# 5.
# Air-Assisted Spraying in Covered Crops, Warehouses and Public Health

Chairman:

# A REVIEW OF THE PERFORMANCE OF AIR-ASSISTED SPRAYERS FOR USE IN GLASSHOUSES.

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## ABSTRACT

The transport and deposition of very small biologically efficient droplets (<50μm diameter) is dominated by air-movement In the absence of air-assistance, only a very small fraction of an electrostatically charged spray penetrates beyond the peripheral foliage of a crop canopy. Low volume movement of air at high velocity may enhance canopy penetration of charged sprays, but deposits a low proportion of droplets on lower leaf surfaces. However, biological effectiveness was not usually correlated with deposition on leaf undersides. When hydraulic sprays were compared with air-atomised charged and uncharged sprays, the biological effectiveness of bifenthrin against the melon aphid, *Aphis gossypii* was greatest with the charged spray; however, when neem-seed extract was applied against whiteflies (*Trialeurodes vaporariorum*), the hydraulic and charged sprays gave equivalent control. An ultra-low volume sprayer/fogger which continually circulated the air in a sealed glasshouse operated on a timer, so labour-input and worker-exposure were minimal and applications of bifenthrin resulted in excellent control of *Tetranychus urticae* and *T.vaporariorum* larvae on poinsettias.

## INTRODUCTION

Greenhouses provide environmental conditions for vegetables and ornamentals that are stable and controllable by comparison with field grown crops. Thus, pesticide sprays applied under glass are physically contained, which essentially eliminates off-target contamination (drift) while air movement may be controlled.

Insect pests of glasshouse crops, primarily the red spider mite, *Tetranychus urticae* and the glasshouse whitefly, *Trialeurodes vaporariorum*, have been the subjects of research designed to determine the most efficient spray deposit (Munthali, 1984; Adams *et al* 1987). The efficiency of utilization of active ingredient (a.i.) invariably increases as the droplet size decreases but at a cost of requiring greater coverage (drops/$cm^2$ leaf surface). Electrostatically charging a spray cloud of small droplets should enhance the likelihood of drops being deposited on the undersides of leaves by the characteristic wrap-around effect (Coffee, 1979). However, the appropriate distribution of efficient deposits on the crop is dependent upon the delivery and transport of the spray cloud from the atomiser to the biological target. In addition, the enhanced efficiency of utilization of a.i. that is possible in theory, needs to be demonstrated in practice.

In this paper, we review the various air-assisted sprayers that have been used to apply insecticides to glasshouse crops. Comparative trials between sprayers are described and the possible reasons for the presence or absence of differences in biological effectiveness are discussed.

## Droplet size

In comparative studies, Mboob (1975) demonstrated that control of *T. vaporariorum* was more effective when a spray with a volume median diameter (vmd) of 15-20 μm (Microgen HCS 1-2) was compared with one of 78 μm (Turbair Tot. 2S). Laboratory investigations demonstrated that the most efficient control of *T. urticae* eggs occurred with droplets of 20 μm (Munthali, 1984). Tests using permethrin against *T. vaporariorum* revealed an influence of formulation and plant species upon efficacy, but the dominant factor was droplet size with a 12-fold reduction in the median lethal quantity of a.i. (ng/cm²) as drop size was reduced from 108 μm to 31 μm (Adams *et al*, 1987).

## Air-assisted and Air-atomized sprayers

The characteristics of various air-assisted sprayers are presented in Table 1. The Tube and M-fan spray oil-based formulations, exclusively, while the Ulvafan can apply oil (as in the studies listed in Table 1) or water. The remaining sprayers apply conventional water-based pesticide solutions.

Air assisted sprayers utilise separate mechanisms to atomise and transport the sprays they produce. A fan is mounted behind the point of atomization, where either a spinning disc (Ulvafan), air-atomization (Mykron LVH-10) or electrodynamics (Microdyne) produces the spray droplets. Conversely, the ENS and ESS BP-4 feature air-atomization and use the same air to force the spray away from the nozzle. Thus, the air-assisted sprays provide a large volume of slow moving air to transport droplets, compared with the high velocity, but rapid deceleration of a smaller volume of air with the ENS and ESS. With one exception, the sprayers are hand-held and, consequently, as labour-intensive as conventional hydraulic sprayers for glasshouse use. However, the Mykron LVH-10 operates off a timer and the air movement produced by the fan (Table 1) provides sufficient circulation that a large greenhouse may be treated without moving the sprayer, so labour input is minimal and pesticide application may commence at the end of the working day.

## Deposition Studies

Most of the studies listed in Table 1 include some assessment of spray distribution, usually based upon fluorescent tracer deposits. Adams and Palmer (1986) demonstrated that the electrostatic spray produced by the Microdyne nozzle provided an even distribution of droplets between upper and lower leaf surfaces on a tomato crop - but without air-assistance deposition was restricted to peripheral foliage. The Ulvafan spray penetrated the canopy, but the only significant underleaf deposits were observed on apical foliage i.e. where the spray was directed upwards (Figure 1). Further examination of the interactions of drop size and air-assistance upon Microdyne spray deposits demonstrated that spray coverage (drops/cm²) generally improved towards the apical foliage, while

