3.
Innovations in Application Methods

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THE DEVELOPMENT OF LOCALISED INSECTICIDE PLACEMENT METHODS IN SOIL

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ABSTRACT

Broadcast applications of granular formulations of insecticides to soil have been superceded largely by band treatments. Although the biological performance of band treatments can be modified by factors such as drill type, insecticide formulation and method and depth of placement in soil, rates of application remain generally at about 1-2 kg a.i. ha^{-1}.

The amounts of insecticide required to protect crops can be greatly reduced by localising their placement in the soil and thus improving the accuracy and uniformity of plant treatments. Plants raised in blocks or modules can be protected with 20-30% of the amounts of insecticide applied in field treatments and it is likely that with some seed treatments rates can be reduced still further. Biological and chemical aspects of the performance of insecticides applied in these ways are presented and their prospects and limitations are discussed.

INTRODUCTION

Much research has been done on non-insecticidal methods of protecting crops against insect pests but it is likely that the protection of vegetables will continue to rely on conventional insecticides for at least the next decade. Economic constraints limit the development of new insecticides for use on even major world crops, so the prospect of compounds being tailor-made solely for 'minor uses' on UK vegetables is not, at present, realistic. Insecticidal control of pests on vegetables will therefore depend very much on the optimum deployment of existing compounds.

When applied to soil at sowing or planting to control either soil-inhabiting insect pests or, with systemic compounds, foliage-feeding insects such as aphids, insecticide treatments often need to be active for several weeks or even months. Granular formulations are favoured for these uses because, as well as being less hazardous and more convenient to handle than liquid formulations, the insecticides persist much longer than when applied as liquids. However, although granular formulations have been used widely in soil for almost 30 years, there have been relatively few developments in methods of application. Despite exhortations to minimise environmental problems by reducing the amounts of insecticide used (Anon., 1979) and recognition that utilisation is extremely inefficient (Graham-Bryce, 1975; 1976), rates and methods of field application used today have not changed much in the past 15 years.

At NVRS, much work has already been done to study ways in which the transfer of soil-applied insecticide doses to target insects can be improved for some specific crop-pest situations. Aspects of this work, together with their prospects and limitations, are discussed in this paper.

BAND APPLICATIONS

Initially, modified fertiliser distributors were used to broadcast granules over field soil, the granules usually being incorporated subsequently into the soil. Although the resulting distribution of insecticide must often have been imperfect, the persistence and toxicity of the organochlorine insecticides, together with the relative mobility of most of the target insects, resulted in consistently high levels of crop protection. Nevertheless, during the mid-1960's, increasing pressures to minimise environmental problems and the introduction of less persistent organophosphorus insecticides to overcome problems of insect resistance led to more localised, band applications of granular products using new techniques and equipment.

The behaviour of an insect in soil determines how it acquires a lethal insecticide dose and, consequently, affects the performance of the insecticide. However, knowledge of the routes of acquisition of insecticide doses by soil-inhabiting insects is almost non-existent. It is not known, for instance, whether control of root-feeding species is achieved mainly by contact, stomach action or even by fumigation.

Insecticides placed more than 8-10 cm away from plant roots are usually less effective against soil-inhabiting pests than if placed closer and may even benefit pest populations by reducing the numbers of predators and parasites. Confining an insecticide to a band along the crop rows might be expected to improve its effectiveness in terms of the level of control achieved per unit of active ingredient applied. It is difficult to explain, therefore, why insecticides concentrated in bands along rows of carrots at drilling were less effective against carrot fly (Psila rosae) than broadcast, incorporated treatments giving much smaller concentrations of insecticide per unit volume of soil (Wheatley, 1972). Although the dose differentials for insecticides applied by these two methods ought to be at least 10:1, in practice they are less than 2:1 (Anon., 1983). With band applications of granules to field-sown or transplanted brassicas, individual plants are protected by probably no more than a 15-cm length of a continuous band so that two-thirds or more of the insecticide applied may be wasted (Wheatley, 1973). In this instance, confining the granules near to the plants would have an obvious advantage. A machine designed by A.S. Orwin of Pershore Horticultural College to deliver granules only at plant positions was tested at NVRS (Thompson & Percivall, 1978a). Despite occasional misplacement of insecticide, control of cabbage root fly (Delia radicum) on transplanted Brussels sprouts was similar to that achieved with twice as much chemical applied in a continuous band.

Band application is a widely-used method of applying insecticide granules to soil in vegetable crops. The effectiveness of band treatments is usually improved by incorporating the granules shallowly into the soil rather than leaving them on the soil surface where the active ingredient (a.i.) is lost by volatilisation and photodegradation. The performance of granular products in soil is nevertheless dependent upon soil moisture and temperature. For example, in microplot experiments, the rapid oxidation of parent disulfoton on the soil surface was followed by the leaching of a substantial proportion of the water-soluble oxidation products. Thus less insecticide remained at the soil surface than would have remained with less water-soluble compounds (Suett, 1977).

The methods used to apply and incorporate granules into the soil are determined initially by the stage at which the crop is to be treated, for example at sowing, or at or after transplanting. For many years, transplanted brassicas were treated after planting with either 'spot' applications to individual plants or band applications to the soil surface. Sometimes crops were planted into bands applied beforehand to the soil surface but the performance of insecticides applied in this way was generally erratic due primarily to errors in alignment. It was not until the early 1970's that the sub-surface method of application was devised to incorporate insecticide granules around the plant roots in a zone along the row about 8 cm wide and 10 cm deep (Bevan & Kelly, 1975). Granular products were more reliably effective when applied in this rather than in other ways.

At sowing, granules may be placed in the furrow with the seed, to one side, above or below the seed, or mixed into the surrounding soil. Application in the seed furrow is not much used on U.K. vegetable crops, partly for reasons of phytotoxicity and partly because the granules may be too shallow to protect plants beyond the seedling stage, especially when persistent systemic compounds are applied to control foliage-feeding pests. A popular and successful procedure is the "bow-wave" technique (Makepeace, 1965) in which a band of granules is delivered to the soil surface just in front of the seeder coulter which, on passing through the band, mixes the insecticide into the soil along the seed row. The effectiveness of this type of application, however, depends on the properties and condition of the soil which affect the distribution of the granules. For example, difficulties may be encountered with applications into wet, heavy soil. The performance of insecticides applied by the bow-wave technique may also be affected by the type of coulter used. In experiments, these effects were most evident when protection of plants was needed during the first few weeks after drilling, especially with relatively non-mobile insecticides (Thompson et al., 1982a). Differences in insecticide placement were less important in influencing insecticide availability and thus performance over longer periods (Suett et al., 1982).

The type and size of carrier particles on which an insecticide granule is formulated can markedly influence the availability and performance of the active ingredient. Few insecticides are formulated on more than one type of carrier and most are coated on to the surface of the granule, although impregnation of the carrier matrix provides a ready means of controlling the rate of release of a.i. (Wheatley, 1976). Manipulation of the rate of release of a.i. from granular formulations seems to have been little explored, even though control of some pests, including carrot fly, is often not needed until several months after the application of treatments at drilling. Thus reliance is generally placed on very persistent compounds, a practice regarded increasingly as undesirable. A more satisfactory way of extending effectiveness is by modifying the formulations to delay the release of the active ingredients until they are needed. Delayed-release formulations also reduce the concentrations of insecticide residues in some mature root crops, including carrots, by preventing seedlings from acquiring high concentrations of insecticide (Suett, 1971).

