7	159
	Dinoseb	5.80	36.3	386	22.0	14.4	7.8	157
	'Tip-off'	4.72	30.6	385	21.5	13.5	9.2	160
15cm	Cut	6.70	46.8	357	21.8	13.8	8.2	157
	Dinoseb	6.52	44.4	379	19.5	12.7*	8.2	157
	'Tip-off'	6.85	44.9	389	19.9	13.0*	7.8	159
Cut regularly		7.13*	50.3*	374	-	-	-	-
S.E. mean ±		0.687	5.50	12.2	1.67	1.01	1.04	3.8
All 5cm		5.06	34.2	367	23.4	15.4	9.8	162
All 10cm		5.53	37.4	373	22.1	14.3	8.6	159
All 15cm		6.69*	45.3	375	20.4	13.2*	8.1	158
All cut (once)		6.03	41.7	360	23.0	15.0	8.8	158
All Dinoseb		5.71	38.1	375	22.1	14.3	8.8	159
All 'Tip-off'		5.55	37.2	381	20.7	13.5*	8.8	162
S.E. mean ±		0.397	3.17	7.0	0.97	0.58	0.60	2.2

*, **, *** Significantly different from Untreated at 5%, 1%, 0.1% level

Exp V Dinoseb and 'Tip-off' were applied along rows of cv. Malling Jewel on 22 April (5 cm), 25 April (10 cm) or 2 May (15 cm) and compared with removal of young cane by cutting on these dates. Also included were regular removal by cutting and an untreated control. Plots were single rows of 6 stools, 3.66 m long, with four replications of each treatment. Dinoseb was applied at 2.7 kg a.i. and 'Tip-off' at 20 l of formulated product in 1000 l water, sprayed to run-off, to ensure complete coverage of treated canes at each date. At 5 cm dinoseb was not completely effective, since leaves were not yet unfurled, growing points were protected and most of he spray landed on bare ground. 'Tip-off', caused distortion and stunting of treated canes, but this was rapidly outgrown. At 10 cm dinoseb was 100% effective, but most canes recovered from initial distortion by 'Tip-off', although a propo tion gradually became brittle and died. At 15 cm dinoseb rapidly killed all young canes, while 'Tip-off' was more effective than previously, fewer treated canes surviving. However, canes severely malformed by 'Tip-off' died only very slowly. New canes soon emerged on all cut plots. The speed of emergence on other plots depended on the speed and degree of kill of treated canes and was much slower on plots treated with 'Tip-off'. Treatments at 10 cm and particularly at 15 cm reduced obstruction by new canes to fruit picking, but treatment at 5 cm did not. Fruit yields on untreated plots were low, but regular cutting of young canes resulted in an increase of 43%, due mainly to greater numbers of berries per cane (Table 5). None of the other individual removal treatments significantly improved yield. Overall comparison across dates of the effects of single cutting or spraying treatments showed no significant differences in fruit production. Similar comparison of height at treatment showed that removal at 15 cm significantly increased yield compared with removal at either 5 cm or 10 cm. The plantation was not retained, but total cane length produced and numbers reaching tipping height on untreated plots were more than adequate for future requirements. Overall, treatment at 15 cm significantly reduced cane numbers >90 cm, but not numbers reaching tipping height (135 cm) in comparison with treatment at 5 cm. Also, treatment with 'Tip-off' was significantly more severe overall on cane numbers >90 cm than single cutting treatments. However, all treated plots produced more than the 7 canes of >135 cm height desired for future fruit production. Mean height of canes reaching tipping height on treated plots was not significantly different from that on untreated plots.

DISCUSSION

Two approaches to the reduction of excessive vigour in raspberry plantations were considered.

a) Cane retardation. Rates of paraquat, diquat or dinoseb used in Expts I & II defoliated young canes. This retarded height extension while new leaves were produced, but did not significantly reduce numbers and heights of canes produced or subsequently retained for fruiting. However, the margin between defoliation and cane death is narrow and some death of growing points always occurred, causing branching of treated canes, impairing their quality and increasing their susceptibility to disease. This last point was particularly evident in Expt III. Retardation rather than defoliation offers more promise, provided the chemicals are not translocated to the fruiting canes. Results with 'Tip-off' were variable, but it may be possible to achieve temporary retardation at low rates of application without the risk of death or injury to young canes. The reaction of the crop to propyzamide was more promising. Treated canes were retarded but recovered well without visible injury. This herbicide is worth further examination at a range of dosages and timings in major cultivars. It is already used as a winter treatment in raspberries for the control of *Agropyron repens*.

b) Cane removal. This method exploits the fact that removal of the first flush of young canes in spring usually stimulates the emrgence of further canes which do not grow as tall as the first flush by the end of the growing season. Removal by cutting is not practicable on a field scale, but investigations in Oregon (Sheets, 1973) and in Washington (Norton, 1974) have resulted in the development of recommendations for the use of dinoseb for this purpose. They stressed the need for quick and complete kill of treated foliage to stimulate emergence of a second flush of healthy vigorous canes. Dinoseb has also given very effective knock-down of treated foliage at Invergowrie when applied at adequate dosage and spray coverage. A water volume of 1123 l/ha (100 gal/ac) was used in the first four experiments, but concurrent investigations (unpublished) on the dosages and spray volumes required for optimum coverage at different heights and densities of vegetation have shown that this volume is not always adequate. Best results were obtained using a rate of 2.7 kg a.i. dinoseb (in oil) in 1000 l water sprayed to run-off. This treatment was used very effectively on canes 10 cm and 15 cm tall in Expt V and has given complete kill of canes up to 60 cm tall in other experiments, although treatment when the leaves are still furled should be avoided. Sheets, (1973) also emphasised the need for high volume to give adequate spray coverage and prevent the survival of partially killed canes.

Paraquat gave less effective initial burn than dinoseb at approximately equal rates of active ingredient in Expts I-III. Considerably higher rates would probably be needed to obtain the speed of knock-down and efficacy of kill required. Experience with paraquat in the United States has been unsatisfactory (Norton, 1974). Diquat was slightly less effective than paraquat. Glyphosate, both because of its rapid translocation to and injury of fruiting canes and its very severe effect on production of young canes is obviously not a candidate for cane removal. Although 'Tip-off' in some situations achieved a high percentage kill of young canes, results were variable and the speed of kill was so gradual that further emergence of young canes was much slower than with cutting or dinoseb. This is not a desirable characteristic of cane removal treatments, since it makes timing of application to ensure even cane growth and adequate cane height by the end of the season extremely difficult in comparison with cutting. Quinlan and Holloway, (1976) have reported that treatment of raspberry suckers with NAA formulations inhibited further emergence and that reduced numbers were also recorded on treated plots. This suggests that the use of this type of material at rates required for cane removal might have a cumulative adverse effect on the plantation.

Regular cutting of young canes up to fruit harvest produced large increases in yield of existing fruiting canes in these experiments, indicating severe competition for resources between fruiting cane and young replacement canes. Substantial yield increases have also been recorded at Invergowrie in the absence of young canes in the first year of experiments on biennial cropping of raspberry plantations (Waister, Cormack and Sheets, 1977). Results from work at Invergowrie and in the United States suggest that increased yields may also be obtained with cane limitation techniques, through partial removal of competition as well as through improved access for fruit pickers at harvest. The main objective remains, however, to reduce cane vigour while still producing enough good cane for the following year. These experiments were carried out to evaluate methods of cane limitation as a necessary preliminary to designing management techniques. In most cases, treatments were either too severe or too lenient at the dosages and timings used. However, they showed quite clearly that there is scope for reduction in cane vigour in cv. Glen Clova and to a lesser extent in cv. Malling Jewel. Further work is needed to integrate the more promising chemical treatments into raspberry management in the United Kingdom.

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GLASSHOUSE SCREENING OF MATERIALS FOR CHEMICAL PRUNING OF YOUNG RASPBERRY CANES

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Summary A technique was devised for the rapid evaluation of chemicals for potential use in cane vigour control in raspberry. Young raspberry plants potted up from root cuttings were sprayed with a wide range of chemicals, their relative efficacy being assessed against the performance of a 9% w/v oil formulation of dinoseb used at a series of standard rates. Comparisons with other formulations of dinoseb at equivalent rates of active ingredient showed that the oil formulation was much more effective than either acetate or amine formulations, the amine being least effective. Alternative chemicals showing sufficient activity to merit further examination in field experiments were paraquat, diquat, chlorpropham, dimexan, nitrofen, two NAA formulations, tar oil, TVO and sulphuric acid. Other materials either had little or no effect or killed the plants by root uptake rather than contact action. The complete absence of phytotoxicity of carbetamide at four times its normal field rate suggested that it is worth evaluation for post-emergence weed control in the raspberry crop.

INTRODUCTION

Investigations in the United States (Sheets, 1973) and Scotland (Lawson & Wiseman, 1976) have demonstrated the usefulness of removing the first flush of young canes as a means of controlling excessive height in tall-growing raspberry cultivars. Effective removal has been accomplished using the herbicide dinoseb. Unfortunately dinoseb is a highly poisonous chemical whose use in the United Kingdom is regulated by the Health and Safety (Agriculture) (Poisonous Substances) Regulations, 1975 and the Pharmacy & Poisons Act, 1933. It was therefore felt desirable to examine alternative materials known to have some contact action on other crops or on weeds.

To speed up the elimination of unsuitable materials and avoid the high costs involved in field screening the experiments were conducted in the glasshouse on potted raspberry plants during the winters of 1974/75 and 1975/76.

METHOD AND MATERIALS

Raspberry plants raised from root cuttings of cvs. Glen Clova and Malling Jewel were potted up into 7.6 cm square pots, one plant per pot, using a technique developed for the production of virus-free raspberry plants (Chambers, 1961) and grown on in the glasshouse until the plants averaged 15 cm high. Treatments were applied in a water volume of 1123 l/ha via a cabinet precision pot sprayer (Mason & Adamson, 1962) operating at a pressure of 2.78 kg/cm^2. Single plant plots were used, with three replicates of each treatment. Pots were returned to the glasshouse and set out in a randomised block design with two sets of untreated plants per replicate.

Plants were kept well watered by overhead spraying commencing 2-3 days after treatment. Glasshouse temperature was maintained at 18°C and the plants were kept for three weeks after treatment. Effects on the plants were assessed every few days using a 0-10 scale (10 = dead). Since efficacy of the cane removal technique depends on speed of initial knock-down as well as complete kill of treated canes, results are presented of scores made 2-3 days after treatment and of the maximum score achieved during the three week period. This was not necessarily the score at the end of the experiments, since many plants recovered from the initial check.

Preliminary experiments showed that a formulation of dinoseb in oil applied at rates between 0.13 and 0.52 kg a.i./ha produced effects ranging from virtually nil to complete kill. Reaction varied according to the degree of maturity of the pot plants at application. These rates were therefore used to give standards against which to compare the performance of alternative materials in the different experiments. Most materials were screened at normal field rates for weed control and a four-fold rate so that inadequate dosage would not be a limiting factor.

Although the experiments were replicated and laid out in randomised blocks, statistical analysis of the results was not considered necessary, since this was primarily a screening operation looking for gross effects. Formal design was however considered desirable to minimise variability in growth in the glasshouse.

RESULTS

Expt I

Comparison of commercial formulations of dinoseb in oil (9% w/v), dinoseb acetate (18.5% w/v) and dinoseb amine (50% w/v) at equivalent rates of active ingred-ient showed dinoseb in oil to be considerably more effective at all rates than either of the other formulations, (Table 1). Dinoseb acetate gave slightly better results than dinoseb amine.

Expt II

Initial knock-down with dinoseb in oil was slower than usual. Dinoseb acetate plus monolinuron was very much less effective than the standard despite higher rates of application. Only chlorpropham at 8.96 kg a.i./ha gave comparable results to dinoseb in oil (Table 2). Other treatments produced virtually no knock-down and the maximum score was attributed to the effects of root uptake by the plant.

Expt III

Dinoseb in oil produced a rapid knock-down of treated canes (Table 2). Dimexan was also effective and scores throughout the period of assessment were comparable to those of dinoseb in oil at 0.39 and 0.52 kg a.i./ha respectively. Asulam, pyrazone/chlorbufam and carbetamide had no worthwhile effect on the crop at either rate. Nitrofen had some scorch effect at both rates but desmetryne had none, although both achieved similar maximum scores probably via root uptake.

Expt IV

Initial knock-down by dinoseb in oil was again rapid. Chlorpropham at 8.96 kg a.i./ha and 35.84 kg a.i./ha was again the only herbicide giving comparable results (Table 3). Neither cycloate nor phenmedipham had any useful permanent effect. Although many of the others achieved high maximum scores, this was not due to foliar activity and was attributed to root uptake.

Table 1

Expt I - Initial (A) and Maximum (B) mean scores for knock-down (0-10)

Rate	Dinoseb in oil		Dinoseb acetate		Dinoseb amine	
kg/ha a.i.	A	B	A	B	A	B
0.13	0	1.0	0.3	0	0	0
0.26	2.7	3.3	0.7	1.0	0	0
0.39	3.3	5.0	1.3	2.3	0.3	0.7
0.52	4.7	8.0	1.0	2.0	0.7	1.7
0.65	4.0	7.0	2.0	3.0	0.7	1.3
0.78	5.0	8.7	1.7	2.7	0.7	1.7

Table 2

Expts II & III - Initial (A) and Maximum (B) mean scores for knock-down (0-10)

Treatment	Rate kg/ha a.i.	Expt II A	Expt II B	Treatment	Rate kg/ha a.i.	Expt III A	Expt III B
Dinoseb in oil	0.13	0	3.3	Dinoseb in oil	0.13	1.0	1.7
	0.26				0.26	2.3	3.7
	0.39				0.39	3.7	7.0
	0.52	2.0	7.0		0.52	6.0	10.0
Dinoseb acetate/ monolinuron	0.32	0.3	1.3				
	1.00	1.0	3.3				
Chlorpropham	2.24	0	5.7	Desmetryne	0.28	0	4.3
	8.96	2.0	7.0		1.12	0	6.0
Pentanochlor	2.24	0	2.0	Nitrofen	1.23	1.3	4.0
	8.96	0.7	4.7		4.90	2.3	7.7
Bentazone	1.68	0	3.7	Asulam	1.12	0	1.0
	6.72	0	7.7		4.48	0	1.0
Sodium chlorate	22.40	0	9.0	Carbetamide	2.35	0	0
	89.60	0.7	9.0		9.40	0	0
				Dimexan	9.38	4.3	6.3
					37.52	5.7	9.0
				Pyrazone/ chlorbufam	2.02	0	0
					8.08	1.0	2.3

Table 3

Expts IV & V - Initial (A) and Maximum (B) mean scores for knock-down (0-

Treatment	Rate kg/ha a.i.	Expt IV A	Expt IV B
Dinoseb in oil	0.13	1.3	3.3
	0.26	4.7	7.3
	0.39	4.7	8.3
	0.52	6.7	10.0
Chlorpropham	8.96	3.3	9.3
	35.84	5.3	10.0
Aziprotryne	2.24	0	7.0
	8.96	1.0	10.0
Chlorbromuron	1.12	0	10.0
	4.48	0	10.0
Cyanazine	1.40	0	10.0
	5.60	0	10.0
Cycloate	2.01	0	0.3
	8.05	0.7	2.0
Linuron	1.12	0.3	9.7
	4.48	0.3	10.0
Methazole	1.68	0	9.0
	6.72	0	10.0
Metoxuron	3.58	0	10.0
	14.34	0	10.0
Metribuzin	0.78	0	10.0
	3.12	0	10.0
Phenmedipham	1.12	0	0.3
	4.48	0.3	2.3
Prometryne	1.40	0	10.0
	5.60	0	10.0
Metamitron	1.96	0	5.3
	7.84	0	10.0

Treatment	Rate kg/ha a.i.	Expt V A	Expt V B
Dinoseb in oil	0.13	0.7	1.7
	0.26	3.7	3.[illegible]
	0.39	4.0	4.[illegible]
	0.52	5.3	6.[illegible]
Paraquat	2.24	4.0	7.[illegible]
	8.96	5.3	9.[illegible]
Diquat	1.57	4.3	7.[illegible]
	6.28	6.3	8.[illegible]
Penoxalin	0.50	0	1.[illegible]
	2.00	0	0.[illegible]
Isoproturon	2.52	0	7.[illegible]
	10.08	0	7.7
Benzoylprop-ethyl	1.12	0	0.[illegible]
	4.48	0.7	2.[illegible]
Barban	0.35	0	0.7
	1.40	0.3	1.[illegible]
	1/ha.		
'Planofix'+	22.5	0.3	2.[illegible]
	89.8	2.7	3.[illegible]
	179.7	2.0	5.7
'Tip-off'+	22.5	3.0	4.7
	89.8	4.0	8.[illegible]
	179.7	6.7	9.[illegible]
Tar oil	89.8	4.0	4.[illegible]
	179.7	4.7	4.7
*Tractor vapourising oil (TVO)	247.1	6.0	8.[illegible]
	494.2	5.0	8.[illegible]
	741.3	5.0	9.[illegible]
Mineral oil ('Shell W')	247.1	3.0	3.7
	494.2	4.3	8.[illegible]
	741.3	3.7	9.[illegible]
Sulphuric acid	247.1	8.7	9.[illegible]
	494.2	9.0	10.[illegible]
	741.3	9.0	10.[illegible]

*Applied as undiluted commercial product   +NAA formulations

Expt V

The plants under test in this experiment were more mature and taller, hence the less effective performance of all rates of dinoseb in oil. Paraquat and diquat gave good initial and final knock-down. Penoxalin, benzoylprop-ethyl and barban were relatively non-phytotoxic even at four times normal field rates, but isoproturon, although initially ineffective, eventually caused considerable plant injury, presumably by root uptake.

'Tip-off' caused greater initial knock-down than 'Planofix' at equivalent volumes of commercial formulation and this differential was maintained throughout the period of assessment. These materials stunted and malformed canes rather than scorched them. The initial knock-down by tar oil was also the maximum, since plants recovered shortly afterwards.

