REVIEW OF THE USE OF A TWIN-FLUID SPRAY SYSTEM ON A BERKSHIRE FARM FROM 1987 TO 1990

H.L. WILSON

Fishers Farm, Shefford Woodlands, Newbury, Berkshire.

ABSTRACT

The use of a twin-fluid sprayer over three seasons on this cereal farm has shown that compared with conventional spraying, considerable savings have been made in spraying time and application rates, which have more than covered the initial extra capital cost.

INTRODUCTION

Fishers Farm is a holding of 235 hectares situated in West Berkshire. The soil is mostly flinty clay cap over chalk classified as Batcombe Association. A flock of 1000 ewes is maintained on about 50 hectares of rotational grass leys, and the rest of the farm carries autumn sown crops of wheat, barley and herbage seed. Over the past three seasons wheat has yielded on average 8t/ha, and barley 7.1t/ha. Hybrid Italian Ryegrass yields have varied between 0.7 and 1.8t/ha.

THE CHOICE OF SPRAYER

Until three years ago all spraying had been done with a 1500 litre trailed sprayer with an 18 metre boom fitted with conventional nozzles. Herbicides were mostly applied in 240l/ha of water, whereas with fungicides the rate was reduced to 180l/ha. These rates allowed between 6 and 8ha of spraying for each full tank.

In June 1987 this sprayer urgently needed replacement, and various factors influenced the choice of replacement machine. These were price, the need to increase workrate because of farm staff reductions, the need to improve timeliness and accuracy of applications, and if possible to minimise wheeling damage to crops and soil.

The final choice was between a 2000 litre trailed machine fitted with an 18 metre conventional nozzle boom, and with wheel tracking to follow accurately the tractor wheels , or a mounted 800 litre sprayer fitted with twin fluid (air/liquid) nozzles, the Cleanacres Airtec System. At today's prices the Airtec machine is about £2000 more expensive than the conventional sprayer.

Despite this addional cost the Airtec was chosen because of the other criteria and also offered the possibility of reducing chemical rates. Reassurances were sought from the manufacturers and from the relevant authorities as to the implications of the forthcoming FEPA legislation on this category of equipment.

ON-FARM PERFORMANCE

Disadvantages

Few problems have been encountered which can be associated with the extra complexity of this twin fluid machine, and in three seasons maintenance costs have been only slightly higher than those of a conventiional sprayer.

Nozzle blockages have been experienced, but at low application volumes of typically 80l/ha they have been no more frequent than would be anticipated with conventional hydraulic nozzles spraying at 200l/ha.

There have been some occasional restrictions in choice of product because of the lower application volumes used with the Airtec, either for fear of poor efficacy, or because of legal limitations. These have been of little practical significance, and the secondary conventional sprayline has rarely been fitted.

Advantages

Increased workrate

Most applications have been carried out at 70 to 80 l/ha, but fungicides have been applied at 60l/ha, and some herbicides have required 100l/ha. Typically the total cycle including filling, travel and spraying takes 60 to 70 minutes. This has allowed large areas to be covered per day with a relatively small tractor-mounted machine.

Improved timeliness

The ability to spray at low volumes without producing a high proportion of fine droplets, and the facility of adjusting droplet size on the move without changing the spraying rate to suit the prevailing conditions considerably increases the oppurtunity for spraying. Suitably adjusted this machine can continue working safely without drift problems when a conventional sprayer could not be used. This considerably improves the chances of applying agrochemicals at the optimum time, at minimum rates before the target problem increases, and at maximum efficacy.

Agrochemical savings

In practice it has been found that considerable savings can be made in agrochemical costs, especially fungicides. Table 1 shows the costs of spray chemicals actually applied to a 46 hectare crop of winter wheat cultivar Riband, compared with the costs which would have been incurred had a conventional sprayer been used.

This subjective assessment shows a saving of about £21.50 over conventional applications, largely achieved through lower fingicide rates. From this a saving of agrochemical costs, and savings of this order have been achieved with no detriment to cereal yields or quality. Although no claims were made by the sprayer manufacturer of the potential for chemical savings, it was found, within the first year, that such savings more than repaid the extra cost involved in the initial purchase of this machine.

TABLE 1. Table showing actual costs of pesticides per hectare on a winter wheat crop using a twin-fluid sprayer as compared to equivalent costs using a conventional hydraulic sprayer.

Pesticide used	Actual Costs Twin-fluid system £/hectare	Equivalent Costs Conventional hydraulic £/hectare
Trace elements	0.76	1.90
Growth regulators	2.24	3.10
Insecticides	2.13	2.50
Herbicides	28.82	29.60
Fungicides	46.75	67.80
TOTAL	£80.70	£102.20

CONCLUSIONS

The operational, ecological and financial advantages experienced on this farm using a twin fluid air/liquid sprayer indicate that it is likely that this type of machine will become increasingly popular with farmers, and sales figures apparently confirm this trend. It is extremely frustrating and confusing to the user that with few exceptions, product label recommendations are rarely given for these sprayers. Agrochemical manufacturers should revise their product labels.

4.

Air-Assisted Spraying of Tree and Bush Crops

Chairman: N. G. MORGAN

IMPROVED PERFORMANCE OF MIST-BLOWER SPRAYERS BY ELECTROSTATIC CHARGING

J.G. ALLEN[1], A.P. SMITH[2], D.J. BUTT[1] and T.M. WARMAN[1]

[1]British Society for Horticultural Research, East Malling, West Malling,
Kent ME19 6BJ, U.K.
[2]The White House, South Green, Kent ME9 7RR, U.K.