TABLE 1. Characteristics of air-assisted sprayers for use in glasshouses

| Sprayer | Electrostatic (Yes/No) | Flow rate (ml/min) | Air movement ($m^3$/min) | Air pressure (kPa) | Drop size vmd ($\mu$m) | Reference |
|---|---|---|---|---|---|---|
| Ulvafan[b] | N | 5 | 4 | - | 42 | Adams & Palmer 1986 |
| | | 8-9 | 4/3 | - | 54 | Abdelbagi & Adams 1987 |
| | | 8 | 3 | - | 54 | Sopp & Palmer 1990 |
| Mykron LVH-10[c] | N | 50-55 | 36 | - | 7 | Lindquist et al (unpublished) |
| ENS[d] | Either | 40-180 | - | 35-207 | 10-80 | Simmons & Lehtinen 1987 |
| | | 75 | - | - | 20 | Lehtinen et al 1989 |
| | | 70-80 | - | 138 | 25 | Adams et al 1989, 1990 |
| ESS BP-4[e] | Either | 250-280 | - | 380 | 31 | Lindquist et al (unpublished) |
| Microdyne[b] ('Tube') | Y | 1.0[a] | 3.5 | - | 20 | Adams & Palmer 1986 |
| | | 0.8-8.0[a] | 3.5/2.0 | - | 18-56 | Abdelbagi & Adams 1987 |
| | | 0.5[a] | 3.5 | - | 18 | Adams & Palmer 1987 |
| | | 0.5 | 3.5 | - | 16 | Sopp & Palmer 1990 |
| M-Fan[b] | Y | 0.5a | 3.0 | - | 16 | Sopp & Palmer 1990 |

a) These flow rates approximately double when sprayer is operating
b) Micron CDA, Bromyard UK
c) Mykron Greenhouse Technology Inc., Leamington, Ontario, Canada
d) Parker Hannifin Corporation, Cleveland OH, USA
e) Electrostatic Spray Systems, Athens GA, USA.

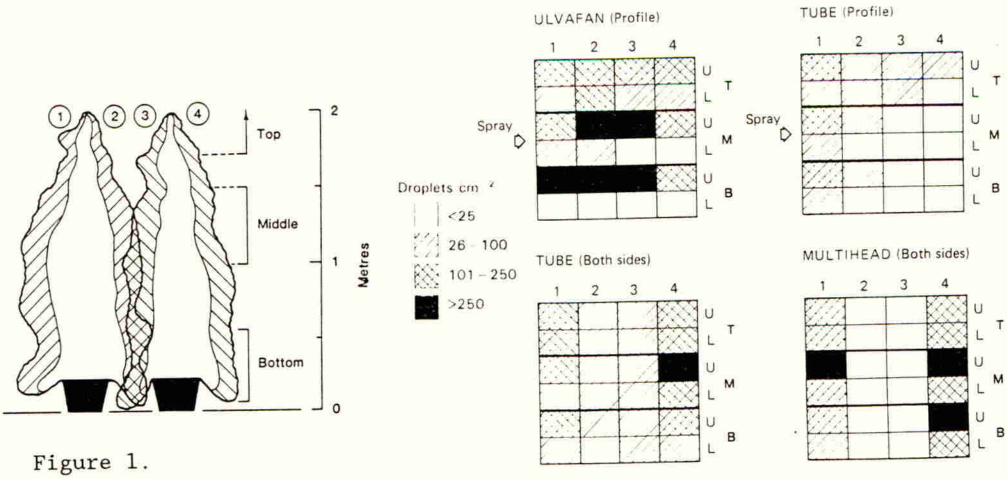


Figure 1.

Diagrammatic section through a row of tomatoes to show the position of the sites where leaves were collected after spraying and a summary of spray droplet distribution on upper (U) and lower (L) leaf surfaces at each site when different application methods were assessed. Adapted from Adams and Palmer (1986) and reproduced by permission of the publishers, Butterworth-Hienemann Ltd.

the ratio of droplets deposited on lower:upper leaf surfaces was best with the smallest droplet size (18 $\mu m$) and smaller fan (moving $2.0m^3$ air/min) (Abdelbagi and Adams, 1987). However, the larger fan ($3.5m^3$/min) resulted in better penetration of the canopy. Biological studies demonstrated that the combination of $18\mu m$ drops and $3.5m^3$/min fan could control T.vaporariorum using low chemical rates when the spray was restricted to apical foliage - the preferred oviposition site for this pest (Adams and Palmer 1989).

Sopp and Palmer (1990) compared spray deposition and biological efficacy of permethrin against T.vaporariorum on a variety of pot plants, using 3 air-assisted sprayers. They showed that coverage was greatest with the Ulvafan, followed by the Microdyne-Tube and the M-Fan. Canopy penetration was in the order Ulvafan > M-Fan > Tube, while efficiency was M-fan > Tube > Ulvafan. Overall mortality on Pelargonium and Impatiens was unaffected by application method and did not correlate with the scoring system possibly because high coverage and penetration compensated for poor efficiency. However off-target contamination was much less with the electrostatic applicators compared with the Ulvafan (Sopp and Palmer, 1990).

Using the ENS in the charged spray mode, similar deposits were found on upper and lower leaf surfaces throughout a cucumber crop, although lower leaf deposits were very poor on central foliage when the spray was uncharged, indicating the benefits of the 'wrap around' effect (Lehtinen et al 1989). On poinsettias, spray coverage on leaf undersides was generally poor and post-spray oviposition by whiteflies showed no correlation with permethrin distribution (Lehtinen et al 1989). When bifenthrin was applied against Aphis gossypii on chrysanthemums, tracer deposits on the undersides of leaves on plants near the centre of the bench were poor and considerably worse than the corresponding upper surface deposits, in spite of electrostatic charging (Adams et al 1989). Figure 2 shows the changes in the ENS spray characteristics as the drops passed into the chrysanthemum canopy and demonstrates the rapid dissipation of air velocity, reduction in vmd and decline in drops measured per unit time (from Adams et al 1989). However, the effectiveness of bifenthrin was unaffected by plant position, demonstrating that spray deposition was not a good measure of the likely biological efficacy. Additional studies revealed that sparse deposits containing a high concentration of bifenthrin could irritate and kill A. gossypii without the aphid physically contacting spray deposits, indicating the presence of a local vapour effect (Adams et al 1990). Since irritation, followed by aphids dropping off the plants and dying, occurred within minutes of spray application, the very fine droplets of the spray cloud may have exhibited vapour activity in the absence of deposition (Adams et al 1990).