TVO gave a higher initial knock-down rate for rate than 'Shell W' (a refined formulation of TVO) and achieved its maximum effect at the lowest rate used. Sulphuric acid gave virtually complete kill of treated plants within two days.

DISCUSSION

Of the dinoseb formulations examined dinoseb in oil was much more effective than either dinoseb amine or dinoseb acetate at equivalent rates of active ingredient. This was presumably due to the presence of the oil constituent. In the United States (Sheets, 1973) the straight phenol formulation of dinoseb is used for cane vigour control and its performance is considerably boosted by the addition of activating oils. Other experiments in this series (unpublished) have shown that the action of the formulation of dinoseb in oil used principally for potato haulm destruction in the United Kingdom is not improved by the addition of commercial oils such as 'Sun oil' or 'Actipron'.

Although a large number of chemicals were included in these experiments, very few compounds produced the desired objective of rapid and effective knock-down. Of those which did show activity, paraquat, diquat and 'Tip-off' have now been examined in field experiments (Lawson & Wiseman, 1976) and found less effective than dinoseb in oil at field rates of application. The initial knock-down achieved by tar oil was only temporary, since the plants rapidly recovered and it may require very high rates of application in the field to give complete kill. This material is included in the Pharmacy & Poisons Act, 1933. Sulphuric acid is highly corrosive, while TVO might pose problems of possible taint, as in the carrot crop. (Removal of the impurities, as in 'Shell W', apparently reduced its efficacy). Tar oil, sulphuric acid and TVO are very old commodity chemicals and it is unlikely that any commercial firm would be prepared to submit recommendations for official clearance for this use in the raspberry crop.

Of the conventional herbicides, chlorpropham, dimexan and nitrofen had not previously been considered as possible candidates for chemical control of cane vigour and these will be further evaluated. However, experience under field conditions with dinoseb in oil (Lawson & Wiseman, 1976) has shown that in order to achieve a knock-down comparable to that achieved in the glasshouse at 0.52 kg a.i./ha, a rate of 3.02 kg a.i./ha is normally required. If rates of alternative chemicals showing promise in the glasshouse have to be increased by the factor suggested with dinoseb in oil then most of them would prove totally uneconomic.

Although the screening technique used in these experiments was unable to distinguish between injury due to contact effect or to translocation, it did eliminate a large number of chemicals as being of no value for chemical cane control in raspberries. At the same time it high-lighted several materials, particularly carbetamide, whose relative lack of phytotoxicity to the glasshouse plants merits their further examination as potential post-emergence herbicides for the raspberry crop.

Acknowledgements

Thanks are due to the chemical firms who supplied the materials tested in these trials, and to R. Wilson and Elizabeth Lowe for technical assistance.

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THE RESPONSE OF CONVOLVULUS ARVENSIS TO 2,4-D APPLIED ALONE OR IN MIXTURES WITH PARAQUAT AND AMINOTRIAZOLE

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Summary The response of *Convolvulus arvensis* (Field Bindweed), to 2,4-D, paraquat and aminotriazole alone and in mixtures is described.

There was almost complete leaf kill in the year of application with 2,4-D amine at both 1 and 3 kg/ha when applied alone or in mixtures. The most rapid kill was achieved by mixtures of 2,4-D with paraquat at 1 kg/ha or aminotriazole at 6 kg/ha and with the three-way mixtures.

2,4-D alone and mixed with aminotriazole gave good control in the year after treatment. There was antagonism between 2,4-D and paraquat. In the year after treatment there was almost as much regrowth with 2,4-D 1 kg/ha plus paraquat 1 kg/ha as on untreated plots. There was less antagonism with a lower dose of paraquat or a higher dose of 2,4-D. Aminotriazole reduced the antagonism between 2,4-D and paraquat.

INTRODUCTION

Earlier work has shown that 2,4-D is one of the most effective herbicides used for ontrolling *Convolvulus arvensis* (Field Bindweed) and that the dose is important in etermining the amount of regrowth in the year following application (Davison and ailey, 1974). Unfortunately the 2,4-D and other growth-regulator herbicides, ncluding proprietary mixtures, used by many orchard fruit growers do not control nnual and perennial grass weeds. To overcome this weakness some growers add either araquat or aminotriazole or both and apply them as a 'tank mix'.

Lange *et al* (1972) reported that the addition of paraquat to 2,4-D did not reduce he regrowth of *C.arvensis* but there are no reports in the literature of paraquat or minotriazole increasing regrowth.

The object of this experiment was to find out if adding paraquat and/or minotriazole to 2,4-D had any effect on the control of *C.arvensis* in the year of reatment or on the subsequent regrowth in the year following application.

METHOD AND MATERIALS

The experiment was on uncropped plots of *Convolvulus arvensis* that had been stablished in a sandy loam soil at Begbroke in 1971. The planting material was from single clone. The plots were 2.75 x 2.75 m and separated by 1.5 m paths. To revent the *C.arvensis* spreading to adjacent plots, the paths were cultivated deeply n the winter and chlorthiamid was incorporated in the spring. Annual weeds were ontrolled with an application of simazine at 2 kg/ha in the spring.

The 27 treatments were; 2,4-D amine at 0, 1 and 3 kg/ha, paraquat at 0, 0.3 and 1 kg/ha and activated aminotriazole at 0, 2 and 6 kg/ha and all possible combinations. All the plots were sprayed on 8 July 1974, when there was 100% ground cover and dense clumps of shoots up to 30 cm tall. There was 20% open flower and a maximum of 15% senescent foliage.

The treatments were applied with an Oxford Precision Sprayer fitted with four Lurmark LP20 fan nozzles to give a 2 m swath; two swaths were needed to cover the plots. The pressure used was 1.1 bars and the volume rate was 360 l/ha. There were four replicates and the design was a three-cubed factorial confounded in blocks of nine units (Cochran and Cox, 1957).

The spray solution for each treatment was made up from prediluted stock solutions of commercial products. It was applied within five minutes and there was no evidence of physical incompatibility.

Four days after application, there was a visual assessment of leaf symptoms. Separate scores were made for the percentage of leaves with epinasty and the percentage leaf area that was chlorotic or necrotic. Subsequent assessments were visual scores for the percentage ground cover of green foliage. These were made two weeks and one month after application and at monthly intervals in the following year. Only the most relevant assessments are presented.

Clear differences are apparent in the initial assessment and the results have not been analysed. The three assessments which have been presented on the regrowth in the year after application have undergone an arc sin transformation. The detransformed means are presented as a percentage of the untreated. Values in excess of 100% occur as a result of transforming and detransforming the field data, which never exceeded 100%. Where differences are stated to be significant, $p = 0.05$.

RESULTS

The assessment four days after treatment shows that 2,4-D alone caused severe epinasty but no chlorosis and very little necrosis (Table 1). The level of epinasty was not affected by the addition of paraquat or aminotriazole. Both of these herbicides alone caused chlorosis, but this was prevented by the addition of 2,4-D. Paraquat caused more necrosis than aminotriazole. The addition of 2,4-D decreased the necrosis caused by paraquat, particularly at the lower dose, whilst increasing that caused by aminotriazole.

Five weeks after application all but one of the treatments receiving 2,4-D had achieved 97 - 100% leaf kill; the exception being 2,4-D at 1 kg/ha plus paraquat at 0.3 kg/ha where the leaf kill was only 92%. All the mixtures containing 2,4-D gave a quicker kill than 2,4-D applied alone. The most rapid kill was with mixtures containing the higher doses of aminotriazole or paraquat or all three herbicides.

There was little regrowth in June in the year after treatment with both doses of 2,4-D but by July there was significantly more regrowth with 1 kg/ha than with 3 kg/ha (Table 2). Neither paraquat nor aminotriazole applied alone or in mixtures reduced the amount of regrowth in the year after treatment. Adding aminotriazole to 2,4-D did not affect the amount of regrowth but it was significantly increased by the addition of paraquat, ie there was antagonism between 2,4-D and paraquat. At a constant dose of 2,4-D there was more antagonism with the higher dose of paraquat, but with a constant dose of paraquat there was less antagonism with the higher dose of 2,4-D. The addition of aminotriazole, particularly at 2 kg/ha, to mixtures of 2,4-D and paraquat reduced the level of antagonism (Table 3).

Table 1

The effect of 2,4-D amine, with or without aminotriazole and/or paraquat, on the foliage of Convolvulus arvensis four days after application.

Paraquat kg/ha	Aminotriazole kg/ha	Epinasty 2,4-D amine 0	1	3	Chlorosis 2,4-D amine 0	1	3	Necrosis 2,4-D amine 0	1	3 kg/ha
0	0	0	85	83	0	0	0	0	3	3
	2	0	90	83	44	0	0	0	0	13
	6	0	90	90	44	0	0	15	25	45
0.3	0	0	88	85	15	0	0	40	15	10
	2	0	90	88	38	0	0	30	18	25
	6	0	90	93	38	0	0	33	50	50
1	0	0	85	90	8	0	0	75	68	53
	2	3	85	88	40	0	0	63	35	48
	6	0	90	83	38	0	0	55	68	68

Table 2

The effect of 2,4-D amine, with or without aminotriazole or paraquat, on the regrowth of Convolvulus arvensis in the year following treatment as indicated by the % of ground covered by green foliage.

Assessment date	2,4-D kg/ha	No addition	Aminotriazole kg/ha 2	Aminotriazole kg/ha 6	Paraquat kg/ha 0.3	Paraquat kg/ha 1
June 24	0	89 (99)	76 (94)	73 (89)	84 (96)	81 (98)
	1	11 (5)	8 (2)	13 (5)	27 (21)	56 (67)
	3	11 (5)	12 (5)	8 (1)	10 (4)	13 (4)
			SE ± 3.9			
July 17	0	90 (100)	81 (93)	74 (92)	84 (94)	96 (101)
	1	20 (17)	12 (5)	22 (16)	50 (58)	81 (94)
	3	13 (6)	17 (11)	14 (5)	14 (6)	27 (24)
			SE ± 5.5			
August 15	0	90 (100)	88 (96)	89 (102)	86 (94)	94 (105)
	1	35 (35)	22 (16)	45 (50)	64 (81)	78 (92)
	3	21 (14)	33 (31)	25 (21)	27 (21)	53 (63
			SE ± 5.5			

Values have undergone an arc sin transformation - detransformed means are in brackets.

Table 3

The effect of 2,4-D amine at 1 kg/ha in a three way mixture with aminotriazole and paraquat, on the regrowth of Convolvulus arvensis in July in the year following treatment as indicated by the % ground covered by green foliage.

		Paraquat (kg/ha) 0	0.3	1
Aminotriazole kg/ha	0	20 (17)	50 (58)	81 (94)
	2	12 (5)	25 (18)	47 (54)
	6	22 (16)	34 (34)	58 (72)
		SE ± 5.5		

Values have undergone an arc sin transformation - detransformed means are in brackets.

DISCUSSION

The results for 2,4-D alone in the year of treatment and in the following year are in agreement with those from previous experiments (Davison and Bailey, 1974).

All the mixtures containing 2,4-D gave good control of C.arvensis in the year of treatment and a more rapid foliar kill than 2,4-D alone. This would appeal to many growers. However, there were no other weeds in this experiment and it cannot be assumed that 2,4-D would not influence the control of weeds that are normally controlled by paraquat or aminotriazole but are resistant to 2,4-D.

To obtain the maximum effect on the root system of C.arvensis the shoots should be sprayed just before flowering (Fryer and Makepeace, 1972). In practice however, many growers apply growth regulator herbicides at an earlier growth stage in a 'tank mix' with other herbicides in the belief that it is more important to ensure a high standard of control of all weeds in the year of treatment than to have improved long term control of C.arvensis. It is also more convenient to spray then.

Some of the differences in regrowth where paraquat was added to 2,4-D are sufficiently large to be important to growers. But, even with the maximum effect that can be expected with a growth regulator herbicide, a further application will probably be needed in the following season. Therefore, some of the smaller differences, although statistically significant, may not be important to growers. However, the results presented show that by careful selection of both herbicide and dose the antagonism between 2,4-D and paraquat can be minimised or overcome. Thus in situations involving C.arvensis aminotriazole should be used in preference to paraquat. When paraquat has to be used the dose should be the lowest needed to control the other weeds but, more important, the dose of 2,4-D should be the maximum safe dose for the crop.

Information is needed on both the long and short term response of other perennial weeds to mixtures of 2,4-D (and other growth regulator herbicides) and paraquat. There may be even greater antagonism in weeds such as Cirsium arvense (Creeping Thistle) that are more susceptible than Convolvulus arvensis to paraquat.

Acknowledgements

Thanks are due to Miss J P Crabtree who assisted with the experimental work, to Mr B O Bartlett and Mr C Marshall for the advice on planning and statistical aspects and to the chemical companies who supplied the herbicides.

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WEED COMPETITION AND THE PERFORMANCE OF ESTABLISHED APPLE TREES

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Summary Trees of Cox/M.26 were grown for seven years in clean herbicide strips with grassed alleys and then subjected to competition from either a good cover of annual weeds (mainly *Capsella bursa-pastoris* and *Senecio vulgaris*) or a light cover of bindweed (*Convolvulus arvensis*). Neither weed treatment significantly reduced total shoot growth although mean shoot length was reduced by annual weed competition in one year. All trees showed a tendency towards biennial cropping. Total crop was reduced by the annual weed treatment in the light crop year and fruit size in both light and full crop years. Competition from annual weeds increased the soil moisture deficit in all years, the effect being most pronounced at depth. Trees in competition with annual weeds had a lower nitrogen and higher phosphorus concentration in the leaves. Leaf mineral composition was not affected by the bindweed treatment. The annual weed treatment reduced apple root activity measured as the uptake of ^{32}P into the leaves, at depths of 5, 20 and 40 cm.

Results suggest that the control of annual weeds in established orchards is important.

INTRODUCTION

The effects of weed competition in young fruit plantations have been described by White and Holloway (1967) for apple, Anon (1976) for apple and black currant and Lawson and Wiseman (1976) for raspberry. The resulting reduction in growth seems to be due to competition for soil moisture (White and Holloway, 1967) and is most severe when weeds are present in spring and early summer (Anon, 1976).

There is less information on the effect of weed competition on the growth of established trees. Rogers and Raptopoulas (1946) found that annual weeds had no effect on the growth of established trees as compared with trees grown under cultivation while Stalder *et al.*, (1973) suggested that weeds such as *Stellaria media* and *Poa annua* were harmless in established vineyards. In intensive orchards under herbicide management the same situation may not exist.

The rising cost of herbicides has caused some growers to neglect the control of annual weeds or of light covers of perennial weeds in established orchards. The effect of competition from either annual or perennial weeds on the growth, cropping, root activity and soil water deficit of an established spindlebush orchard has been assessed.

METHOD AND MATERIALS

Trees of Cox/M.26 were planted in winter 1965/6 at a spacing of 2.4 m in the row and 3.7 m between rows and grown from planting as spindlebushes in a 1.8 m wide herbicide strip (maintained principally with Paraquat Simazine and Diuron) with the alleys grassed down with S50 timothy (*Phleum nodosum*). In spring 1973 the plot was divided and trees were either maintained with a clean herbicide strip (control) or the herbicide strip was allowed to be invaded by annual weeds (mainly *Capsella bursa-pastoris* and *Senecio vulgaris*) or by bindweed (*Convolvulus arvensis*) supplemented by planting bindweed obtained from the Weed Research Organisation (8 plants/tree) in 1974. There were two other weed treatments not described here.

In the annual weed treatment a cover of annual weeds developed gradually during 1973, and during 1974-1976 there was a good cover contaminated by some *Convolvulus arvensis*, *Plantago major* and *Agropyron repens*. In the bindweed treatment, following the planting of potted material, there was a light cover of bindweed present during 1974-5 but not in 1976.

The control treatment received a spring application of Paraquat (1.2 kg ai/ha) and Simazine (2.3 kg ai/ha) in all years. The annual weed and bindweed treatments received an application of Paraquat (1.2 kg ai/ha) to areas containing unwanted weeds, while treatment weeds were left largely unsprayed. In spring 1975 all plots received aminotriazole (11.6 kg ai/ha) applied to a narrow (15 cm) band along the edge of the herbicide strip to check the ingress of *Agrostis stolonifera* into the strip. All treatments consisted of three fully guarded trees which were replicated in four blocks.

Growth was assessed as the total length of extension (one year) shoots per tree and as the average length of a single shoot (mean shoot length). Crop was recorded as the total picked weight of fruit per tree. Treatment effects were assessed by analysis of variance of the complete experiment (5 treatments) and the errors quoted were derived from this.

Leaves without petioles were removed from the middle of extension shoots of all trees in mid-August and analysed for major nutrients.

Soil moisture deficits were determined with a neutron moisture meter using a calibration curve for the soil type (J.E. Goode, personal communication). Measurements were made at 25, 50 and 75 cm depth using access tubes inserted 50 cm from the tree base.

Root activity was assessed by measuring the uptake of ^{32}P into apple leaves as described by Atkinson (1974). Twenty-two polythene tubes were inserted as two rows of 11 on either side of a tree, 50 cm from the trunk in both the control and the annual weed treatments. Each tree was given 1.16 m ci of ^{32}P injected as 22 mil of solution on 4th June 1976. Placements were made using separate trees, to depths of 5, 20 and 40 cm. All depth placements were replicated four times. Mid-position extension leaves were sampled on 16th June and activity determined using Cerenkov radiation (Atkinson, 1974). Samples were counted on an Intertechnique liquid scintillation counter with a window setting of 40-560.

RESULTS

Tree Performance

Variation between trees within any given treatment was very large (coefficient of variation per plot for total shoot growth in 1974 70.2%) although there were no significant differences in girth and shoot growth between treatment blocks prior to the imposition of the treatments. The effect of treatments on tree growth in 1974 and 1975 is shown in Table 1.

