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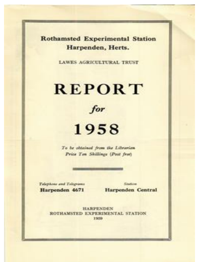
Full Table of Content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The Use of Insecticidal Seed Dressings

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THE USE OF INSECTICIDAL SEED DRESSINGS

By

M. J. Way

Jameson, Thomas and Woodward (1947) showed that the chlorinated hydrocarbon insecticide γ-BHC applied as a seed dressing at about 0·02 mg./seed could protect the young cereal plant from wireworm attack. This was a most important step in insect pest control of agricultural crops, for it has led to widespread use of insecticide seed dressings against many insect pests, mainly soil insects, including, in Britain, wireworms (*Agriotes* spp.), flea beetles (*Phyllotreta* spp.), wheat-bulb fly (*Leptohylemyia coarctata* Fall.), and onion fly (*Delia antiqua* Meig.). The minute amounts of insecticide used, sometimes as little as 1 oz./acre, avoid undesirable effects such as destroying beneficial soil insects and the accumulation of residues liable to harm the plant or affect its flavour and food value. Cost is small, especially as no extra machinery or labour is needed to apply the insecticide in the field.

At about the time that the chlorinated hydrocarbon insecticides, γ-BHC, dieldrin, aldrin and heptachlor were being developed as seed dressings against soil insects, some organic phosphorus compounds taken up by roots and seed were shown to move throughout the plant and to kill insects feeding on aerial parts of the plant by their " systemic " action. (Schrader, 1951; Ivy, Iglinsky and Rainwater, 1950; Ripper, Greenslade and Hartley, 1950; Jancke, 1951; David and Gardiner, 1951, 1955.) Some systemic phosphorus insecticides, notably demeton and demeton-methyl, have since proved especially valuable as aerial sprays against aphids (Way, Smith and Potter, 1954; Way, Bardner, Aitkenhead and Van Baer, 1958; Broadbent, Burt and Heathcote, 1956; Hull, 1958), but until recently their use as seed dressings has not been examined in detail with field crops. The systemic phosphorus insecticides yet tested have not been very effective against soil insects (Bardner, 1958; Walker, 1958); conversely, except for γ-BHC (Starnes, 1950; Shapiro, 1951; Ehrenhardt, 1954; Bradbury and Whitaker, 1956; Jameson, 1958), the chlorinated hydrocarbons have had little systemic activity against insects attacking aerial parts of the plant. Thus, they may be conveniently considered separately. All work on insecticide seed dressings cannot be covered in this review and as seed dressing with chlorinated hydrocarbons is now well established in practice, it is appropriate to discuss mainly their limitations which have led to the recent work at Rothamsted on mode of action and on methods of application. Phosphorus insecticide seed dressings have been used only experimentally except with cotton; results will therefore be given mainly to show where they are likely to prove useful.