The persistence of the effectiveness of granular insecticide formulations can also be influenced by manipulating chemical conversion processes in the soil environment, as with granular formulations containing carbosulfan, CGA73102 and benfuracarb (Maitlen & Sladen, 1979;

Bachman & Drabek, 1981; Goto et al., 1983) which are hydrolysed in the soil to release carbofuran. Dose-for-dose differences in the performance of the parent insecticides against carrot fly and in the uptake of insecticide residues by carrots were influenced also by the method of application (Suett et al., 1984a). The effects of these and other variables on the relative uptake and performance of these compounds clearly warrants further investigation.

The behaviour of conventional formulations has also been modified by incorporating them into the gels used for fluid-drilling pre-germinated seed, placing a narrow (ca 1 cm) band of insecticide precisely along the row. In the field, rates of insecticide degradation were slower following application in gels than when granular formulations were applied directly to the soil (Suett & Padbury, 1981) and substantial control of carrot fly was achieved on maincrop carrots by incorporating some granular and liquid formulations into gels (Thompson et al., 1981). It was shown that the a.i. was released rapidly from granules added to the gels (Thompson et al., 1982b) and it seemed that the gels themselves acted as slow-release carriers.

Increasing reliance will probably be placed on the development of modified insecticide formulations, a striking example being the production of the first dual component granular formulation for use on vegetables (Sinclair & Purnell, 1977). The introduction of the product, containing fonofos and disulfoton for the control of cabbage root fly and cabbage aphid (Brevicoryne brassicae) respectively, followed extensive studies at NVRS into the compatibility of active ingredients applied simultaneously (Thompson & Percivall, 1977). Other combinations of insecticides have since been formulated on granules to control these pests (Thompson et al., 1979) but there seem few opportunities to extend this particular approach to other vegetable pest problems in the UK.

In general, band application methods used at drilling restrict the granules within 1-2 cm immediately below the soil surface. However, in microplot studies, the performance of several insecticides against carrot fly improved as the depth of placement was increased from 1 to 10 cm and all were very effective at 25 cm, a greater depth than carrot fly larvae generally reach (Wheatley & Hardman, 1967; 1968). At least some of the insecticide may reach the feeding larvae by being absorbed and translocated along the fibrous carrot roots. The participation of the plant roots has been exploited by placing insecticides more deeply alongside carrots (Wheatley, 1972) or Brussels sprouts (Suett & Padbury, 1977). With carrots, both sides of the crop row needed protection. Inconsistencies in the relative effectiveness against carrot fly of bow-wave and deep-side-placement applications in experiments were attributed to differences in carrot rooting characteristics in different seasons or at different times of the same season, all likely to influence optimum placement depth. In contrast, Brussels sprouts were protected against cabbage aphid with granules placed at distances up to 25 cm from the plants on only one side of the row. As deep-side-placement limits the uptake of insecticides by young seedlings and plants, high levels of insecticide performance are achieved invariably with lower residue levels in root crops at harvest (Suett, 1975).

Deep-side-placement can sometimes be achieved in mid-season, close to expected times of infestation. Insecticide doses can then be reduced and residues in the crop further minimised. For example, control of aphids on potatoes by granular formulations of aldicarb or thiofanox was, dose-for-dose, generally better when granules were side-banded into potato drills 6 wk after planting than when applied in-furrow at planting (Woodford & Gordon, 1984). Final yields were then unaffected by the side-placement (S.C. Gordon, pers. comm.). With carrots, however, the benefits from deep-side-placement were often limited and it is far from being a practical answer to the problem of carrot fly control on late-harvested crops (Wheatley, 1972).

A drawback of late deep-side-placement is the limited protection afforded to seedlings. However, the recently-developed technique of vertical-band application of insecticide granules enables the toxicant to be distributed in a pattern which should ensure the protection of the developing carrot seedling as well as the bulk of the mature tap-root. Using a vertical-band applicator, Whitehead *et al.*(1981) achieved fairly even distribution of a granular nematicide formulation from the soil surface to a depth of about 15 cm. In 1983, control of carrot fly by phorate applied in this way to carrots at drilling on a black fen soil was compared with a standard bow-wave application (Thompson *et al.*, 1984a). The deeper distribution of the insecticide achieved by the vertical band application provided more effective protection against carrot fly larvae than the bow-wave application in each 5-cm depth stratum down to 20 cm.

PEAT BLOCK AND SEED TREATMENTS

The accurate placement of precise amounts of insecticides in a critical region in the soil offers advantages in terms of effectiveness and economy of insecticide usage. Band applications instead of broadcast treatments provided a significant move in this direction. Some recent developments have shown that even more localised treatments can permit spectacular reductions in the amounts of active ingredient needed, without reducing levels of pest control.

Incorporation of insecticides in peat blocks

The advantages of raising transplants in blocks or modules containing peat or other media include the shortening of the time required by the plants in the glasshouse and the field and the more accurate scheduling of harvesting dates (Anon., 1980). The incorporation of insecticides into peat blocks avoids relatively inefficient row applications in the field and enables more accurate doses to be applied to plants, irrespective of variable soil and weather conditions which can introduce large variations in plant-to-plant dosing with field treatments. The distribution of insecticide between individual blocks can be exceptionally uniform, more than 90% of the blocks often containing within 10% of the target dose, irrespective of the formulation of the insecticides used (Suett & Padbury, 1982). Most of the insecticides that have been tested were more stable in peat blocks than in soil, due largely to the greater adsorptive capacity of the peat. This stability is influenced little by the type of peat or by the concentrations or formulations of the insecticides.

The uptake of insecticides, particularly of systemics, is often greater in plants raised in treated peat blocks than in those treated in the field (Suett & Padbury, 1980a). This can create problems with short season crops. For example, doses of some insecticides needed to protect lettuce against foliage aphids and the lettuce root aphid (*Pemphigus bursarius*) (Thompson & Percivall, 1981) produced unacceptably high concentrations of residues in mature heads (Suett & Padbury, 1980b). In contrast, with a relatively long season crop such as Brussels sprouts, the extensive uptake of a systemic aphicide can protect the plants against the cabbage aphid for several months without leaving excessive residues in the sprout buttons at harvest (Suett & Padbury, 1981).

In general, the incorporation of non-systemic insecticides into peat blocks seems unlikely to produce problems with residues in crops. 'Approval' has already been given by the Ministry of Agriculture, Fisheries and Food Agricultural Chemicals Approval Scheme to the 'block-incorporation' of two non-systemic insecticides for the protection of brassicas against the cabbage root fly (Saynor & Davies, 1977; Thompson & Percivall, 1978b; Dunne et al., 1979). Effective pest control is achieved using only 20-30% of the a.i. needed with band treatments in the field.

Seed treatments

By using the seed as a carrier, pesticides can be transferred economically and precisely into the soil. However, traditional mixing methods of applying pesticides to seeds have major limitations (Graham-Bryce, 1973), with very uneven distribution of insecticide between individual seeds. The uniformity of dosing is especially poor when powders are used without adhesives and the average dose may be well below target (Lord et al., 1971). Seed-coating, however, can achieve more accurate dosing by mixing the pesticide with an inert material and coating the seed with the mixture (Jeffs & Tuppen, 1978).