Table 1

Total shoot growth (m) and mean shoot length (cm)

Treatment	1974 Total shoot length	length/shoot	1975 Total shoot length	length/shoot
Control	12.6	27.0	37.2	44.6
Annual weeds	4.1	19.8	22.1	34.8
Bindweed	10.0	24.3	29.8	36.0
LSD P = 0.05	11.4	5.4	17.3	14.1

Neither the annual weeds nor the bindweed significantly reduced growth in either year although as a proportion of control growth that of the annual weed treatment decreased by 40% in 1974 (annual weed/control (1972) x 100 - annual/control (1974) x 100) and 13% in 1975 while that of the bindweed treatment fell by 37% in 1974 and 35% in 1975. Individual shoot length was significantly reduced by the annual weed treatment in 1974.

The effect of treatment on cropping is shown in Table 2.

Table 2

Total weight of fruit (kg/tree) and mean fruit weight (g)

Treatment	1974 Crop/tree	Weight/fruit	1975 Crop/tree	Weight/fruit
Control	9.0	162	15.3	128
Annual weeds	3.6	132	12.1	107
Bindweed	10.0	130	12.9	135
LSD P = 0.05	4.4	27	4.5	14

All trees showed a tendency towards biennial bearing which was most pronounced in the trees with the annual weed treatment. Total crop in 1974, the light crop year, was significantly lower in the annual weed treatment. Neither treatment significantly affected cropping in 1975. Mean fruit size was reduced by the annual weed treatment in both years and by the bindweed treatment in 1974. The number of spur fruit buds per tree showed a parallel trend to that of cropping (control 152, 292 and 156 buds/tree 1974-1976; annual weeds 109, 295, 116 buds/tree).

Mineral nutrition

Leaf mineral content was affected by the annual weed but not by the bindweed treatment (Table 3).

Table 3

Leaf mineral nutrient concentrations in 1974 (% DW)

Treatment	N	P	K	Ca
Control	2.62	0.217	1.70	0.643
Annual weeds	2.10	0.253	1.80	0.747
Bindweed	2.82	0.232	1.68	0.707
LSD P = 0.05	0.34	0.023	0.18	0.182

Annual weeds reduced the concentration of N to a deficient level and increased the concentration of P.

Soil water deficit

The soil water deficit (swd) in the herbicide strip was affected by the annual weed treatments in all years and by the bindweed in 1975 (Table 4). In early summer 1974 the swd was higher in the annual weed treatment than the control at all depths but in 1975 and in June and August 1976 only at 75 cm depth. In 1974 the swd in the bindweed treatment was lower than that of the control but was higher in 1975 at 75 cm depth.

Table 4

Soil water deficit (cm)

Treatment	30th May 1974 Depth (cm)			6th August 1975 Depth (cm)		
	25	50	75	25	50	75
Control	1.54	0.85	0.63	2.41	1.59	0.82
Annual weeds	1.98	1.30	1.14	2.14	1.30	1.86
Bindweed	0.87	0.37	0.46	2.43	1.77	1.38
LSD P = 0.05	0.23	0.28	0.37	1.33	1.08	0.37

Root activity

Root activity at three depths, measured as the uptake of ^{32}P into the tree leaves is shown in Table 5.

Table 5

^{32}P uptake by apple leaves (counts per minute/g DW)

Treatment	Depth (cm) 5	20	40
Control	372 ± 95	1037 ± 329	28 ± 23
Annual weeds	138 ± 101	25 ± 16	1 ± 0.4

Annual weed competition reduced the uptake of ^{32}P from all three depths. Uptake was greatest from 20 cm by the control trees and from 5 cm by the annual weed trees.

DISCUSSION

The sensitivity of young trees to weed competition has been demonstrated by White and Holloway (1967). The greater variability of older material makes this type of effect more difficult to detect in established plantations. Experiments involving weeds are further confounded by the variability of weed populations. In this experiment variation within treatments was high and although shoot growth in treatments where weeds were present fell by 40% differences in total shoot growth were not statistically significant.

All trees in the experiment showed a tendency towards biennial bearing. This was accentuated by weed competition. Total crop was reduced by annual weed competition in a light crop year but less affected in a year with full cropping. This is similar to the effect of grass competition on apple described by Atkinson and White (1976). In both cases competition appeared to work via effects on fruit bud formation. Powell (1976) found that drought experienced prior to mid-July retarded fruit bud formation. In this study soil moisture deficits were higher where weeds were present. Differences in the deficit present in early summer were found in 1974 at all depths. Weed competition reduced mean fruit size in both 1974 and 1975.

In all years water depletion was greater from 75 cm depth where weeds were present. This increased water depletion at depth was not associated with increased apple root activity at depth. Annual weed competition reduced apple root activity at all depths.

A light cover of bindweed had few significant effects on either growth or cropping although in 1975 the water deficit was increased at depth.

The results obtained show that annual weed competition can reduce the cropping of established trees while the difficulties found in managing annual weed plots suggest that they may hide the establishment of some perennial weeds. The control of annual weeds in established orchards remains important.

Acknowledgements

We would like to thank P.F. Dudley for applying the herbicide treatments and making tree measurements during 1973-5, J.J.J. Langeslag for help in summarizing the data, Mrs. C.H. Thompson for advice on statistical analysis and Miss J.J. Vokes for assistance with the measurement of root activity.

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THE RESPONSE OF PEARS AND APPLES GROWING IN SAND TO 2,4-D, MCPA AND 2,4,5-T APPLIED TO THE ROOTS

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Summary 2,4-D, MCPA and 2,4,5-T were applied to pots of sand containing one-year-old apple and pear trees. Treatments were carried out between May and October and assessments continued until June in the year after treatment.

All three herbicides caused severe damage to all varieties tested:- pear-Conference, Williams and Comice on Quince A and apple - Cox/M26, Cox/MM106, Bramley/MM106. Pears were more susceptible than apples to 2,4-D.

The main effect of all 3 herbicides on both crops was to induce bud dormancy, resulting in bare wood in the year after treatment. Leaf formative effects were confined to pears treated with 2,4-D and only occurred in the year after treatment.

Date of application had a greater influence on the degree of response than the herbicide used or the crop variety tested, but there was no consistent trend in response in relation to the month of application.

The amount of herbicide needed to cause damage to the trees was very small (eg 1.2 mg/plant for 2,4-D on pears); this represents only a small proportion of the amount normally applied beneath trees. It is concluded that the main factor influencing the degree of damage in field conditions is probably the amount of herbicide reaching a significant proportion of the root system.

INTRODUCTION

Growth-regulator herbicides are commonly used in apple and pear orchards in England. Occasionally, damage is caused by either foliage uptake from drift or misdirected sprays or by root uptake (Davison, 1973). The factors influencing damage by root-uptake are not fully understood. They could include the persistence and distribution of herbicide in the soil (Benson and Covey, 1974).

Most of the damage reported in experiments and commercial crops has been on pears. The amount of damage has been related to variety of both stock and scion, the herbicide used, the dose applied and soil moisture conditions (Benson, 1970; Davison and Clay, 1970; Goddrie, 1970 and Larsen, 1974). There has been no apparent association with the time of year or stage of crop growth when the growth-regulator was applied.

The present work was done primarily to find out the relative inherent tolerance of apples and pears to root application of 2,4-D, MCPA and 2,4,5-T. Treatments were applied from May to October. Most of the tests were on the pear Conference/ Quince A and the apple Cox/M26. The response of other varieties was also test

The trees were grown in sand-culture to ensure that the herbicide reached roots. The main assessments were in the year after treatment because earlier had shown that some symptoms do not develop until then (Davison and Clay, 1970

METHOD AND MATERIALS

Three tests were carried out on trees growing individually in 25 cm black plastic pots containing 8 kg of sand. Water containing nutrients was applied necessary, any excess drained away except during the treatment period. One-ye old field-grown trees were planted in the spring and lightly pruned. Treatmen were applied between May and September as shown in Table 1. The following for ulations were used:- 2,4-D amine a.c. (32% a.e.); MCPA, K salt, a.c. (25%a.e.) 2,4,5-T triethanolamine, a.c. (11% a.e.). Not all of the possible combination shown in the table were applied each year.

Table 1

Herbicide treatments, application dates and varieties

Year of test	Herbicide	Dose ppm	Application dates	Varieties treated
1973	2,4-D MCPA 2,4,5-T	0.1 1.0 10.0	10 August	Apple, Cox/M26
1974	2,4-D MCPA 2,4,5-T	0.2 1.4 9.8	6 May, 6 June 11 July 7 August	Pear - Conference, Comice, Williams on Quince A. Apples - Cox/M26, Cox/MM106, Bramley/MM106
1975	2,4-D	0.35 1.4	6 July, 8 August 3 Sept., 30 Oct.	Pear - Conference/Quince A.

Dose is expressed as concentration of active ingredient (ppm) in dry sand there was 8 kg of sand in each pot a dose of 1 ppm is equivalent to 8 mg per Treatments were applied by adding the appropriate amount of herbicide to 500 nutrient solution which was then poured over the surface of the sand from a be or measuring cylinder. The treatment period lasted for 7 days, during which pots were stood in individual aluminium saucers. Any liquid that drained from pot was retained in the saucer and reabsorbed by capillary action. The pots then leached with 3 applications of nutrient solution. Analysis of sand for residue showed that pots that were treated with 0.7 ppm in October had 0.63 p before leaching and none was detectable after leaching. The limit of detecti 0.05 ppm and the method used was that described by McKone and Hance (1972).

The trees were assessed at intervals in the year of treatment and in May June in the year after treatment using a 0-9 scale to indicate crop damage:-

0 = plant dead	5 = 50% growth inhibition
1 = plant dormant, leafless	7 = readily distinguishable growth inh
3 = very stunted, still growing	9 = plant healthy, normal growth/size

In some of the tests there were additional assessments for new growth in spring. These included leaf area, the proportion of leaves that were normal, leaf formative effects, the proportion of stem without leaves. They were expressed as a percentage of the untreated control plants. Extension growth was also measured and the number of flower clusters counted.

RESULTS

All 3 herbicides produced similar symptoms on the pears and apples in the year of treatment. Epinasty and bending of the apical leaves and bending of the shoot tips were followed by leaf chlorosis, discoloration, senescence and shedding of the apical leaves. Growth of some shoots was arrested, but any further growth was normal. Some shoot tips became flaccid and died. The most consistent trend was for greater damage with larger doses. On pears, 2,4-D was the most damaging and 2,4,5-T the least damaging, particularly at the maximum dose (9.8 ppm). With apples, however, 2,4,5-T was more damaging than 2,4-D to Cox/M26 and Cox/MM106. Bramley/MM106 was more sensitive than Cox/MM106 to 2,4-D.

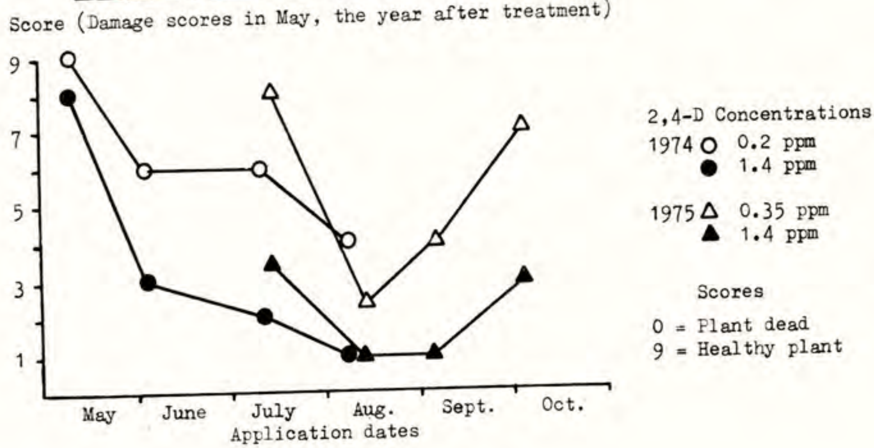
In May and June in the year after treatment the most obvious effect was the amount of bare wood. On many trees there was virtually no leaf development and this is reflected in the scores in the figures. In some cases leaf development was merely delayed but in the majority a large proportion of the buds remained dormant. Formative effects, consisting of narrow leaves with reduced mesophyll development between the veins only occurred on pears treated with 2,4-D. They were found on trees treated in May, June, July and August.

Tha number of flower clusters in 1975 on Conference/Quince A and Cox/M26 treated in 1974 was less than might be expected from the overall plant damage scores for 1.4 and 9.8 ppm in Figure 2 and 9.8 ppm in Figure 4.

On some of the apples that had been treated later in the season with 2,4-D or MCPA, the lower leaves of the following years growth were chlorotic. On both pears and apples there was some discoloration of the basal bark as well as splitting and peeling. Both crops also developed swellings on some of the nodes that failed to produce leaves.

Figure 1

The response of Conference/Quince A to different concentrations of 2,4-D amine applied to the roots



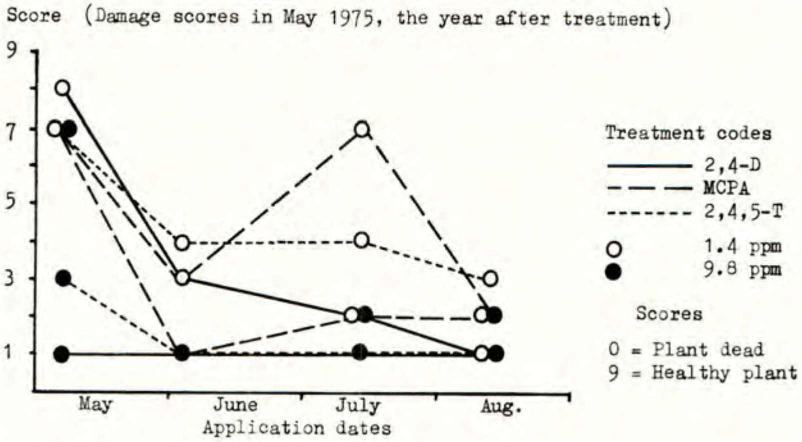
The results in Figure 1 show that the amount of damage that 2,4-D produced on Conference/Quince A varied greatly with the application date and dose. On all but two of the application dates, doses of 0.2 and 0.35 ppm caused a readily distinguishable effect and increasing the dose to 1.4 ppm caused appreciably more damage.

The results from the June, July and August applications to Conference/Quince A in 1975 are from trees that were making extension growth. A set of dormant but otherwise similar trees that were treated in June and July gave a similar response. In August there were no naturally dormant trees for comparison and an attempt to induce dormancy by reducing watering caused the death of some shoot tips. On these trees 2,4-D caused less damage than on those that were actively growing, the amount of damage being comparable with the October treated trees which were naturally dormant.

The results in Figure 2 show that when 2,4-D, MCPA and 2,4,5-T at 1.4 and 9.8 ppm were applied to Conference/Quince A, all but one of the treatments (2,4-D at 1.4 ppm in May) caused readily distinguishable effects in the year after treatment, and in most cases the effect was severe. Although 2,4-D was considerably more damaging than MCPA and 2,4,5-T on some dates, there were no consistent differences between the herbicides. At the maximum dose they all caused comparable amounts of damage.

Figure 2

The response of Conference/Quince A to 2,4-D, MCPA and 2,4,5-T applied to the roots



The effect of 2,4-D and MCPA at 0.2 and 1.4 ppm on Conference, Williams and Comice, all on Quince A, is shown in Figure 3. Conference was the most susceptible variety to 2,4-D and Comice the most tolerant. The differences, although not large, were consistent for both doses and both application dates. Williams was the most tolerant variety to MCPA which always caused less damage than 2,4-D to this variety.

The results in Figure 4 show that there were large differences in the response of Cox/M26 to 2,4-D, MCPA and 2,4,5-T. At the lower doses 2,4-D was safe, MCPA caused moderate damage on only one occasion whereas 2,4,5-T caused severe damage. At the higher doses all 3 herbicides caused severe damage.

Figure 3

The response of Conference, Williams and Comice Pears on Quince A to 2,4-D and MCPA applied to the roots

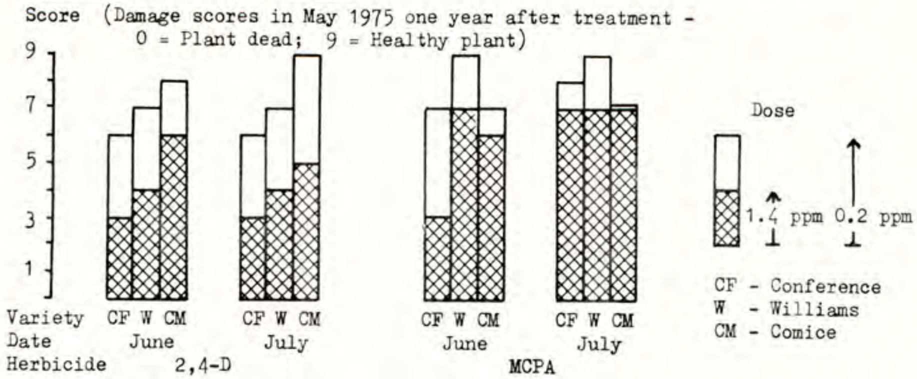
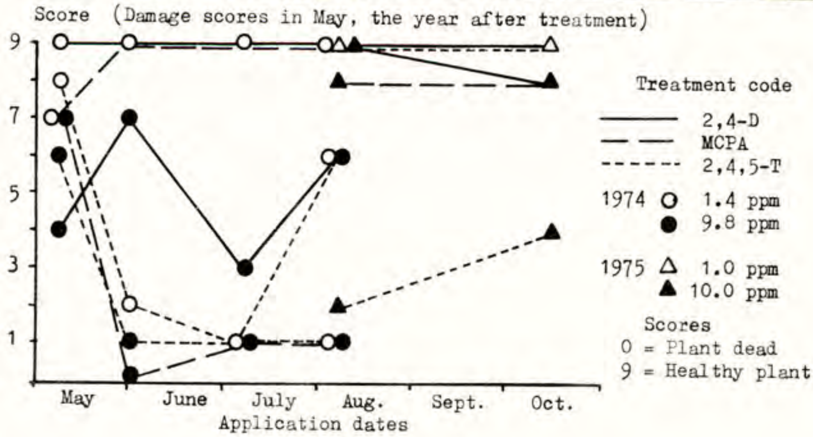


Figure 4

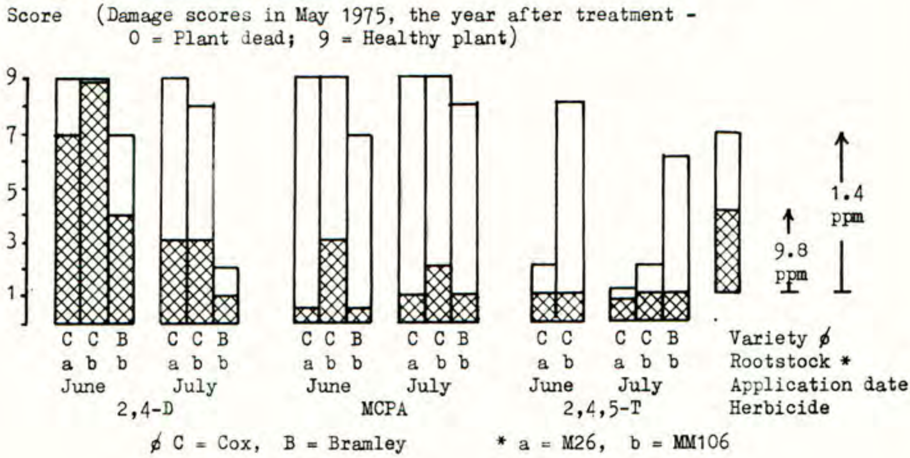
The response of Cox/M26 to 2,4-D, MCPA and 2,4,5-T applied to the roots



The results in Figure 5 for 2,4-D and the low dose of MCPA indicate that response is related more to the scion variety than to the rootstock variety. However, with the high dose of MCPA and the low dose of 2,4,5-T there was considerably more response from Cox/M26 than Cox/MM106. None of the varietal differences to 2,4-D and 2,4,5-T were greater than the differences due to time of application.