Chlorinated Hydrocarbon Insecticides

Wireworm control

Since it was first demonstrated that γ-BHC seed dressing could protect young cereals from wireworm attack, much work has been done on wireworm control by γ-BHC, aldrin, dieldrin and heptachlor seed dressings especially in North America. Some of this is reviewed by Lilly (1956), Potter, Healy and Raw (1956) and Raw and Potter (1958). Seed dressings have usually protected various seedling crops in the year of application, but there is conflicting evidence about their ability to lower the wireworm population. Potter, Healy and Raw (1956) and Raw and Potter (1958) have made a special study of this problem. In one experiment a seed dressing of 1·2 oz. γ-BHC/acre on wheat sown in November 1947 was compared with soil treatments where the insecticide was combine drilled at 6 oz. γ-BHC and broadcast at 1 lb. γ-BHC/acre. Grain yields in 1948 were respectively 24·0, 24·8 and 30·6 cwt./acre compared with 8·9 in untreated plots. The plots were redrilled with wheat in the autumn of 1948 without further insecticide treatment, and in 1949 yielded 24·2, 37·3 and 39·6 cwt./acre, the yield of the untreated being 28·4. The seed dressing therefore gave a good response in yield, but less than the soil treatments, and unlike these it had no effect on the subsequent crop. The second-year wireworm populations (numbers per plot, square root transformation) were: untreated, 3·30; seed dressing, 3·73; combine-drill, 2·20; broadcast, 1·33, showing that the seed dressing did not kill the wireworms. Presumably it deters them from feeding during early stages of growth when the young plant is especially susceptible, and this would decrease losses of crop when the infestation is small. With large infestations, however, attack at a later stage of growth when the deterrent effect has worn off and when the plant would normally be able to withstand moderate damage, could be harmful, and this may explain why a γ-BHC seed dressing has sometimes failed to protect a crop against large wireworm populations (Dogger and Lilly, 1949; Kulash, 1953). There are, however, further difficulties in our understanding of how seed dressings act against wireworms, for a seed dressing sometimes kills wireworms—for example, in experiments by Lange, Carlson and Leach (1949), 70–95 per cent of wireworms in the immediate area of the treated seed were killed, and the total population was reduced by about 50 per cent. These, and similar results of Starks and Lilly (1955), were obtained in experiments with late-sown crops, when the wireworms were immediately attracted to the ungerminated or newly germinated seed, in contrast to the conditions studied by Potter, Healy and Raw, in which the crop was sown about 4 months before the wireworms became active; by then the growing seedling would have long since exhausted the seed, and the wireworms would attack the shoot. Therefore, wireworms attacking the ungerminated or newly germinated seed may be either deterred (Long and Lilly, 1958) or killed by contact with the insecticide seed dressing, whereas in attacking the older plant they are unlikely to be killed, but may be deterred by systemic action of insecticide translocated to the shoot. This confirms the general conclusion that seed dressings as used at present against wireworms become less effective as the plants age (Kulash and Munroe, 1955); also, that they must be regarded as methods of obtaining temporary protection and note as a means of destroying the wireworm population in the field (Lange, Carlson and Leach, 1949). It seems certain, however, that seed dressings are not yet being used to the best advantage against wireworms; for example, it would be valuable to know more about their mode of action and to study methods of increasing the dose of insecticide on the seed to levels approaching those which have been successfully applied by combine-drill or as a broadcast treatment.

Mode of action of seed dressings against certain Diptera

A wireworm may spend 5 years in the soil before pupating, and populations of overlapping generations can persist many years feeding on the underground parts of many plant species. By contrast, the larvae of soil-inhabiting species of Anthomyidae and Chloropidae (Diptera) normally pupate within 2–8 weeks of hatching; they are mostly specific in their choice of plant hosts, and they usually appear only after the host has been planted. Unlike wireworms, they would soon die if deterred by a seed dressing, not only from lack of alternative wild hosts, but also because they attack the plant as newly hatched larvae which cannot survive without food. It seems their control ought to be simpler than that of wireworms, but in practice the effectiveness of the seed dressings differs greatly with different insect species. A dieldrin seed dressing, for example, can almost completely protect the young onion crop from damage by the larval onion fly, *Delia antiqua* Meig.; it will kill the larva of the closely related wheat-bulb fly, *Leptohylemyia coarctata* Fall., but does not prevent the plant from being damaged; finally, it usually has little or no effect on the larval frit fly, *Oscinella frit* L. Chloropidae.

Way (1950a, 1959b) studied the mode of action of the seed dressings in an attempt to find the circumstances that effect their action against the three species. The simplest and most effective way in which a seed dressing can act is by direct contact with the insect before it attacks the plant. For this to happen, the larva must pass close to the treated seed; therefore, much depends on the position of the eggs and on the behaviour of the newly hatched larva.

Onion-fly eggs are laid on the soil surface close to the plant, but even when the seed was sown 1 inch deep, most of the larvae crawled down to enter the plant at the base of the bulb close to the position of the treated seed. The normal behaviour of newly hatched onion-fly larvae seems to ensure that almost all are killed by contact action before they can damage the plant. This was confirmed by preliminary experiments which showed the onion seedlings, replanted after removal of the dieldrin-treated seed, were no longer protected from onion-fly attack (Way 1959a).

