7.
Other Localised Treatments with Pest Control Agents

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IMPROVED BIOTARGETING OF SOIL-APPLIED PESTICIDES

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ABSTRACT:

Current application technology for soil-applied pesticides has not kept pace with recent advances in pesticide chemistry. Concerns over economics, the environment and the health of users are forcing government and industry to look at alternatives in pesticide application technology. Banding and in-furrow application techniques are the oldest and most widely used granular application methods that stress targeting. Newer application methods such as skid, slot, and point injection are under intense review in the USA and some examples are described in this paper.

WHY IMPROVE METHODS FOR APPLYING PESTICIDES TO SOIL?

Pesticides provide innumerable benefits through the control of pests which destroy almost 33% of all food crops. However, the use of pesticides has also resulted in significant costs to public health and the environment (Pimentel & Levitan, 1986). In general, the amount of agrochemicals released into the environment has risen 1900% in the 50 year period between 1930 and 1980 (Hess, 1987). The improved efficacy of the more recent pesticides has allowed doses to be reduced in some instances to a few grams per hectare, but the capability to deliver these reduced amounts of agrochemicals remains suspect, numerous researchers estimating "1-2% arriving at the target". Graham-Bryce (1983) discussed the increasing efficacy of modern pesticides and suggested that further improvements in efficacy may not be as rewarding to agriculturists as unlocking such secrets as biological availability and developing bio-targeting through improved methods of delivery. Geissbuhler *et al.* (1987) predicted that future activities for research in agrochemicals will be governed by factors including 1) advances in the knowledge of crop biochemistry and pest biology, 2) decreased successes in conventional approaches, 3) increased use of electronic information and data development and transfer, and 4) increased economic and ecological pressures leading to a modified crop technology and regulatory environment. As a consequence of this environment we will see 1) biotechnology becoming an increasing component of research, 2) more "biorational" designs of pesticides, 3) more sophisticated evaluation systems, and 4) development of target-oriented delivery systems.

Pesticides are applied to the soil to control a large range of pests. Herbicides dominate soil-applied pesticide use followed by insecticides and nematicides. Concern over groundwater contamination and non-point source pollution is growing in North America and has led to the banning of the herbicide alachlor in Canada (McDonald, 1987). Current non-point pollution laws in the USA would curtail pesticide use severely if rigidly enforced. Dissipation of pesticides throughout the soil profile has been studied intensely in conventional tillage. Although Baker (1985) found that minimum and no-tillage schemes reduced pesticide run-off in surface water drastically, the final position of the residues is not clear. If the pesticide does not move laterally with run off, does it move vertically? Edwards (personal communication, 1987) hypothesized that reducing runoff would allow pesticides to be degraded by biotic and abiotic factors.

The economic problems caused by pesticides not reaching the target are astounding. Pimentel & Levitan (1986) estimated that only 0.1% of the [actual] pesticide reaches the target and recommended strongly that the target must be defined more accurately. Application technologies, especially with soil-applied pesticides, offer many possibilities for increasing the efficiency of pesticide usage.

Commodity surpluses have eroded profitability at the production and market levels. This situation was brought about partly by the ease of use of agrochemicals and the neglect of key factors such as the timing of pesticide application in integrated pest management programs. Resistance management is another factor which has recently been given increased consideration (Dover & Croft, 1984). Cotton, a crop with rigid integrated pest management programs, has benefited from the present state of application technology (Metcalf, 1980). In other cropping schemes, timing and resistance management could only be implemented if application technology were to be improved.

Health risks to pesticide users are being scrutinized more often by various agencies. One study in Kansas reported a significant correlation between pesticide exposure and certain types of cancers (Hoar *et al*. 1986). One bright spot reducing operator exposure is the use of no-touch dissolvable pesticide pouches (Miller, 1987) . An area of intense study in agricultural engineering is the direct injection of pesticides from the original container (Reichard & Ladd, 1983) and this also shows potential for no-touch technology.

Regulatory concerns and actions may force an increased restriction on pesticide use if application technologies are not improved. Presently, modification of pesticide formulations is viewed as the most expedient way around some of these problems as well an opportunity to improve bioavailability. In the future, targeting of pesticides to the pest will be emphasized to a greater extent.

PRINCIPLES OF TARGETING

Placing pesticides as close to the target as possible is clearly fundamental to good pest management, but as Courshee (1960) concluded, the target needs to be defined in terms in space and time.

Increased knowledge of insect biology should reveal the most vulnerable stage in the life cycle and a greater understanding of insect movement should increase the probability of impingement or encounter with pesticide residues within the crop or soil environment.

Plant pathogens and weeds also elicit difficulties in targeting, one of the major problems being the identification of the specific target sites and subsequent delivery protocols. Matthews (1983) summarized the problems relating to insects, pathogens and weeds and the parameters of equipment selection and modification, and clearly much has been accomplished in defining the appropriate principles. However, many opportunities for improving the selective placement of toxicants within the crop environment remain. Graham-Bryce (1983) succinctly identified a major problem by comparing laboratory and field toxicities of DDT and deltamethrin (Table 1). Although more potent, deltamethrin loses a significant proportion of

TABLE 1

Comparison of intrinsic activities and application rates for representative insecticides (after Graham-Bryce, 1983).

Insecticide	Typical application rate, g/ha	Relative application rate	Relative lethal dosage[a]
DDT	1000	50	1600
Dimethoate	500	25	1039
Deltamethrin	20	1	1

[a] Mean value calculated from data for four species; Phaedon cochleariae, Anopheles stephensi, Choristoneura occidentalis, and Musca domestica.

this advantage relative to DDT when placed in a field situation. Further, although optimum ranges of droplet sizes for selective targets have been determined (Table 2), the ability to deliver these specifications is often wanting (Matthews, 1983). We also have a great deal yet to learn about the optimum placement strategies and criteria for major pests (Hislop, 1987). With the increasing pressures from ecologists, economists, and environmentalists it is now clearly up to us, as responsible scientists, to delineate the parameters which would allow more precise delivery of agrochemicals.

TABLE 2

Optimum droplet size ranges for selected targets (after Matthews, 1983).

Target	Droplet sizes (um)
Flying insects	10-50
Insects on foliage	30-50
Foliage	40-100
Soil (and avoidance of drift)	250-500

CURRENT TARGETING: PROBLEMS AND OPPORTUNITIES

Soil is a complex "organic soup" and its variability has a profound impact upon the performance of pesticides which are expected to move out of the targeted area, diluting themselves in the process, or to just stay put.

In either case, pesticides are exposed to numerous biological and chemical processes which decrease their persistence and performance. Pesticides are expected to be applied easily, reach the target pest, kill it and then dissipate.

The availability of a soil-applied toxicant to its target is a function of the toxicant's concentration in soil solution or soil air. With incorporation into the soil, these concentrations also control movement of the toxicant (Hance, 1983).

Kuhlman (1984) suggested that misapplication of pesticides was an overlooked reason for many failures of soil insecticides. In a survey initiated in 1983 to determine the accuracy of granule applicators in Nebraska, c. 80% over-applied soil insecticides. Although cooperators in the survey relied upon useage directions on the pesticide label and the granule applicator manual, 90% were misapplying soil insecticides (Sommers 1985). Similarly, Suett (1987) concluded that operator error was the main cause of inaccurate and non-uniform spray application of preplant insecticides to peat blocks and loose-filled cells. Pre-blocking incorporation of granular formulations was the most uniform treatment. An additional conclusion was that inadequate performance of insecticides against target pests was not being reported by growers. This suggested that the current recommendations are sufficiently wasteful of insecticide products to withstand this lack of application accuracy.

The study of Rider & Dickey (1982) illustrated vividly the problem issues of calibration and the lack of reliable methodology, frequency and accuracy. Their data showed that 25% of the applicators underapplied by c. 21% and 1 in 3 overapplied by c. 40%. In addition, 4 of 10 boxes on the same equipment had more than 50% variation error. Reichard & Hedden (1970) showed the variation in delivery patterns, the lack of consistency with rotor speed changes and deficiencies in flowability, pulverizing, and delivery rates. Studies by ICI (personal communication, Bates 1984) with granular pesticide formulations metered with Noble V-belt units showed variations in repeated runs ranging from 18-104% with the same formulation. Variation between products was even higher, demonstrating that each formulation has its own characteristics of flow, degradation and bridging. Ellis (1982), in a study of grower-applied granular pesticides, showed that 13% of the equipment delivered less than 80% of the recommended rate and 50% of the equipment varied the delivery rates by more than 20%. Ellis also confirmed that increasing travel speeds confounded patterns of granule delivery.

New carriers being utilized in granular formulations may impart characteristic flow patterns. Products now take the form of granules with 5, 10, or 15% active ingredient and each has its own flow characteristics. The increase in the activity of present day insecticides against pests has not been met with a similar increase in studies of delivery characteristics of these materials in new and innovative granular applicators. A more coordinated effort is needed between the agricultural chemical industry and agricultural equipment manufacturers if we are to make significant improvements in the targeting and delivery of pesticides.

Erbach & Tollefson (1983) observed irregular distribution of fluorescent coated blank insecticide granules in soil and they concluded that some form of active incorporation would be helpful. They also alluded to the possible disturbing effect of wind on granule distribution. Bergman *et al.* (1986) demonstrated that the density of granular products played a significant role in the performance of the compounds, i.e., the more dense granules had less drift potential. When wind shields consisting of vinyl floor molding were put into place, little if any drift occurred. This relatively simple and inexpensive modification could be accomplished easily by farmers. However, in the absence of meaningful incentives, i.e., well documented economic benefits, and/or regulatory statutes, this simple but effective modification is not likely to occur on the average farm.

LESS PESTICIDE, INCREASED EFFICACY - HOW?

Improved targeting of soil insecticides is of paramount importance in solving these problems. Firstly, the formulation of the compound must be considered. Granules require moisture to release insecticide to the soil and furthermore, the release pattern is unlikely to be uniform due to variability in the carrier and the soil. Therefore, a liquid formulation which has higher quality control in its manufacture and is already in a uniform state may significantly increase the effect of targeting.

Targeting of pesticides in turf presents a unique situation. The thatch layer, which is an accumulation of dead organic matter, provides a unique microenvironment that was overlooked until recently. Niemczyk (personal communication, 1987) suggested that a point injection system might hold much promise as a new means of applying products to control turf insects. Diazinon, a principle turf insecticide, is bound in the thatch layer, a phenomenon which underlines the importance of developing placement stategies to overcome identified physical/chemical barriers (Sears & Chapman, 1979). Although any cosmetic disruption of turf is likely to be discouraged by industry, the practicality and feasibility of this approach for some purposes may outweigh such a disadvantage. Further, pressure by environmental groups may force additional attention to the efficiency of chemical usage within the turf industry. The opportunity to circumvent this constraining parameter would allow more efficient utilization of a chemical tool <u>without</u> resorting to higher use levels.