The ESS BP-4 uses a similar atomization system to the ENS, with a higher flow rate and air pressure (Table 1). Almost 100% control of T.vaporariorum nymphs was recorded on poinsettias when bifenthrin was applied at 1/12th the recommended rate (Lindquist et al, unpublished). However, as Table 2 shows, control was variable when other combinations of plant, pest and insecticide were tested. Evaluations of bifenthrin, avermectin $B_1$, and neem seed extract were also made when the Mykron LVH-10 was used to treat a $350m^2$ (floor area) greenhouse. Fluorescent tracer deposits showed that coverage of leaf undersides was poor and concentrated

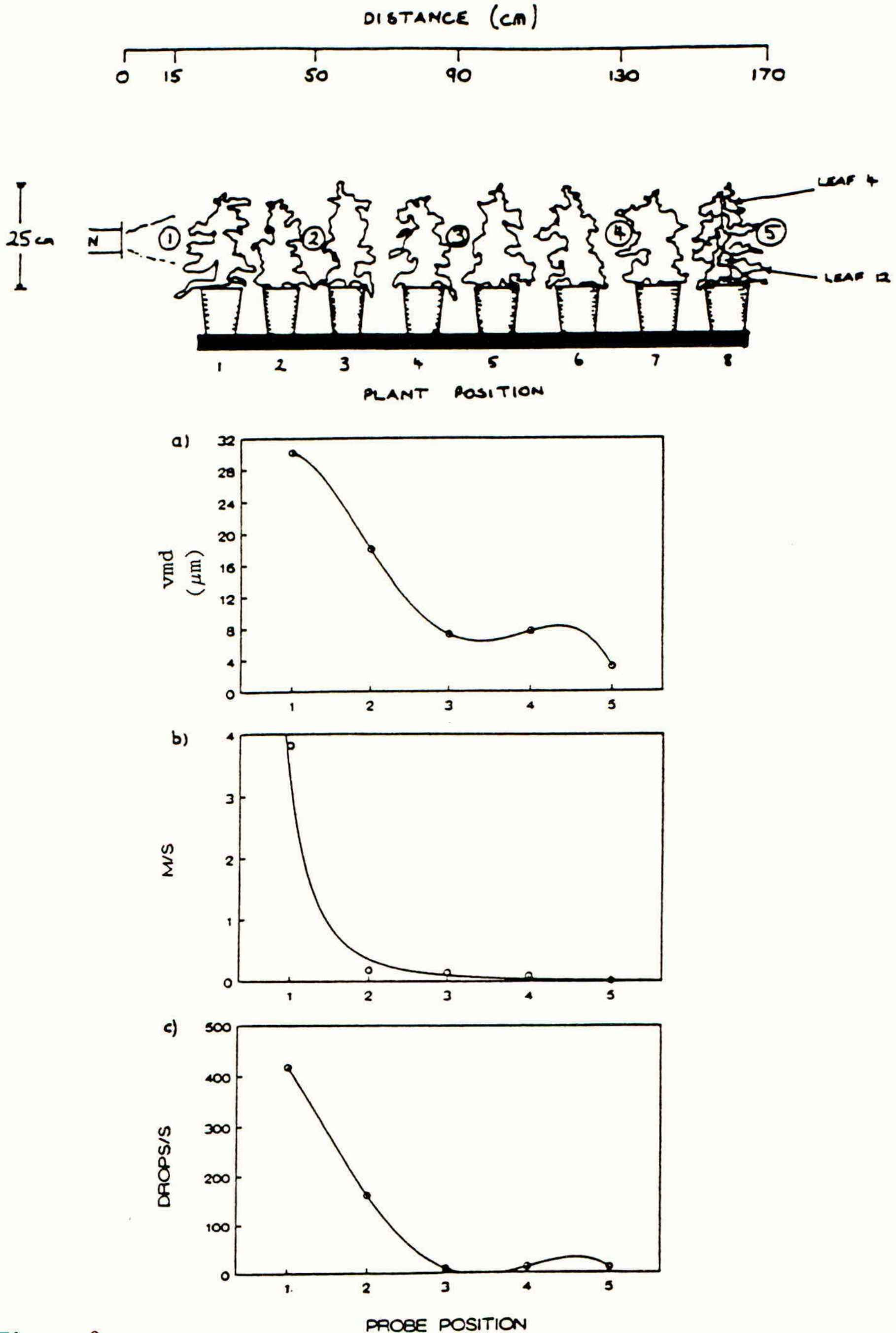


Figure 2.

Diagrammatic representation of a chrysanthemum plot to show locations of probe (1 - 5) for intra-canopy spray characterisation. The probe measured a) vmd b) air-velocity (m/s) and c) number of droplets counted per second. Adapted from Adams et al 1989. Copyright ASTM. Reprinted with permission.

near leaf margins (Lindquist et al, unpublished). Biological effectiveness was similar to the ESS (Table 2) and, again indicated tracer distribution did not reflect efficacy.