Frit-fly eggs are laid both on the plant and in the soil. Larvae hatching from the former can enter the oat or wheat shoot from within the ensheathing coleoptile and sometimes above soil level. In these circumstances, kill by direct contact with the seed dressing seems unlikely. Larvae hatching from eggs in the soil normally reach and enter the shoot above the seed at, or just below, soil level and thus are unlikely to meet the insecticide unless the seed is shallow

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sown (Way 1959b). Experimental results have confirmed these conclusions: when dieldrin-dressed wheat seed was sown at three depths—just below the soil surface, at ¼ inch and at 1 inch, the percentages of shoots damaged by frit larvae were 17, 29 and 41 respectively for treated, and 40, 47 and 50 for equivalent untreated control plants. The mean numbers of larvae per plant were 0·3, 0·6 and 0·7 for treated seed and 1·0 for all sowing depths of the untreated. Larvae from eggs in the plant probably formed the majority of the survivors of the shallow-sown treatments. Unfortunately, it is not normally practicable to sow oats or wheat less than about 1 inch deep; hence, the lack of protection from dieldrin seed dressings in practice.

The wheat-bulb fly is unusual because its eggs are laid in August and September well before the host plant, winter wheat, is drilled. The eggs are distributed in the soil by cultivations to a depth of 8 inches or more, and eventually hatch in the following February–March. The newly hatched larvae move upwards, and most reach the surface soil, where they search for the young wheat plant. Therefore, irrespective of the position of the eggs, they mostly behave like onion and frit-fly larvae and reach the plant from near the soil surface. The shoot is entered at a depth of about ¼–1 inch, suggesting that, as with frit-fly larvae, contact action is unlikely unless the seed is shallow sown. This was confirmed by experiments with dieldrin seed dressings, where the calculated kill, probably by direct contact, varied from 0 per cent for a 3 inch sowing depth to 45 per cent at ½ inch (Way 1959a). Experiments in which seedlings were replanted and infested after removing the treated seed, confirmed that the latter was needed to protect the plant from attack.

Thus the contact action of the seed dressing may depend on at least three biological factors: the behaviour of the newly hatched larva (onion, frit and wheat-bulb fly), the position of the seed (frit and wheat-bulb fly) and the position of the egg (frit fly).

Apart from direct contact with the treated seed, the larva may be affected outside the plant by fumigant action and by insecticide picked up by tips of roots and shoots as they emerge from the germinating seed. More important, however, is the possibility that chlorinated hydrocarbon insecticides can act systemically. γ-BHC is taken up by the plant, and it has already been suggested that wireworms are deterred by insecticide translocated from the seed to the underground parts of the shoot. Furthermore, Gough and Woods (1954) found that larvae of wheat-bulb fly may die after feeding inside wheat shoots growing from dieldrin-treated seed. Experiments in which larvae died after feeding on pieces of shoot, no part of which could have come into contact with the seed dressing, show that the kill is by systemic action (Way, 1959a). This property has made dieldrin, aldrin and heptachlor seed dressings the recommended control measure for wheat-bulb fly, for although the larva usually destroys the first shoot, it is killed before destroying any more. The action of γ-BHC seed dressing is less clear; γ-BHC appears to be absorbed and lost by the plant more readily than the other chlorinated hydrocarbons. In the very young seedling, therefore, the higher concentration in the plant, and perhaps inherently greater toxicity, ensures that the wheat-bulb fly larva is usually either killed or deterred before it causes serious damage. The insecticide is then quickly lost, perhaps mainly by volatilization (Bradbury and Whitaker, 1956) at a stage when dieldrin, for example, is still present in lethal concentration in the shoot.