McCracken (1987) described a new application system utilizing specific lengths of microtubules to deliver low volumes of agrochemicals into open seed furrows at sowing time. The usefulness of this approach was borne out by the fact that targeting of the chemical into the root area to achieve improved uptake by plants and insects can be an alternative to seed treatment and is more accurate than conventional banding. Additionally, liquid formulations give quicker responses than granules. Tests done in Australia and the USA have shown good potential for further development using a neat form as well as mixtures, and include developments of a closed system of handling the chemical. Serious consideration is being given to this system for control of the Russian Wheat Aphid (<u>Duraphis noxia</u>) a recent and devastating pest in the USA (FMC and Mobay, personal communication).

Problems such as an increased environmental burden as a result of repeated applications, premature leaching, or increased applications used to guarantee the required effect are challenges that will have to be addressed. One solution to reducing these problems is with the use of controlled release technology. The use of EVA (ethylene vinyl acetate copolymers) films, incorporated with pesticides with different stability, release rates, and biological efficacy showed promise for control of some pests (Bahadir & Pfister, 1987). In general, synthetic pyrethroids do not exhibit significant activity against soil insects because of their propensity to bind with soil organic matter. In another study at the Gesellschaft für Strahlen-und Umweltforschung München, the formulation of products with special carrier materials enabled the bioavailability of pyrethroids to soil insect pests to be increased (Bahadir, personal communication, 1987). In tests using potted cauliflower plants, the materials were scattered next to each stalk and infested with 20 cabbage root fly eggs (Delia radicum). Compared to the normal development rate of c. 40%, the pyrethroids exhibited excellent potential for field trials (Table 3). Trimnell *et al.* (1981) successfully doubled the half life of

TABLE 3

Results of a greenhouse test with stablized synthetic pyrethroids for control of cabbage root fly (Delia radicum) (after Bahadir, personal comm.).

Treatment	Development Rate (%)
Control	34.9 a
Control with carrier (no insecticide)	40.3 a
Chlorfenvinfos	0.4 b
Deltamethrin[a]	7.1 b
Cypermethrin[a]	0.0 b

[a] Pythrethroids used at 1/10th the rate of the standard chlorfenvinfos.

diazinon, a highly volatile organophosphorus insecticide, using a starch xanthate microencapsulation process. The application of this technique also extended the efficacy of the thiocarbamate herbicides EPTC and butylate (Schreiber & White,1980). Weed control was increased by 50% using only 75% of the active ingredient in the regular emulsifiable concentrate formulation.

To increase the efficiency of liquid delivery systems, other liquid agrochemicals could be applied simultaneously. An example of this was reported by Clapp *et al.* (1985) who used a skid injector to deliver insecticide, fertilizer and combinations of both to corn. Unfortunately, the mechanics of the skid injector did not permit the insecticide to penetrate the root zone to the required depth of 0.5 to 1.5 cm. Corn rootworms (Diabrotica sp.) were not controlled because only a minute amount of insecticide, if any, reached the rootworms (Table 4). Differences in water solubility of the insecticide and fertilizers also influenced the efficacy of the individual compounds, stressing the importance of matching the physical properties of soil insecticides to the mechanics of the application system.

TABLE 4

Effects of using a skid injector to apply insecticide treatments for control of corn rootworm larval damage to corn (after Clapp *et al*. 1985).

	Mean Root Damage Rating (1-6 scale)[a]		
	Type of Postemergence Application		
Time of Application	Nutriblast	Cultivator	Mean
Planting time	2.56 a	1.90 b	2.35 a
Postemergence	3.15 b	1.55 a	2.24 a
Untreated	3.10 b	4.45 c	3.78 b

a/ Means within columns sharing a common letter do not differ signficantly according to Duncan's multiple range test (P = 0.05).

Another example of environmental issues driving research in order to continue use of a product was that experienced by Union Carbide (now Rhone Poulenc AG). Wildlife impact assessments for the Environmental Protection Agency are now required for many granule delivery systems in that the efficiency of the incorporation process needs to be documented. Recent studies using ultraviolet light photography of inert fluorescent dyed granules validated the efficiency of the incorporation process when applied as specified on the product label. A more interesting and recent development by Rhone Poulenc AG was the use of the intermittent delivery concept of Reichard & Ladd (1981) to apply aldicarb to citrus trees in a localized manner. The conventional means of banding aldicarb granules to a row of trees may be replaced by a technique which uses an infrared photocell to sense the tree and automatically meters out a quantity of aldicarb granules in two narrow streams. A rolling cultivator behind the unit incorporates the granules. The methodology accomplishes the same biological effect as conventional techniques with significantly less material and has been successfully utilized on large acreage in Florida and Texas in 1987.

Another example of refined targeting of soil-applied pesticides for surface and subterranean pests was the blowing of granular pesticides into 15 cm deep vertical bands in freshly prepared seedbeds prior to lateral distribution (Whitehead, 1983). This method of application does not depend upon leaching for moving toxicant to soil pests. In addition, the technique is faster than rotary hoeing the soil. Readers are encouraged to read the paper by Suett & Thompson (1985) which describes banding and subsurface treatments, carrier types, and also peat block and seed treatments.

Slot injection is another type of placement for soil insecticides in which a nozzle is placed directly behind the coulter, the penetration depth of which can be varied, and the pesticide is "shot" into the slot. The advantage of this system over others currently in use is the direct placement of the compound at the target site, the mechanical simplicity, the flexibility of delivery depth, liquid formulation uniformity and low application rate. The lateral movement of the insecticide to the target area remains a slight problem. Physical properties of the pesticide such as vapour pressure, water solubility, and soil adsorption must be investigated with more scrutiny in this type of system.

A study was initiated in 1987 with a slot injection device to compare the performance of the injector for controlling corn rootworm with other application methods. Two soil insecticides (diazinon and isazophos) were selected on the basis of water solubility and vapor pressure. These physical parameters were selected in order to identify what physical property may be responsible for lateral movement of insecticide to the root mass. A cornfield continuously cropped and with a defined soil type and severe rootworm pressure was selected for the study and two-row injection

TABLE 5

Influence of application and timing on control of rootworm on corn.

Treatment	Formulation & Rate AI/ha		Root rating[a]
DIAZINON			
Planting Time	14G	1.12 kg/ha	3.33 a
Cultivation	14G	1.12 kg/ha	2.82 ab
Injection	4E	1.12 kg/ha	2.43 b
Injection	4E	0.37 kg/ha	2.87 ab
LSD = 0.76 (p = 0.05)			
ISAZOPHOS			
Planting Time	10G	1.12 kg/ha	2.25 b
Cultivation	10G	1.12 kg/ha	4.15 a
Injection	4E	1.12 kg/ha	2.15 b
Injection	4E	0.37 kg/ha	2.45 b
LSD = 1.02 (p = 0.05)			
UNTREATED CHECK			
Pooled			4.50

[a] Iowa Root Rating Scale: 1 = no damage; 2 = pruning; 3 = heavy pruning, economic threshold; 4 = one node of roots destroyed; 5 = two nodes destroyed; and 6 = three nodes of roots destroyed.

equipment was used to deliver 93.54 litres of finished spray per hectare at 70310.0 ATm. Treatments of diazinon and isazophos were planting time application, cultivation rescue (both 1.12 kg/ha with granular formulations) and injection at 1.12 kg/ha and 0.37 kg/ha using the 4E formulations. Planting time application of diazinon performed poorer than cultivation or injection treatments which may have been due in part to the highly volatile nature of diazinon (Table 5). Hence, shorter persistence left little active ingredient for the target rootworm larvae. Isazophos controlled rootworms very well except in the cultivation treatments. This may have been due to the highly water soluble nature of the insecticide. Since moisture was not readily available to activate the granules during the three week post application period, performance was poor. Injection treatments provided good to excellent control while the checks demonstrated consistent rootworm pressure. Overall, the injection treatments at lower rates show much promise for the future.

CONCLUSIONS

While soil-applied materials do not exhibit the drift-accountability problems of atomized sprays, they clearly have unique and mounting problems of groundwater contamination, enhanced biodegradation, application efficacy and accuracy, and predictability.

The dynamics of the many soil processes to which pesticides are subjected in the soil environment are numerous and complex. If the physical properties of the soil insecticide cannot be exploited by formulation to elicit a satisfactory response, then targeting efficiency may be improved through application technology. Although the skid injection system was unsuccessful due to water solubility and poor penetration, one way to circumvent this obstacle is to inject the pesticide into the soil.

The opportunity to increase user-awareness of the principles of calibration, with its economic advantages and ecological ethics, is clearly our responsibility to undertake via application technology programs. Clearly, the calibration (or lack of it) issue remains a nagging problem <u>in spite</u> of our increased educational efforts. If improvements in delivery efficiency are not achieved via cost containment incentives, then perhaps regulatory restrictions will force the move towards a "more prescriptive environment encompasssing the principles of biotargeting technology".

Environmental issues will continue to force attention on the potential for better targeting of soil-applied pesticides. As concluded by Hance (1983) "The theoretical opportunity of improving the efficiency of chemicals by devising better procedures to transfer them to the target site remains a tantalizing technical possibility which justifies continuing research on the physical and biological processes that control the distribution, concentrations and persistence of pesticides in the soil."

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TECHNIQUES FOR THE APPLICATION OF PENCYCURON TO CONTROL BLACK SCURF *(RHIZOCTONIA SOLANI)* ON POTATOES

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ABSTRACT

Several techniques were used to apply a suspension concentrate and a dry seed treatment formulation of pencycuron for the control of black scurf in potatoes caused by *Rhizoctonia solani*. The suspension concentrate formulation was sprayed onto soil and incorporated prior to planting or into the furrow from nozzles mounted on the planter. The latter method allowed treatment of tubers and soil.

The theoretical loading on individual tubers was calculated and the control of black scurf at three sites was reported. The results show that where infection was principally seedborne, seed treatment was the most efficient method but soil sprays were essential to control soil borne infection. The factors affecting treatment performance at each of the sites are discussed.

INTRODUCTION

The fungus *Rhizoctonia solani* Kühn, mycelial state of *Thanatephorus cucumeris* (Frank) Donk, occurs in potato growing regions throughout the world and causes several types of damage to the crop. The biology of the pathogen was described by Brenchley and Wilcox (1979) and recent investigations into some aspects of the disease were discussed by Hide *et al*. (1985a, 1985b). In addition to stem cankers, it produces irregular, entirely superficial, black encrustations (sclerotia) of varying size on the surface of the tubers. Although the sclerotia do not affect the flesh of tubers, their conspicuous presence on washed tubers sold in plastic packs can be unacceptable. On seed potatoes sclerotia are an important source of inoculum which may lead to rejection, particularly if the seed is for export. Hence there is a need to control the disease.

Pencycuron is a fungicide with specific action against diseases caused by *R. solani* and was developed initially for the control of sheath blight in rice. It has a low vapour pressure ($< 10^{-3}$ Pa at 20°C) and water solubility (0.4 x 10^{-3} g/l) and is a non systemic fungicide capable of giving a long lasting protectant effect.