Initial studies of a film-coating process in which seeds are suspended in a fluidised bed during treatment showed that coefficients of variation of about 20% were usually achieved between doses on individual seeds treated in a batch of several kg (Suett et al., 1983a; 1984b). However, the accuracy and uniformity of dosing were influenced by seed type and size and the use of similarly-sized seed would seem to be an essential pre-requisite to any substantial reduction of variability. Studies with chlorfenvinphos-treated seeds showed that the insecticide transferred rapidly from seed into the soil and that this movement was influenced little by soil type. However, the uptake of insecticide by the emerging seedlings differed markedly from crop to crop (Suett et al., 1984b). The numbers of carrot fly larvae were reduced by 85% following seedcoat-treatment of carrots with 75 g chlorfenvinphos/kg seed (200-300 g a.i./ha) (Thompson et al., 1982c) and residues in the mature crop were much smaller than in carrot roots from an adjacent bow-wave application at 70 mg a.i./m row, equivalent to 1.4 kg a.i./ha..

To date, film-coating of vegetable seed with insecticides has been investigated almost exclusively with non-systemic compounds. There is also potential for applying systemic insecticides in this way, although the risk of phytotoxicity may be greater. To exploit the technique fully, however, a more detailed understanding is required of the processes governing the release of insecticides from what are essentially "point" sources and their mobility and availability in different soil types.

Block incorporation and seed treatment are convenient methods of applying pesticide mixtures to control seed- and soil-borne diseases as well as soil-inhabiting insect pests. In peat blocks, however, the presence of systemic fungicides can affect the uptake of systemic and non-systemic insecticides by seedlings and young plants (Suett & Padbury, 1980b; Suett et al., 1983b; Suett & Thompson, 1983). Differences in residues between lettuce plants grown in blocks with or without fungicide diminished rapidly after planting out and effects on performance and residue levels seemed unlikely to be important. However, enhanced uptake by the young plants caused phytotoxicity with some combinations of insecticide and fungicide. With seed treatments, insecticide behaviour seems less likely to be influenced by the presence of fungicides applied to treat seed-borne diseases than by those applied to control soil-borne pathogens.

Seed loading techniques have as yet been little studied. Preliminary analyses of seeds following film-coating with mixtures of insecticides and fungicides (Suett, unpublished data) indicated that loading and distribution can be influenced markedly by the treatment sequence. With better appreciation of the interactions between pesticides, rapid development of this efficient and flexible method of insecticide application seems likely.

DISCUSSION

With the unpredictability of the climate and of the incidence of target pests, scant knowledge of modes of insecticide action and the non-specificity of a declining armoury of insecticides, it is remarkable that consistently high levels of performance continue to be achieved by present-day insecticide treatments against most insect pests of vegetables. Although it should be possible to improve dosage-transfer, and hence reduce application rates, it is unrealistic to expect dramatic developments in all pest/crop situations. Insecticides transferred to the soil in blocks or modules or on seeds can, in some situations, achieve satisfactory control with only 10% of the amount of a.i. normally applied. Application rates have been reduced, without sacrificing performance, to only 3% of recommended rates, in experiments involving the transplanting of treated radish seedlings into field soil (Suett _et_ _al_., 1984c).

One factor which is readily overlooked in all of these methods is that of treatment uniformity. With modules, seed treatments and treated seedlings, each plant receives a similar dose of insecticide. In contrast, even the best methods of applying insecticides in the field lead to non-uniformity which leaves a significant fraction of the crop insufficiently protected. Residue analyses have shown that, within any one treatment, damage was always greatest on plants containing the lowest residue concentrations (Suett, 1975). There is much room for improvement in the accuracy of field applications. In 1984, a survey of equipment used commercially to apply granular formulations of insecticides to soil to control cabbage root fly showed that only 48% of the functional outlets delivered within ±10% of the required recommended rates (Thompson _et_ _al_., 1984b). Similarly, modification of a recommended peat-block treatment method by a grower led to a seven-fold variation in dose between individual blocks, the mean dose being less than 50% of the target (Suett, unpublished data).

Much can yet be achieved to improve the performance of insecticides. For the immediate future, techniques such as seed treatment and the incorporation of insecticides into blocks or modules promise a degree of flexibility which is particularly relevant to UK horticulture. It is almost 10 years since the concept of individual crop protection "packages" was presented (Graham-Bryce, 1975). Recent progress suggests that at least partial exploitation is imminent.

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BIOLOGICAL RESULTS OBTAINED WITH THE HANDHELD "ELECTRODYN" SPRAYING SYSTEM

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ABSTRACT

ICI Plant Protection Division have developed and commercialised the 'Electrodyn' Sprayer, for pesticide application which has already proved to be a commercial success.

This paper presents the scope of the 'Electrodyn' [1] Spraying System showing its use for insect, weed and disease control in a wide range of crops in countries throughout the world.

INTRODUCTION

In 1981 the 'Electrodyn' (ED) sprayer with the cypermethrin ED formulation was sold into the cotton markets of Thailand and Paraguay, where the system was well received. Today ICI are selling the ED sprayer in a total of 10 markets, with the system under full development in a further 13 countries and under evaluation in at least 15 others. The lead market remains cotton but with a significant development in cowpea centered on an expanding market in Nigeria and in other African countries. Although insecticide products still dominate the system, the development of herbicide and fungicide formulations are progressing rapidly.

INSECT CONTROL : 1 COTTON

The commercial introduction of the ED system was stimulated by the efficacy of cypermethrin against bollworm, Heliothis spp.,(Morton 1981). In large scale commercial trials the ED system gave superior pest control and better yield than conventionally applied pyrethroids (Durand et al 1984). The acceptance of the system by small holder farmers demanded the means to control a wider range of pests which made it essential to develop additional ED products. Formulation effort was intensified to produce a wider range of insecticides which went through a screening process to assess spray characteristics, phytotoxicity, chemical stability, dermal toxicity, and biological efficacy.

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[1] 'Electrodyn' is a registered trade mark of Imperial Chemical Industries PLC

The first target investigated was the early season sucking pest complex, in which the aphid, Aphis gossypii, is a key pest in Paraguay, Burma and Thailand. In Paraguay the cotton aphids are susceptible to most organophosphate (OP) insecticides with dimethoate being the most commonly used product. From a series of trials pirimiphos-ethyl proved to be the most effective OP with clocythrin [2], (PP321) a new synthetic pyrethroid, also giving a high level of control (see Table 1).

TABLE 1

Percent reduction of the cotton aphid, Aphis gossypii, on cotton in Paraguay

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT 1	3	7
Dimethoate	Knapsack	250	160	70	56	52
Malathion	'Electrodyn'[2]	1.0	500	77	80	75
Amitraz	'Electrodyn'	0.5	100	59	68	54
Pirimiphos -ethyl	'Electrodyn'	0.5	150	93	85	89
Chlorpyrifos	'Electrodyn'	0.5	125	75	80	76
PP321	'Electrodyn'	0.5	10	91	89	97

In Burma a degree of OP tolerance was present borne out by the exceptionally high rate of malathion used conventionally (>2kg a.i. per hectare). In comparison 250 g a.i. of malathion applied in 0.5 l/ha ED gave equal control to the high volume application (see Table 2).

Thailand presented a much tougher test for the system. The cotton aphid is a vector for a stunting virus which, if not controlled, can drastically reduce yield. The aphid is also resistant to dimethoate and other OP's. The key technical requirement, therefore, is the need for fast aphid knockdown combined with longterm protection in the height of the monsoon season. From extensive trials over two seasons carbosulfan ED proved to be highly effective against aphids in both Thailand and Burma. It gave excellent 24 hour knockdown and at least 7 day persistence superior to conventionally applied monocrotophos and malathion (see Table 3).