It is surprising that, although systemic action is particularly important for wheat-bulb-fly control and probably in protection from wireworm damage, there is little evidence that either frit- or onion-fly larvae are affected in this way by chlorinated hydrocarbon seed dressings. For example, in experiments with frit fly using dieldrin-dressed seed, the number of dead larvae found in treated plants and the proportion of larvae which survived to become pupae were the same as in untreated plants (Way, 1959b). Systemic action may depend on a delicate balance between uptake and loss of insecticide that is influenced especially by temperature; this would increase loss from dilution by plant growth and by volatilization in late May and June, when frit- and onion-fly larvae are hatching, above that in the colder weather of March to early April when wheat-bulb-fly larvae and wireworms are active.

The importance of placement of insecticide around the seed

Way (1959a) showed that, although dieldrin and aldrin need to be placed in contact with either the shoot, roots or seed of the wheat seedling to act systemically against wheat-bulb fly, contact between the insecticide and the seed seemed particularly important. For example, when wheat seeds were planted together in pairs, one dead and one alive, with either the dead or the live seed dressed with dieldrin, contact action killed as many larvae whether the live or dead seed had been treated, whereas systemic action killed a calculated 50 per cent of the larvae when the live seed was treated and only 18 per cent when the dead seed was treated. The value of applying the insecticide to the seed was also convincingly shown by Bardner (1959a), in field trials when aldrin, dieldrin and heptachlor dressings at 3 oz. active ingredient/acre controlled wheat-bulb fly better than aldrin or dieldrin combine drilled at 24 oz./acre. Further, in the control of the aphid, *Myzus persicae* Sulz. on potatoes, Burt (1959) showed that the effect of spot treatments of the systemic phosphorus insecticide "Thimet" lessened as the insecticide was placed at increasing distance from the "seed" tuber. Seed dressings should therefore be valuable when systemic action is important, and also, as in onion-fly control, when seed treatment concentrates the insecticide where the larva is likely to meet it before attacking the plant. This does not necessarily mean that seed treatment is better for systemic action than other methods of soil application, at any rate where persistence is needed. For example, Burt (see above, p. 128) has shown that "Thimet" combined with the fertilizer protected potatoes from aphids better, and for longer, than the same amount placed under the "seed" tuber. This is probably because lasting protection by systemic phosphorus insecticides depends on their continued uptake by the roots, the absorbing region of which may not only grow beyond the area of the treated seed (Way and Needham, 1957) but also becomes concentrated where the fertilizer is placed (Cooke, 1954).

https://doi.org/10.23637/ERADOC-1-91

Seed dressings have lacked persistence partly because the dose of insecticide has been limited to what would adhere as a dry dust to the seed. Bardner (see above, p. 130) has recently studied methods of applying larger doses using different " stickers " and " carriers " to enhance both initial and persistent effects. A methyl cellulose sticker for increasing the dose of dieldrin, aldrin and heptachlor has already given promising results in wheat-bulb-fly control (Bardner, 1959; Way, 1959a). Unfortunately, insecticides, especially γ-BHC and many phosphorus insecticides, are likely to be more phytotoxic as seed dressings at high rates than when applied in other ways, but there is preliminary evidence (p. 130 above) that carriers, such as activated charcoal, and stickers, such as polyvinyl acetate, can release the insecticide comparatively slowly, thereby lessening phytotoxicity and enhancing persistence of systemic action.