During 1984 pencycuron was marketed as a wettable powder formulation in the Netherlands with the trade name 'Monceren'. Further development lead to the replacement of this by suspension concentrate (SC) and dry seed treatment (DS) formulations during 1985. The SC formulation was particularly effective in the Netherlands where the intensities of cropping and soil inoculum are higher than in the UK leading to the need for a soil treatment, as infection can come from either the soil or seed. The DS seed treatment is used largely for the ware crop.

Trials commenced in the UK during 1985 to investigate the performance of pencycuron in dry seed treatment and suspension concentrate form. During 1986, further small plot trials were established using a modified Johnson planter. This paper describes the equipment and treatments used in three trials and the effects of chemical placement.

MATERIALS AND METHODS

The trials comprised four replicates, plots being 10m long by 4 rows wide with 40 tubers planted per row. Plots were planted using a modified Johnson, semi-automatic, manned, 2-row planter. Band sprays were applied from nozzles attached to the planter framework (Fig. 1; Table 1). The overall incorporated soil treatment was applied with a CO_2-pressurised knapsack sprayer and subsequently worked into the top 3cm of soil with hand cultivators. The seed treatment was applied by scattering the required dose of chemical over potatoes in a large plastic bag and then rolling the bag five times in one direction and then in the other.

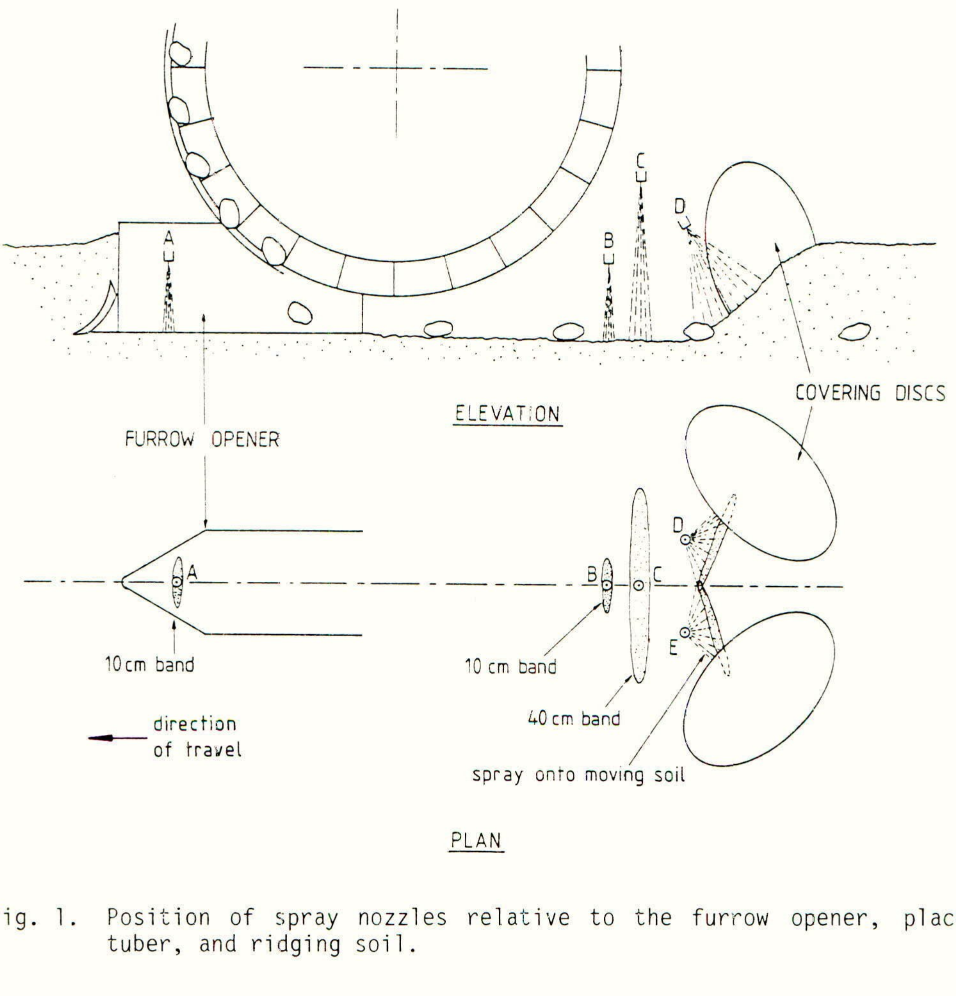

Fig. 1. Position of spray nozzles relative to the furrow opener, placed tuber, and ridging soil.

TABLE 1

Application and treatment details for pencycuron on potato tubers

Type of Application	Dose (a.i.)	Application details
Pre-planting, powder tuber treatment with 12.5% wt/wt dry seed treatment (DS)	25 g/ 100 kg tubers	Applied by rolling tubers with powder in a plastic bag
Sprays using 250 g/l suspension concentrate (SC):		
40cm band	5 kg/ha	1 8002E nozzle C @ 583 l/ha
40cm band	5 kg/ha	1 6501 nozzle A 2 80015 nozzles D, E @ 1168 l/ha
10cm band	10 kg/ha	2 6501 nozzles A, B @ 2335 l/ha
Overall	5 kg/ha	6 8003 nozzles (Suffolk) @ 400 l/ha (Lincs) @ 300 l/ha

(a) Band sprays were applied at 0.15 MPa,;overall sprays at 0.20 MPa.
(b) Band applications made to each crop row are expressed as the rate applied to the sprayed area. The rate per hectare of crop is dependent on the row spacing hence, for the same dose rate a 40cm band application on an 80cm row spacing would treat twice the crop area treated by an overall application.
(c) For nozzle positions A - E, see Fig. 1.

Spray treatments were designed to achieve different placement of active ingredient in the immediate vicinity of tubers (tubersphere) and in the ridge.

The single nozzle 40cm band treatment gave a simple furrow application targeting on the upper surface of the tuber and on the soil to either side. Some incorporation of the treatment occurred during ridge formation with the possibility of more active ingredient being moved into the tubersphere.

The three nozzle 40cm band treatment applied the fungicide to a 10cm band in the opened furrow before tubers were planted. Two further nozzles were directed at the covering soil and the tubers to spray the upper surface of the tuber and the moving soil as the ridge was formed, thus achieving good incorporation.

The two nozzle 10cm band treatment provided a simple in-furrow tuber treatment, spraying pre- and post-tuber placement to place the fungicide underneath and on top of tubers.

The overall, soil-incorporated spray was designed to achieve good distribution throughout the ridge.

In Table 2, rates of pencycuron are given for the applications at three sites. The calculations used to derive tuber loadings were based on the tuber spacing, row spacing, tuber weight and size (Table 3) but they did not take into account the loading efficiency of the seed treatment process nor, where sprays were applied, did they fully compensate for the three dimensional nature of the tubers. The theoretical doses were the amounts applied to the tuber area irrespective of treated soil being folded in over the tubers.

TABLE 2

Pencycuron: active ingredient/ha and on the tuber surface

	Active Ingredient g/ha of crop			Theoretical dose (mg a.i.) applied to tuber surface		
Type of Application	Suffolk	Lincs	Warks	Suffolk	Lincs	Warks
Tuber treatment (DS)	750	725	1100	14.4	15.6	20.8
40cm band 1 nozzle	2631	2325	2631	1.0	1.1	1.4
40cm band 3 nozzles	2631	2325	- -	1.7	1.8	- -
10cm band 2 nozzles	1316	1163	- -	2.0	2.2	- -
Overall incorporation	5000	5000	- -	- -	- -	- -

ASSESSMENTS

Seed tuber infection

Samples of 100 tubers were washed and examined for the presence of black scurf. The level of infection was recorded.

Progeny tuber infection

Following storage for 36 to 82 days after harvest, samples of 100 tubers per plot were washed and examined for the presence of black scurf and the number of infected tubers was recorded.

TABLE 3

Site details for experiments with pencycuron on potatoes

	Suffolk	Lincolnshire	Warwickshire
Potato cultivar	Bintje	Cara	Desiree
Nos. tubers/50 kg	870	800	600
% infected with black scurf	100	36	82
Average size of tubers (mm diameter)	50	52	60
Date of planting	16.5.86	8.5.86	26.3.86
Date of lifting	14 & 20.10.86	4.11.86	1.10.86
Date of assessment	25.11.86	10.12.86	22.12.86
Soil type	Sandy clay loam	Fine sandy silt loam	Stony coarse sandy loam
pH	7.5	7.2	5.7
Organic matter (%)	1.8	1.8	1.2
Seedbed conditions	Coarse, cloddy	Medium; some aggregates up to 5cm diameter	Moist and fine
Tuber spacing	25cm	25cm	25cm
Row spacing	76cm	86cm	76cm
Seed rate (t/ha)	3.0	2.9	4.4
Previous crop	Winter wheat	Onions Potatoes '81	Potatoes

RESULTS

The modified Johnson planter enabled the application of in-furrow treatments and in particular, the three nozzle treatment, where two nozzles sprayed the moving soil as it covered the tubers. Treatment changeover between plots was simply and quickly achieved. The only problem encountered was where the seedbed was less than optimal when ridging and hence soil incorporation, was inadequate.

Seed treatments were applied to fairly clean, dry tubers at the Suffolk and Warwickshire sites. Tubers at the Lincolnshire site had soil on their skin and were stored in the polythene bags prior to treatment which resulted in some sweating.

Seedbed conditions at the Warwickshire and Lincolnshire sites were suitable for good in-furrow incorporation during ridge formation but less satisfactory for overall treatment in Lincolnshire. At the Suffolk site soil conditions were cloddy which affected soil applications and lead to poor ridge formation requiring subsequent re-ridging.

Two trials included all of the application techniques, but the third trial had only a single nozzle 40cm band treatment (Table 4). All the trials gave statistically significant levels of disease control (P=0.05) and differences between means are indicated by superscripts.

TABLE 4

Percent reduction in the numbers of black scurf infected tubers

Application method	Dose (a.i.)	Suffolk	Lincs	Warks
Tuber treatment (DS)	25 g/100 kg	98.9[a]	95.0[a]	32.0[b]
40cm band 1 nozzle	5 kg/ha	54.2[c]	89.0[a]	79.0[a]
40cm band 3 nozzles	5 kg/ha	51.0[c]	97.6[a]	- -
10cm band 2 nozzles	10 kg/ha	78.8[b]	90.4[a]	- -
Overall incorporated	5 kg/ha	44.1[c]	51.5[b]	- -
Untreated (% tubers infected)		(91.8)[d]	(42.5)[c]	(46.5)[b]

Band applications are expressed as the rate applied to the sprayed area.

At each site, treatments with the same superscripts are not significantly different (P=0.05) based on transformed (arcsin) data.

DISCUSSION

The variability of results when chemically controlling potato tuber diseases is well known. In the case of seed treatments, this variability can be due to a number of factors including poor application resulting in low and uneven deposits, site conditions such as amounts of infection at harvest, soil inoculum, and soil on tubers as reported by Hyde (1986). The results in Table 4 show large variations between sites.

The source of the inoculum is known to be an important factor. The Suffolk site had no previous history of potato production and the seed was highly infected. At both the other sites seed-borne infections were also present but in addition these sites had histories of scurf infected potato crops. Potatoes had been grown five years previously at the Lincolnshire site and were the preceeding crop at the Warwickshire site.