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[2] BSI proposed common name for ®-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2, 2-dimethylcyclopropanecarboxylate a 1 : 1 mixture of the (Z)-(1R,3R), S-ester and (Z),(1S,3S),R-ester

TABLE 2

Percent reduction of the cotton aphid, Aphis gossypii on cotton in Burma

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT 1	3	7
Malathion	Knapsack	170	2041	64	62	28
Malathion	'Electrodyn'	0.5	250	68	62	38
Amitraz	'Electrodyn'	0.5	100	67	85	69
Pirimiphos -ethyl	'Electrodyn'	0.5	150	73	37	24
Carbosulfan	'Electrodyn'	0.5	75	94	89	85

TABLE 3

Percent reduction of the cotton aphid, Aphis gossypii on cotton in Thailand

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT 1	3	7
Monocrotophos	Mistblower	250-325	150	92	91	61
Carbosulfan	Mistblower	250-325	125	97	91	55
Carbosulfan	'Electrodyn'	0.5	75	97	96	77
Amitraz	'Electrodyn'	0.5	100	88	83	54
PP321	'Electrodyn'	1.0	7.5	98	99	78

In Thailand and Burma the aphid is frequently part of a pest complex with the jassid, Amrasca devastans and the thrip, Thrips palmi, increasing the stress on the host plant. Thus to be acceptable to the farmer, the early season product must have a broad spectrum of activity and control the full range of sucking pests. Of the ED formulations tested in Thailand three have shown outstanding activity against jassids (see Table 4); carbosulfan; amitraz and PP321. Against thrips (see Table 5) several of the formulations gave good knock down and up to 7 days persistence; carbosulfan and pirimiphos-ethyl were the most effective.

TABLE 4

Percent reduction of the jassid, Amrasca devastans, on cotton in Thailand

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT		
				1	3	7
Monocrotophos	Mistblower	250-325	150	97	90	27
Amitraz	Mistblower	250-325	100	81	85	12
Carbosulfan	'Electrodyn'	0.5	75	96	94	64
Amitraz	'Electrodyn'	0.5	100	99	97	65
PP321	'Electrodyn'	0.5	10	99	98	64

TABLE 5

Percent reduction of the cotton thrips, Thrips palmi, on cotton in Burma

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT		
				1	3	7
Malathion	Knapsack	170	2041	94	76	50
Malathion	'Electrodyn'	0.5	250	94	86	65
Pirimiphos -ethyl	'Electrodyn'	0.5	150	97	88	85
Carbosulfan	'Electrodyn'	0.5	75	96	82	94
Amitraz	'Electrodyn'	0.5	100	85	66	74

Against the white mite, Hemitarsonemus latus, ED sprays of both dicofol and pirimiphos-ethyl gave good control (see Table 6). While against the red mite, Tetranychus urticae, dicofol, amitraz, pirimiphos-ethyl and PP321 all gave superior control to binapacryl (See Table 7).

TABLE 6

Percent reduction of the white mite, Hemitarsonemus latus on cotton in Brazil

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT		
				3	6	10
Dicofol	Knapsack	120	370	82	60	79
Propargite	Knapsack	120	1089	37	0	28
Dicofol	'Electrodyn'	0.5	200	83	80	79
Pirimiphos -ethyl	'Electrodyn'	0.5	200	87	89	78

TABLE 7

Percent reduction of the red mite, Tetranychus urticae, on cotton in South Africa

Chemical	Application Method	l/ha	g a.i./ha	% Reduction DAT	
				2	7
Triazophos	Knapsack	200	107	39	51
Binapacryl	Knapsack	200	126	38	63
Dicofol	'Electrodyn'	1.0	400	90	95
Amitraz	'Electrodyn'	1.0	200	72	84
Pirimiphos -ethyl	'Electrodyn'	1.0	400	73	78
PP321	'Electrodyn'	1.0	20	68	82

In Brazil, trials against the bollweevil, Anthonomus grandis, have proved the ED system to be a very effective tool when used on a 3 to 5 day spray schedule (see Fig 1).

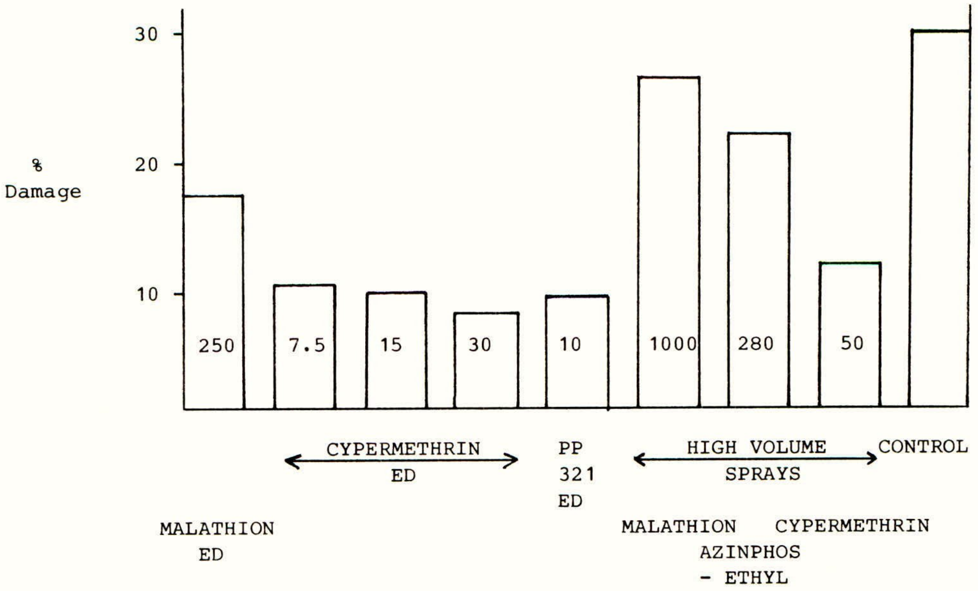

FIG 1 : Seasonal average of percent damaged squares by the boll weevil, Anthonomus grandis on cotton in Brazil. (Rate in g a.i./ha)

In order to be considered a complete spraying system for cotton insect pests, the ED system must be effective against the key lepidopterous species. The bollworms *Heliothis spp*. and *Earias spp*. present a very similar and easy spray target occuring initially on the growing points of the crop. The leafworm, *Alabama argillacea*, and the armyworms, *Spodoptera spp*., both have very mobile larvae. All four genera are well controlled by ED sprays as is the stem borer, *Eutinobothrus brasiliensis*. The pink bollworm, *Pectinophora gossypiella*, is a more difficult spray target occuring lower down in the cotton canopy. However the ED system has given effective levels of control against this pest as compared to conventional application (see Table 8).

TABLE 8

Efficacy of cypermethrin against lepidopterous pests on cotton when applied through the 'Electrodyn' sprayer

Heliothis armigera - Australia	% Reduction of square damage			
	3DAT[2]	6 DAT[3]	5DAT[4]	5DAT[5]
Cypermethrin 60 g a.i. in 50 l/ha	96	85	98	94
Endosulfan 400 g a.i. in 50 l/ha	81	76	72	81
Cypermethrin 15 g a.i. in 0.5 l/ha	96	88	92	97

Earias insulana - Pakistan	Mean % Reduction of infestation	% Increase in yield over control
Cypermethrin + profenofos 16 + 160 g a.i. in 250 l/ha	68	6.83
Cypermethrin 22.5 g a.i. in 0.75 l/ha	67	24.36

Alabama argillacea - Brazil	% Reduction of larval numbers		
	DAT		
	1	3	7
Cypermethrin 12.5 g a.i. in 167 l/ha	98	100	100
Cypermethrin 3.125 g a.i. in 0.25 l/ha	93	98	97

Spodoptera littoralis - Mozambique	% Reduction of larval numbers	
	DAT	
	4	11
Cypermethrin 100 g a.i. in 4 l/ha(ULV)[3]	97.4	99.2
Cypermethrin 36 g a.i. in 0.6 l/ha	95.9	99.4

Eutinobothrus brasiliensis - Brazil	% Reduction in larval numbers		
	DAT		
	5	13	21
Ethyl-parathion 300 g a.i. in 166 l/ha	81	90	90
Cypermethrin 15 g a.i. in 0.5 l/ha	95	98	84

Pectinophora gossypiella - Brazil	% Damaged bolls		
	10DAT[2]	10DAT[3]	10DAT[4]
Cypermethrin 45 g a.i. in 200 l/ha	18.5	0.8	10.3
Cypermethrin 45 g a.i. in 0.75 l/ha	17.5	5.0	5.1

[3] ULV = Ultra low volume with spinning disc sprayer.