Figure 5

The response of Cox/M26, Cox MM 106 and Bramley/MM106 to 2,4-D, MCPA and 2,4,5-T applied to the roots



DISCUSSION

The symptoms produced on pears in the year of treatment and the year after treatment were similar to those observed on field-grown crops (Davison and Clay, 1970; Larsen, 1974). The absence of leaf formative effects, except on pears treated with 2,4-D, means that it is possible for both apples and pears to be affected without showing any of the symptoms generally associated with growth-regulator damage.

The greater susceptibility of pears than apple to 2,4-D; of Conference pears than Williams to 2,4-D, and of Bramley than Cox apples to 2,4-D are in agreement with earlier field experiments (Davison and Clay, 1970). However, there were greater differences due to the various dates of application but severe damage was produced by all herbicides at all dates. Both dormant and actively-growing pears were damaged. Therefore the variable amounts of damage are probably associated with some factor other than growth rate at the time of treatment. Benson and Covey (1974) have shown the influence of irrigation on 2,4-D movement in the soil and the effect of temperature on its persistence. The normal variations that occur in orchards in soil conditions and rooting depths offer the most probable explanation for the variable results experienced in the field (Davison and Clay, 1970; Goddrie, 1970).

In the present tests the amount of herbicide that entered the trees could be affected by the extent to which it was degraded during the 7 day treatment period, its distribution in the sand and the amount of water taken up by the tree. The amount of damage did not seem to be related to evaporation from a free water service. Of the other two factors it is probable that distribution of herbicide in relation to tree roots was the most important.

The actual amount of growth-regulator needed to produce damage was very small in relation to the dose used for weed control. Pears were damaged by 2,4-D at 0.2 ppm which is equivalent to 1.6 mg in the rooting zone. If all the tree roots were confined to an area of $1 m^2$ this concentration is equal to 16 g/ha. But if the roots occupied an area of $4 m^2$ then only 4 g/ha would be needed. On this basis

200 g/ha 2,4-D would be equivalent to 10 ppm - the maximum dose in these tests, and this is only 10% of the 2 kg/ha often applied.

The general safe use of 2,4-D, MCPA and 2,4,5-T in commercial plantations of apples and particularly pears cannot be attributed to their inherent tolerance. Minor differences in the inherent tolerance of varieties and rootstocks may account for some of the reported differences in field tolerance. The influence of rootstock and soil type may modify root distribution to favour certain crops and varieties. However, these tests indicate some other factor is responsible for the variation experienced under field conditions, the most probable being the amount of herbicide in contact with a significant proportion of the root system.

Acknowledgements

Analyses of 2,4-D in sand were carried out by the WRO Chemistry Group.

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Proceedings 1976 British Crop Protection Conference - Weeds'

NORFLURAZON HERBICIDE FOR WEED CONTROL IN FRUIT TREES, NUT TREES AND OTHER PERENNIAL CROPS IN THE U.S.A.

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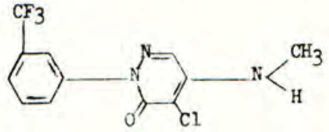
Summary Norflurazon herbicide is a broad-spectrum weed control chemical which has been extensively evaluated in the United States during the past six years. The commercial product of norflurazon (Solicam™ 80 WP) has been submitted for a full registration in the United States as a weed control agent in stone fruits and certain edible nut crops. The recommended rates of application for norflurazon are from 2.2 to 4.4 kg/ha of active ingredient depending on soil type. It should be applied preemergence to weeds or with a suitable burndown agent when there are existing weeds. As would be expected, moisture promotes activation of norflurazon. It is capable of giving full season weed control. Norflurazon controls many problem weeds and compared to simazine it is less phytotoxic to the trees. Norflurazon also shows promise for weed control in other perennial crops such as grapes, hops, citrus and pome fruits.

Résumé Norflurazon est un herbicide à large spectre d'activité ayant fait l'objet d'une évaluation intensive aux Etats-Unis durant ces six dernières années. Le produit commercial de norflurazon (Solicam 80 PM) a été pétitionné aux E.U. pour l'emploi dans les vergers de fruits à noyaux et certains arbres à noix commestibles. Norflurazon est recommandé en pré-levée des adventices ou en post-levée en mélange avec un herbicide de contact à raison de 2,2 à 4,4 kg/ha m.a. selon les types de sol. Ainsi qu'attendu, norflurazon est activé par l'humidité. Sa persistance lui permet de tenir les vergers propres durant toute une saison. Norflurazon contrôle de nombreuses adventices et comparé à la simazine il est moins phytotoxique envers les arbres fruitiers. Norflurazon est également prometteur dans d'autres cultures vivaces telles que la vigne, le houblon, les agrumes et les fruits à pépins.

INTRODUCTION

Norflurazon herbicide was synthesized in the laboratories of Sandoz Ltd. in Basle, Switzerland. It is a pyridazinone herbicide with the chemical name 4-chloro-5-(methylamino)-2-(alpha, alpha, alpha-trifluoro-m-tolyl)-3(2H)-pyridazinone.

Structural formula



Solubility in water: 28 ppm at 25°C
Commercial product: SOLICAM™ 80 WP

Toxicity: oral rat (technical norflurazon) LD_{50} 9300 mg/kg of body weight
dermal rabbit (80 WP norflurazon) 20,000 mg/kg of body weight (no skin irritation)

Mode of action: Norflurazon is a relatively long lasting soil preemergence herbicide with little post-emergence activity. Norflurazon affects plants by inhibiting carotenoid synthesis which causes chlorophyll destruction in susceptible species as reported by Bartels, et al (1970) and Hilton, et al (1969).

METHOD AND MATERIALS

Norflurazon has been tested extensively on fruit trees, nut trees and other perennial crops in the United States during the past six years. Approximately 250 small plot trials and 50 large scale trials were conducted by universities, extension services, private cooperators and field development personnel of Sandoz, Inc. The majority of the work has been done in the western United States, where norflurazon has provided excellent weed control. A petition for tolerance and request for federal registration has been submitted for certain tree crops grown in California, Oregon and Washington.

In most tests, simazine and napropamide were used as the standard products. All materials were applied preemergence surface to the weeds or with a suitable burndown agent when weeds were present.

RESULTS

Crop tolerance

Typical norflurazon chlorosis is evident as a white discoloration of the leaf along the veins which moves gradually outward interveinally. Under severe conditions leaves can become completely white. If norflurazon injury occurs it appears as chlorosis on the lower portions of the tree first, usually in sucker growth. Light chlorosis usually disappears by harvest time with no apparent adverse effect to the tree.

The stone fruits, apricots, nectarines, peaches, plums and prunes, have been evaluated under varying commercial conditions and no symptoms of crop injury have been observed. The nut crops, walnuts and filberts, also appear very tolerant. Almonds proved to be slightly less tolerant as injury occurred in six out of 28 trials. It should be noted though, that in five trials on coarse soils low in organic matter up to 15% chlorosis resulted only at the double rate of norflurazon with no chlorosis at the normal rate. Severe damage to young trees occurred in only one trial where the trees were subjected to abnormally heavy basin flood irrigation for frost protection.

Limited testing has been done in grapes, hops, citrus, pears and apples and results are favorable but not conclusive. Initial work in grapes indicates that norflurazon is quite safe on established plants, but rather injurious on new plantings and planted cuttings. Pears and apples also appear to be tolerant to norflurazon. Chlorosis to pear tree sucker growth was observed at the double rate in only one trial out of 18. Citrus and hops show excellent tolerance.

Compared to simazine, norflurazon proves to be substantially less phytotoxic since on coarse soils simazine can be injurious to most tree species. In the trials where norflurazon and napropamide were tested together, napropamide caused no damage.

Weed control

A summary of the main results can be found in Table 2. The individual comparisons given in the table are results obtained from the same trials and are therefore directly comparable. It appears that norflurazon is primarily an annual grass killer with good activity on many broadleaf weeds. It also has some effect on certain perennial weeds.

a. Annual grasses controlled: Poa annua, Digitaria spp., Echinochloa crus-galli, Lolium sp., Setaria spp., Hordeum spp., Panicum sp.

b. Annual broadleaf weeds controlled: Capsella bursa-pastoris, Stellaria media, Amsinckia spp., Matricaria sp., Malva spp., Amaranthus spp.*, Erigeron canadensis, Salsola kali*, Erodium spp.*, Portulaca sp.*, Tribulus terrestris*, Sisymbrium irio, Calandrinia ciliata, Chenopodium album*, Taraxacum officinale*.

    The weeds marked with an * are adequately controlled under good environmental conditions. Their control becomes somewhat erratic when some unfavorable factor interferes with the activity of norflurazon, i.e. lack of moisture.

c. Weeds showing marginal susceptibility: Lamium sp., Sonchus sp., Polygonum spp., Senecio spp.

d. Perennial grasses showing susceptibility: Cyperus rotundus, Cynodon dactylon, Agropyron repens.

Length of control

Length of control is somewhat dependent on the climatic conditions and soil type. In general, norflurazon is a long term residual material capable of lasting a full season even when applied in the fall.

Table 1

Average % general weed control, 3 months and 9 months after application

	3 months			
Soil* Type	norflurazon 2.2 kg/ha	norflurazon 4.4 kg/ha	simazine 2.2 kg/ha	napropamide 4.4 kg/ha
C+M	81 (20/21)			
F		71 (10/23)		
C+M	83 (11/19)		87 (11/21)	
M+F		80 (14/27)	84 (14/25)	
C+M	86 (9/12)			61 (9/29)
M+F		79 (7/22)		59 (7/34)

* C = coarse, M = medium, F = fine. () = Number of trials/Standard deviation.

Table 1

Average % general weed control, 3 months and 9 months after application

Soil* Type	9 months			
	norflurazon 2.2 kg/ha	norflurazon 4.4 kg/ha	simazine 2.2 kg/ha	napropamide 4.4 kg/ha
C+M	63 (20/28)			
F		62 (10/17)		
C+M	65 (11/28)		70 (11/29)	
M+F		78 (14/20)	53 (14/34)	
C+M	83 (9/11)			70 (9/30)
M+F		78 (7/20)		50 (7/34)

* C = coarse, M = medium, F = fine. () = Number of trials/Standard deviation.

The breakdown in general weed control at the end of the season is generally the result of less susceptible weeds starting to invade the treated plots.

Influence of environmental factors on the performance of norflurazon

a. Rainfall or irrigation. Being somewhat photodegradable, norflurazon can lose activity if exposed at the surface of the soil for an extended period of time. As would be expected, moisture promotes penetration and activation. If rainfall does not occur within two weeks after application, irrigation is recommended. While flood and sprinkler irrigation are fully adequate to activate norflurazon, furrow irrigation is less suitable since the ascendant water moving to the top of the furrows prevents norflurazon from penetrating the soil.

b. Weed cover. Heavy weed cover, whether dead or alive, intercepts part of the spray and prevents norflurazon from reaching the soil. Best results are obtained when the ground is free of weeds at application; or if when weeds are present, a burndown agent is added to the spray mix. Mowing is also advisable if weed growth is above four inches.

c. Time of application. Applications snould be made in late fall to early spring since this is the best timing for complying with the guidelines of a and b as mentioned above.

d. Mechanical incorporation is generally detrimental to norflurazon as it reduces its activity on shallow germinating weeds.

Comparison with the standards

Norflurazon vs. simazine. The biological activity of norflurazon and simazine is quite different. While norflurazon is a better grass killer, simazine is a better broadleaf weed killer.

Norflurazon vs. napropamide. Norflurazon proves to be more effective than napropamide in general weed control. It is somewhat more efficacious on grasses and comparable on broadleaf weeds. Each product has a different broadleaf spectrum of control.

Combinations of norflurazon and simazine

Combinations of both herbicides have shown complementary activity. Substantial improvement is shown in the control of some broadleaf weeds marginally controlled by norflurazon alone. This includes Amaranthus spp., Lamium sp., Chenopodium album, Erodium spp.

In an average of 12 trials, general broadleaf weed control with norflurazon at 2.2 kg/ha a.i. was 72% and with norflurazon + simazine at 2.2 + 1.1 kg/ha a.i. was 87%.

DISCUSSION

Norflurazon is a useful herbicide for the fruit and nut tree growers in the western United States. Its safety to stone fruits and certain nut crops is excellent on all soil types. Initial results indicate that other perennial crops such as grapes, hops, pome fruits and citrus also possess adequate tolerance. Used at 2.2 to 4.4 kg/ha a.i. depending on soil type, norflurazon is capable of fulfilling the herbicidal requirements of modern cropping management. Its usage in strips 3-10 feet wide along the tree line eliminates the need for expensive hand labor or mechanical removal of weeds around the base of the tree. Norflurazon will reduce the amount of damage to trees caused by mechanical devices and reduce the required number of trips through the field with burndown type materials.

Although norflurazon compares very favorably with the standard materials, it also posesses the drawback of all residual herbicides in allowing resistant weeds to become predominant. The growers must be aware of this and consider combination treatments or alternate treatments of different materials to broaden the spectrum of control.

Acknowledgements

The authors wish to thank the university specialists, the extension services and private cooperators for their cooperation in conducting field trials, and the growers who kindly provided trial sites.

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TABLE 2

Average % weed control obtained with norflurazon, simazine and napropamide 3-4 months after application

Weeds	Soil* Type	norflurazon 2.2 kg/ha	norflurazon 4.4 kg/ha	norflurazon 2.2 kg/ha	simazine 2.2 kg/ha	norflurazon 2.2 kg/ha	napropamide 4.4 kg/ha
General weeds	C+M	81 (39/20)		83 (11/19)	87 (11/21)	80 (23/19)	67 (23/24)
	F		75 (15/22)	80** (14/27)	84 (14/25)	79** (7/22)	59 (7/34)
General broadleaves	All			62 (9/24)	88 (9/20)		
Echinochloa c. galli	C+M	98 (12/4)		99 (8/3)	66 (8/29)	98 (10/4)	93 (10/9)
Poa annua	C+M	99 (18/3)		98 (12/3)	90 (12/19)	100 (9/0)	96 (9/10)
Digitaria spp.	C+M	97 (8/5)		95 (3/7)	72 (3/40)	100 (2/-)	100 (2/-)
Lolium sp.	C+M	100 (2/-)			97 (2/-)		
	F		98 (4/3)		85 (4/13)		
Setaria spp.	C+M					92 (3/6)	75 (3/18)
Hordeum spp.	C+M	99 (6/3)		100 (3/0)	100 (3/0)		
	F			94 (4/4)	95 (4/9)		
Panicum capillare	C+M	90 (4/7)	94 (4/4)				
Cynodon dactylon	C+M		89 (3/6)				10 (2/-)
	F		35 (2/-)		0 (2/-)		
Cyperus spp.	C+M	73 (4/35)	100 (4/0)		50 (4/50)	64 (5/35)	58 (5/43)
Agropyron repens	F		64 (4/30)				
Amaranthus spp.	All	84 (15/20)	92 (15/9)	86 (5/17)	92 (5/14)	88 (2/-)	91 (2/-)
Stellaria media	All	84 (20/23)	99 (9/2)	87 (9/17)	92 (9/22)	85 (9/23)	77 (9/35)

* C = coarse, M = medium, F = fine. ** Norflurazon at 4.4 kg/ha. () = Number of trials/Standard deviation.