TABLE 2. Summary of biological effectiveness of ESS BP-4 and Mykron LVH-10 using various insecticides, ornamental plants and pest species (Lindquist et al, unpublished data)

| Insecticide | Applied Rate: Recommended | Ornamental | Pest | % Control ESS | % Control Mykron |
|---|---|---|---|---|---|
| Bifenthrin | 1/12 | Poinsettia | *T. vaporariorum* | >90[d] | >90[d] |
| (Capture 2EC)[a] | 1/6 | " | " | >95[d] | >98[d] |
| Avermectin $B_1$ (Avid 0.15EC)[b] | 1 | " | " | 48-62[d] | - |
| | 1 | Impatiens | *T. urticae* | 100 | 100 |
| | 1 | " | *Aphis* sp. | 75[e] | >80[e] |
| Neem seed extract | 2/5 | Poinsettia | *T. vaporariorum* | 0 | 0 |
| (Margosan-O)[c] | 2/3 | " | " | 30-70[f] | - |
| | 2/3 | French bean | *Frankliniella occidentalis* | 0 | - |
| Sunspray 6E+ | 3/4 | Poinsettia | *Bemisia tabaci* | 0-40[d] | - |

a FMC, Princeton NJ
b Merck and Co., Rahway NJ
c Grace - Sierra
d Based on larval mortality
e Based on percent reduction compared with control
f Based on adult emergence

## Comparison of air-atomizing and conventional sprayers

None of the studies listed in Table 1 included a conventional hydraulic sprayer as a comparison for biological effectiveness. Figure 3 shows the result of using the ENS in the charged and uncharged mode, compared with a hydraulic sprayer (Model CS-5AGS, Dramm Co., Manitowoc WI, flow rate 1600 mls/min, applying approximately 1200L/ha). The canopy of chrysanthemums was similar to that depicted in Figure 2 and the charged spray was the only treatment providing acceptable control of *T.vaporariorum* using bifenthrin. Similar studies using neem seed extract showed no difference between application methods. (Lindquist et al unpublished).

## Practical Considerations

Logistical and user-friendly advantages would need to be associated with new technology if it were to become a viable alternative to the reliable hydraulic nozzle. A consequence of the low to ultra-low volume application rates common to all the sprayers is that drying time and, hence, re-entry interval is much shorter than for conventional sprays.

Some of the sprayers described in Table 1 are portable, and the low flow rates of the Tube and M-fan in particular mean that a considerable area of greenhouse may be treated between refills. This would be ideal for ready-to-use insecticide bottles that would eliminate the hazard associated with mixing pesticides. The spray may be directed at specific parts of the crop for 'spot' treatments while off-target contamination appears to be very low. Unfortunately, both these sprayers require formulations of specific resistivity and this severely limits their use.

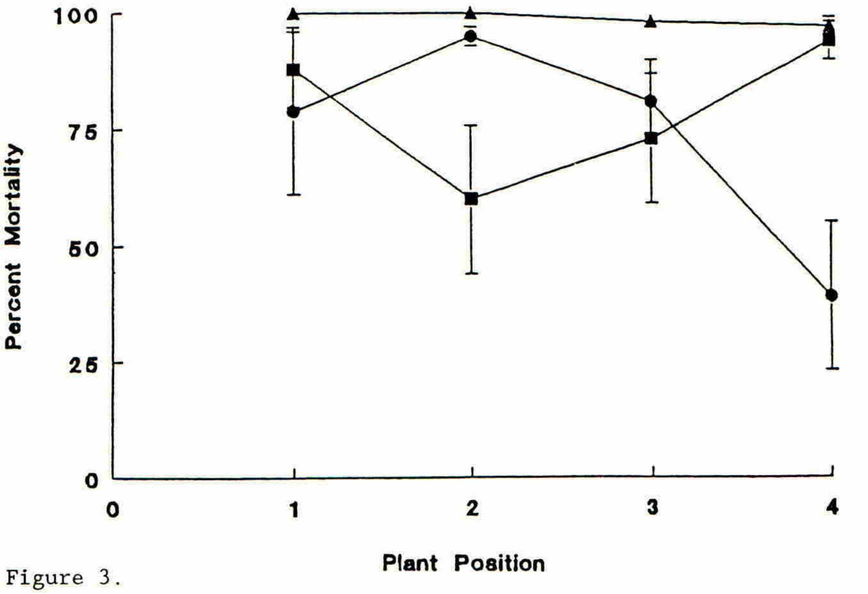


Figure 3.

Mean mortality (± SEM) of <u>T.vaporariorum</u> larvae on chrysantheum following application of 20g/ha bifenthrin with the ENS sprayer in the charged (▲) and uncharged (●) mode and with a hydraulic sprayer (■). Plant positions correspond with those shown in Figure 2.

Both the ENS and ESS have considerable air blasts that carry the spray away from the operator and up into tall canopies, without the need to hold the sprayer much above waist height. While spray distribution may not be as consistent as with the other electrostatic sprayers, any conventional pesticide formulation may be applied.

Combining sufficient air circulation to carry small droplets to all parts of a large greenhouse, with a timer to allow treatment to occur when staff have finished work, gives a considerable logistic advantage to the Mykron sprayer. However, some insecticide will be collected on the air intake, so careful handling is required when the sprayer is retrieved.

CONCLUSIONS

There is often a poor correlation between spray distribution and biological effectiveness which may reflect the influence of insect behaviour, mode of action of a.i., or a misleading impression of a.i. distribution provided by tracer deposits. Deposition studies have only demonstrated consistently high proportions of spray on leaf undersides when air-assisted, electrostatic sprayers were examined, whereas charged air-atomised sprays provided poorer underleaf coverage. This may be attributed to slow movement of a large mass of air being more compatible with spray cloud distribution and small drop deposition by electrostatic forces. The few comparative studies using air-atomized and conventional sprays have not shown a large biological advantage of the new technology possibly because the proportion of a.i. reaching the biological target is not greatly enhanced through the canopy. Thus far, the potential efficiency of ultra-low volume sprays and small droplet deposits shown in the laboratory has not been exploited consistently in glasshouses.

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# AIR ASSISTED APPLICATION OF BENDIOCARB ULV FOR INSECT CONTROL IN BUILDINGS

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## ABSTRACT

Air-assisted application of Ultra Low Volume (ULV) insecticide treatments has been increasingly used for control of arthropod pests inside buildings. Use of the technique has the advantage of fast uniform treatment of these often large enclosed structures without the possible risk of damage to stored commodities by quantities of diluents.