The method of application used for the dry seed treatment provided a very uniform tuber deposit with high loading, a condition very difficult to achieve in commercial practice. This is reflected in the high level of control achieved at the Suffolk site and similar results at the Lincolnshire site. Consequently seed tuber infection was indicated as the major source of the disease. Although seed treatments provide a high level of active ingredient around the tubers and potentially seven times more than sprays, (Table 2) they provide limited protection against soil-borne infections. Thus the insignificant control at the Warwickshire site suggests strongly that infection of progeny tubers arose largely from inoculum in the soil.

Spray treatments can be considered to consist of two components, firstly that applied directly to the tuber and, secondly that which is applied to the soil around the mother tuber where the progeny tubers develop. The sprays described provided different proportions of active ingredient to seed tubers and the surrounding soil.

It is interesting that the 10cm band, 2 nozzle application gave such good control at both sites indicating that, despite lack of incorporation, it provided a chemical barrier around infected mother tubers.

The incorporation of fungicide in the soil was designed to protect the progeny tubers, irrespective of inoculum source. The significantly more effective control achieved with the spray application at the Warwickshire site further indicates the presence of inoculum in the soil. The efficacy of soil treatments is likely to depend on the efficiency of incorporation, itself largely dependent on soil tilth (Harris,1985). This could explain the differences illustrated at the three sites by the single nozzle treatment which was less effective on the cloddy Suffolk site. In spite of the theoretically better treatment of the mother tuber and the better soil incorporation, the three nozzle treatment gave no clear improvement in control over that given by the single nozzle.

The overall incorporation treatment provides no chemical directly to the seed tubers and relies on good even distribution throughout the ridged soil following thorough incorporation. It should protect daughter tubers from infection, irrespective of source though it did require the highest level of active ingredient per hectare of crop. Failure of the treatment at the Suffolk and Lincolnshire sites was likely to be due to the poor seedbed at the former and poor incorporation at the latter site. The treatment is known to be effective in the Netherlands on the Polder soils where seedbeds are generally good.

The results of these trials illustrate the importance of application techniques when using pencycuron to control black scurf. Source of infection and application conditions are the two major factors which affect the performance of this fungicide since it is immobile in the soil. Where seed-borne disease is the problem, seed treatment is the most efficient method of application. If the infection is soil, or seed and soil-borne, spray treatments are likely to be essential but their efficacy depends on soil conditions and placement.

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CONTROL OF ALLIUM WHITE ROT IN MODULE-RAISED BULB ONIONS

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ABSTRACT

Control of Allium white rot was achieved with pre-planting drenches of various fungicides applied to peat blocks and cellular trays. In comparative trials myclozolin and procymidone gave control of infection up to harvest and increased yields of clean onions from 2.4 kg to 25.0 and 28.7 kg respectively in 1984 and from 1.3 kg to 28.1 and 30.2 kg respectively in 1985. Procymidone gave significantly better disease control when applied at planting than stem base sprays applied 5 or 10 weeks post planting. Drench sprays of procymidone applied within a day of planting were very effective if applied in at least 1 l water/m^2. Enhanced degradation was thought to have reduced the effectiveness of iprodione and vinclozolin at some sites.

INTRODUCTION

Allium white rot caused by the fungus Sclerotium cepivorum is a widespread and increasing problem in the main areas of bulb onionproduction in the UK. Although control of this disease with fungicide has been successful in salad onions (Entwistle & Munasinghe, 1980), fungicide treatments have been of limited value on direct-sown bulb onions (Gladders, Pye & Wafford, 1984). However, the development of production systems for module-raised bulb onion transplants by the Agricultural Development and Advisory Service (ADAS) over the past 10 years provided the opportunity to investigate the control of Allium white rot in peat blocks and cellular trays. Currently about 25% of bulb onion production in the UK is from modular plants (D. Lancaster, personal communication).

This paper reviews ADAS experiments on the control of Allium white rot using module-raised transplants.

MATERIALS AND METHODS

The fungicides used were iprodione (50% a.i. w.p., Rovral WP or 10% a.i. granule, Rovral 10G; May and Baker); myclozolin (50% a.i. w.p., BAS436F; BASF) procymidone (50% a.i. w.p., Sumisclex; Sumitomo) quintozene (20% a.i. w.p., Brassicol; Burts and Harvey) thiabendazole (45% a.i. flowable suspension, Storite Flowable; MSD Agvet) tolclofos methyl (50% a.i. w.p., Basilex; Fisons Plc) and vinclozolin (50% a.i. w.p., Ronilan WP; BASF). Transplants were raised in commercial composts at Kirton Experimental Horticulture Station using recommended seeding and propagation regimes (Anon, 1987). Fully randomised block designs with at least 3 replicates were used for field experiments. Generally weeds were removed by hand and nitrogen fertiliser was applied according to local practice. Assessments and yields were taken on the whole plot.

In 1980 seed of bulb onion cv Rijnsberger Robusta treated with iodofenphos (50% a.i. w.p., Elocril 50WP; Ciba Geigy) at 10 g a.i./kg seed was sown into 2.7 cm^3 peat blocks (5 seeds/block) on 28 March. Iprodione was incorporated into Fenmere compost at two rates (see Table 1) equivalent to 7.5 and 60.0 mg a.i./block; the lower rate was equivalent to the commercial drench rate on salad onions. Vinclozolin was used only at the higher rate. Blocks were planted at Little Downham, Cambs on a white rot infested peaty loam on 9 May. A stem base spray treatment of iprodione or vinclozolin was applied by knapsack sprayer on 12 June at 0.3 g a.i./m row in 0.1 l water/m row as indicated in Table 1. Seeded blocks were planted 20 cm apart with 38 cm between rows. Final disease assessments and plant counts were made on 3 replicates of 100 blocks per treatment on 5 September.

A peaty loam site at Feltwell, Norfolk was used in 1982 to evaluate pre-planting drenches of iprodione or vinclozolin (20.5 g a.i./m^2 blocks applied by knapsack sprayer watering can in 4 l water), two rates of iprodione granules (0.15 and 0.30 g a.i./m row) applied by hand to shallow drills in which the blocks were placed and lightly covered and stem base sprays (see Table 2) applied at 0.15 g a.i./m row in 0.03 l water/m row by knapsack sprayer. Variety and block size were identical to 1980 but modules were sown with 6-7 seeds/block on 9 March and planted on 14-15 April 25 cm apart with 40 cm between rows. Disease assessments were carried out on 3 replicates of 100 blocks per treatment up to harvest on 10-11 August.

Iprodione and vinclozolin were evaluated as pre-planting drenches alone and with 2 stem base sprays (see Table 3) applied at rates used in 1982 in the trial on fine sandy loam at Dartford, Essex in 1984. Vinclozolin was applied by knapsack sprayer at two additional rates of 10.25 and 41.0 g a.i. in 4 l water/m^2 to Hassy modules. Seed (cv Copra) was sown on 6 February in 2.7 cm^3 blocks and on 13 February in Hassy 308 (14 ml volume) cellular trays. Modules were planted on 17 April and assessed regularly up to harvest on 31 July. Modules were planted 22 cm apart with 30 cm between rows and received irrigation immediately after planting and at weekly intervals during July. Treatments had 3 replicates and comprised 50 modules. Double controls were used for Hassy modules.

Experiments at Kirton have been carried out on a severely infested area of the Experimental Horticulture Station on very fine sandy loam. Trials in 1984 and 1985 (Table 4) used cv Copra and Hyton respectively raised in Hassy 308 trays (390 x 610 x 40 mm). Treatments were applied in 0.4 l water/tray in 1984 and 1 l water/tray in 1985 as follows; myclozolin, procymidone, tolclofos methyl and vinclozolin at 3.08 g a.i./tray and quintozene at 1.77 g a.i./tray. Stem base drench sprays were applied by knapsack sprayer at 0.15 g a.i./m row except thiabendazole at 0.135 g a.i./m row and quintozene at 0.7 g a.i./m row using 0.1 l water/m row applied as a band spray 100 mm wide. Plots had 70 modules in 5 rows (1.83 m) x 4 m long. Six replicates per treatment were used. In 1984 modules were planted on 13 April, received drench sprays on 21 May and 26 June and were harvested on 28 August. Modules were planted on 9 April in 1985, given drench sprays on 9 May and 28 June and harvested on 28-29 August.

The timing of procymidone treatments was investigated using cv Hyton in 2.7 cm^3 blocks and Hassy 308 cells in 1985 at Kirton. Fungicide was applied as a pre-planting drench on 9 April (13.75 g a.i./m^2 in 4 l (to blocks) or 1.6 l (to cells) water and as stem base sprays (0.15 g a.i./m row in 0.1 l water/m row) on 9 May and 28 June in a factorial experiment (Table 5). The trial was planted on 10 April using 70 modules per plot and six fold replication and harvested on 28-29 August.

Three different water rates were compared at Kirton in 1985 to apply iprodione and procymidone each at 0.15 g a.i./m row one day after planting cv Hyton in Hassy modules on 16 April, 21 May and 28 June. Disease assessments and yields were taken on six replicates of plots of 70 modules. Water rates used were 18, 100 and 500 ml water/m row applied to a 100 mm wide band.

RESULTS

Although plants were hand watered for three days after planting in 1980 (Table 1), vinclozolin incorporated into compost was very phytotoxic and virtually no seedlings survived. White rot developed slowly in untreated plots and only traces of infection were found on 6 August. At harvest no treatment gave control of white rot.

White rot appeared in early June in 1982 and disease control at this stage was achieved with pre-planting drenches of iprodione and vinclozolin (Table 2). Subsequently heavy rainfall in June enabled plants to recover but yield increases were associated with early control of white rot and increased plant survival. At harvest on 10 August only vinclozolin gave significant control of white rot. Iprodione granules gave results comparable to the pre-planting drench.

In 1984, all treatments applied to blocks reduced white rot up to harvest on 31 July (Table 3). White rot was first detected on 22 May and had killed some plants by 26 June. Block-raised transplants had significantly higher white rot infection than those in Hassy cells (Table 3) and at harvest plant losses were about 25% of block-raised plants and 10% of those from Hassy cells. In Hassy modules only the highest rate of vinclozolin applied at planting gave significant control of white rot and increased yield. The weight of severely affected (unmarketable) bulbs averaged 5 t/ha for all treatments.

Experiments in 1984 and 1985 identified myclozolin and procymidone as effective treatments for the control of Allium white rot (Table 4).