TABLE 2

Average % weed control obtained with norflurazon, simazine and napropamide 3-4 months after application

Weeds	Soil* Type	norflurazon 2.2 kg/ha	norflurazon 4.4 kg/ha	norflurazon 2.2 kg/ha	simazine 2.2 kg/ha	norflurazon 2.2 kg/ha	napropamide 4.4 kg/ha
Amsinckia spp.	All	88 (11/15)		98 (4/3)	100 (4/0)	80 (5/18)	84 (5/19)
Erodium spp.	All	81 (13/21)	90 (13/21)	82 (6/19)	88 (6/19)		
Capsella b. pastoris	All	92 (26/24)	100 (12/0)	100 (10/0)	93 (10/10)	91 (12/25)	75 (12/28)
Chenopodium album	All	78 (15/30)	91 (6/11)	97 (3/4)	100 (3/0)	77 (4/34)	97 (4/4)
Malva spp.	All	85 (15/20)	93 (11/11)	81 (7/23)	83 (7/15)	94 (8/11)	86 (8/22)
Erigeron spp.	All	99 (4/1)					
Salsola kali	F	79 (6/14)	97 (4/4)	75 (3/9)	90 (3/14)		
Matricaria sp.	All	96 (10/12)	100 (7/1)	89 (4/17)	93 (4/8)	100 (3/0)	100 (3/0)
Lamium sp.	All	58 (13/30)	72 (6/35)			45 (6/33)	54 (6/38)
Senecio spp.	All	64 (9/36)	81 (4/14)			65 (6/31)	70 (6/32)
Tribulus terrestris	All	79 (4/18)	93 (4/5)	79 (3/21)	96 (3/1)		
Sonchus spp.	All	61 (4/37)	87 (5/9)				
Portulaca sp.	All	80 (9/30)	89 (9/21)	100 (3/0)	100 (3/0)	74 (5/38)	85 (5/25)
Taraxacum officinale	All		70 (4/41)				
Calandrinia ciliata	All	96 (6/7)					
Polygonum spp.	All	57 (4/40)	53 (5/34)				

* C = coarse, M = medium, F = fine. ** Norflurazon at 4.4 kg/ha. () = Number of trials/Standard deviation.

Proceedings 1976 British Crop Protection Conference - Weeds

CONTROL OF OXALIS PES-CAPRAE L. WITH PRE-EMERGENCE AND POST-EMERGENCE TREATMENTS

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Summary Six experiments to investigate the effect on *Oxalis pes-caprae* L. of pre-emergence and post-emergence herbicide treatments were carried out. The results indicated that chlorthiamid and dichlobenil as pre-emergence treatments gave complete control of oxalis while glyphosate and paraquat as post-emergence treatments gave also a very efficient control of the weed. Regrowth of the weed the following year suggests that a 2 to 3 year herbicide application program is necessary for total eradication.

INTRODUCTION

Oxalis pes-caprae L. is an indigenous plant of South Africa and was introduced to Mediterranean countries at the beginning of the 19th century (Galil,1968). Today the most infested areas in Greece are the olive groves and vineyards of Crete and South Peloponnese where it is found to be the dominant weed in many locations. In Greece oxalis is considered the 9th weed in order of importance (Damanakis,1973). In areas where hand picking of olive fruits from the ground is the common practice it is especially troublesome, making the job almost impossible. It also causes sheep poisoning due to its oxalate content (Healy,1967; McIntosh,1972) resulting in many deaths. Sheep can consume as much as 750 g of dry matter of oxalis per head per day, containing about 12% of oxalate (Dodson,1959).

Oxalis is propagated mainly by the small bulbils (10-40 per plant) which are formed on the vertical shoot between the old bulbil and the surface of the ground as well as on the rootless horizontal stem which bears a large contractile root at the end (Galil,1968). New bulbils can be found 40 cm from the parent bulbil and can be dispersed great distances by machinery used for cultivation. This is the reason for the faster spread of oxalis in Greece during the last 20 years.

Satisfactory control of oxalis in other countries has been achieved with monuron, diuron, fenoprop, oxadiazon, chlorthiamid and aminotriazole (Australia,1965 and 1973; Catt,1972 a and b; Fraselle & Rondia,1973; Michael,1965 b). So far only two studies have been published in Greece on this important weed. The first by Mentzelopoulos & Michaelidis (1957) recommended 2,4-D and DNOC while in the second by Rissakis (1968) dinoseb-acetate and paraquat were found to be more effective herbicides.

The purpose of the present work was to search for more effective herbicides for the control of oxalis under Greek conditions. The need for new herbicides giving satisfactory control was considered urgent because of the continuous dispersal of the weed in areas not still infested.

METHODS AND MATERIALS

Six experiments were conducted during the period 1971-1973. Details of methods and materials are included in Tables 1 to 8.

Clay pots of a diameter 12 cm and a height of 15 cm were used in all pot experiments and were filled with a soil classified as a sandy clay loam marl. Ten bulbils were planted in each pot and covered with 1.5 cm of soil.

The doses of herbicides and the number of replications are shown in the tables of results of the relevant experiments. In most of the experiments there were two controls to each replicate of the treatments. They are referred to in the tables as Control (a) and (b). In all pot experiments sprays were applied with a precision-sprayer moving along a track at 0.28 m/sec and fitted a 'Tee-jet' 8001 nozzle located 45 cm above the plant or soil to be sprayed. The spray volume was 600 l/ha and the pressure inside the tank remained constant at 3 kg/cm^2. The granular formulations were broadcast uniformly by hand.

Table 1

Methods and materials

Expt No	Year	Kind of expt	Herbicides	Method of application
1	1971	Pot experiment in the open	Oxadiazon	Pre-emergence
			Nitralin	" "
			Simazine	" "
			Trifluralin	" "
			Dichlobenil	" "
			Chlorthiamid	" "
2	1972	Pot experiment in the open	Dichlobenil	Pre-emergence
			Dichlobenil	Pre-em. incorp.
			Chlorthiamid	Pre-emergence
			Chlorthiamid	Pre-em. incorp.
			Oxadiazon	Pre-emergence
			Oxadiazon	Pre-em. incorp.
3	1972	Pot experiment in glasshouse	Paraquat	Post-emergence
			MSMA	" "
			Aminotriazole + Simazine	" "
			Glyphosate	" "
4	1972	Very small plots in the field	Dichlobenil	Pre-emergence
			Chlorthiamid	" "
			Oxadiazon	" "
5	1972	Small plots in the field	Paraquat	Post-emergence
			Glyphosate	" "
6	1973	Pot experiment in the open	Paraquat	Post-emergence
			Glyphosate	" "

In Experiment 1 bulbils were planted on October 11 and spraying took place the following day. The appearence of the shoots above the ground occurred 10 days after planting and their number and height were measured 24 days after spraying.

In Experiment 2, the incorporated granular herbicides were mixed with the amount of soil which covered the bulbils. Bulbils were planted and spraying took place on September 21. Emergence of the plants commenced after 10 days. Fresh weight of shoots was taken 52 days after spraying.

Table 2

Herbicide formulations used in the experiments

Common name and formulation	Trade name	Manufacturer
Aminotriazole 36% + Simazine 18% WP	Saminol 1089	Ciba-Geigy
Chlorthiamid 7.5% G	Prefix	Shell
Dichlobenil 7.5% G	Casoron	Philips-Duphar
Glyphosate 36% AC	Roundup	Monsanto
MSMA 34.8% AC	Ansar 529	Ansul
Nitralin 75% WP	Planavin	Shell
Oxadiazon 2% G	RP 17623 G	Rhône-Poulenc
Oxadiazon 25% EC	RP 17623 EC	Rhône-Poulenc
Paraquat 20% AC	Gramoxone	I.C.I.
Simazine 50% WP	Gesatop	Ciba-Geigy
Trifluralin 48% EC	Treflan	Elanco

In Experiment 3 the bulbils were planted on October 5 and spraying was done 43 days later when the shoots were about 10 cm high. The results were scored a month after the treatments were applied using an empirical scale 0-10.

Experiment 4 was conducted in very small plots in the field. In order to choose uniform plots completely covered with oxalis the location of each plot was marked with a stake in the previous year (1971). The granular herbicides were applied by hand to the plot area using a quadrat (25 X 25 cm) the center of which coincided with that of the stake. The frame was moved after the application and later re-placed for ease of observation. The herbicide were applied to wet soil on September 21 before the germination of the weed and the results evaluated 45 days later using a 0-10 empirical scale.

Experiment 5 was carried out in an olive grove in the Kyriana area of Crete. The plots were 2 X 5 m in size and untreated bands of 1 m were left between the treatments. The herbicides were applied with a knapsack sprayer at a constant pressure of 2 kg/cm^2 using a volume of 800 l/ha. At the time of spraying the oxalis was 15 cm high. Spraying was done on November 27 about 60 days after the germination of the weed. Five mm of rain occurred about 26 hours after application. Michael (1965 a and b) found that the best results were obtained after the old bulbils were exhausted (53 days) and before the appearance of the new bulbils (76 days) and this was the reason for choosing the above stage for spraying. Fresh weights of oxalis were taken a month after application from 4 quadrats (25 X 25 cm) of each treatment and a final assessment of the results was done 13 months after the application.

Experiment 6 was done in order to find the minimum effective dose of paraquat and glyphosate. Spraying was carried out 25 days after germination on November 5. At this stage oxalis was 15 cm high. Fresh weight of shoots was taken 65 days after spraying.

RESULTS

In Experiment 1 (Table 3) the benzonitriles, chlorthiamid and dichlobenil gave 100% control of the aerial parts of the weed followed by trifluralin which gave 74% reduction of the shoot length. Oxadiazon, nitralin and simazine showed little or no effect.

The benzonitriles chlorthiamid and dichlobenil also gave 100% control of the aerial parts of oxalis in Experiment 2 (Table 4) while the two formulations of oxadiazon reduced the fresh weight of shoots by 63 and 75% respectively.

Table 3

Expt 1 - Number and total length of shoots (means of 7 replications)

Herbicides	Doses (kg/ha)	Number of shoots	Total length of shoots (cm)
Control a	-	26.3 ± 11.0	10.4 ± 3.7
Control b	-	26.0 ± 9.2	10.4 ± 3.1
Oxadiazon 25% EC	16	2.1 ± 1.2	9.7 ± 2.5
Nitralin 75% WP	1.5	34.4 ± 6.8	14.8 ± 3.0
Simazine 50% WP	7.5	26.1 ± 11.4	12.4 ± 3.6
Trifluralin 48% EC	2	3.7 ± 2.5	2.7 ± 1.6
Chlorthiamid 7.5% G	100	0	0
Dichlobenil 7.5% G	100	0	0

Among the post-emergence treatments of Experiment 3 (Table 5) glyphosate gave total control of the aerial parts of the weed followed by paraquat. Aminotriazole plus simazine and MSMA did not control the weed sufficiently.

Table 4

Expt 2 - Fresh weight of shoots (means of 6 replications)

Herbicide treatment	Doses (kg/ha)	Fresh wt of shoots per pot (g)
Control a	-	8.79 ± 2.17
Control b	-	8.55 ± 1.22
Chlorthiamid 7.5% G	100	0
Chlorthiamid 7.5% G incorp.	100	0
Dichlobenil 7.5% G	100	0
Dichlobenil 7.5% G incorp.	100	0
Oxadiazon 25% EC	15	2.20 ± 1.70
Oxadiazon 2% G incorp.	100	3.18 ± 1.93

Table 5

Expt 3 - Scores of herbicide effect (means of 6 replications)

Herbicides	Doses (kg/ha)	Scores of herbicide effect*	Range
Paraquat 20% AC	5	9.66	9-10
Glyphosate 36% AC	10	10.00	10-10
Aminotriazole 36% + Simazine 18% WP	15	6.00	5-8
MSMA 34.8% AC	20	2.83	2-4

* 0=no effect, 10= total killing of the weed

In Experiment 4 (Table 6) the benzonitrile herbicides chlorthiamid and dichlobenil again appeared to give 100% control of the earial parts of the weed under field conditions but in this case a final assessment 14 months after the application showed that the weed had recovered and all plots were covered again with oxalis.

In Experiment 5 (Table 7) glyphosate and paraquat gave almost total control of aerial parts of the weed under field conditions. Death occurred three days after the paraquat treatments while in the case of glyphosate the first phytotoxic symptoms were seen on the seventh day. The leaves of glyphosate treated plants were chlorotic and the lobes of the trifoliate leaves down-curved giving a closed appearance such as normally occurs only during the night. At the final assessment 13 months after treatment the plots sprayed with paraquat had growth similar to that of the controls while those treated with glyphosate showed a 40% reduction in the number of shoots and an 80% reduction in growth.

Table 6

Expt 4 - Scores of herbicide effect (means of 4 replications)

Herbicides	Doses (kg/ha)	Scores of herbicide effect*	Range
Dichlobenil 7.5% G	100	10.00	10-10
Chlorthiamid 7.5% G	100	10.00	10-10
Oxadiazon 2% G	150	5.25	4-6

* 0=no effect, 10=total killing of the weed

Table 7

Expt 5 - Fresh weight of oxalis shoots (means of 4 replications)

Herbicides	Doses (kg/ha)	Fresh weight of oxalis per m^2(g)	Range
Control	-	1208	1166-1250
Paraquat 20% AC	5	195	165-250
Glyphosate 36% AC	10	28	0-50

In Experiment 6 (Table 8) in which lower doses of paraquat and glyphosate were tested, glyphosate proved to be superior to paraquat even at one quarter of the recommended dose (higher dose used in expt 6). One week after application there appeared to be 50-100% kill in the paraquat treatments while treatment with glyphosate showed only chlorotic and curved leaves as in experiment 5. At the end of the second week the effect of the two herbicides appeared quite similar but at the end of the third week the results were reversed. At this time the weed started to regrow in the paraquat treatments.

DISCUSSION

The results of this work show that there are effective herbicides for the control of oxalis as pre-emergence or post-emergence treatments. Nevertheless assessment done a year after the application showed that the weed is capable of regrowing although it was apparently controlled completely in the previous year. The regrowth is obviously attributable to the dormant bulbils which seem to be unaffected by the herbicides. These results suggest that a herbicide application program of 2 to 3 years is necessary for the eradication of the weed.

The best control with pre-emergence herbicides was achieved with the benzonitriles chlorthiamid and dichlobenil with or without incorporation.

Table 8

Expt 6 - Fresh weight of oxalis shoots (means of 8 replications)

Herbicides	Doses (kg/ha)	Fresh weight per pot (g)
Control a	-	13.82 ± 3.69
Control b	-	19.72 ± 6.35
Paraquat 20% AC	5	3.97 ± 0.93
Paraquat 20% AC	2.5	4.88 ± 2.36
Paraquat 20% AC	1.2	8.63 ± 3.39
Glyphosate 36% AC	10	0.47 ± 0.47
Glyphosate 36% AC	5	1.11 ± 0.98
Glyphosate 36% AC	2.5	0.83 ± 0.69

Satisfactory control was also obtained with trifluralin and oxadiazon.

In the post-emergence treatments glyphosate proved to be superior to paraquat. In the case of glyphosate a considerable reduction in the number of the emergent shoots and growth was observed the year following application, suggesting that fewer sprays are necessary for the complete eradication of the weed.

As Michael (1965 a and b) showed in his experiments the best results with post-emergence sprays are achieved after the old bulbils are exhausted and before the appearance of the new bulbils.

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THE TOLERANCE OF NEWLY PLANTED ORNAMENTALS TO A RANGE OF CONTACT HERBICIDES

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Summary Results are presented which show that phenmedipham at 0.96 l/ha, aziprotryne at 1.96 kg/ha and ethofumesate at 1.4 l/ha are tolerated by newly planted ornamentals. Plots treated with methazole at 2.24 kg/ha or desmetryne at 0.28 kg/ha recovered satisfactorily after initial plant damage.

The levels of phytotoxicity produced with ioxynil at 0.70 l/ha and the mixture ioxynil at 0.84 l/ha plus linuron at 0.24 kg/ha was unacceptable although excellent weed control was achieved.

Where residual herbicides fail to give the desired weed control results indicate that an application of foliage acting herbicides could be justified in spite of a minimal check in growth.

INTRODUCTION

In openground shrub production weed control has always presented a problem. Residual herbicides depend for their effectiveness upon favourable climatic conditions and are therefore often unreliable. In addition phytotoxicity can be a problem with some subjects before establishment. Increasing labour costs have made hand weeding uneconomic.

To meet this problem a preliminary trial using contact herbicides on a range of plant subjects was undertaken in 1975 (Loughgall Annual Report 1975). As results were encouraging a further trial in 1976 was undertaken to establish the tolerance of newly planted species to a range of foliage acting herbicides.

MATERIALS AND METHODS

All subjects were propagated in Autumn 1975 and overwintered under protection. Planting took place on 16 June 1976 in a sandy clay loam in rows 45 cm apart. A randomised plot experimental design was used with three replicates of each plot. The herbicides were applied at right angles to the way of planting. All herbicides were applied overhead on 16 July 1976 using an Oxford precision sprayer and 560 l/ha. At time of spraying the plant and weed foliage was dry but soil conditions were moist. No rainfall was recorded for 24 hours after application and total rainfall for seven days after application was 3.1 mm.

Herbicides applied were phenmedipham, desmetryne, methazole, ioxynil, aziprotryne, ioxynil + linuron and ethofumesate. A hand weeded plot was used as the control.

Ornamental species planted in the experiment were:-

Berberis x stenophylla
Berberis thunbergii 'Atropurpurea Superba'
Berberis x ottawensis 'Purpurea'
Cotoneaster horizontalis
Cotoneaster 'Skogholm'
Escallonia 'Alice'
Hebe 'Autumn Glory'
Hebe 'Wakeham Seedling'
Hypericum 'Hidcote'
Olearia solandri
Pyracantha atalantioides
Ribes alpinum 'Pumilum'
Rubus tricolor
Spiraea x bumalda 'Anthony Waterer'
Ulex europaeus 'Plenus'
Viburnum tinus
Weigelia florida 'Variegata'

All species had established and were producing extension growth at time of spraying. Although weed height was approximately 13 cm all species were still visible above the canopy. Plant damage scores were taken every 7 days from time of application and weed scores were taken 14 days and 28 days after application. Plant damage scores were on a 0-10 scale with 0 = no damage and 10 = complete necrosis. Weed scores were on a 0-10 scale with 0 = no weeds and 10 = weeds dominant. Weeds present on plots before spraying were Polygonum persicaria, Capsella bursa pastoris, Poa annua, Chenopodium album, Senecio vulgaris and Stellaria media.

RESULTS

Table 1 presents mean plant damage and mean weed score following the application of the seven herbicides. It was impracticable to include the evaluation of damage on all shrub species in tabular form.

Results show that ioxynil caused significantly more plant damage than any of the other herbicides. Hebe, Spiraea and Hypericum were the most severely damaged. Berberis x stenophylla, Olearia solandri and Escallonia 'Alice' were unaffected and Viburnum tinus, Ribes and Ulex showed only a slight scorch.