Intensive tests of a new bendiocarb 20% ULV formulation in a large experimental chamber are described . These show a high level of direct contact action against a variety of insect pests, and a limited residual effect. Trials in infested commercial premises have demonstrated substantial reductions in pest populations following treatment as well as the logistical advantages of the formulation and technique. In addition a number of factors concerning the fate of the ULV droplets in these enclosed structures and their mode of acquisition by insects have been examined.

## INTRODUCTION

The application of pesticides (particularly insecticides) in buildings has much in common with the much greater use of pesticides in agriculture. Few of the techniques for the treatment of growing crops have not been adopted on occasion for use in buildings. However the obvious differences in scale, substrate, micrometeorology, and the general nature of the problem have resulted in a different emphasis being placed on the techniques adopted. High volume spraying using contact insecticides has been commonplace, although the risk of spoilage of stored produce by the quantities of diluent used has limited its use to empty buildings or to commodities not at risk from spoilage. The enclosed nature of buildings has made the use of fumigants relatively easy as compared with agriculture, and indeed all too frequently the deep-seated infestation of old stored produce has rendered the use of penetrating fumigants as the only effective treatment. Space treatments with thermal-fogging equipment have also long been a popular approach, although in recent years the fire hazard and the risk of taint from the solvent carriers have limited their use. More recently, ULV treatments, normally with air-assisted sprayers, have been used with increasing frequency. The simplicity of use and lack of disruption as compared with other space spraying techniques and with fumigation, have made ULV air-assisted treatments increasingly attractive. However the roles of fumigation and of air assisted ULV treatments have become somewhat confused and a number of misconceptions have, on occasion, arisen about what and what not the use of air assisted ULV application in buildings is capable of achieving. In order to examine the advantages and limitations of the use of air-assisted application of ULV insecticides, the following tests were carried out.

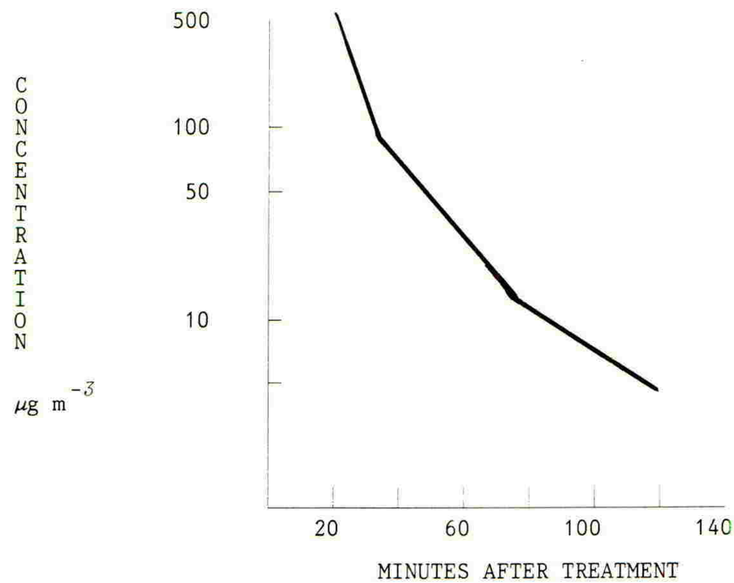
TECHNIQUES AND MATERIALS

The insecticides evaluated were Ficam® ULV, a liquid formulation containing 200g/l bendiocarb intended for application through ultra low-volume-sprayers and Brimpex ULV 500, a liquid formulation containing 4g/l phenothrin, 2g/l tetramethrin and 8g/l piperonyl butoxide, also designed for ULV application. Insecticides were applied through either Microgen E2 or Microgen G2 sprayers; the latter being used only for larger-scale field trials.

Droplet sizing was carried out in the field using Teflon coated glass slides mounted on an electrically powered rotator standing in the treated premises. Slides were removed after sampling, returned to the laboratory and counted using a compound microscope. Additionally, the droplet spectrum produced by each of the sprayers was measured using a Malvern Particle Analyser. Repeated assessment of both sprayers on different occasions with either formulation gave lmds in the range 10 to 20$\mu$m.

Measurement of the rate of fall-out of airborne droplets was carried out in a 1000$m^3$ chamber. 22.5 $cm^3$ bendiocarb ULV was applied using a Microgen E2 sprayer to give a rate of 4.5mg a.i. $m^{-3}$ equivalent to 45mg a.i. $m^{-2}$. Droplet size was measured as 13$\mu$m lmd using Teflon slides. The airborne concentration was measured by use of open-ended glass tubes packed with absorbent granules. These were mounted horizontally at 1.5m above floor level and connected to an air pump that pulled air through the tubes at a constant rate. The pump was started immediately spraying ceased and the tubes removed and replaced with fresh tubes at intervals after treatment. The bendiocarb was extracted with a solvent and quantified using HPLC. Additionally, filter papers were placed on the floor of the chamber to determine deposition. These were changed at 2 hours after treatment and were eventually removed at 24 hours after treatment. These were again analysed to determine the bendiocarb deposit.

FIGURE 1. Bendiocarb air concentration following treatments at 4.5 mg $m^{-3}$



Air sampling data (Fig. 1) showed a rapid decline in airborne concentration, with 90% of the target concentration having been lost within 20 minutes and 99% within an hour. Analysis of the fallout pads indicated that 90% of the total fallout occurred within the first two hours of treatment.

Efficacy of the formulations was examined in three ways. Direct exposure tests were carried out on the German cockroach Blattella germanica (L.), the flour beetle Tribolium confusum (Jacquelin du Val) and the Pharoahs ant, Monomorium pharaonis (L.) to represent a range of insects pests. Of the true storage pests T. confusum is one of the more insecticide hardy and thus represents a severe challenge. The insects were contained in batches of 10 in 12cm diameter glass crystallising dishes which had been coated on the internal wall with PTFE to prevent escape. A total of five replicate containers of each insect type were placed at different locations on the floor of an 800m$^3$ experimental chamber. The chamber was treated with the required dosage of product using a Microgen E2. In order to obtain a reasonably uniform distribution of insecticide within the chamber the operator stood at the centre of the chamber and pointed the spray upwards at about 45° and then rotated slowly until the required amount of insecticide had been discharged. At one hour after treatment the insects were removed from the chamber and transferred to clean containers where they were held for a further 24 hours and mortality then recorded. Results are shown in Table 1.