Systemic Phosphorus Insecticides

Laboratory work on systemic phosphorus insecticides has mainly demonstrated their uptake and translocation to aerial parts of the plant where they kill various insects. Early work by Andersson and Ossiannilsson (1951) and Ashdown and Cordner (1952) indicated that crops might be protected from aphids by schradan and demeton seed dressings. Using a demeton seed dressing on spring-sown field beans (*Vicia faba*), Way and Needham (1957) found that, although the insecticide protected the seedling shoot from damage by adult pea and bean weevil (*Sitona lineatus* L.), it had little effect on the bean aphid (*Aphis fabae* Scop.) which colonizes the crop 2–4 months after the seed is sown. The aphid was controlled by demeton dust applied to the seed drill at sowing time, but the dose of active ingredient needed was about 180 times more than that required by a suitably timed demeton aerial spray. In an experiment with potatoes, demeton dust put in the planting hole around the " seed " tuber at rates of 0·125–0·25 gm. of active ingredient/tuber, killed the aphid *Myzus persicae* Sulz. for 40–60 days after planting, whereas 0·5–1 gm. per tuber was needed to protect the plant for more than 112 days. Way and Needham concluded that seed dressings of systemic phosphorus insecticides should be valuable for protecting the young plant shoot soon after germination, especially as an aerial spray is not only difficult to apply at the right time but is wasteful and does not persist in the small, rapidly growing shoot.

The young plant is particularly susceptible to viruses; therefore, the initial protection and persistence provided by a systemic insecticide may be useful in preventing early virus transmission by insects. In this connection Burt (see above, p. 128) showed that " Thimet " and " Rogor " at 0·31 and 0·35 gm. active ingredient/potato seed tuber put in the planting hole kept the crop almost completely free from aphids throughout the period when they usually infest it. The rates, like those of demeton used by Way and Needham, were high, but less insecticide might still give the necessary initial protection. Dunning (see above, p. 194) also obtained promising results with seed dressings of " Thimet ", " Disyston " and " Rogor " on sugar beet. These chemicals not only controlled aphids but also lessened the spread of aphid-transmitted yellows virus in the young plants.

Although demeton as a seed dressing may be slightly better than "Thimet" and "Disyston" against aphids (Reynolds, Fukuto, Metcalf and March, 1957), the last-named chemicals are less specific, and as seed dressings they protect the aerial parts of some young crops from various species of Aleyrodidae, Thysanoptera, Diptera, Lepidoptera and Coleoptera as well as Aphidae. (Reynolds, Fukuto, Metcalf and March, 1957; Parencia, Davis and Cowan, 1957; Dunning (see above, p. 194)). Disadvantages of the systemic phosphorus insecticides are that they can be phytotoxic and they are poisonous to mammals and birds. Evidence so far (Reynolds, Fukuto, Metcalf and March, 1957; Burt (see above, p. 129)) showed that dangerous residues can be avoided in some food plants, and the main problem is the handling of such poisonous chemicals as "Thimet", "Disyston" and demeton as concentrated seed dressings during and after their application to the seed. In this respect "Rogor" is apparently less dangerous and is an advance towards the ideal of the safe systemic phosphorus insecticide which, as a seed dressing, should have many uses in agriculture.

Conclusion

This review has dealt mainly with some of the biological factors that are important in the action of insecticide seed dressings. Little has been said about some other factors that need to be considered before seed dressings can be used to the best advantage, and so that what has been discussed can be put in proper perspective, the main ones are listed below under three main headings. It will be seen that many of the factors are likely to interact.

(1) *The relationship between the seed dressing and the seed*

Something has been said about the special value and limitations of applying insecticides direct to the seed and also about methods of varying the dose, but the safety margin between the dose which is insecticidal and that which is phytotoxic is especially important, because seed dressings are more likely to harm the young plant than are other methods of soil application.

(2) *The fate of the insecticide in the soil and in the plant*

This will influence the immediate and lasting effects of insecticides against insects in the soil and on the plant, and is also relevant to the problem of harmful residues. Soil factors include the spread of insecticide through the soil and its rate of disappearance, especially in relation to soil type and root distribution. Plant factors include rate and period of uptake as well as distribution and disappearance of the insecticide in the plant in relation to plant species and age. Little is known about soil problems, and few plant studies relate directly to the action of seed dressings. They are not discussed in this review.

https://doi.org/10.23637/ERADOC-1-91

(3) *The relationship between the insect and the insecticide in the soil and plant*

This involves inherent resistance of the insect, the reaction of the insect to the insecticide and the behaviour of the insect in relation to the plant and to the position of the treated seed. Except for inherent resistance, these problems are discussed in the review.

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