The mixture ioxynil plus linuron initially caused slight scorch. After 21 days symptoms indicating secondary damage were observed on all species except Berberis x stenophylla, Ulex, Viburnum, Olearia and Escallonia. This damage developed as a moderate chlorosis.

Methazole after 21 days had severely scorched Spiraea, Rubus and Hebe 'Autumn Glory' but Hebe 'Wakeham Seedling' and Hypericum were unaffected.

All species except Spiraea and Hebe were tolerant to desmetryne and after 28 days had recovered from the initial damage.

Phenmedipham, aziprotryne and ethofumesate gave slight initial scorch but after 21 days all species had recovered with the exception of Spiraea.

Acceptable weed control was obtained with all herbicides except ethofumesate. Ioxynil, ioxynil + linuron and desmetryne acted quickly severely retarding weed growth within 14 days of application. Methazole although acting more slowly gave the most satisfactory level of control after 28 days. On 13 August Poa annua was the dominant weed in all plots with the exception of methazole.

Table 1

Effect of herbicides on plant growth and weeds in newly planted ornamentals

Herbicide	Rate/ ha	Plant Damage				Weed Score	
		23 July	30 July	6 Aug.	13 Aug.	30 July	13 Aug.
Phenmedipham	0.96 l	0.12	0.43	0.63	0.57	3.33	5.67
Desmetryne	0.28 kg	0.06	0.82	1.12	0.86	2.67	5.33
Methazole	2.24 kg	0.07	0.75	1.65	2.65	4.00	1.33
Ioxynil	0.70 l	0.59	2.09	3.20	3.53	1.33	3.00
Aziprotryne	1.96 kg	0.14	0.67	0.86	0.80	3.33	4.67
Ioxynil + Linuron	0.84 l+ 0.24 kg	0.37	0.84	1.24	1.45	1.67	2.33
Ethofumesate	1.4 l	0.04	0.24	0.24	0.25	9.33	8.67
S.E. of a difference (d.f.error 12)		±0.13	±0.22	±0.22	±0.21	±0.49	±0.64

DISCUSSION

This experiment shows that acceptable weed control can be achieved by the use of foliage acting herbicides. Ethofumesate caused minimal shrub phytotoxicity but failed to control the weeds. Methazole and desmetryne when used on this limited range of subjects appear to be useful as a short term control measure. Ioxynil at the rate used caused an unacceptable level of plant damage although weed control was good.

Acknowledgements

The authors wish to thank Mr W.G. Stevenson who undertook the statistical analysis and Mr A.L. Hogg whose help in carrying out this experiment was much appreciated.

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FURTHER INFORMATION ON THE TOLERANCE OF WOODY ORNAMENTALS TO SIMAZINE

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Summary Simazine is now widely used for weed control in landscape plantings of trees and shrubs but nurserymen, landscape designers and gardeners require more information on its safety on woody ornamentals. In particular, information is required on whether the tolerance of a species is due to the plant being inherently tolerant of simazine or whether it is due to the herbicide being retained close to the soil surface so that it does not come into contact with the major portion of the plant's root system.

When an amenity area containing a wide range of woody plants was treated twice annually with simazine at 1.4 kg/ha for 8 years it was observed that many species of trees and shrubs developed naturally from seed. These species included Myrtus luma, Cupressus macrocarpa, Erica arborea, Berberis darwinii, Cotoneaster frigidus, C. simonsii and C. wardii. Greenhouse tests confirm that young seedlings of these species show considerable tolerance of simazine even when a dose in excess of 1.4 kg/ha is incorporated in the soil before planting. Betula jacquemontii and Eucalyptus pulverulenta, plants which did not establish themselves from seed in the amenity area, were susceptible. The results suggest that many species of woody ornamentals will tolerate simazine and do not depend on depth of rooting.

As more established amenity areas are treated with simazine and other herbicides on a routine basis, useful information can be accumulated on the inherent tolerance of ornamental species by recording plants that are seeding themselves in herbicide-treated ground. Such information will assist in the design and maintenance of landscapes on light soil and will reduce the risk of plant injury as a result of unusually wet weather or injudicious spray applications.

Sommaire La simazine est aujourd'hui largement utilisée pour l'élimination des mauvaises herbes dans les plantations paysagères d'arbres et d'arbustes. Les pépiniéristes paysagistes et jardiniers demandent cependant de plus amples informations sur la sécurité de son emploi sur les arbres d'ornement. Il s'agit plus précisément de savoir si la tolérance de certaines espèces est due au fait que la plante a une résistance inhérente à la simazine ou au fait que l'herbicide restant près de la surface du sol n'entre pas en contact avec les racines de la plante.

Il a été observé que de nombreuses espèces d'arbres et d'arbustes se reproduisaient naturellement quand un terrain d'agrément contenant de nombreuses plantes des bois était traité deux fois par an pendant huit ans à la simazine à raison de 1.4 kg/ha. Parmi ces espèces on peut nommer la Myrtus luma, Cupressus macrocarpa, Erica arborea, Berberis darwinii, Cotoneaster frigidus, C. simonsii et C. wardii. Des tests en serre ont prouvé que de jeunes plants de ces espèces ont une grande tolérance à la simazine même quand une

dose supérieure à 1.4 kg/ha est incorporée au sol avant plantation. Betula jacquemontii et Eucalyptus pulverulenta qui ne reproduisent pas d'elle mêmes étaient beaucoup plus susceptibles. Ces résultats montrent que de nombreuses espèces de plantes et d'arbustes d'ornement tolèrent la simazine et ne dépendent pas de la profondeur des racines.

A mesure que les terrains d'agrément déja établis seront traités à la simazine et autres herbicides de manière régulière, d'autres informations seront obtenues sur la tolérance inhérente des différentes espèces de plantes d'ornement en prenant note des plantes qui se reproduisent d'elles mêmes en terrain traité à l'herbicide. Ces informations pourront aider à l'étude et à l'entretien de parcs paysagers en terre sablonneuse et diminueront les risques de dommages occasionnés aux plantes par un temps trop rigoureux ou une application intempestive d'herbicides.

INTRODUCTION

Many woody ornamentals are tolerant of simazine (Fryer and Makepeace 1972). However, there is little information on whether tolerance is due to differential physiological responses between these plants and weeds or simply to the greater depth of rooting of most ornamental species compared with weed seedlings.

Such information is difficult to obtain because many hundreds of different species of ornamentals are used in landscaping. Consequently the value of each individual species is small and few are important enough to justify the research work necessary on this aspect. Some studies have been made on the tolerance of a woody species, blackcurrant, to simazine but although these suggested methods whereby the tolerance of other woody plants and ornamentals could be examined, little further work was carried out (Shone and Wood 1972 and personal communication 1975). Consequently much of the information on woody plants has come from field observations by growers which simply record whether or not damage occurred. Nevertheless information on ornamentals with physiological tolerance of simazine would be useful. For example it would assist in the design and maintenance of shrub and tree plantings on light soil and would reduce the risk of plant injury as a result of unusually wet weather or unskilled or careless spray applications.

It has been noted that many species of shrubs and trees develop naturally from seed when an amenity area containing a wide range of plants was treated twice annually with simazine at 1.4 kg/ha for 8 years (Robinson 1974). Genera that established themselves naturally in spite of a hard crust on the soil surface included Myrtus, Cotoneaster and Berberis. It was not known if seedlings of these plants developed readily in simazine-treated soil because they had a high degree of physiological tolerance or because they were able to establish themselves in localised areas of simazine-free soil. Such areas can occur because it is impossible to cover the soil uniformly with a herbicide when it is applied over low shrub and ground cover plants. If it could be shown that the species that had established themselves readily from seed were not dependent on depth protection but had a physiological tolerance of simazine, then it would be expected that amenity areas in other localities containing different ornamentals should provide further useful information.

Consequently the tolerance to simazine of a number of ornamental species was examined by growing small seedlings in soil in which the herbicide had been incorporated before planting.

MATERIALS AND METHODS

Several greenhouse experiments were conducted at Kinsealy Research Centre between April and September, 1976. Herbicide-free soil to a depth of 12 cm was lifted from an unsprayed field beside the amenity area in north county Dublin which had been treated with simazine for 8 years. The soil, a medium loam, derived from Cambrian shale and quartzite, contained approximately 25% clay and 4.5% O.M. in the top 8 cm. The soil was passed through a $\frac{1}{4}$ in. sieve and mixed with fertilised moss peat (1 part peat to 4 parts soil by volume) to improve transplanting and growing conditions for the young seedlings. Simazine was mixed thoroughly with sub-samples to provide a series of doses equivalent to 0, 0.25, 0.5, 1.0, 2.0 and 4.0 kg/ha incorporated 8 cm deep. The soil was placed in plastic 8 cm diam. pots. Seedlings of a number of woody ornamentals were transplanted into this soil with 2-4 plants in each pot. There were 3-5 replicates of each treatment.

Test plants included a number of species that had been observed growing naturally in large numbers in simazine-treated soil viz. Cotoneaster frigidus, C. wardii, C. simonsii, C. horizontalis, Myrtus luma, Berberis darwinii, Cupressus macrocarpa and Erica arborea. Also included were the two species Betula jacquemontii and Eucalyptus pulverulenta which, although producing viable seed on trees within the amenity area, had not established themselves from seed on simazine-treated soil. In addition three other Cotoneaster species, C. dielsianus, C. conspicuus and C. franchetii, were included in the experiment. The seedlings of most species were raised under glass but some were lifted from the amenity area where suitable numbers of uniform seedlings were available. The source, stage of development and average weight of the shoot growth of the seedlings when transplanted into simazine-treated soil are shown in Table 1.

The pots containing the seedlings were placed on a glasshouse bench and watered by overhead irrigation. Care was taken to avoid flooding and thereby leaching simazine from the pots. After 8-11 weeks when it was evident that the test plants were either killed, unaffected or were growing away from the effects of the herbicide, they were cut off at ground level and weighed.

Weed seedlings that germinated in the pots were removed carefully by hand as they appeared.

Table 1

Source and stage of growth of seedlings when transplanted into simazine-treated soil

Species	Source of seedling	Stage of growth	Av. fresh wt of shoot growth (g)
Berberis darwinii	Simazine-sprayed area	Seed leaves	0.01
Cupressus macrocarpa	" " "	10 cm tall	0.80
Myrtus luma	" " "	8 true leaves	0.07
Betula jacquemontii	Greenhouse raised	2 " "	0.01
Cotoneaster conspicuus	" "	6 " "	0.04
C. dielsianus	" "	1 true leaf	0.03
C. franchetii	" "	2 true leaves	0.06
C. frigidus	" "	3 " "	0.05
C. horizontalis	" "	4 " "	0.06
C. simonsii	" "	4 " "	0.07
C. wardii	" "	4 " "	0.07
Eucalyptus pulverulenta	" "	Seed leaves	0.01
Erica arborea	" "	1.5 cm tall	0.02

RESULTS

Typical symptoms of simazine damage, viz. marginal chlorosis and necrosis occurred within a week on leaves of Betula jacquemontii and Eucalyptus pulverulenta planted into pots containing simazine levels of 1 kg/ha and higher. Cupressus macrocarpa, Myrtus luma, Cotoneaster frigidus, C. wardii and C. simonsii showed no visual evidence of damage to the foliage.

The effect of the simazine levels on the fresh weight of the test plants is shown in Tables 2, 3 and 4. The herbicide had a significant effect on the growth of C. horizontalis ($P. \leq 0.001$), C. dielsianus, C. frigidus, C. wardii ($P. \leq 0.01$), C. conspicuus and C. franchetii ($P. \leq 0.05$) and no significant effect on the growth of C. simonsii. The results indicate that C. frigidus, C. simonsii and C. wardii have a high level of tolerance as growth was not checked even by the highest dose compared with the untreated control. C. horizontalis, C. franchetii and C. conspicuus also showed good tolerance, grwoth being checked only by the 4 kg/ha dose. C. dielsianus was the most susceptible Cotoneaster species tested and growth was significantly reduced by the 2 and 4 kg/ha doses.

Table 2

Effect of simazine on 7 species of Cotoneaster

Dose kg/ha incorporated 8 cm deep	Mean fresh weight (g) of shoot						
	C. conspicuus	C. dielsianus	C. franchetii	C. frigidus	C. horizontalis	C. simonsii	C. wardii
0	0.41	0.31	0.23	0.30	0.24	0.53	0.25
0.25	0.46	0.24	0.23	0.39	0.24	0.61	0.24
0.50	0.38	0.28	0.18	0.53	0.23	0.73	0.37
1.0	0.34	0.24	0.23	0.48	0.20	0.76	0.36
2.0	0.32	0.19	0.21	0.50	0.18	0.65	0.34
4.0	0.09	0.06	0.11	0.28	0.11	0.71	0.27
F-test	x	xx	x	xx	xxx	NS	xx
SE of mean	0.062	0.034	0.031	0.045	0.017	0.077	0.023
df	15	10	20	20	15	20	20

The results (Table 3) show that Cupressus macrocarpa has a high tolerance of simazine and was not affected by the highest dose. Berberis darwinii and Myrtus luma also showed good tolerance and although seedling growth was checked by the highest level, the 2 kg/ha dose had no adverse effect. Erica arborea was slightly but not significantly stunted by the 2.0 kg/ha dose (Table 4). In contrast, Betula jacquemontii (Table 3) and Eucalyptus pulverulenta (Table 4) proved to be susceptible, both being significantly reduced by simazine at 1 kg/ha.

Weed seedlings (mainly Poa annua and Holcus lanatus) germinated in pots containing no simazine and in pots containing the 0.25 kg/ha level. A few seedlings also germinated in pots containing the 0.5 kg/ha level but not in those containing higher amounts.

Table 3

Effect of simazine on 4 woody ornamentals

Dose kg/ha incorporated 8 cm deep	Mean fresh weight (g) of shoot			
	Berberis darwinii	Myrtus luma	Cupressus macrocarpa	Betula jacquemontii
0	0.17	1.09	2.99	0.76
0.25	0.16	1.28	2.41	0.78
0.5	0.19	1.25	2.88	0.89
1.0	0.23	1.09	3.13	0.43
2.0	0.18	1.06	3.10	0.25
4.0	0.09	0.65	2.54	0.00
F-test	x	x	NS	xxx
SE of mean	0.023	0.12	0.49	0.071
df	15	15	5	15

Table 4

Effect of simazine on Erica arborea and Eucalyptus pulverulenta

Dose kg/ha incorporated 8 cm deep	Mean fresh weight (g) of shoot	
	Erica arborea	Eucalyptus pulverulenta
0	0.13	0.08
1	0.10	0.03
2	0.08	0.00
4	0.01	0.00
F-test using non-zero means	xx	x
SE of non-zero means	0.017	0.0095
df	9	3

DISCUSSION

Some of the genera tested e.g. Cotoneaster and Berberis are able to establish themselves readily from seed under a wide range of conditions in Britain and Ireland. Self-sown seedlings of Betula and Eucalyptus species are also found occasionally in ground that has not been treated with simazine but Erica arborea is seldom found propagating itself in this way.

Soil used in the greenhouse testswas supplemented with peat to improve growing conditions for the young seedlings. Because of adsorption by organic matter, simazine would be less likely to damage these seedlings than those growing in a substrate containing less organic matter. Nevertheless the absence of weed seedlings in pots containing levels of simazine of 1 kg/ha and higher, along with the data presented in Tables 2 and 3, confirm that the species that had established themselves naturally in ground treated regularly with simazine had a high level of tolerance of this herbicide and could survive in soil in which herbicidal doses had been incorporated throughout the rooting depth. Eucalyptus pulverulenta and Betula jacquemontii, the two species tested that did not establish themselves naturally, but were known to produce viable seed, were shown to be susceptible to the herbicide. The high level of tolerance of Cotoneaster frigidus and C. wardii to simazine is shown by the significant increase in fresh weight due to the stimulating effect of simazine levels as high as 2 kg/ha (Table 2).

This experiment was carried out with small seedlings which are much more susceptible to simazine than established plants. None of the trees of Eucalyptus pulverulenta and Betula jacquemontii in the amenity area showed any symptoms of damage although the results of greenhouse experiments suggest that these species have little inherent tolerance. In the soil type tested, established plants of such species as C. frigidus, C. simonsii and C. wardii, Cupressus macrocarpa and Myrtus luma should be able to tolerate higher doses of simazine than the highest level of 4 kg/ha used in this experiment. This level is greatly in excess of the amount needed to control most annual weeds. It seems likely that some of these species could be used more widely by organisations responsible for landscape planning and maintenance wherever accurate application of herbicides cannot be guaranteed.

Although not tested in these experiments, other ornamental species that established themselves in the herbicide-treated amenity area are Olearia macrodonta, Libertia ixioides and Cyclamen neapolitanum. Although species of roses grew in the treated area, very few rose seedlings established themselves. This suggests that the rose relies largely on depth protection for survival.

The large number of seedlings of woody ornamentals that appear in simazine-treated amenity plantings is both an advantage and a disadvantage. On the one hand these seedlings have to be eliminated either manually or by chemical means. On the other hand they can provide an inexpensive supply of young plants of such species as Erica arborea which are sometimes in short supply.

More and more areas are being treated with simazine and other herbicides on a regular basis. In these areas it is likely that other species, in addition to those listed here, will establish themselves naturally according to the range of parent plants present. If greater publicity can be given to those plants that show tolerance of simazine and other herbicides in this way, a large amount of information on plants that have a high level of inherent tolerance could be built up without the need for expensive greenhouse or laboratory experiments. This information could greatly assist the planning and planting of amenity areas and plant nurseries.

While Berberis darwinii and Myrtus luma show considerable tolerance of simazine, growth of both plants was significantly reduced by the highest dose of simazine (Table 3) although neither species showed any symptoms of simazine damage to the foliage. This suggests that although simazine has been successfully used by many fruit growers and nurserymen during the last 15 years to reduce costs and increase yields, cases of plant stunting may occur occasionally without any evidence of leaf injury.

Acknowledgements

We wish to thank Mr. John Sherrington for the statistical analysis.