TABLE 1. % Mortality following direct treatment

| Treatment Dose mg ai m$^{-2}$ | Bendiocarb 22.5 | | Phenothrin + Tetramethrin 29 | |
|---|---|---|---|---|
| Time after Treatment (h) | 1.3 | 24 | 1.3 | 24 |
| B. germanica | 54 | 100 | 93 | 80.5 |
| T. confusum | 100 | 100 | 98 | 22 |
| M. pharaonis | 100 | 100 | 100 | 100 |

In order to determine the penetration of insecticide droplets into refugia, and dishes of T. confusum were placed on the floor of the chamber under a 50 x 50 cm rigid sheet before treatment, with a 6cm clearance between the underside of the sheet and the top of the dishes. Treatment of the chamber and handling of insects was carried out exactly as previously. Results are shown in Table 2.

TABLE 2. Effect of shielding on ULV insecticide efficacy against T. confusum % Mortality at 24 hours

| Location | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Exposed | 77 | 77 | 100 | 72 | 100 | 36 |
| Shielded | 57 | 45 | 97.5 | 0 | 24.6 | 29 |

Residual activity of the deposit on exposed surfaces arising from these treatments was assessed using the same chamber and treatment technique described earlier. In this case 15 x 15cm tiles of glass, plain plywood and quarry tile were placed on the floor of the chamber before treatment. At 24h after treatment the tiles were removed from the chamber and T. confusum confined on the tile using PTFE coated glass rings. Mortality was noted at 24h after exposure. The same tiles were reassayed 7 days later. The results are shown in Table 3.

TABLE 3. Residual activity of ULV formulations on T. confusum

| Formulation | Target Dosage mg ai $m^{-2}$ | Percentage Mortality Days after Treatment 1 G | 1 W | 1 Q | 7 G | 7 W | 7 Q |
|---|---|---|---|---|---|---|---|
| Bendiocarb ULV | 90 | 100 | 100 | 100 | 100 | 100 | 100 |
| Bendiocarb ULV | 45 | 100 | 90 | 90 | 100 | 60 | 22 |
| Phenothrin + tetramethrin | 30 | 9 | 7.5 | 0 | 2.5 | 0 | 0 |

G = Glass  W = Plywood  Q = Quarry Tile

Field evaluation of pesticide efficacy were carried out in a variety of premises including flour mills, animal feed mills and food-processing establishments. Insect populations were monitored both before and after treatment by commercially available pheromone traps for moths of the Phycitidae family, and by bait-bags for beetles. A number of traps and bait bags were positioned in each premises and left in situ for three days before removing, identifying and counting the insect catch. Trapping rounds were carried out twice before treatment to assess the natural population and then at intervals after treatment to determine the impact of the treatment. Results of these field trials are shown in Tables 4 and 5.

TABLE 4. Impact of ULV on coleopetran pest populations

Oryzaephilus surinamensis (L.)  Cryptolestes ferrugineus (Stephens)  Stegobium paniceum (L.)  Ptinus tectus (Boieldieu)

| Treatment | Dosage mg ai $m^{-2}$ | Average Pre-treatment Catch | Post-treatment Catch Days After Treatment 1-10 | 11-30 | 31-60 | 61-100 |
|---|---|---|---|---|---|---|
| Bendiocarb | 90 | 2152 | 10 | 30 | 57 | 14 |
| Bendiocarb | 90 | 13 | 0 | 0 | 1 | 1 |
| Bendiocarb | 45 | 7 | 1 | 0 | 1 | 0 |
| Phenothrin + tetramethrin | 30 | 20 | 33 | 66 | 14 | 37 |

TABLE 5. Impact of ULV treatments on lepidopteran pest populations

*Ephestia kuhniella* (Zeller) and *Plodia interpunctella* (Hüpner)

| Treatment | Dosage mg ai $m^{-2}$ | Average Pre-Treatment Catch | Post-treatment Catch Days After Treatment 1-10 | 11-30 | 31-60 | 61-100 |
|---|---|---|---|---|---|---|
| Bendiocarb | 45 | 1325 | 38 | 37 | 8 | 6 |
| Bendiocarb | 45 | 21 | 0 | 0 | 0 | 1 |
| Bendiocarb | 90 | 235 | 1 | 6 | 1 | 0 |
| Phenothrin + tetramethrin | 30 | 26 | 176 | 119 | 87 | 268 |

## DISCUSSION

The droplet size measured for the ULV generators are typical of those produced by this type of equipment. At the outset of the study some thought was given to tailoring the droplet size of the equipment to maximise efficacy, as has been done in other pest control situation e.g. mosquitoes (Mount, 1970), locusts (Dubs *et al* 1985), etc. However in indoor pest control a different set of factors prevail. The motion imparted to the droplets during treatment may cause some initial impaction but this energy quickly dissipates and is probably more important in determining the overall distribution of droplets within the building, rather than the nature of the deposit. Given the absence of significant consistent air movement in buildings and the sedentary behaviour of most of the insect pests, then sedimentation is probably a more important mode of droplet acquisition than impaction. This importance of sedimentation, together with the diversity of insect targets within buildings e.g. typical infested premises can simultaneously harbour five different insect pests with correspondingly different behaviour and morphology, suggested that precise definition of 'ideal' droplet sizes for indoor treatments would not be a fruitful line of investigation.