TABLE 1

Effect of block incorporation and post planting drench treatments of iprodione and vinclozolin on Allium white rot and plant stand, at harvest; Little Downham, Cambs, 1980

Treatment	Rate of Block Incorporation (g a.i./kg compost)	Drench applied 12 June	% Blocks* with AWR	% Plants* with AWR	Mean number of plants/block
Untreated	-		35	25	2.82
Iprodione	0.15	-	39	35	2.24
Iprodione	0.15	+	39	29	3.07
Iprodione	1.20	-	28	21	2.19
Iprodione	1.20	+	30	23	2.21
Iprodione	-	+	31	21	2.72
Vinclozolin	1.20	-	N/A	N/A	0.01
Vinclozolin	-	+	27	16	2.70
SED (18 df)			7.1	6.0	0.411

*Angular transformation of percentages
N/A - Not assessed

TABLE 2

Effect of iprodione granules and drench treatments of iprodione and vinclozolin on Allium white rot (AWR) and yield; Feltwell, 1982

Treatment	Timing*	% Blocks* with AWR 3 June	% Bulbs* with AWR 10 August	Plot Yield (kg)	
				Clean Onions	Total Yield
Untreated		28.6	35.3	19.5	26.5
Iprodione	1	4.3	32.8	28.3	37.2
Iprodione	1 + 2	10.8	34.5	24.6	34.1
Iprodione 0.15G	1	15.2	38.1	21.6	30.9
Iprodione 0.15G	1 + 2	20.4	32.4	27.2	35.6
Iprodione 0.30G	1	13.4	38.9	25.5	35.9
Iprodione 0.30G	1 + 2	12.7	35.1	23.9	33.9
Vinclozolin	1	1.9	26.5	38.6	46.5
Vinclozolin	1 + 2	3.3	23.9	39.0	46.4
SED (30 df)		6.05	4.13	3.75	2.99

*Timing: 1 At planting on 14 April
2 Drench sprays applied 20 May and 25 June
*Angular transformation of percentages

TABLE 3

Effect of iprodione and vinclozolin treatments on Allium white rot (AWR) and total yield of module raised bulb onions; Dartford, Essex, 1984

Treatment	Timing*	% Modules with AWR 26 June	% Modules with AWR 10 July	Total Yield (t/ha)
Blocks				
Untreated	-	32	77	18.0
Iprodione	1	9	54	24.2
Vinclozolin	1	0	23	36.5
Iprodione	1 + 2	9	45	27.5
Vinclozolin	1 + 2	2	35	38.3
Hassy Cells				
Untreated	-	10	42	26.6
Iprodione	1	7	45	24.4
Vinclozolin x ½	1	8	43	26.5
Vinclozolin x 1	1	5	33	31.2
Vinclozolin x 2	1	1	14	34.8
Iprodione	1 + 2	3	37	30.1
Vinclozolin x 1	1 + 2	2	27	33.3
SED (48 df)		5.0	9.2	4.30
SED (Hassy untreated v. other treatments)		4.4	6.5	3.04

*Timing 1 - Pre-planting drench
2 - Drench sprays applied 22 May and 26 June

TABLE 4

Comparison of fungicides for their effect on Allium white rot (AWR) and yield of cell-raised bulb onion; Kirton, 1984 and 1985

Treatment	1984 % Blocks with AWR 30 July	1984 Plot Yield (kg) Clean Onions	1984 Plot Yield (kg) Total Yield	1985 % Blocks with AWR 22 August	1985 Plot Yield (kg) Clean Onions	1985 Plot Yield (kg) Total Yield
Untreated	90	2.4	4.0	80	1.3	7.9
Iprodione	83	4.4	7.5	53	4.4	10.1
Vinclozolin	60	10.4	16.3	67	2.6	11.2
Myclozolin	5	25.0	27.0	0	28.1	37.5
Procymidone	3	28.7	30.7	0	30.2	37.4
Thiabendazole	54	8.8	12.4	42	6.3	17.5
Tolclofos methyl	84	3.6	6.2	43	7.6	22.8
Quintozene	61	9.0	12.9	13	8.7	23.8
SED (35 df)	7.7	1.86	1.95	7.6	2.92	3.71

TABLE 5

Timing of procymidone treatments for control of Allium white rot (AWR) in blocks (B) and Hassy cells (H) and effects on yield; Kirton, 1985

Timing*	% Modules with AWR 22 August		Plot Yield (kg)			
			Clean Onions		Total Yield	
	B	H	B	H	B	H
0	56.0	66.0	7.6	4.4	17.3	13.3
1	3.8	0.5	21.3	19.0	30.7	32.4
2	22.1	22.1	14.7	14.4	27.7	27.8
3	39.0	40.0	9.2	11.0	22.9	23.9
1 + 2	0.5	1.0	25.5	26.3	37.2	35.2
1 + 3	0	2.6	32.6	22.0	41.8	34.6
2 + 3	29.8	26.0	17.2	10.0	29.5	20.7
1 + 2 + 3	0	0	27.1	24.3	39.3	35.3
SED (75 df)	7.15		3.34		3.40	

*1 - Pre-planting
2 - 9 May
3 - 28 June

Variable results were given by quintozene which gave good control of white rot in 1985. All treatments except iprodione and tolclofos methyl increased the yield of healthy onions in 1984 (Table 4) but only myclozolin, procymidone and quintozene gave a similar increase in 1985. In these trials the development of white rot was monitored weekly and incidence in controls increased as follows in 1984: 7% modules affected on 11 June, 31% on 25 June, 67% on 9 July whilst in 1985 3% modules were affected on 7 June, 8% on 25 June, 49% on 10 July and 65% on 31 July.

The importance of early applications of fungicide was clearly shown with procymidone treatments (Table 5). All treatments gave control of white rot up to harvest but the single treatments all differed significantly from each other. The post planting treatment applied on 28 June did not increase the yield of clean onions significantly although it did improve total yield in Hassy cells. There were no differences between blocks and Hassy cells in disease levels or yields.

In the 1985 trial comparing fungicides applied in different rates of water, white rot symptoms were first seen on 22 May and affected 10% of untreated modules on 25 June and 81% on 22 August. All the procymidone treatments gave better control of white rot on 22 August than all the iprodione treatments. Application rate did not affect the performance of iprodione but 15% infection of modules receiving procymidone in the lowest water rate was significantly different from both 0.10 l water (2% affected) and 0.50 l water (0% affected) treatments. Plot yields of clean onions were not affected by iprodione but procymidone treatments all increased yield from 0.8 kg in untreated to 9.6 kg (0.018 l) 18.7 kg (0.10 l) and 25.3 kg (0.50 l).

DISCUSSION

Module propagation offers the opportunity to use pesticides efficiently if treatments can be confined to the modules. Incorporation of iprodione (ADAS unpublished results from 1981) and vinclozolin into blocking compost caused stunting of seedlings and vinclozolin caused death of plants (Table 1). The rates used were about twice those used safely by Ryan and Doyle (1981) in larger (3.7 cm^3) blocks. Subsequent work therefore concentrated on pre- and post-planting drench sprays.

Results in Tables 2 and 3 confirmed observations by Ryan and Doyle (1981) that iprodione applied as a pre-planting drench gave control of white rot during May and June, improved plant survival and increased yield. However, vinclozolin appeared to be a more active fungicide. Stem base sprays applied 5 and 10 weeks after planting had little effect on disease or yield.

At Kirton, myclozolin and procymidone gave better control of white rot and higher yields than other fungicides (Table 4), supporting observations on salad onions (Entwistle, 1986). All sites had been cropped with onions and are thought to have received several applications of dicarboxymide fungicides. It is therefore likely that enhanced degradation impaired the performance of iprodione and vinclozolin (Walker, Brown & Entwistle, 1986) and this has now been confirmed at Kirton (A. Walker, personal communication).

White rot symptoms appeared earlier in trials with module transplants than in adjacent plots of drilled onions sown on the same day as the modules were planted. This was probably due to earlier and more vigorous root production of transplants. There was no consistent difference between blocks and Hassy cells. Typical yellowing of foliage was first apparent 5-7 weeks after transplanting and increases in foliar symptoms continued to appear until the crop senesced. The importance of early treatments was shown in 1985 (Table 5).

The use of fungicide treatments applied within a day of transplanting can also provide very effective control of white rot if an adequate volume of water is used. An alternative may be to use irrigation after application of fungicide in a low volume of water. Although there may be difficulties in achieving uniform distribution of fungicide (Suett,1987), a pre-planting drench appeared to be a simple and effective treatment for modules. At present no fungicides are recommended for control of Allium white rot in modules.

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CONTROL OF DOWNY MILDEW IN MODULE-RAISED CAULIFLOWERS

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ABSTRACT

Chemical control of downy mildew (Peronospora parasitica) was investigated in early summer cauliflower raised in peat blocks or Hassy 308 trays, and in summer cauliflowers raised in Hassy 308 trays only.

Metalaxyl, milfuran + manganese zinc dithiocarbamate or propamocarb incorporated in the compost provided control on block raised early summer plants. With plants raised in Hassy 308 trays no control was obtained with the following treatments: fosetyl-aluminium incorporated in the compost; drenches of propamocarb (these two treatments being supplemented with dichlofluanid foliar sprays starting at first appearance of the disease); and a dichlofluanid foliar spray programme starting at first emergence of seedlings.

In summer cauliflowers good control was achieved by drenching the compost with propamocarb, fosetyl-aluminium foliar sprays and by applying a dichlofluanid foliar spray programme. Fosetyl-aluminium was more effective incorporated in the compost than as a compost drench or a foliar spray. Chlorothalonil applied as a foliar spray at first appearance of the disease was ineffective.

INTRODUCTION

Downy mildew caused by the fungus Peronospora parasitica is an important disease of cauliflower. The disease affects young plants in the propagation stage and, in severe cases, young plants may be stunted or killed. In the field, there may not be further development of the disease on the leaves until curd symptoms develop pre-harvest. Crute and Gordon (1986) suggested that, in the absence of foliar downy mildew development in the field, invasion of the curd resulted from early seedling infection. There were also indications that yield and crop uniformity were affected adversely by early infection. Post-harvest spoilage of cauliflower curds caused by downy mildew was reported for the first time in the UK by Lund and Wyatt (1978) who observed curd symptoms after 3 to 6 days storage of unblemished heads in conditions resembling those on supermarket shelves.

Traditionally in Lincolnshire, most cauliflowers were grown as bare root transplants, propagated initially in frame yards and later in Venlo glasshouses. Occasionally, overwintering spring-heading cauliflowers (broccoli) were propagated in plant beds in the field; early summer cauliflowers were, and to some extent still are, propagated in 6 cm peat blocks or 7 cm pots. Since 1979 there has been a steady increase in the numbers of plants raised in loose-filled cells (modular) in expanded polystyrene or plastic trays, eg 'Speedling', 'Hassy' or 'SWC' trays. At present, approximately 80% of summer and autumn cauliflowers in Lincolnshire are propagated in small cells (R W P Hiron, Personal Communication). The production of cauliflower plants in small cells was reviewed by Symonds (1984). Control of mildew is based on spray programmes of dichlofluanid or propamocarb fungicides incorporated into the compost or applied as a drench at seeding.

This paper reviews ADAS experiments on the control of downy mildew in module-raised cauliflowers in Lincolnshire.

MATERIALS AND METHODS

Various fungicides applied to modules as compost drenches, incorporated in dry compost or applied as foliar sprays were evaluated for their effects on downy mildew during propagation. Compost incorporation was achieved by spraying each chemical in 200 ml water evenly over a thin layer of 10 l dry compost on a polythene sheet and then gathering the sheet together to facilitate mixing or by incorporation in a compost mixer (Universal Fabrications). Fungicide drenches were applied to compost in Hassy 308 trays with a watering can. Foliar sprays were applied with a hand-held sprayer (Polyspray 2-ASL).