2 COWPEA

The evaluation of the 'Electrodyn' spraying system against the insect pests of cowpea has centered on work in Nigeria in co-operation with the International Institute of Tropical Agriculture (IITA) in Ibadan. The ED sprayer has been tested against a range of insect pests including the flower thrips *Megalurothrips sjostedti* and the legume pod borer, *Maruca testulalis*, on new high yielding varieties under development as part of the Grain Legume Improvement Programme (Gowman 1984). Mixed formulations of cypermethrin and an OP have given excellent pest control (see Table 9) which in practice has significantly increased the yield (Durand et al 1984).

TABLE 9

Performance of 'Electrodyn' formulations on cowpea pests in Nigeria - flower thrips, *Megalurothrips sjostedti*, and legume pod borer, *Maruca testulalis*

Chemical	Sprayer type	l/ha	g a.i./ha	% Reduction Thrip No. DAT 10	15	Pod Damage	Increase in yield over control
Cypermethrin + dimethoate	Knapsack		50+400 1	94	64	92	10.3x
Cypermethrin + dimethoate	'Electrodyn'	0.5	15+20	87	51	78	9.5x
Cypermethrin + thiometon	'Electrodyn'	0.5	15+50	83	45	73	7.1x
Cypermethrin	'Electrodyn'	0.25	15	77	47	60	5.9x

3 RICE

Following the introduction of a swinging mode of use (Pascoe and Jackson 1983) the ED system was developed for the control of the green leaf hopper, *Nephotettix virescens*,in the Philippines to reduce tungro virus transmission. The system was equally effective against the whorl maggot, *Hydrellia philippina*, and the leaf folder, *Cnaphalocrocis medinalis*, once again using cypermethrin (see Table 10).

The brown plant hopper, *Nilaparvata lugens*, is a more difficult spray target due to its location deeper within the rice canopy. However, ED applications of carbosulfan and carbophenothion have equalled the performance of conventional high volume applications (see Table 12).

4 VEGETABLE CROPS

Insecticide sprays through the ED system against pests of vegetable crops have produced a series of encouraging results. So far information is limited to the efficacy of cypermethrin against *Spodoptera spp.*, whitefly, and Colorado beetle (see Table 11).

TABLE 10

Efficacy of ED formulations against rice pests when applied through the 'Electrodyn' sprayer

Hydrellia philippina - Philippines	% Crop damage
	7 DAT
Cypermethrin 25 g a.i. in 500 l/ha	20.0
Cypermethrin 30 g a.i. in 1.0 l/ha	17.5

Cnaphalocrocis medinalis - Indonesia	% Control	
	7 DAT[1]	7 DAT[2]
Cypermethrin 30 g a.i. in 500 l/ha	50	58
Cypermethrin 30 g a.i. in 1.0 l/ha	54	84

Nephotettix virescens - Philippines	% Reduction in hopper numbers		
	19 DAT[1]	3 DAT[2]	14 DAT[2]
Monocrotophos 500 g a.i. in 500 l/ha	63	82	72
Cypermethrin 20 g a.i. in 0.5 l/ha	78	89	78

Nilaparvata lugens - Philippines	% Reduction in hopper numbers		
	7 DAT[1]	3 DAT[2]	14 DAT[2]
Carbophenothion 600 g a.i. in 500 l/ha	46	73	29
Carbosulfan 375 g a.i. in 500 l/ha	44	81	66
Carbophenothion 375 g a.i. in 1.5 l/ha	59	86	65
Carbosulfan 375 g a.i. in 1.5 l/ha	57	89	80

TABLE 11

Efficacy of cypermethrin against insect pests of vegetables.

Leptinotarsa decemlineata on Aubergine in Spain	% Plant damage		
	7DAT[1]	4DAT[2]	7DAT[2]
Cypermethrin 50 g a.i. in 250 l/ha	12.4	14.3	12.0
Cypermethrin 25 g a.i. in 0.83 l/ha	1.4	0.4	1.4

Trialeurodes vaporariorum on Tomato in Spain	% Control of adults		
	6DAT[1]	4DAT[2]	1DAT[3]
Quinalphos 480 g a.i. in 400 l/ha	17	20	22
Cypermethrin 15 g a.i. in 1 l/ha	53	82	73

Spodoptera exigua on Chilli in Thailand	% Fruit damage		
	7DAT[3]	7DAT[5]	4DAT[8]
Profenofos 750 g a.i. in 750-1125 l/ha	5.8	5.8	5.2
Cypermethrin 45 g a.i. in 0.75 l/ha	3.8	1.9	1.4

Spodoptera litura on Cauliflower in Thailand	Larvae/20 plants	% Plants harvested
Cypermethrin 45 g a.i. in 500-1000 l/ha	44	66
Cypermethrin 45 g a.i. in 0.75 l/ha	8	79

WEED CONTROL : GRASSES

Until recently most of the research and development effort within the project has been concentrated on insecticides. However following the establishment of the ED system for insecticide application to both cotton and cowpea the development of herbicides is now receiving increased attention.

TABLE 12

Control of grass weeds in various crops using an ED application of fluazifop-butyl[4] assessed 4 weeks after treatment[5]

Crop	Crop height (cm)	Grass Weed	Country	% Weed Control	
				ED	HV[6]
Cotton	50-70	Echinochloa crus-galli	Spain	100	100
		Digitaria sanguinalis		90	100
		Setaria viridis		100	100
	12-20	Echinochloa colona	India	80	53
		Chloris sp.		100	98
		Dactyloctenium aegyptium		92	43
	15	Ishaemum sp.	Sudan	100	95
Soya	30-40	Digitaria horizontalis	Brazil	54	87
	20-25	Digitaria sanguinalis	India	100	100
		Chloris sp.		100	98
		Dactyloctenium aegyptium		92	43
		Echinochloa crus-galli		97	63
		Echinochloa colona		80	53
	28-35	Eragrostis megastachya	Spain	98	100
	20	Cynodon dactylon	France	90	13
Ground nut	12-16	Eleusine indica	)		
		Echinochloa colona	Malaysia)	85	85
		Digitaria adscendens	)		
	15	Echinochloa crus-galli	India	97	63
		Echinochloa colona		80	53
		Digitaria sanguinalis		100	100
		Dactyloctenium aegyptium		92	43
		Chloris sp.		100	98
Sun-flower	40-45	Elymus repens	France	91	50
Stubble-wheat	-	Sorghum halepense	Italy	83	86

[4] ED sprays applied at 250-300 g a.i. in 0.83 - 1.0 l/ha

5 Except Malaysia when assessed at 8 DAT

[6] High volume application at 250-300 g a.i. in 200-700 l/ha

The first commercially available herbicide product is fluazifop-butyl for the control of grass weeds in a wide range of broad-leaved crops. Trial work has shown that using a formulation of 300 g a.i./l, at volumes of 1 l/ha or less, equal or better control of annual and perennial grass weeds when compared to high volume sprays can be achieved (see Table 12).