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WEED CONTROL IN NARCISSUS WITH HERBICIDES APPLIED POST-FLOWERING

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Summary Evaluation for crop tolerance and weed control efficiency in narcissus showed that bentazone could be applied safely after flowering to control spring-germinating weeds. Metoxuron damaged the crop in one of three experiments, but merits further examination. Cyanazine, metribuzin and especially methazole were too phytotoxic at this growth stage of the crop. No herbicide controlled all the major weed species present, and resistant weeds, especially *Polygonum aviculare* and *Fumaria officinalis* spread to fill the gaps left by those eradicated. However the range of species which were effectively controlled by bentazone, metoxuron and the standard pyrazone/chlorbufam indicated that they had a useful place in combination with each other and with suitable residual herbicides in programmes of weed control for this crop. In one experiment, untreated weeds reduced bulb yield by 34% compared with weed-free control plots. Weeds also affected the performance of bulbs lifted and forced in the glasshouse.

INTRODUCTION

Investigations into crop/weed competition in narcissus (Lawson & Wiseman, 1976) have demonstrated the importance of preventing competition from spring-germinating weeds during late spring and early summer. Weed growth can also obstruct bulb harvesting operations. Herbicides suitable for application after flowering could play a useful role in removing potentially troublesome weeds. At present, however, only pyrazone/chlorbufam is officially approved for this purpose (MAFF, 1976a). Several weed species of importance in the bulb crop in Eastern Scotland are resistant to this herbicide (Lawson & Wiseman, 1972). Experiments were therefore carried out to examine the safety and efficacy of a number of new materials with known contact and residual activity on annual weeds.

METHODS AND MATERIALS

The experiments were situated at Invergowrie on sandy clay loam soils. Organic matter contents were between 6% and 9% by loss on ignition. Crops were grown in ridged rows 70 cm apart, in plots 2.4 m long by 2.1 m wide, each plot consisting of two rows for recording purposes with shared guard rows. Evenly graded bulbs of narcissus Carlton were planted by hand in single rows, which were then re-ridged. No further soil cultivation occurred and no residual herbicide was applied during the winter. Autumn-germinating weeds were controlled by application of paraquat at 1.1 kg a.i./ha before crop emergence. Herbicide treatments were applied at the end of the flowering period, after removal of the flower heads. Application was made overall, by Oxford Precision Sprayer, using a water volume of 730 l/ha. Dosages were based on those recommended for use in other arable crops, with double rates included to give an estimation of margin of safety. Details of individual herbicide treatments are given in the tables.

Main plots were split, prior to herbicide application, half of each plot being kept weed-free (by hand) while weeds were allowed to develop on the other half and remain until crop harvest. In all three experiments, treatments were arranged in a split-plot randomised block design, Experiments I and II having four and Experiment III having three replications of each treatment.

Regular visual assessments of percentage ground covered by weeds and of percentage crop foliage shaded by weeds were made on weedy plots throughout the growing season. Weeds were harvested prior to bulb lifting, separated into component species and weighed. Weed records are presented in the tables using the following contractions: Polygonum aviculare (Pav); Matricaria spp. (M spp.); Galeopsis tetrahit (Gt); Fumaria officinalis (Fo).

The bulbs were lifted from the two centre rows of each plot at the end of the first growing season, cleaned and graded in increments of 2 cm circumference. Bulbs were selected from each of the weed-free treatments and from the untreated unweeded control plots and forced in the glasshouse during the following winter. Records were taken of flower numbers and size, stem length and mean flowering date. Flowers were picked and recorded as soon as they were fully open.

Management details	Expt I	Expt II	Expt III
Crop planted	22 Sep. 1971	9 Oct. 1972	4 Oct. 1973
Bulb size (cm)	8-10	10-12	10-11
Mean wt (g.)	28	47	38
No./plot	100	50	80
Tonnes/ha	7.7	6.5	8.4
Herbicides applied	13 Apr. 1972	20 Apr. 1973	26 Apr. 1974
Crop harvested	20 July 1972	25 July 1973	22 Aug. 1974

RESULTS

Expt I (1971-73) Emergence of the main species P. aviculare had already commenced when herbicide treatments were applied. Matricaria spp. and G. tetrahit emerged after treatment application. Ground cover by weeds on untreated plots reached 28% by 1 June and a maximum of 85% by mid July. Shading of crop foliage by weeds was not a major problem, reaching only 20% by mid July on untreated plots. All three herbicide treatments (Table 1) delayed the development of dense weed cover until July and virtually prevented shading of crop foliage, but none was able to keep the crop free from major obstruction by weeds at harvest. Pyrazone/chlorbufam reduced numbers of P. aviculare considerably but failed to control the other two major species. Metoxuron largely prevented emergence of Matricaria spp. and eliminated G. tetrahit, but had little effect on P. aviculare, even at the double rate. Resistant weeds on all treated plots expanded to fill the space available, particularly during July.

The presence of weeds advanced foliage senescence, but had no significant effect on bulb records taken at harvest on untreated or herbicide-treated plots (Table 1). On plots treated with metoxuron marked yellowing of leaf tips was noted in June, particularly at the double rate. Although this did not lead to earlier senescence or a reduction in foliage weights compared with weed-free control plots, adverse effects were recorded on mean weight per bulb which in turn reduced bulb yield per hectare. Bulb numbers were unaffected by weeds or by herbicide treatment.

Forcing records were taken on boxes of thirty bulbs of 12-14 cm circumference and of approximately equal total weight. Herbicide treatment had no effect on any

Table 1

Expt I - Crop and weed records at bulb harvest - July 1972

Herbicide	Kg a.i./ha		Fresh wt bulbs (t/ha)	No. bulbs /plot	Mean wt(g) /bulb	Fresh wt weeds (t/ha)	% by weight Pav	M spp.	Gt
Untreated		a)	16.1	102	57	-	-	-	-
		b)	15.2	103	53	20.9	54	32	11
Pyrazone /chlorbufam	1.1 0.9	a)	16.8	106	57	-	-	-	-
		b)	16.1	103	56	13.9*	34	39	8
Metoxuron	2.7	a)	14.5	105	50*	-	-	-	-
		b)	14.1*	103	50*	15.1*	91**	6*	0**
Metoxuron	5.4	a)	14.0*	106	47**	-	-	-	-
		b)	13.7*	103	48**	9.7***	90**	5**	0**
S.E. mean ±		1)	0.43	1.2	1.6	-	-	-	-
S.E. mean ±		2)	0.60	1.4	2.0	1.85	7.6	6.5	2.6

a) = Weed-free 1) for comparison of 1) & b) within herbicide treatments
b) = Weedy 2) for other comparisons

Table 2

Expt I - Crop forcing records - February 1973

Herbicide	Kg a.i./ha		No. of flowers produced /box	/kg bulbs	Flowering mean date (days after 9 Feb.)	Mean stem length (cm)	Mean flower diam. (cm)
Untreated		a)	39.5	23.7	11.9	24.4	9.75
Pyrazone /chlorbufam	1.1 0.9	a)	39.0	24.4	12.0	26.7	9.84
Metoxuron	2.7	a)	39.0	24.6	11.4	28.0	9.68
Metoxuron	5.4	a)	40.3	25.6	12.0	26.5	9.56
Untreated		b)	31.3**	19.5**	11.1	28.5	10.18*
S.E. mean ±			1.93	1.01	0.82	1.81	0.148

*,**,*** Significantly different from Untreated a) - Crop, b) - Weeds at 5, 1 or 0.1% level

aspect of flower production, but the presence of untreated weeds in the field led to a significant reduction in flower numbers and an increase in flower size compared with the weed-free control (Table 2).

Expt II (1972-74) Emergence of P. aviculare and F. officinalis had already commenced when treatments were applied, the former again being the predominant species. Matricaria spp. and G. tetrahit emerged after herbicide treatments had been applied. Ground cover by weeds on untreated plots rose very sharply from late May onwards and reached 85% by the end of June. Shading of crop foliage by weeds was first recorded on these plots in early June and rose to 80% by mid July. No useful delay or reduction in the development of dense cover by weeds was achieved by metoxuron or by either rate of bentazone (Table 3). Pyrazone/chlorbufam was effective initially, but weeds spread rapidly on these plots from late June onwards, causing severe shading during July. Both rates of metribuzin maintained a high level of overall weed suppression during June, but surviving plants of P. aviculare spread during July.

Weights of weeds at harvest again demonstrated results of the failure of herbicide treatments to control all major species. The weed flora on plots treated with metribuzin or bentazone was almost completely composed of P. aviculare. Pyrazone/chlorbufam had considerably reduced numbers of this species, but their place had been taken by F. officinalis and a late germination of Chenopodium album. Metoxuron also failed to control F. officinalis and was only partially effective on P. aviculare. The virtual absence of F. officinalis on untreated control plots and the lower total weight of weeds compared with several herbicide treatments reflected earlier senescence and therefore lower fresh weights of the untreated flora. Plots where weed development occurred late in the season gave relatively higher yields of weeds at harvest.

Both metoxuron and metribuzin significantly advanced senescence of crop foliage. Yellowing of leaf tips was first noted in early June and became more marked during July, especially on plots treated with the double rate of metribuzin. On weed-free plots this did not result in any decrease in fresh weight of foliage compared with control plots, nor did any weed-free herbicide treatments significantly reduce total bulb yield (Table 3). However, treatment with metribuzin at both rates reduced bulb numbers by 20%. Bentazone had no adverse effect on any aspect of crop growth.

Table 3

Expt II - Crop and weed records at bulb harvest - July 1973

Herbicide	Kg a.i./ha		Fresh wt bulbs (t/ha)	No. bulbs /plot	Mean wt(g) /bulb	Fresh wt weeds (t/ha)	% by weight Pav	Fo	M spp.
Untreated		a)	13.4	63	66	-	-	-	-
		b)	8.9+++	42+++	64	18.5	79	1	4
Pyrazone	1.1	a)	12.6	58	66	-	-	-	-
/chlorbufam	0.9	b)	10.8*	48++**	69	26.2*	47**	15*	5
Metoxuron	2.7	a)	12.2	56	66	-	-	-	-
		b)	8.0+++***	39+++***	64	19.0	78	19**	0
Metribuzin	1.0	a)	11.6	50*	71	-	-	-	-
		b)	11.0*	48**	70	16.4	95	0	0
Metribuzin	2.0	a)	11.6	51*	68	-	-	-	-
		b)	10.9*	49*	67	6.1***	99	0	0
Bentazone	1.7	a)	12.4	53	72	-	-	-	-
		b)	9.7+**	48**	62	22.6	91	0	0
Bentazone	3.4	a)	13.4	57	72	-	-	-	-
		b)	9.9++**	46++**	65	27.0*	93	2	0
S.E. mean ±		1)	0.68	2.3	2.7	-	-	-	-
S.E. mean ±		2)	0.74	3.6	3.0	2.23	6.7	4.5	2.8

a) = Weed-free 1) for comparison of a) & b) within herbicide treatments
b) = Weedy 2) for other comparisons
*,**,*** Significantly different from Untreated a) - Crop, b) - Weeds at 5, 1, or 0.1% level. +,++,+++ Significant effect of weed presence at 5, 1, or 0.1% level

Table 4

Expt II - Crop forcing records - February 1974

Herbicide	Kg a.i./ha		No. of flowers produced /box	/kg bulbs	Flowering mean date (days after 8 Feb.)	Mean stem length (cm)	Mean flower diam. (cm)
Untreated		a)	44.8	27.9	7.3	31.1	8.94
Pyrazone /chlorbufam	1.1 0.9	a)	46.3	28.3	7.5	30.6	8.96
Metoxuron	2.7	a)	46.3	29.3	7.1	32.6	8.97
Metribuzin	1.0	a)	45.0	28.7	7.5	32.2	8.99
Metribuzin	2.0	a)	45.0	28.9	7.3	31.8	8.96
Bentazone	1.7	a)	46.5	30.0	7.5	29.8	8.86
Bentazone	3.4	a)	43.8	27.8	6.8	29.9	9.16
Untreated		b)	39.3	24.6	4.8***	33.8*	9.62***
S.E. mean ±			2.69	1.48	0.44	0.84	0.084

*,**,*** Significantly different from Untreated a) - Crop, b) - Weeds at 5, 1, or 0.1% level

Weeds also accelerated foliage senescence. Their presence on untreated plots reduced bulb yield by 34% and yields were also significantly reduced by resistant weeds on plots treated with metoxuron and both rates of bentazone. In every case, the presence of resistant weeds significantly reduced yield on herbicide-treated plots below that of the untreated weed-free control. Mean bulb weight after grading was not significantly affected by any treatment in this experiment.

Twenty-five bulbs per plot (5 from each of 5 size grades between 8 and 18 cm circumference) were boxed for forcing. Numbers in individual size grades were too small for more uniform selection, but bulbs were chosen to give approximately the same total weight and as near as possible the same number of noses per box. There were no indications that herbicide treatment had any adverse effect on forcing characteristics when compared with the weed-free control (Table 4). However, the presence of untreated weeds in the field resulted in forced bulbs having an earlier mean flowering date, longer stems and larger flowers than bulbs from weed-free control plots. The reduction in flower numbers was not quite significant at the 5% level.

Expt III (1973-75) Only a very few weed seedlings had emerged by the date of spray application. Herbicide efficacy was therefore largely dependent on residual activity. Weed cover on untreated plots was slow to develop during May, but expanded very rapidly in June to 85% by early July. Shading was first recorded on these plots at the beginning of June, reaching 60% by mid July. All herbicide treatments (Table 5) delayed the spread of weed cover during June, but only metribuzin (at both rates) and the double rate of cyanazine prevented the development of dense cover by weeds during July. These were also the only treatments which effectively prevented shading of crop foliage by weeds. Differences in weights of weeds present at harvest illustrate the relative efficacy of metribuzin and the species selectivity of the treatments. Untreated plots were dominated by *Matricaria* spp., followed by *P. aviculare* and *F. officinalis*. All herbicide treatments gave some control of *Matricaria* spp., the most effective being metoxuron, bentazone and cyanazine. Reduction in numbers of this species was offset on most plots by increased growth of *P. aviculare*, and to a lesser extent of *F. officinalis*. Methazole gave excellent control of *P. aviculare* while metribuzin was the most effective on *F. officinalis*. Other than on untreated plots and those treated with pyrazone/chlorbufam or methazole, *P. aviculare* was the

Table 5

Expt III - Crop and weed records at bulb harvest - August 1974

Herbicide	Kg a.i./ha		Fresh wt bulbs (t/ha)	No. bulbs /plot	Mean wt(g) /bulb	Fresh wt weeds (t/ha)	% by weight Pav	M spp.	Fo
Untreated		a)	18.8	125	49	-	-	-	-
		b)	15.6+++	117	43++	28.3	27	59	11
Pyrazone	1.1	a)	19.0	120	52	-	-	-	-
/chlorbufam	0.9	b)	17.1+	121	46++	22.3	21	53	23
Metoxuron	2.7	a)	17.7	124	46	-	-	-	-
		b)	17.0*	117	48	18.8**	61*	1***	32*
Metoxuron	5.4	a)	17.7	124	46	-	-	-	-
		b)	16.9*	122	45	19.2**	72**	8**	8
Metribuzin	1.0	a)	17.2	126	44*	-	-	-	-
		b)	18.0	124	47	10.8***	73**	9**	10
Metribuzin	2.0	a)	15.4***	119	42**	-	-	-	-
		b)	15.5***	119	42**	8.4***	55	30*	4
Bentazone	1.7	a)	18.2	120	50	-	-	-	-
		b)	16.9*	123	45	23.5	75**	10**	11
Bentazone	3.4	a)	18.0	122	48	-	-	-	-
		b)	16.3+**	118	45	27.3	75**	0***	25
Cyanazine	1.7	a)	16.6*	127	43*	-	-	-	-
		b)	16.9*	126	44*	21.6*	74**	6***	16
Cyanazine	3.4	a)	16.2**	123	43*	-	-	-	-
		b)	15.8**	122	42**	15.1***	76**	4***	18
Methazole	2.1	a)	14.6***	125	38***	-	-	-	-
		b)	13.9***	115	39***	18.4**	9	34	55***
Methazole	4.2	a)	13.0***	122	35***	-	-	-	-
		b)	12.2***	116	34***	15.5***	2	35	33*
S.E. mean ±		1)	0.54	3.7	1.3	-	-	-	-
S.E. mean ±		2)	0.58	3.8	1.6	2.21	9.7	9.2	6.3

a) = Weed-free 1) for comparisons of a) & b) within herbicide treatments
b) = Weedy 2) for other comparisons
*,**,*** Significantly different from Untreated a) - Crop, b) - Weeds at 5, 1, or 0.1% level
+,++,+++ Significant effect of weed presence at 5, 1, or 0.1% level

major component of the weed flora at harvest. Doubling the dosage made no major difference to the performance of individual herbicides.

No visible effect of herbicide treatment on the crop occurred until early June, when foliage on plots treated with metoxuron, metribuzin, cyanazine and particularly methazole began to show yellowing, mainly at leaf tips. Symptoms on plots treated with both rates of methazole and the double rate of metribuzin became very severe, causing early senescence. These treatments and both rates of cyanazine significantly reduced bulb yield and mean bulb weight on plots kept weed-free, compared with weed-free control plots (Table 5). Neither metoxuron nor bentazone

Table 6

Expt III - Crop forcing records - February 1975

Herbicide	Kg a.i./ha		No. of flowers produced /box	/kg bulbs	Flowering mean date (days after 12 Feb.)	Mean stem length (cm)	Mean flower diam. (cm)
Untreated		a)	28.7	19.0	4.4	30.6	9.97
Pyrazone /chlorbufam	1.1 0.9	a)	30.7	20.3	4.8	31.4	9.80
Metoxuron	2.7	a)	29.7	19.7	4.6	32.2	9.62
Metoxuron	5.4	a)	28.7	19.1	3.9	30.6	9.76
Metribuzin	1.0	a)	28.3	18.6	4.2	30.7	9.84
Metribuzin	2.0	a)	30.0	20.0	4.3	31.6	9.61
Bentazone	1.7	a)	30.0	19.9	4.7	29.4	10.08
Bentazone	3.4	a)	29.7	19.6	4.4	29.0	9.70
Cyanazine	1.7	a)	32.0	21.2	4.9	31.8	9.61
Cyanazine	3.4	a)	31.3	20.8	3.9	31.7	9.52*
Methazole	2.1	a)	32.0	21.4	3.7	32.8	9.41**
Methazole	4.2	a)	38.7***	25.9***	4.1	34.0*	9.53*
Untreated		b)	34.7*	23.0*	3.8	32.9	9.74
S.E. mean ±			1.63	1.09	0.43	1.04	0.130

a) = Weed-free b) = Weedy

*,**,*** Significantly different from Untreated a) at 5, 1, or 0.1% level

adversely affected bulb growth. Differences between treatments in numbers of bulbs graded per plot were not significant. Weeds accelerated crop senescence, and competition from them significantly reduced bulb yield at harvest on unweeded control plots and on those treated with pyrazone/chlorbufam and the double rate of bentazone.