Trials were made on early summer and summer cauliflowers. The former were sown mainly in October and overwintered in frames, or under glass with or without frost protection. The planting-out stage was March or April. Summer cauliflowers were sown from mid February to mid May, propagated under glass, and planted out from April to June. Disease assessments were made at the planting-out stage when affected and unaffected plants were counted.

The trials were carried out in commercial frames or glasshouses. Plants were grown according to local practice using the compost, and the fertiliser and watering regimes applied to other crops during propagation.

The trials used randomised block designs with 3-6 replicates/treatment. In frames, 6 cm peat blocks were used and each plot was 1 x 1.5 m. Under glass, each plot consisted of one 0.25 m^2 Hassy tray with 308 plants.

Early summer cauliflowers

Various fungicides were compared in two trials on early summer cauliflower at Kirton EHS. In 1980, cv Snowball was sown on 4 November in 6 cm blocks containing 12.5 g metalaxyl (50% a.i. w.p.; Ridomil)/m^3, 12.5 g milfuran + manganese zinc dithiocarbamate (11.3% + 58.3% a.i. w.p.; RE 20615, ICI Plant Protection)/m^3 or 262 g propamocarb (72.2% a.i. w.v.;

Filex)/m^3. Final disease assessments and plant counts were made on three replicates of 100 blocks per treatment on 25 March 1981 (Table 1).

In 1985, cv Paloma was sown in Hassy trays on 15 October and treated with propamocarb drenches at: 0.45 g a.i. in 500 ml/tray; 0.45 g a.i. in 875 ml/tray; 0.45 g a.i. in 1.25 l/tray or 1.80 g a.i. in 800 ml/tray. Propamocarb was also applied post-sowing at 0.45 g a.i. with 0.125 g tolclofos-methyl (50% a.i. w.p.; Basilex) in 500 ml/tray. Fosetyl-aluminium (80% a.i. w.p.; Aliette) was incorporated in the compost at 720 g a.i./m^3 prior to sowing. Nine fortnightly applications of foliar sprays of 0.085 g dichlofluanid (50% a.i. w.p.; Elvaron) in 50 ml/tray were applied to supplement the drench and incorporated treatments, commencing at the first sign of disease on 24 December 1985. These treatments were compared with nine fortnightly foliar spray applications applied at 25 ml/tray from the first signs of disease using 0.02 g mancozeb (80% a.i. w.p.; Dithane 945), 0.04 g dithiocarbamate containing manganese, zinc and ferric ions (85% a.i. w.p.; Trimanzone) or 0.13 g chlorothalonil (50% a.i. s.c.; Repulse). In addition, a standard dichlofluanid programme was applied, comprising 0.045 g dichlofluanid in 25 ml/tray at first emergence of cauliflower seedlings (day 0), and 3, 5, 7 and 10 days later, and a further 4 sprays at weekly intervals using 0.085 g dichlofluanid in 50 ml/tray. In addition, a further 6 sprays of 0.085 g dichlofluanid at 50 ml/tray were applied at fortnightly intervals. Wetter (PBI Spreader) was added to all foliar sprays at 1.25 ml/l. Disease assessments were made on the three replicates on 31 December, 31 January and 17 March.

Summer cauliflowers

With summer cauliflowers, fungicides were compared at various sites on different sowing dates. Two comparable trials were made on Hassy-raised cv White Fox sown on 14 February 1985 at Kirton EHS and on 8 March 1985 at Leverton, Lincs. Drench treatments with 1.44 g propamocarb in 200 ml/tray (0.361 g propamocarb in 200 ml/tray at Leverton only) and 1.44 g propamocarb + 0.2 g tolclofos-methyl in 200 ml/tray were compared with three foliar sprays of 0.002 g metalaxyl + 0.008 g mancozeb (10% + 48% a.i. w.p.; Fubol 58 WP) applied fortnightly or 0.05 g fosetyl-aluminium in 25 ml/tray first applied at 100% emergence (22 March at Leverton and 4 March at Kirton EHS). Chlorothalonil (50% a.i. s.c.; Daconil Flowable) was applied at 0.13 g a.i. in 25 ml/tray when the first disease symptoms were observed. A standard dichlofluanid programme was included, starting at 50% emergence (on 19 March at Leverton and on 1 March at Kirton EHS) with an additional six foliar sprays of 0.085 g dichlofluanid in 50 ml/tray at weekly intervals. Wetter (PBI Spreader) was added to all foliar sprays at 0.5 ml/l. Regular disease assessments were made on plants in the 6 replicates and final disease assessments were made at Leverton on 29 April and at Kirton EHS on 7 May (Table 2).

Fosetyl-aluminium was compared at different rates and with different application methods on Hassy-raised cv White Fox sown on 12 February 1985 at Kirton EHS. Compost-incorporation treatments of 720 g a.i./m^3 compost and 1440 g a.i./m^3 compost were compared with post-sowing drenches of 1 g and 2 g a.i. in 250 ml/tray and foliar sprays with 0.03 g a.i., 0.045 g a.i., 0.075 g/a.i. and 0.1 g/a.i. in 25 ml/tray, applied at 40-100% emergence and 14 days later. There were 6 replicates of each treatment.

Regular disease assessments were made and final scores and plant counts were made on 7 May (Table 3).

Effects of fungicides on a late sown crop were also evaluated. Two identical trials were set up at Leverton, Lincs, on Hassy-raised cv White Fox sown on 22 May 1984. Drenches of propamocarb at 1.44 g a.i., 0.722 g/a.i. or 0.036 g/a.i. in 200 ml/tray were compared with three propamocarb foliar sprays applied at fortnightly intervals using 0.027 g a.i. or 0.013 g a.i. in 25 ml/tray. Also included were drench treatments with 1.44 g or 0.036 g propamocarb in 200 ml/tray supplemented with three propamocarb foliar sprays using 0.013 g/a.i. in 25 ml/tray, applied at fortnightly intervals. Foliar sprays with 0.02 g metalaxyl + 0.008 g mancozeb in 25 ml/tray were applied at 100% emergence and a further two sprays at fortnightly intervals. A dichlofluanid standard programme of 0.05 g a.i. in 25 ml/tray applied at first emergence of seedlings and 3, 5, 7 and 10 days later with a further 4 sprays at weekly intervals using 0.085 g dichlofluanid in 50 ml/tray was also included. Wetter (PBI Spreader) was added to all foliar sprays at 1.25 ml/l. Six replicates were used and final disease assessments and plant counts were made on 26 June (Table 4).

RESULTS

In the Tables, means with a similar suffix do not differ significantly at the 5% level of probability by Duncan's Multiple Range Test. The results of incorporating fungicides in blocks in 1981 are given in Table 1. Significant disease control was achieved with all treatments.

TABLE 1

Effects of incorporating fungicides in peat blocks on the incidence of downy mildew on early summer cauliflower, Kirton EHS, 25 March 1981

Treatment	Dose (g a.i./m^3)	Mean % plants affected (angular transformation)
Untreated	-	28.86[a]
Metalaxyl	12.5	4.62[b]
RE 20615	12.5	4.05[b]
Propamocarb	262.0	5.18[b]
SED (6 df)		1.04

The effects of various fungicides applied by compost incorporation, drenches or foliar sprays were studied in a Hassy-raised crop in 1985. Downy mildew was first recorded on 24 December. There were no significant differences between the fungicide treatments and the untreated control on 31 December, 31 January or at the final assessment on 31 March.

The effects of applying fungicides as drenches, treatments incorporated in the compost and foliar sprays to early sown summer cauliflowers at two sites in 1985 are given in Table 2.

TABLE 2

Effects of fungicide drenches, treatments incorporated in compost and foliar sprays on downy mildew on summer cauliflower, Leverton and Kirton EHS 1985

Treatment		Mean numbers of plants affected with downy mildew	
Fungicide	Dose	Leverton 29 April	Kirton EHS 7 May
Untreated	-	88.7[b]	90.8[c]
Propamocarb drench	1.44 g a.i./200 ml/tray	5.8[a]	25.2[a]
Propamocarb drench	0.361 g a.i./200 ml/tray	9.8[a]	NT
Propamocarb + tolclofos-methyl drench	1.44 g a.i. + 0.2 g a.i. in 200 ml/tray	10.8[a]	15.3[a]
Fosetyl-aluminium sprays	0.05 g a.i. in 25 ml/tray	10.7[a]	52[b]
Metalaxyl + mancozeb sprays	0.002 g a.i. + 0.008 g a.i. in 25 ml/tray	18.2[a]	27.8[a]
Chlorothalonil spray	0.13 g a.i. in 25 ml/tray	90.7[b]	101.5[c]
Dichlofluanid sprays*		1.5[a]	6.8[a]
SED (45 df) Leverton (30 df) Kirton		20.8	10.69

NT - not tested

* 0.0425 g dichlofluanid in 25 ml/tray at 50% emergence and repeated after 3, 5, 7 and 10 days. A further ten weekly sprays were applied using 0.085 g dichlofluanid in 50 ml/tray.

At Leverton, mildew was first recorded on 19 April and one chlorothalonil spray was applied. Except for the chlorothalonil treatment, all the fungicide treatments gave significant control of downy mildew. At Kirton EHS, chlorothalonil was applied on 19 April when downy mildew was first recorded. In total, three foliar sprays of metalaxyl + mancozeb and of fosetyl-aluminium were applied, compared with one chlorothalonil and 10 dichlofluanid sprays. The results were similar to those obtained from Leverton, with significant disease control obtained with all treatments apart from chlorothalonil. No significant differences were found in plant numbers at Kirton on 7 May.

A comparison was made between the effects of various application methods and doses of fosetyl-aluminium on summer cauliflower (Table 3).

TABLE 3

Effects of application methods and doses of fosetyl-aluminium on downy mildew on summer cauliflower, Kirton EHS 1985

Fosetyl-aluminium treatments		Mean numbers of plants affected with downy mildew/tray on 7 May
Application method	Dose	
Untreated	-	213[c]
Compost incorporated	720 g a.i./1 m^3	10[a]
Compost incorporated	1440 g a.i./1 m^3	37.7[a]
Compost drench	1 g a.i./250 ml/tray	256.5[c]
Compost drench	2 g a.i./250 ml/tray	106.7[b]
Foliar sprays	0.1 g a.i./25 ml/tray	219.7[c]
Foliar sprays	0.075 g a.i./25 ml/tray	238.8[c]
Foliar sprays	0.045 g a.i./25 ml/tray	259.4[c]
Foliar sprays	0.03 g a.i./25 ml/tray	249.5[c]
SED (41 df)		9.36

TABLE 4

Effects of fungicides, drenches and foliar sprays on downy mildew on summer cauliflower, Experiment B, Leverton 1984

Treatment		Mean numbers of plants affected/tray on 26 June
Fungicide	Dose	
Untreated	-	238.5[b]
Propamocarb drench	1.44 g a.i./200 ml/tray	168.8[b]
Propamocarb drench	0.722 g a.i./200 ml/tray	143.7[ab]
Propamocarb drench	0.036 g a.i./200 ml/tray	151.7[ab]
Propamocarb sprays	0.01 g a.i./25 ml/tray	176.7[ab]
Propamocarb sprays	0.02 g a.i./25 ml/tray	62.8[a]
Propamocarb drench + propamocarb sprays	1.44 g a.i./200 ml/tray + 0.01 g a.i. in 25 ml/tray	132.5[ab]
Propamocarb drench + propamocarb sprays	0.036 g a.i./200 ml/tray + 0.01 g a.i. in 25 ml/tray	123.3[a]
Metalaxyl + mancozeb sprays	0.002 g a.i. + 0.008 g a.i. in 25 ml/tray	107.0[a]
Dichlofluanid sprays*		108.3[a]
SED (45 df)		50.15

* 0.0425 g dichlofluanid in 25 ml/tray at 50% emergence and repeated after 3, 5, 7 and 10 days. A further three sprays were applied weekly using 0.085 g dichlofluanid in 50 ml/tray.