The droplet fall-out data produced by both air sampling tubes and fall-out pads agrees reasonably well with published information on droplet terminal velocities The implication of these data is that airborne concentrations decline so rapidly that any insect that is protected for the first hour after treatment is likely to be able to escape significant contact with sedimenting droplets. This conclusion supports that of Bernhard and Bennett, 1981. Given that at any one time the majority of storage pests within a building tend to be concealed, reliance on direct sedimentation of droplets onto exposed insects is unlikely therefore to produce an adequate proportion of insects contacted.

The data in Table 1 show the breadth of activity of the formulations against exposed insects. The poor activity of pyrethrin/pyrethroid ULV formulations against *T. confusum* has been documented previously. (Bernhard and Bennett, 1981). The shielded assay data show a significantly greater survival of insects in the refuge. Clearly the data indicates that the protection afforded by even a simple shelter is sufficient to reduce insect mortality and therefore the overall efficacy of a treatment.

The implications therefore of the rapid fall-out, the large proportion of insects hidden at any one time, and the protection offered by refugia are clear. Unless the sedimented droplets remain active and available for uptake later by insects emerging from a harbourage,or unless premises are treated very frequently, then the potential of air-assisted ULV treatments of the type described is very limited. Accordingly the residual life of the bendiocarb and pyrethroid formulations was determined as described earlier. Results (Table 3) show that unlike the pyrethroid formulation the bendiocarb ULV provides residual control of insects that encounter treated surfaces up to at least a week after treatment.

This bendiocarb formulation was therefore considered to have the characteristics of a successful product for control of pests within warehouses and a series of field trials was set up. Tables 4 and 5 show results obtained from a variety of premises against both lepidopteran and coleopetran storage pests. Results show that at 45mg bendiocarb $m^{-2}$, the pest population is substantially reduced for up to three months after treatment. By comparison the commercially available pyrethroid formulation with direct contact activity only, appears to have a little lasting effect although numbers of dead insects were observed immediately after treatment.

Turning lastly to the logistics of treatment an interesting example arose at a recent trial of bendiocarb ULV applied to a large bonded warehouse of 90,000 $m^3$. Table 6 shows an analysis of the inputs required for the standard pyrethrin treatment and projected figures based on a treatment of bendiocarb ULV in the warehouse.

TABLE 6. Logistic comparison

| | Pyrethrin Treatment | Bendiocarb ULV |
|---|---|---|
| Dose | 1 litre/5000$m^3$ | 25$cm^3$/100$m^2$ |
| Volume | 18 litres | 1.8 litres |
| Treatment time | 4h | 0.5h |
| Treatment interval | weekly | 6 weeks |
| Time per year | 208h | 4.3h |
| Total volume applied | 936 litres | 15.6 litres |

One fundamental difference apparent in Table 6 is whereas the recommendation for use of most indoor ULV treatments is based on an insecticide-per-unit-volume of the premises, bendiocarb ULV is applied at an insecticide-per-unit-floor-area basis. In the face of the preceeding data showing the very short life of significant air-borne insecticide concentrations, and the importance of deposit in achieving effective control, it was felt that a dose based on the floor area of the premises was more closely related to the degree of control achieved. In addition such an approach again helps differentiate air-assisted ULV treatments from true fumigation.

## CONCLUSION

Tests on the physical behaviour and the efficacy of air-assisted ULV insecticide treatments in warehouses have been conducted. Results show that non-residual treatments, although active on individual exposed insects, do not have a significant impact on real pest populations, unless perhaps used very frequently. Formulations, such as bendiocarb ULV however, that confer a limited degree of residual effect can provide lasting control of pest population with a single treatment.

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# MOSQUITO CONTROL USING MIST-BLOWER SPRAYERS FOR RESIDUAL DEPOSIT OF BENDIOCARB ULV IN MEXICO

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ABSTRACT

Insecticides for the control of mosquitoes by residual deposit on surfaces have traditionally been applied using knapsack compression sprayers with a single nozzle lance. Recent work in Mexico has shown that the air-assisted application of a bendiocarb ULV formulation can give control of malarial vector An. albimanus equivalent to that achieved with twice the dose rate of a wettable powder formulation with very considerable operational and labour savings.

## INTRODUCTION

Mosquitoes remain the most important insect vectors of disease, carrying infections caused by viruses, protozoa and helminths. Of these infections the most serious is malaria, with 2100 million people, that is 41% of the world's population, living in malarious areas. Of these 270 million are infected and 110 million develop the acute disease - more than 2 million new cases per week. The overall malaria situation is not improving "At present malaria is at a cross-roads, a really concentrated effort will be required to reverse the present highly unsatisfactory trend" (Gilles 1990). Similarly other mosquito borne diseases, such as dengue fever and the encephalitides caused by viruses are problems of increasing seriousness.

Control of mosquito borne diseases is possible in a number of ways at various points of the parasite's life cycle, for example by treating the patient with drugs, protection by vaccines and control of mosquitoes, either with insecticides against adults and larvae or by reduction of breeding sites by drainage etc.

This paper concentrates on control of adult mosquitoes by interior house spraying with insecticide, which especially for malaria mosquitoes can be very effective. This is because the female anopheles mosquito enters houses in search of the blood meal which she must have in order to lay viable eggs, usually at night when the occupants are resting. After feeding she rests inside the house and, if the house has been sprayed, picks up a lethal dose of insecticide and dies. The house may be regarded as a trap and its occupants the bait.

## CONTROL METHODS

Traditionally house spraying for malaria control uses aqueous suspensions or emulsions of insecticides at the quite high volume of 25 square metres per litre (Fontane 1978). Treatment rates of older insecticides were up to 2g ai/m$^2$ or 4g product/m$^2$ if a 50% formulation was used and 1kg product in a 10 litre spray charge is required to treat one house of 250 m$^2$. Whilst effective the procedure is obviously labour intensive and time consuming. The latter consideration is particularly important as insecticide needs to be in place on the house walls only just before the beginning of malaria transmission so treatments need to be applied over quite a short time scale. At one time this labour intensive operation was acceptable but nowadays in some countries especially it has become burdensome and there is a need for a quicker and more cost effective application technique.