Farmer evaluation of the ED system with fluaziflop-butyl in the United States of America produced a very positive response. The work was limited to spot spraying in cotton and soya for the control of Johnsongrass, Sorghum halepense, Bermudagrass, Cynadon dactylon, volunteer corn and annual grasses (Sherman 1984).

DISEASE CONTROL : MILDEW

Evaluation of the ED system in vegetable crops has increased the need for fungicide products to be available for the system. Chemical formulation and field evaluation work is already in hand on a range of active ingredients but as yet trial data is limited to the control of powdery mildew, Sphaerotheca fuligmea, on cucumber with bupirimate (see Table 13). These early results in which the ED applications have matched high volume application are encouraging.

TABLE 13

Control of powdery mildew, Sphaerotheca fuliginea, on cucumber in Spain

Chemical	Sprayer type	l/ha	g a.i./ha	% mildew on leaf					
				1983		1984			
						upper leaves		lower leaves	
				DAT		DAT			
				7	17	14	22	14	22
Bupirimate	Knapsack	1000	250	0	5.4	6.5	53	21	49
Bupirimate	'Electrodyn'	2.5	250	0	1.2				
Bupirimate	'Electrodyn'	1.25	250			9.9	54	15	52
Control	-	-	-	35	43	56	82	59	90

DISCUSSION AND CONCLUSION

After several years of commercial use the 'Electrodyn' sprayer is an accepted application system in many of the cotton markets of the world. It is proving to be an invaluable tool for pest control in new high yielding varieties of cowpeas which rely on good crop management and simple effective pest control methods. Successful control of the green leaf hopper and early results against brown plant hopper encourage further development of the system in rice. An expanding range of insecticide formulations plus the beginning of fungicide trials will hopefully lead into commercial opportunities in the vegetable markets of the world. The development of a grass weed herbicide is already well advanced with research aimed at broadleaf weed control underway. The ultimate success of the system relies on the expansion of the product range plus the realisation of the agronomic advantages offered by this revolutionary spraying system.

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REVIEW OF THE RELATIONSHIP BETWEEN CHEMICAL DEPOSITS ACHIEVED WITH ELECTROSTATICALLY CHARGED ROTARY ATOMISERS AND THEIR BIOLOGICAL EFFECTS

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ABSTRACT

Over the last four years we have evaluated the performance of electrostatically charged rotary atomisers for the control of a range of crop pests and diseases. In general at identical application rates these sprayers gave larger pesticide deposits on plants than hydraulic sprayers, however these increased deposits did not always enable the reduction of application rates without loss of biological activity. The biological effectiveness of sprays applied with this equipment are discussed in relation to the size and location of spray deposits. Results are presented to indicate how modifications in sprayer design and operation can change the penetration of crop canopies by charged drops.

INTRODUCTION

The recent development of electrostatic sprayers (Coffee 1980; Arnold & Pye 1980; Law 1978; Marchant & Green 1982) has led to a resurgence in interest in spraying technology which has given rise to increased research into conventional methods of pesticide application as well as to the new techniques. The ability of CDA and the newer electrostatic techniques to apply low volumes of pesticide sprays to crop plants with a controlled drop size has led to the need to define the requirements for the optimum biological effectiveness of the sprays.

In most cases the optimum drop size and required distribution of deposits for maximum biological efficacy of sprays is unknown although several groups of workers have started to collect information of this nature. (Herrington & Baines 1983; Scopes 1981; Merritt 1982a,b). Considerable information exists on chemical deposits and their biological effects achieved by the 'Electrodyn' system, embedded-electrode spray charging nozzles and charged hydraulic sprayers (Hislop et al. 1983; Morton 1982; Parham 1982; Law 1982). Recently information has been reported (Arnold et al. 1984a,b,c; Griffiths et al. 1981, 1984) on the performance of boom-mounted electrostatically charged rotary atomisers i.e. the APE 80 described by Arnold & Pye (1980) and the Jumbo (Arnold, 1983).

In this paper we review published work on electrostatic rotary atomisers and present new information obtained during 1984.

MATERIALS AND METHODS

Spray machinery

The Jumbo electrostatically charged rotary atomiser (Arnold 1983) is a charged version of the Micron Micromax CDA atomiser (Bals 1978) operated at a disc speed of 4500 r.p.m. with application volumes of between 5 and 10 litres/ha, giving a drop spectrum with Volume Median Diameter of

80 µm. The APE 80 unit, applying between 2 and 5.6 litres/ha was also operated at 4500 r.p.m. to give a droplet VMD of 100 um. Both sprayers were operated at 30 kV. For comparison a hydraulic sprayer operating at about 300 Kpa to give either 200 litres/ha (F110-200 Lurmark jets) or 380 litres/ha (F80-10 Lurmark jets) was included in each trial. Air assistance was supplied to the charged sprayers using a Briggs and Stratton 5 hp engine driving a centrifugal fan linked to a manifold system and a series of ducts to produce a curtain of air at velocities up to 30 m/s.

Field procedures

All trials were designed as randomised blocks and cultural operations were done according to local practice. Experimental spray treatments of commercial pesticide formulations were applied at times appropriate for the hydraulic sprayer. Measurements of chemical deposits, weeds, pests and diseases have been described elsewhere. (Arnold *et al*. 1984a,b,c; Griffiths *et al*. 1981, 1984).

RESULTS AND DISCUSSION

Many trials have shown that at identical application rates electrostatically charged rotary atomisers often give increased chemical deposits on crop plants and substantially decreased soil contamination compared to a hydraulic sprayer. The biological effectiveness of the sprays if often directly related to the total chemical deposit on the plants or on parts of the plant but in other instances there appears to be little correlation between chemical deposits and the level of weed, pest or disease. In this paper we have chosen examples to illustrate each of these situations and to emphasise the advantages and disadvantages of electrostatic spraying.

TABLE 1

Effect of permethrin deposits on the control of pea moth

Sprayer and dose	(Permethrin deposits µg/g) tendril	growing point	flowers & pods	leaves	on soil $\mu g/cm^2$	% damaged pods
Untreated	-	-	-	-	-	11.1
H1	4.5	1.7	2.7	2.9		
	± 0.25	± 0.10	± 0.10	± 0.25	nr	8.1
H2	7.7	3.7	5.3	5.1		
	± 0.80	± 0.15	± 0.35	± 0.0	0.16	5.1
E1	20.3	10.6	5.2	6.0		
	± 0.95	± 2.05	± 0.25	± 0.25	nr	4.1
E2	52.8	26.1	11.9	16.2		
	± 5.50	± 4.25	± 1.25	± 1.15	<0.03	2.6
S.E.D. (12 D.F.)						

H = hydraulic; E = electrostatic; 1 = 25 g.a.i./ha; 2 = 50g a.i./ha.
nr. = not measured

There was excellent agreement between the chemical deposits and their biological effects in the trial on pea moth (*Cydia nigricana*). All treatments decreased the number of damaged pods but the electrostatic treatments gave better control than the hydraulic treatments at both application rates (Table 1). Approximately 30% of the chemical applied using the hydraulic sprayer passes through the crop and is deposited on the soil whereas the deposits on the soil from the electrostatic sprayer were smaller than the limit of detection of permethrin, less than 6% of the applied dose. The relative capture of spray drops by pea plants illustrates the difference between the two sprayers. The tendrils, generally protruding above the crop canopy, were very efficient in capturing small highly charged drops and the growing point being the next highest part of the plant, received relatively more chemical from the electrostatic sprayer than the hydraulic sprayer. The flowers, pods and leaves, to one node below the lowest pod or flower, captured twice as much chemical from the electrostatic sprays as from the hydraulic and the biological effectiveness correlated well with these deposits as these were the sites on which the eggs are laid or which the larvae attack (Anon 1979).