The crop reached 40-100% emergence on 4 March and the foliar spray treatments were applied then and two weeks later. Downy mildew was first observed on 22 April and final disease counts were made on 7 May. Only the post-sowing drench of fosetyl-aluminium at the higher dose and the two compost treatments gave significant control of downy mildew; no significant differences were found between the two incorporation rates. No significant differences were found in the numbers of plants at the planting out stage and no phytotoxic effects were observed.

In the late sown summer cauliflower trials at Leverton in 1984, various doses of propamocarb drenches were compared with various foliar sprays. Mildew was first observed on 11 June and developed very rapidly. In Experiment A no significant differences were found between any of the treatments. In Experiment B, significant control was achieved on 26 June by a propamocarb spray at the higher rate, the propamocarb drench at the lower rate supplemented with a propamocarb spray, and metalaxyl + mancozeb or dichlofluanid foliar spray treatments (Table 4).

DISCUSSION

One advantage of the propagation of cauliflowers in small modules is that many plants may be grown per unit area. For example, in systems using Hassy 308 trays there are approximately 1250 plants/m^2. However, with such high plant densities, downy mildew is more likely to be a problem than in plants propagated for bare root transplanting where there are approximately 400 plants/m^2, or in 6 cm blocks with 250 plants/m^2. With such high plant densities, a single treatment such as a fungicide incorporated in compost or applied as a pre-sowing drench would be more economic than numerous foliar sprays. In addition, total cover of plants is difficult to achieve with sprays.

Very good control of downy mildew was achieved in early summer cauliflowers in 1981 by incorporating fungicides in blocks. The unregistered use of metalaxyl in the early 1980s in Lincolnshire was common and resistance of downy mildew to metalaxyl was first confirmed in 1983 (Crute,1984). In collaboration with ADAS in 1984, isolates of downy mildew from Lincolnshire were tested and most were found to be resistant to metalaxyl. In a detailed survey in 1985 of 16 sites where metalaxyl resistance was detected, resistance remained prevalent in those populations where the fungicide was no longer used (Crute and Gordon, 1986). There has yet been no evidence of resistance to propamocarb in downy mildew (Crute and Gordon, 1987).

At Leverton in 1984 using Hassy 308 raised plants significant control was achieved with metalaxyl + mancozeb foliar sprays despite the fact that tests showed that the downy mildew was resistant to metalaxyl (I R Crute, personal communication). Also in the 1985 trials using Hassy 308 raised plants, significant control was achieved with foliar sprays of metalaxyl + mancozeb: resistance to metalaxyl was not tested but was known to be widespread. There is no recommendation for the use of metalaxyl + mancozeb on cauliflowers. In the 1985/86 early summer cauliflower trial, no significant control of mildew was achieved with any treatment. Propamocarb supplemented by dichlofluanid sprays gave no control. It is likely that a higher rate of propamocarb and/or an earlier prophylactic application of dichlofluanid would have increased the effectiveness of this treatment.

The 1985 trial with summer cauliflowers demonstrated the effectiveness of incorporating fosetyl-aluminium in the compost as opposed to compost drenches or foliar sprays. However, only two foliar sprays were applied, the last being applied one month prior to the first appearance of mildew. There is no recommendation for the use of fosetyl-aluminium on cauliflowers. In the 1984 trials where there was a rapid late development of downy mildew, no control and poor control was observed in the two trials. This result is difficult to explain. In the 1985 trials, all treatments gave good results apart from chlorothalonil when only one spray was applied. Possibly its application was too late to give adequate protection.

Commercially, growers treat routinely with propamocarb + tolclofos-methyl drenches supplemented by foliar sprays with dichlofluanid, or with a standard dichlofluanid programme, supplemented by chlorothalonil when the maximum number of permitted dichlofluanid sprays has been reached. In some crops, especially early summer cauliflower, poor control has been achieved; this may reflect application methods. However, good control has been achieved in summer cauliflowers. Propamocarb has an effect on the disease but is not adequate on the over-wintered crop using Hassy 308 raised plants. Other materials should be evaluated.

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IMPROVING THE PERFORMANCE OF CARBOSULFAN AGAINST CABBAGE ROOT FLY WITH LOW VOLUME LIQUID TREATMENTS APPLIED UNDER FIELD-SOWN SEED

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ABSTRACT

The performance of carbosulfan was evaluated in two experiments with radish on a sandy loam in 1986 and 1987. A 10% granular formulation (Marshal 10G; FMC) was applied in conventional bow-wave treatments in both experiments. Wettable powder (WP) (1986) and emulsifiable concentrate (EC) (1987) formulations with 25% a.i. were delivered in water to a seed coulter modified to inject liquid under the seed.

Severe cabbage root fly attacks damaged 82% of radish raised from seed drilled without water or insecticide in 1986; in 1987 77% were damaged. In 1986, the dose of carbosulfan estimated to decrease the numbers of larvae by 90% was 21.2 mg a.i./m with the WP and 46.3 mg a.i./m with the granular formulation, the liquid application achieving more than a 50% reduction in insecticide requirement. In 1987 differences between the granular and EC formulations were less pronounced with the higher doses tested over a range from 13.6 - 107 mg a.i./m. However, at 20 mg a.i./m row, the liquid application gave 95% undamaged radish compared with 90% from those treated with granules.

Reduced dependence on soil conditions and improved safety to operators are significant additional advantages of the liquid treatments described in the paper.

INTRODUCTION

Granular insecticide formulations, in which the active ingredient is absorbed on, or mixed with, one of a wide range of carriers which also act as diluents, provide a relatively easy and efficient method for treating soil. In the UK they are used widely at drilling and planting to protect crops against attacks of root-feeding insect larvae, for example of cabbage root fly (*Delia radicum*) and carrot fly (*Psila rosae*). However, the use of granules is not without difficulties and disadvantages. For example, large amounts of increasingly expensive carriers are required for their formulation and the equipment used to meter granules from tractor-mounted hoppers often does not encourage its regular calibration and maintenance (Thompson *et al*. 1984). Also, the tilth and moisture status of the soil when granules need to be applied often do not facilitate the required flow and placement of granules around seed or transplants and crops are protected inadequately.

The precise placement of accurate doses of liquid formulations of insecticides into soil at drilling, using small-bore plastic microtubes to apply as little as 10 l liquid/ha, offers an opportunity to increase the efficacy of field treatments and to make application equipment safer to operate (McCracken,1985). This paper summarises results obtained from two field experiments on a sandy loam at Wellesbourne to evaluate the performance against cabbage root fly on field-sown radish of carbosulfan applied as a granular formulation in conventional, bow-wave treatments (Makepeace,1965) and as wettable powder and emulsifiable concentrate formulations delivered in water under the seed at drilling. Some advantages of applying liquid formulations in this way are discussed.

MATERIALS AND METHODS

Experiment designs

In both experiments single row plots were used, 5 m long in 1986 and 20 m long in 1987.

In each of the four replicated blocks in 1986, the liquid and granular formulations, with their respective nil-insecticide 'check' plots, were assigned to separate beds distributed at random. Each bed comprised three plots and, within beds, individual treatments were assigned to plots at random. Each block comprised one plot for each of the 10 insecticide treatments and five check plots, four drilled with dry seed only and the fifth with water using microtube equipment.

The 1987 experiment comprised five replicated blocks. In each block, treatments not using water were assigned at random to the centre row of each three row bed. Individual liquid treatments were assigned at random to outer rows in beds.

Crops

Radish (cv French Breakfast) was field-sown in 1.52 m wide beds in both experiments using a tractor-mounted, Stanhay precision seed-spacing drill. On 29 July 1986, plots were drilled at 51 cm centres and on 27 April 1987 44 cm spacings were used between plots.

Insecticide treatments

Granules

In both experiments, a 10% a.i. granular formulation of carbosulfan (Marshal 10G; FMC Corporation (UK) Ltd) was applied by the bow-wave technique (Makepeace,1965) using belt-delivery equipment on the seed drill to apply pre-weighed granules accurately (Thompson et al. 1983).

In 1986, doses equivalent to 4.4, 8.8, 17.5, 35.0 and 70.0 mg a.i./m row were applied to individual plots. In 1987, continuous, exponentially-changing doses (log-doses) were applied using a grooved trough (Wheatley,1971) to place the granules on the applicators. A median dose equivalent to 13.6 mg a.i./m row was applied to the first of the ten 1.9 m subplots in each 20 m plot, the first and last 0.5 m of each plot being discarded. The dose increased by regular increments (x 1.2574) to 107 mg a.i./m row in the final subplot of each treated plot.

Liquids

For the liquid applications, a 25% a.i. WP formulation was used in 1986 and a 25% a.i. EC formulation in 1987. Both formulations were delivered to the soil at drilling through a modified seed coulter designed to inject liquids under seeds. The design of this coulter is the subject of UK patent application 8619933 made by the British Technology Group.

The equipment used in 1986 to meter the liquid formulations and deliver them to the seed coulter was based on that described by McCracken (1985). A variable stroke, piston-injection pump driven from the landwheel of the seed drill metered a concentrated dispersion of the WP formulation in water. To minimise pulsing in the flow of liquid from the pump, the concentrate was fed into water circulating rapidly around a pipework loop. An electric pump circulated the water and maintained the pressure in the loop by pumping in water from a reservoir. For any given pressure set in the loop by a variable pressure release valve, the rate of flow of diluted insecticide to the soil was determined by the length and diameter of the plastic microtube connecting the manifold in the loop to the final delivery point. The total volume of liquid applied in the 1986 experiment was 4.0 ml/m row, equivalent to 78.4 l/ha, and the doses of carbosulfan were similar to those used with the granular formulation.

For each seed row in 1987, a peristaltic pump driven from the landwheel of the drill delivered diluted insecticide from a common manifold. Log-dose treatments were achieved by another pair of peristaltic pumps diluting continuously a constant volume of insecticide concentrate. Of this pair, one pumped water into a container of concentrate pre-measured for each plot and the other pumped diluted insecticide from the container into the manifold. The rate of injection of concentrate into the manifold and the flow rate of diluted insecticide to the individual delivery points in the soil were determined by the bore of the tubes used in the pumps. The total volume of liquid applied was 8.2 ml/m row, equivalent to 186.4 l/ha, and the range of insecticide doses was similar to that used with the granular formulation.