Ultra low volume insecticide treatments have been in use for many years to control mosquitoes in outbreaks of dengue fever. Whilst intended to be effective only at the time of application, against flying mosquitoes, it was noted that if directed onto surfaces there could be a residual effect. Recently workers at the Malaria Research Centre at Tapachula in Mexico have investigated the use of ULV formulations applied inside houses using knapsack mist-blower sprayers for the control of the important malaria vector in that region Anopheles albimanus.

## PRODUCT

Bendiocarb is a carbamate insecticide with a broad spectrum of activity and excellent residual effect. It is highly active giving a rapid knockdown, it is non-irritant and non-repellant to insects (particularly important for malaria control where, as described above, the treated house can be regarded as a baited mosquito trap and repellant insecticides are completely inappropriate); and, just as important for malaria control, it is very acceptable to householders because of its lack of smell. Formulated as an 80% WP (Ficam[R] VC) the insecticide has become well established for vector control over the last five years, being used operationally in ten or so countries of the world. Application has been in the conventional way except that because of its high level of activity a dose rate of only 400 mg ai/m$^2$ is required and this, together with the high concentration of the formulation, enables the 125 g spray charge to be supplied pre-weighed and sachet packed. This approach has proved highly popular, saving labour and time as well as ensuring accurate spray charge preparation and limiting exposure of operators to concentrated insecticide.

A ULV formulation of bendiocarb (Ficam ULV) has also been developed for use primarily against mosquitoes, by aeroplane and truck-mounted generators and by back-pack equipment. Use so far has been mainly for control of nuisance mosquitoes but of course control of disease vectors is also an important objective. Bendiocarb ULV has also been evaluated and approved by FAO for locust control. In a rather different situation Bendiocarb ULV is used for control of stored product and other pests in warehouses where an interesting residual effect has been demonstrated.

## EQUIPMENT AND SPRAYING TECHNIQUE

The objective is to spend the minimum time in each room to apply the reduced volume of product to all walls and ceiling surfaces, whilst ensuring an adequate and effective deposit.

The sprayers used are motorised knapsack mist-blowers such as the Fontan R12 or Volpi "Super Jolly". These are fitted with ULV atomizer attachment at the end of the air discharge tube.

TABLE 1. Comparison between the application techniques and operational performance of ULV method compared to the conventional knapsack nozzle sprayer.

| | Conventional nozzle sprayer | ULV mist-blower sprayer |
|---|---|---|
| Active dose rate | 400 mg/m$^2$ | 200 mg/m$^2$ |
| Product dose rate | 500 mg/m$^2$ | 1.0 ml/m$^2$ |
| Spray volume rate | 40 ml/m$^2$ | 1.0 ml/m$^2$ |
| Atomizer | 8002 at 2 bar | ? |
| Sprayer output | 600 ml/minute | 60 ml/minute |
| Deposit width | 0.5 metre | 1.0 metre |
| Spraying speed | 0.5 m/s | 1.0 m/s |
| WORK RATES | | |
| - spot rate | 15 m$^2$/minute | 60 m$^2$/minute |
| - 15 m$^2$/room | 188 sec + pumping | 47 seconds |
| - time/refill | 18 minutes | 3 hours |

In practice using a conventional single-nozzle sprayer, the nozzle must be kept at a set distance from the wall (0.5 m) and moved at a constant speed (0.5 m/s) in straight lines at regular spacing (0.5 m) to achieve a uniform deposit. Compression sprayers must be regularly checked for pressure and pumped up.

In contrast the low-volume mist-blower technique involves directing the air-assisted discharge from the atomizer head towards the target surface from a distance of about 1 metre and moving it across the surface at 1 metre/second at about 1 metre spacing to achieve a satisfactory deposit. This dramatically reduces the time spent in a room as seen in Table 1. Typically, two horizontal swaths are made along each wall and two or three across the ceiling.

It is recommended that close attention is paid to protective clothing and that coveralls, gloves, hat and face-mask are worn to protect the operator from the higher quantity of air-borne droplets produced by the ULV technique. This hazard is balanced by the much reduced time spent actually spraying.

## TRIALS

The Mexican studies (Arredondo, JL et al 1990) showed that low volume application can be nearly as effective as conventional wettable powder spray with hand-compression sprayers, with mosquito mortality of 70% or more in wall bioassays up to 10 weeks post-treatment. Twenty four hour mortality of indoor and outdoor human bait collected mosquitoes was similar with both spraying techniques. The low volume spraying was associated with an important reduction in the mean annual parasite index (API), from 110.32 cases per thousand population to 42.14 when low volume spraying was carried out. The low volume technique compared very favourably with respect both to insecticide cost per house and operational costs, as the doseage of active ingredient was halved to 200 mg/m$^2$ and three times as many houses were treated per spray man per day.

Further larger scale trials against malaria vectors are in progress in Mexico and other countries and trials are also in progress against Aedes aegypti, the vector of dengue fever. In the past ULV treatments against Aedes have been directed at the flying adult, with application by aeroplane, truck, or back-pack generators. Recent studies in Puerto Rico have shown that adult Ae. aegypti rests very much inside houses and that malathion applied in the conventional way does not penetrate inside the houses where the vector is resting, thus accounting for the poor performance of malathion in dengue control. Application of Bendiocarb ULV inside houses, as described above for An. albimanus, is expected to give good control of house resting Ae. aegypti and dengue outbreaks.

In summary, air assisted application of a bendiocarb ULV formulation has given control of the malaria vector An. albimanus equivalent to that achieved with twice the treatment rate of a wettable powder formulation, with very considerable operational savings in labour. This technique may also be applicable to control of other house haunting species such as Ae. aegypti.

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