In some instances there was an apparent rather than a real correlation between total chemical deposit and biological effect. Thus the control of eyespot (*Pseudocercosporella herpotrichoides*) in winter wheat apparently reflected the amounts of chemical deposited on the whole plant by the different sprayers. At the time of application, growth stage 30 (Tottman & Makepeace 1979) the crop canopy was not completely closed and the electrostatic sprayer deposited three times as much fungicide on the plants as did the hydraulic sprayer (Table 2).

TABLE 2

Control of eyespot in winter wheat with Sportak alpha (1983)

Sprayer	Prochloraz deposit µg/g	% stems with eyespot
Hydraulic	138 ± 5.8	28.1
Rotary Atomiser C	450 ± 46.4	10.7
Rotary Atomiser U	207 ± 14.5	15.7
Unsprayed	-	40.8
S.E.D.	-	7.30

C = charged: U = uncharged.
Sportak alpha applied at GS 30 at 1.5 litres product/ha.

However it would be expected that the electrostatic sprayer would give increased deposits on the leaf blades but not in the axil of the lowest leaf where chemical is required for maximum effectiveness (Janicke *et al.* 1984) and this was subsequently confirmed in 1984 (Table 3). Neither of the pesticides used in 1983 are volatile or phloem mobile; thus the improved control achieved with the electrostatically applied sprays must have depended on a physical redistribution of the fungicide.

TABLE 3

Comparison of propiconazole deposits (μg/g) on leaves and stem bases of winter wheat applied at growth stage 30. (1984)

Site	deposits on leaves H	E	deposits on stem base H	E
A	52.0 ± 1.60	183 ± 1.40	10.2 ± 1.35	9.6 ± 0.81
B	95.4 ± 6.85	219 ± 18.2	20.0 ± 1.34	19.8 ± 8.31
C	53.0 ± 4.55	149 ± 3.2	9.5 ± 1.93	5.1 ± 2.05

H = hydraulic; E = electrostatic
Hispor applied at growth stage 30-31 at 0.5 kg product/ha.

The field performance of sprays is also dependent on the physicochemical properties of the pesticide and its formulation. If a contact pesticide is used to control a non-mobile pest then for maximum effectiveness there must be an exact correspondence between the inital spray deposit and the distribution of the pest. Permethrin applied electrostatically gave poor control of *Aphis fabae* on field beans even though the deposit on the upper part of the plant was twice as large as that achieved by the hydraulic sprayer (Table 4). This can be attributed to the failure of the charged spray to penetrate the tightly bunched foliage and therefore the spray drops cannot impinge directly on the aphids. The initial distribution of demeton-S-methyl applied electrostatically would be expected to be similar to that of permethrin but in this case the pesticide could redistribute in the vapour phase or by translocation and control of the pest was at least as good as that achieved by the hydraulic treatment.

TABLE 4

Control of the black bean aphid

Treatment	chemical deposit	% stem infected
Untreated		35.6
Permethrin H 100g a.i./ha	6.1 ± 0.63	2.5
E "	10.6 ± 0.98	20.6
Demeton-S-methyl		
H - 240g a.i./h.a.	16.0 ± 0.53	0
E - "	45.2 ± 2.49	0.6
E - 120g a.i./h.a.	27.4 ± 1.45	0.6
E - 60g a.i./h.a.	8.9 ± 0.36	4.4
S.E.D. (27 D.F.)*		6.31

*some data from larger trial omitted from table.
H = Hydraulic; E = Electrostatic

In other circumstances redistribution can be disadvantageous. For example a twenty-fold increase in deposit of pirimicarb on cereal ears with the electrostatic sprayer (Table 5) gave poorer control of grain aphids than the hydraulic sprays. Under the prevailing weather conditions 65% of pirimicarb was lost from cereal ears in 140 minutes whereas with the hydraulic sprayer the larger deposits deeper in the crop canopy may have been released over a longer period giving a more persistent biological effect. In these circumstances oil formulations, from which volatilisation of pesticides is often slower than from water, applied electrostatically may give much better biological performance. In a subsequent trial under cooler conditions and using a less volatile insecticide, dimethoate, the increased deposits achieved with the electrostatic sprayer gave improved control of grain aphids (Table 5).

TABLE 5

Insecticide deposits on winter wheat ears and control of aphids

(i) Pirimicarb 1982

Sprayer	insecticide deposits ear (μg/g)	 leaf 2 (μg/g)	Aphids/20 ears
Electrostatic	131.3 ± 36.05	27.5 ± 6.41	3.0
Hydraulic	5.5 ± 0.27	45.6 ± 4.43	1.4
Untreated			7.1
S.E.D. (6 D.F.)			2.06

(ii) Dimethoate 1983

Sprayer	insecticide deposit on ear (μg/g)	% stems with aphids
Hydraulic	2.9 ± 0.31	26.2
Electrostatic (C)	22.3 ± 1.01	8.1
" (U)	4.9 ± 1.28	21.2
Unsprayed		51.2
S.E.D. (12 D.F.)		4.8

C = charged; U = uncharged.

It is well established that effectively charged spray clouds can deposit considerable amounts of pesticide on the abaxial surface of leaves (Arnold & Pye 1980; Coffee 1979) and this could be biologically advantageous. Often the deposits on the abaxial leaf surfaces on field crops are much less than obtained in the laboratory (Arnold <u>et al</u>. 1984a) but results from a trial on the control of aphids on small sugarbeet plants indicated that this could still give a useful improvement in pest control (Table 6). The differences in deposits achieved with various

TABLE 6

The use of pyrethroids for the control of aphids on sugar beet

Sprayer and application volume	Chemical deposits µg/g	% aphid control
Hydraulic 500 1	56.9 ± 5.6	60
Hydraulic 3 bar 60 1	59.2 ± 8.4	60
Charged hydraulic 3 bar 60 1	87.7 ± 6.3	53
Hydraulic 6 bar 60 1	73.9 ± 4.5	55
Ape 80 1 1	100.6 ± 5.8	91
Electrodyn 3.7 1	115.9 ± 48.0	97

hydraulic sprayers did not affect the efficacy of the treatments and it was only with the APE 80 and 'Electrodyn' sprayer, which give a small further increase in deposit, that aphid control with a contact pyrethroid was good. Observations with the fluorescent tracer, Uvitex, confirmed that only the APE 80 and 'Electrodyn' sprayers deposited significant amounts of chemical on the abaxial surface of sugar beet leaves where the aphids resided.

The increased capture of charged drops by crop plants often causes reduced penetration of crop canopies (Griffiths et al. 1981; Morton 1982; Hislop 1983). This can cause decreased biological efficacy of pesticide, for example in the use of isoproturon for control of black grass in cereals (Table 7). Chemical deposits on black grass hidden beneath a taller cereal crop were small when the Jumbo electrostatic sprayer was used (Table 7). Even when chemical deposits were equivalent to those

TABLE 7

Effect of method of application on the control of black grass in winter wheat using isoproturon

	Isoproturon deposits on w. wheat mg/g	Isoproturon deposits on grasses mg/g	black grass heads/m^2	yields t/ha
H1	2.13 ± 0.05	2.48 ± 0.21	101	10.15
H2	4.28 ± 0.16	5.30 ± 0.18	3	10.75
E1	3.00 ± 0.25	2.25 ± 0.10	219	9.54
E2	5.41 ± 0.32	4.23 ± 0.29	44	10.26
M1	2.04 ± 0.18	1.57 ± 0.13	284	8.78
M2	4.39 ± 0.14	3.11 ± 0.25	24	10.58
Untreated			327	8.51
S.E.D.				