Assessment of seedling emergence

Seedling emergence was not assessed in 1986 but, on 19 May 1987, all emerged seedlings in each 1.9 m subplot were counted and the numbers were subjected to an analysis of variance.

Assessment of cabbage root fly damage

In 1986, damage caused by cabbage root fly larvae was assessed on all roots in 2 m samples of row taken from each plot on 15 September, 7 weeks after drilling. In 1987, all radish in each subplot were assessed for the presence of damage on 7 July, 10 weeks after drilling.

With both experiments, a generalised linear modelling technique (Nelder & Wedderburn, 1972; Phelps, 1982) was used to regress the log-log transformation of the % undamaged radish in each sample against the log dose (1986) or the log median dose (1987) to estimate the numbers of undamaged radish produced by each treatment. The models were also used to estimate the extent to which the insecticide treatments decreased the numbers of cabbage root fly larvae (Wheatley & Freeman, 1982; Phelps & Thompson, 1983).

RESULTS

Emergence of radish seedlings

Three weeks after drilling in the 1987 experiment, the mean numbers of seedlings on subplots drilled with seed alone (87) did not differ significantly from those on subplots treated with the granular formulation of carbosulfan over the dose range tested (88) ($P=0.01$). However, drilling seed with the modified coulter using water decreased the mean numbers of seedlings significantly (69) and the application of the EC formulation of carbosulfan through this coulter decreased the mean numbers further to 65/subplot.

Cabbage root fly damage

The intensity of the cabbage root fly attack in both years provided a severe test of insecticide performance. In 1986, 83% of radish grown on check plots without insecticide were damaged by larvae, damage being similar on roots raised from seed with and without water applied at drilling (Table 1). In 1987, 77% of radish grown without insecticide and water applied at drilling were damaged but the application of 8.2 ml water/m row at drilling decreased the numbers damaged by cabbage root fly to 74% ($P=0.01$).

The dose/response models fitted the data well, Figs 1 and 2 showing the goodness of fit of the 1986 and 1987 data respectively. The estimates of the parameters of the models are given in Table 2. The parameter α gives the intercept of the dose/response line on the vertical scale and is of little practical value but β (the slope parameter) indicates the rate of change of response to dose, a useful estimate of insecticide performance. The greater the negative value of β, the greater is the response to increasing insecticide dose.

In 1986, the value of the slope parameter was greater for the microtube applications than for the bow-wave treatments (Table 2) and the greater efficiency of the insecticide in decreasing the numbers of larvae (Wheatley 1973) when applied through the microtube equipment is further seen in the estimates of larval mortality for the three doses interpolated from the dose/response models (Table 1). Thus doses equivalent to 20, 40 and 70 mg a.i./m row decreased the numbers of larvae by 89, 95 and 98% when applied with the WP formulation but by only 78, 89 and 93% when applied with the granular formulation. The estimated dose of carbosulfan required to decrease the numbers of larvae by 90% was 46.3 mg a.i./m row with the granular formulation but only 21.2 mg a.i./m with the WP (Fig. 1), a reduction of more then 50% in the insecticide requirement.

In 1987, the bow-wave treatment performed better than in 1986, doses of 20, 40 and 70 mg a.i./m row decreasing the numbers of cabbage root fly larvae by 93, 99 and 99.6% (Table 1). The EC formulation applied through the modified coulter was more efficient than the granular formulation over the lower part of the dose range tested but, at higher doses, the two treatments performed similarly (Table 1, Fig 2).

With only slight or moderate levels of cabbage root fly infestation, levels of efficiency in the order of 90% might have resulted in acceptable levels of treatment effectiveness. However, the severe infestations sustained in both experiments mitigated against this (Table 1; Figs 1, 2). For example, only 82% undamaged radish were obtained in 1986 with a dose equivalent to 40 mg a.i./m row applied by the bow-wave technique giving 89% larval mortality (Table 1). The additional 6% mortality achieved by a similar dose of the WP formulation resulted in 92% undamaged radish.

DISCUSSION

The excellent performance against cabbage root fly of doses of carbosulfan approximately 30% of that recommended commercially for granular treatments to protect brassicas was striking. It confirmed the considerable potential for decreasing insecticide usage with low-volume, liquid formulations applied accurately to the soil at drilling.

Bow-wave treatments in which granules are incorporated into the

TABLE 1
Estimates of the performance of doses of carbosulfan applied by the bow-wave (BW) technique or in liquid treatments to field-sown radish, interpolated from linear regressions of log-log % undamaged radish against log dose

Year/Performance parameter	Carbosulfan dose (mg a.i./m row), method of application and formulation										
	0		20			40			70		
	BW	Water	BW	Liquid		BW	Liquid		BW	Liquid	
				WP	EC		WP	EC		WP	EC
1986											
% undamaged radish	18	16	68	83	-	82	92	-	89	96	-
% decrease in nos. larvae	-	-6	78	89	-	89	95	-	93	98	-
(± S.E.)	-	(8.8)	(2.5)	(1.5)	-	(1.9)	(1.0)	-	(1.5)	(0.7)	-
1987											
% undamaged radish	23	26	90	-	95	98	-	98	99	-	99
% decrease in nos. larvae	-	7	93	-	96	99	-	99	99.6	-	99.6
(± S.E.)	-	(2.1)	(0.6)	-	(0.5)	(0.3)	-	(0.3)	(0.12)	-	(0.15)

TABLE 2
The parameters α (= intercept) and β (the slope) of the linear dose/response models for bow-wave and liquid treatments with carbosulfan applied to field-sown radish

Year	Application method	Parameters (± S.E.)	
		α	β
1986	Bow-wave	1.2 ± 0.26	-2.1 ± 0.24
	Liquid	1.2 ± 0.29	-2.7 ± 0.29
1987	Bow-wave	4.2 ± 0.51	-5.2 ± 0.42
	Liquid	1.9 ± 0.68	-4.0 ± 0.54

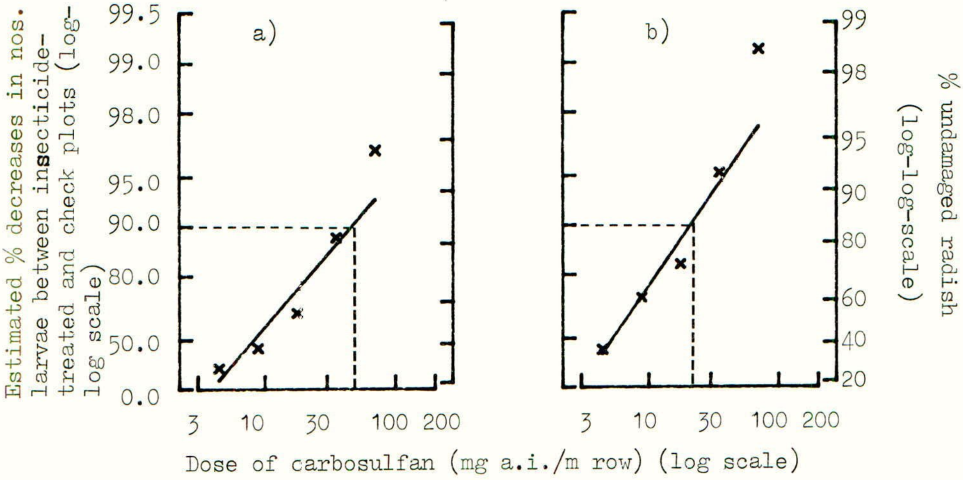

Fig. 1. The relationship between doses of carbosulfan applied in 1986 a) by the bow-wave technique using a granular formulations and b) through microtube equipment using a WP formulation, the % field-sown radish undamaged by cabbage root fly larvae and the estimated decreases in the numbers of cabbage root fly larvae achieved by the insecticide treatments.

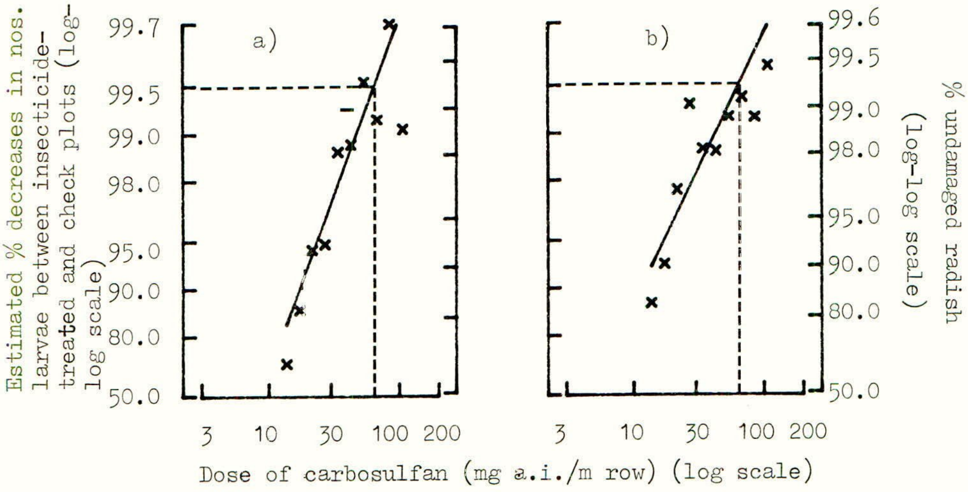

Fig. 2. The relationship between doses of carbosulfan applied in 1987 as continuous log-doses a) by the bow-wave technique using a granular formulation and b) using an EC formulation, the % field-sown radish undamaged by cabbage root fly larvae and the estimated decreases in the numbers of cabbage root fly larvae achieved by the insecticide treatments.

surface soil depend for maximum effectiveness on the tilth and moisture status of the soil permiting the granules to flow around the seed. The liquid treatments described here may be applied whenever the soil is suitable for drilling, thus reducing the dependence of insecticide application on soil conditions. The reasons for the modified coulter decreasing the numbers of radish seedlings are being investigated.

The liquid application systems also offer significant advantages with regard to the safety of those operating pesticide application equipment. 'Closed systems' in which pesticide concentrates, in their original containers, are diluted only as required with water from a small tank on the tractor decrease the risk of operators contacting undiluted concentrates (McCracken, 1985). They also reduce problems associated with the disposal of diluted wastes.

The volumes of water applied in our experiments, almost an order of magnitude greater than those specified by McCracken (1985), were selected in light of previous experience at the AFRC Institute of Horticultural Research, Wellesbourne on the benefits of injecting liquid fertiliser under seeds at drilling (Costigan *et al*. 1987). The application equipment used in 1987 was designed to permit a wide range of volumes to be applied, depending on specific crop requirements. It is well-suited for the experiments that are now required to explore the potential of combining insecticides, fertilisers and possibly other chemicals in liquid treatments applied accurately in the field to sown, and possibly transplanted, crops.

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