Fifteen bulbs from each of two size grades (10-12 and 12-14 cm circumference) were boxed and forced. Herbicide treatments had no adverse effects on forcing characteristics, except that methazole at both rates and cyanazine at the double rate significantly reduced mean flower diameter in comparison with the weed-free control (Table 6). Mean stem length and flower numbers were however significantly greater on plots treated with methazole at the double rate than on weed-free control plots. The presence of weeds on untreated plots in the field also resulted in increased flower numbers from bulbs of equivalent size and weight in the glasshouse.

DISCUSSION

Crop tolerance Visible yellowing of crop foliage by treatment with metribuzin, methazole and cyanazine indicated adverse effects on bulb size or number. In England (M.A.F.F., 1974, 1976b) investigations have suggested that methazole may be too phytotoxic for use at any stage post-emergence of narcissus and that the safety margin of metribuzin may be small, even for pre-emergence use. Experiments in England and Scotland with cyanazine applied before and shortly after crop emergence at rates up to 4.48 kg a.i./ha have not shown phytotoxicity to narcissus (Jones & Haddow, 1974), but the adverse effects with the lower dose range used at Invergowrie suggest that post-flowering treatment may not be feasible. The phytotoxicity of metoxuron is more difficult to assess. Leaf tip symptoms occurred in all three experiments and although bulb yields were below those of the weed-free control in each case, the reduction was significant only in Expt I and there was no indication of adverse effects on forcing quality. Earlier application has been found to be safe (MAFF, 1974) and this herbicide merits further examination, possibly at lower rates. Pyrazone/chlorbufam and bentazone were the only herbicides to show no phytotoxicity in the field or the glasshouse. Trials in England (MAFF, 1976b) have confirmed the safety of bentazone at most stages of growth of the narcissus crop.

Weed control None of the herbicide treatments was able to deal adequately with the range of spring-germinating species encountered. Application was timed to suit the stage of growth of the crop rather than that of the weeds, and was made overall, so that weeds in the crop row were to some extent sheltered by crop foliage. Both factors may have reduced the efficacy of weed control. Nevertheless the major problem was not so much the failure of herbicides to control normally susceptible species, but rather the ability of resistant weeds to expand to fill all available space in a relatively non-competitive crop. In many cases, herbicide treatment simply changed the balance of the weed flora present at harvest, without substantially reducing its bulk. Similar situations were reported by Lawson & Wiseman (1972) where pyrazone/chlorbufam applied to a mixed weed flora produced virtually pure stands of F. officinalis or G. tetrahit. Weed control in these circumstances must be virtually 100%, if it is to be effective, and is likely to be achieved only by means of herbicides with complementary weed control spectra. Both bentazone and metoxuron controlled Matricaria spp. very well; the former also controlled emerged F. officinalis and the latter, G. tetrahit, three species resistant to pyrazone/chlorbufam, which, however, was more effective than either of the others on P. aviculare. Post-flowering applications of all three herbicides, despite individual shortcomings, obviously have a useful place in programmes of weed control for the narcissus crop, in association with appropriate pre-emergence residual herbicides and with each other. The possibility of reducing rates of application in these circumstances merits investigation.

Effects of weeds Early shading of crop foliage by weeds and below average rainfall in spring and early summer were thought to have been largely responsible for the 34% reduction in bulb yield on untreated plots in Expt II. The extent of bulb reduction in the other two experiments was more typical of experience at Invergowrie. Bulbs from weedy plots in Expts I & II produced fewer flowers but with longer stems and of larger diameter than bulbs from weed-free plots. However the opposite situation occurred in Expt III with bulbs from weedy plots and from plots showing herbicide injury in the field. Lawson & Wiseman (1976) similarly found that flower numbers per plot from bulbs left in the field for a second year were on occasion as numerous on originally weedy as on weed-free plots, despite reductions in bulb yield. This was due to weedy bulbs producing a higher percentage of flowering shoots than those from weed-free plots. Differences in forcing performance in the glasshouse were presumably also related to numbers of flowering noses present in bulbs of equivalent size and weight.

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DIKEGULAC: A NOVEL GROWTH RETARDANT AND BRANCHING AGENT FOR HEDGES

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Summary Dikegulac is a new growth regulator with extremely low bee, fish, bird and mammalian toxicity. It has been found to be particularly effective as a growth retardant and pinching agent on woody plants. Hedges pruned in the autumn and treated the following spring did not require pruning during the entire growing season. Furthermore the labour of autumn trimming and collection of the cut shoots is much reduced as the shoots are short and soft. Dikegulac is effective on many species in several countries. The optimum concentration varies with species and environmental conditions. Dikegulac was also shown to increase branching in hedges thus leading to a thicker, better quality hedge. Dikegulac can inhibit fruiting where this is desirable. Three annual applications to the same privet hedge have not produced any signs of phytotoxicity or accumulation of the compound.

Résumé Le dikegulac est un nouveau régulateur de croissance dont la toxicité pour les abeilles, les poissons, les oiseaux et les mammifères est extrêmement faible. On a trouvé que ce produit est particulièrement efficace pour ralentir la croissance et pour pincer des plantes ligneuses. Des haies taillées en automne et traitées au printemps suivant ne doivent plus être taillées pendant toute la saison. En outre, la taille d'automne est moins laborieuse, car les nouvelles pousses sont courtes et tendres et il ne reste que peu de déchets à ramasser. Le dikegulac agit sur beaucoup d'espèces dans différentes régions. La concentration optimale dépend de l'espèce et des conditions de croissance. On a constaté que le dikegulac stimule la ramification des plantes de haies, procurant des haies plus denses et de meilleure qualité. Appliqué juste avant la floraison, le dikegulac empêche si on le désire la formation des fruits. Un triple traitement d'une haie de troêne n'a occasionné aucun symptôme de phytotoxicité ou d'accumulation.

INTRODUCTION

The biological activity of dikegulac, the active ingredient of ATRINAL®, was reported by Bocion et al (1975). Heursel (1975) reported a loss of apical dominance and stimulation of axillary shoot production in azaleas. Sachs et al (1975) demonstrated that dikegulac inhibited shoot elongation for more than 3 months on many shrubs and trees in California. Bocion and Walther (1976) described growth retardatory effects on hedge plants in Switzerland. More detailed physiological studies have been reported by Bocion and de Silva (1976) and Arzee et al (in press).

The aim of the investigations reported here are itemised below.

1. To ascertain if dikegulac is active on a wide range of woody plants growing under differing environmental conditions.

2. To check if extension growth can be sufficiently retarded over the entire growing season.

3. To examine the effects on branching (hedge quality).

4. To control fruiting.

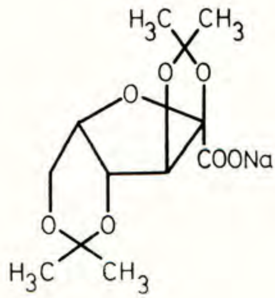
5. To check for phytotoxicity in short and long term experiments.

Chemical Properties

Common name dikegulac

Chemical name sodium 2,3:4,6-di-O-isopropylidene-2-keto-L-gulonate

Structure



Physical Properties

Dikegulac is a white, odourless solid with a m.p. > 300°C. It is not light sensitive and is stable in aqueous solutions at pH7 and above. In the dry state it has a shelf life of several years.

Solubilities (g/l at 20°C):		
	water	590
	methanol	390
	ethanol	230
	chloroform	60
	acetone	< 10
	cyclohexanone	< 10
	hexane	< 10

Formulation Dikegulac is formulated as an aqueous concentrate containing 200 g a.i./l. The wetting agent is supplied separately as the concentration of dikegulac used, unlike that of the wetting agent, varies with species.

Toxicity

Acute LD_{50}, p.o. rat, male	: 31'000 mg ai/kg
Acute LD_{50}, p.o. rat, female	: 18'000 mg ai/kg
Acute LD_{50}, p.o. mouse, male + female	: 19'500 mg ai/kg
LD_{50} p.o. mouse, 5-day repeated dose	: > 8'000 mg ai/kg
90-day feeding, rat, up to 2'000 mg/kg daily	: without significant negative effects.
90-day feeding, dog, up to 3'000 mg/kg daily	: without significant negative effects.
Inhalation toxicity, rat	: > 0.4 mg/l air
LD_{50}, bees, topical application	: > 0.1 g
LD_{50}, birds, 5-day repeated dose Japanes quail Mallard duck Chicken	: > 50'000 ppm in the food

Egg hatchability: no effect on the hatchability of fertile quail eggs, or on the survival and weight gain of the chicks produced.

CL_{50}, fish, 96 hours Bluegill sunfish	: > 10'000 ppm in water
Rainbow trout Harlequin fish Goldfish	: > 5'000 ppm in water

Dikegulac is not an eye or skin irritant.

METHOD AND MATERIALS

The plants, which were at least 4 years old and growing vigorously, were pruned either in the autumn or the following spring and treated in the spring. The species tested, spray volumes and concentrations used are indicated in the tables. Nonoxynol wetter was added to the spray solution to give a concentration of 0.1 %. A knapsack or handsprayer was used. Shoot length measurements and axillary shoot number counts were made on at least 20 shoots per plot.

RESULTS AND DISCUSSION

Dikegulac reduces extension growth on many species of hedge plants. This effect has been demonstrated in Switzerland (Table 1), Japan (Table 2), Spain (Table 3), U.K. (Table 4), Italy (Guerry, personal communication) and USA (Sachs et al, 1975).

The retardant effect produced from a single application in the spring lasted the length of the growing season (Tables 1 + 2). Furthermore the labour requirement for trimming and collection of the cut shoots in the autumn is much reduced as the shoot diameter is less than that of untreated hedges.

Table 1

Mean length of untreated shoots and percent reduction in shoot length on hedge plants grown in Switzerland

Dikegulac	Ligustrum ovalifolium	Thuya fastigiata	Crataegus oxyacantha	Carpinus betulus	Berberis thunbergii
0	64.9 cm	31.4 cm	79.0 cm	77.3 cm	38.2 cm
0.5	63 %				
1.0	75 %	80 %			
2.0		88 %	89 %		58 %
5.0			100 %	69 %	76 %
Length of new shoots at treatment	8-15 cm	8-12 cm	8-10 cm	10-25 cm	3-6 cm
Date of treatment	21.V.75	5.VI.75	13.V.75	6.VI.75	12.V.75
Date of assessment	18.IX.75	18.IX.75	11.IX.75	9.IX.75	18.IX.75

All plants pruned in Nov. 1974, Spray volume 100 ml/m^2

Table 2

Mean length of untreated shoots and percent reduction in shoot length on hedge plants grown in Japan

Dikegulac g/l	Ligustrum japonicum	Evonymus japonicus	Chamaecyparis pisifera
0	439 cm	167 cm	237 cm
2	86 %	84 %	78 %

Date of treatment 10.VI.75

Date of assessment 9.XII.75

Spray volume 100 ml/m^2

Table 3

Growth retardation of Cupressus sempervirens in Spain

Dikegulac g/l	Spray vol ml/m^2	Weight of clippings g/m^2	Length of longest shoot cm
0		6840	99.5
1	200	420	14.6
2	100	480	16.2

Date of treatment 4.VIII.75
Date of assessment 27.V.76

Table 4

Mean length of untreated shoots and percent reduction in shoot length of Ligustrum ovalifolium in U.K.

Dikegulac g/l	Mean shoot length, cm	Percent reduction
0	22.6	
1.4	4.0	82

Date of treatment 11.VI.75

Date of assessment 22.IX.75

Spray volume 150 ml/m^2

In none of the experiments reported here was necrosis or deformation recorded. However slight chlorosis of new shoots was seen 2 - 4 weeks after treatment. This effect was of short duration when recommended concentrations and growth stages are used. For instance with C. betulus treated when new shoots are <5 cm long chlorosis of expanding leaves was seen. However when treatment was delayed until the 2 oldest leaves on each shoot were fully expanded chlorosis was negligible. Conversely with Nerium oleander treatment immediately following pruning overcame this problem (Sachs et al, 1975).

Table 5

Number of axillary shoots per branch

Dikegulac g/l	Ligustrum ovalifolium	Berberis thunbergii	Carpinus betulus
0	0	17 ± 1.1	11 ± 0.7
1	34 ± 1.8		
2		22 ± 1.5	
5			26 ± 1.6

Date of treatment 7.V.76

Date of assessment 16.IX.76

Standard errors are indicated.

Spray volume 100 ml/m^2

Pruned in Nov. 1975

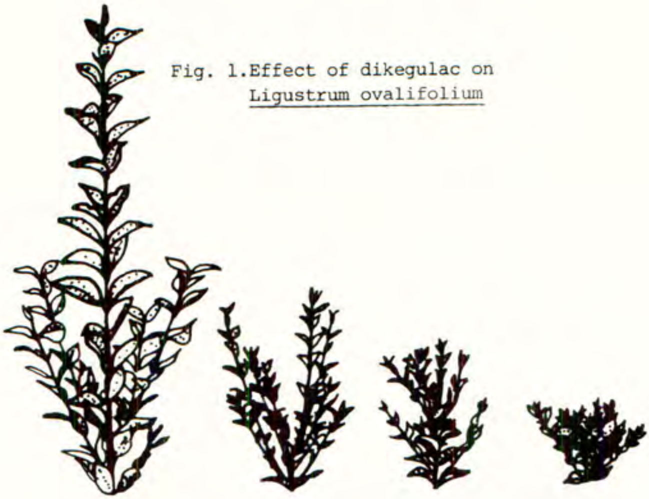


Fig. 1. Effect of dikegulac on <u>Ligustrum ovalifolium</u>

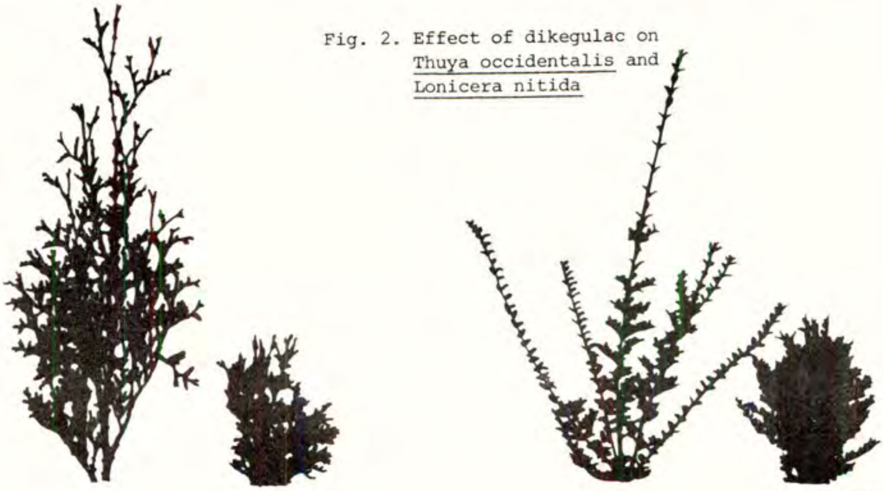


Fig. 2. Effect of dikegulac on <u>Thuya occidentalis</u> and <u>Lonicera nitida</u>

As a result of the early work with dikegulac (Bocion <u>et al</u>, 1975) it was reasonable to expect a stimulation of axillary shoot production. The results presented in Table 5, Fig. 1 + 2 show that a considerable stimulation of axillary shoot production was achieved with the species investigated. This results in a thicker, better quality hedge.

Table 6

Fruit production of Ilex crenata

Dikegulac g/l	Flower buds/ branch	Fruits/branch
0	86	78
2	92	0.5
4	96	0

Date of treatment 30.V.75

Date of assessment 31.VI.75

Plants were sprayed to run off.

Another effect often desired in amenity areas is an inhibition of flowering and fruiting. Some flowers produce pollens which evoke an allergic reaction in a section of the population. Many fruits cause a fouling problem when they abscise and others may be poisonous. The results presented in Table 6 show that dikegulac prevented fruiting in Ilex crenata treated before flowering. Similar effects have also been achieved on I. crenata and other species sprayed at mid and post-flowering stages.

Table 7

Effect of repeated applications on Ligustrum ovalifolium

Dikegulac concentration (g/l) used in 1974	1975	1976	Length of shoots produced in 1976, cm
0	0	0	49.2
0.5	0.5	0.8[1]	5.2
2.0	1.5	0.8[2]	7.0

	1974	1975	1976	
Date of treatment	19.IV.74	13.V.75	14.V.76	
Date of assessment				17.IX.76

(1) Spray volume 150 ml/m^2

(2) Spray volume 200 ml/m^2

Spray volume 100 ml/m^2 in 1974 + 1975

Pruned in Oct. or Nov. of year previous to treatment.

The effect of repeated annual applications is under investigation. The interim results (Table 7) show that there is no carry over effect of the high concentrations used in 1974 and 1975. Shoot length in 1976 was solely the result of applications made this year. The concentration and spray volume were changed in 1976 to conform with the label recommendations.

Acknowledgements

We would like to record our gratitude to Messrs. A. Albors, P. Bocion, K. Oliver and H. Yoshioka for providing us with their unpublished data.

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