Sprayer H = Hydraulic; E = Jumbo; M = Micron-X electrostatic rotary atomiser. 1 = 1.05 kg a.i./ha; 2 = 2.1 kg a.i./ha achieved with a hydraulic sprayer, biological effects were less. The explanation is probably that isoproturon acts also via the soil (Blair, 1978) and soil deposits are also less (Arnold et al. 1984a) with the electrostatic sprayer.

Attempts have been made to increase the penetration of crop canopies by charged drops by varying the charge/mass ratio on the spray drops (Parham 1982; Pye 1983). However, the work of Pye (1983) showed that decreasing the charge/mass ratio decreased the total amount of chemical captured by the crop and so is likely to decrease the effectiveness of electrostatic sprayers. Alternatively air assistance can be added to electrostatic sprayers (Hislop et al.1983b) and this when used with electrostatically charged rotary atomisers significantly changed the distribution of spray deposits in a spring barley crop (Table 8). Deposits on the lower leaves (leaf 3) were increased and those on the upper leaves (leaf 1) decreased without affecting the overall amount of chemical deposited. Subsequently, Tilt Turbo applied through an APE 80 sprayer with air assistance gave improved control and higher yields than the unassisted sprayer (Table 9).

TABLE 8

Effect of air assistance on the deposition of tracer chemicals in spring barley achieved using electrostatic sprayers

	Deposits of tracers (µg/g)				
Sprayer	E	E + A1	E + A2	Hydraulic	SED (45DF)
leaf 1	119.8	94.0	100.0	26.5	6.54
leaf 2	49.9	45.4	53.7	31.7	3.47
leaf 3	17.9	22.6	31.4	34.7	4.44

tracers applied at growth stage 37-39
Sprayer E = electrostatic rotary atomisers; A1 air assistance at 15 m/s; A2 air assistance at 30 m/s.

TABLE 9

The effect of air assistance on the performance of electrostatic sprayers for the control of mildew in spring barley

Sprayer	% leaf area with mildew	chemical deposit µg/gm	yield tonnes/ha
Hydraulic	6	7.9 ± 0.99	6.30
Electrostatic	9	7.9 ± 1.03	5.74
Electrostatic + air	5	8.0 ± 0.60	6.19
Untreated	59.5	-	5.42
S.E.D. (40 D.F.)*	3.77	-	0.185

* some data from larger trials omitted from table

The addition of air-assistance to a sprayer designed for ULV application increases the complexity and removes some of the advantages of these sprayers and so other methods of improving crop canopy penetration should be investigated. Newer designs of electrostatic sprayers show considerable promise (Pye & Cayley unpublished) and more consideration should be given to the timing of electrostatic applications. For mildew control in barley at least two fungicide sprays are often required. In late autumn the crop is an ideal target for electrostatic sprays and treatments applied at half the recommended rate can give equivalent control to the full rate applied hydraulically (Table 10). Similarly when treatments are applied to protect the flag leaf from disease the electrostatic sprayer can deposit more chemical on the upper parts of the plant than the hydraulic sprayer and can give better disease control (Table 11). Thus using appropriate timings it should be possible to obtain good biological results with decreased doses using these sprayers.

TABLE 10

Control of mildew and leaf blotch in winter barley

Sprayer	Rate*	propiconazole deposit (μg/g)	% leaf area infected mildew 24/11/83	% leaf area infected leaf blotch 18/4/84	yield tonnes/ha
Hydraulic	2	120.7 ± 11.41	10.7	14.0	6.65
	1	59.7 ± 8.36	25.7	17.1	6.64
Jumbo E	1	171.7 ± 8.98	9.6	14.3	6.53
APE 80 E	1	135.7 ± 8.88	12.6	16.5	6.64
Untreated			40.1	42.3	5.96
S.E.D. (21 D.F.)			3.47	3.87	0.238

Some data from a larger trial omitted from this table
*Rate 2 = 125g a.i./ha; 1 = 62.5g/ha
Sprays applied at GS 13, 21 on 3/11/83 and at GS 24 on 14/3/84.

TABLE 11

Spring barley - mildew

Sprayer	Rate	triadimefon deposit (μg/g)	% leaf area infected with mildew	yield tonnes/ha
Hydraulic	1	31.9 ± 2.20	21.1	6.15
	4	84.2 ± 36.15	0.6	6.34
Electrostatic	1	108.7 ± 39.26	10.0	6.09
	4	283.6 ± 28.01	0.2	6.48
Untreated			37.3	5.92
S.E.D. (27 D.F.)			4.75	0.362

Some data from a larger trial omitted from this table
Rate 1 = 31g a.i./ha; 4 = 125g a.i./ha
Sprayed 13/6/84 at GS 41.

The logistic advantages of ULV spraying are obvious and the addition of electrostatic charging often allows dose rates to be reduced without significant loss of biological effectiveness. Environmental pollution is further reduced since a larger proportion of the applied dose is attracted to the target plants. Although there are still problems for electrostatic sprayers their many advantages make them worthy of intense investigation.

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USING THE SEED AS A CHEMICAL CARRIER

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ABSTRACT

Seed treatments are a very effective and efficient method of applying chemicals to a crop. Field trials have shown that in order to control all three of the important soil and seed-borne diseases of peas it is necessary to use a seed coating process, as it was impossible to stick sufficient material onto the seed using standard seed dressing techniques. Using the coating process it was possible to include an insecticide in the seed dressing which gave excellent control of the pea and bean weevil (*Sitona lineatus*). Previously *Sitona* control had only been possible with costly sprays or phorate granule treatments.

INTRODUCTION

Each year the large chemical companies spend many millions of dollars developing new chemicals for agriculture. These new herbicides, fungicides and insecticides are safer than their forerunners, more active and more selective.

However, despite these advances in chemistry, the process of applying these chemicals to the crops has hardly changed in the last 50 years. The vast majority of these chemicals are simply mixed with water and sprayed through a nozzle to produce small droplets which land on the crop. It is widely acknowledged that this process is very inefficient as only a very small proportion of the chemical actually reaches the target site. The remainder is thus wasted.

The work presented in this paper is from a series of trials conducted over three years on the development of a new seed treatment for peas. Seed treatments have been widely used for the last forty years to control some seed-borne diseases and the 'seedling damping-off' diseases with materials such as mercury, thiram, captan and drazoxolon. However, the recent development of various systemic fungicides and insecticides has meant that it is now possible to control a wide range of fungal and insect pests using seed dressings. Probably the best known example is the control of powdery mildew on cereals with ethirimol and triadimenol.

Peas can be subjected to attack by a number of diseases including the 'seedling damping-off' diseases (primarily *Pythium ultimum*), leaf and pod spot (caused by several closely related fungi *Ascochyta pisi*, *Mycosphaerella pinodes*, *Phoma medicaginis* var. *pinodella* and downy mildew (*Peronspora viciae*).

The development of 'damping off' diseases, caused primarily by the soil-borne fungus *Pythium ultimum*, is favoured by cool, wet conditions.