ABSTRACT

To improve the efficiency of mist-blower sprayers and reduce environmental contamination, a system was developed for electrostatically charging the output from this type of machine. Units consisting of annular electrodes and standard hydraulic nozzles were made to replace the normal nozzles. A charge to mass ratio of c. 1.2 mC/kg spray was achieved with such a modified Commandair sprayer. This sprayer was tested against powdery mildew (Podosphaera leucotricha) in an apple orchard. Two treatments, charged and uncharged, were compared as replicated routine spray programmes of 13 applications of nitrothal-isopropyl applied at normal chemical rate in 150 l/ha. On two cultivars studied, charging increased the mean concentration of deposit ($\mu g/cm^2$) on the youngest unfurled leaves by c. 30% and also improved the evenness of droplet spacing and increased the amount of deposit on the undersides of leaves. The improvement in performance reduced the incidence of powdery mildew on three apple cultivars by c. 10% throughout the growing season. In an unreplicated trial on hops with a similarly modified Victair sprayer, charging more than doubled the deposition of cypermethrin for the control of damson-hop aphid (Phorodon humuli).

INTRODUCTION

The limitations of mist-blower spraying are well known. Only a small proportion of spray is retained by trees in orchards (Herrington et al., 1981), and the amount deposited on young apple leaves can vary by almost 3-fold (Allen et al., 1978). In hop gardens, the difficulty experienced in the control of damson-hop aphid is due partly to inefficient spray application in this crop.

To increase efficiency of deposition and decrease environmental contamination, electrostatic charging of the aqueous spray from conventional hydraulic sprayers has been investigated experimentally (Hardcastle, 1986; Inculet et al., 1981; Moser et al., 1983; Howell & Maitlen, 1983). The subject has been reviewed by Matthews (1989). The main problems are maintaining charge on the electrodes under field conditions, where there may be earthing through water and other material, and achieving a high charge to mass ratio on the spray. The spray charge must be sufficient to produce a significant attraction of the drops to the leaves in comparison with the force of the sprayer's air stream on the drops.

The work described in this paper concerns the performance of an experimental electrostatic spray-charging system, developed in an attempt to improve chemical deposits and hence enhance disease control and reduce wastage. The equipment was a combined nozzle and electrode unit designed to replace the nozzles on commercial sprayers. This system was fitted to a Commandair mist-blower sprayer (Drake & Fletcher plc) and was used in apple orchard trials over a four year period from 1985-1988. The work conducted in the final year is presented in this paper. A Victair sprayer (Drake & Fletcher plc), similarly modified, was used in a hop garden for 3 months during the latter part of 1989 and its performance was compared with an unmodified sprayer of the same type.

MATERIALS AND METHODS

Apple orchard trial

Technical details of the modified sprayer

The curved outlets from which air and spray are emitted on the Commandair sprayer were extended to a vertical position which largely prevented spray from passing over the tops of the orchard trees. The air output was c. 12.3 m^3/s at 80 km/h, drawn from the front of the sprayer. Nozzles were replaced on each side with seven electrode-and-nozzle units; these inductively charged the spray. The nozzles were Spraying Systems TY3 (65°) hollow cone, operated at 1103 kPa. Each annular electrode had a voltage of c. 5 kV, and the electrodes on each side were supplied from a small amplifier on the sprayer, with a maximum output of 200 μA. A detector indicated if electrodes became earthed. Power for the system was supplied from the tractor battery, with controls and indicators in the cab. Tractor and sprayer were both earthed with chains. The measured speed was 5.1 km/h. No special maintenance of the electrostatic system was required; the normal practice of cleaning with a hose and water before chemical had dried was adequate.

Orchard

The trial was conducted in 1988 at the Research Station, East Malling, in a 0.6 ha orchard with spindle-bush apple trees spaced 4.1 m x 2.0 m apart in 13 rows. The trees were c. 2 m high at the start of the season. Each row consisted of sequences of ten trees, each of a different cultivar; the sequences were repeated six times. This provided 12 plots arranged in six randomised blocks, with pairs of plots separated by a minimum of five rows or trees. Spray drift was found to be insignificant over this distance. In each plot, two trees of cvs. Cox's Orange Pippin (Cox), Golden Delicious and Suntan were recorded for mildew (Podosphaera leucotricha); other trees of Cox and Suntan in each plot were used for observation and determination of spray deposits.

Spray programme

Fungicides were applied according to manufacturers' recommendations (in terms of kg/ha) and in a volume of 150 l/ha. Thirteen applications were at weekly intervals but the final three sprays, after shoot growth ceased, were applied solely to obtain information on sprayer performance and not for purposes of disease control. Pallitop (nitrothal-isopropyl), a non-systemic fungicide, was applied at 0.6 kg/ha to control powdery mildew. Apple scab (Venturia inaequalis) was controlled by the addition of captan to alternate applications.

Records

Disease. Apple powdery mildew was recorded on five extension shoots on each of two trees of cvs. Cox's Orange Pippin, Golden Delicious and Suntan in each plot. A tag was tied to the internode above the youngest unfurled leaf on these shoots after each application, and the two leaves above the tag and the three leaves below were subsequently examined for colonies of secondary mildew associated with each application.

Fungicide deposition. The amount of fungicide deposit per unit area was measured on twenty of the youngest unfurled leaves (i.e. those most susceptible to mildew) per cultivar in each plot. Leaf samples were taken from two Cox and two Suntan trees in each plot immediately the spray was dry after each application. Leaves were measured and fungicide was extracted and the amount determined by gas chromatography. Leaf deposits throughout the tree canopies were observed on four occasions by adding a soluble fluorescent dye (Stardust at 0.5%) to the spray mix, and subsequently observing sampled leaves under u.v. light.

Drop size. The spray drop size was calculated from crater sizes on magnesium oxide slides. Ten slides were evenly spaced vertically in a frame placed between trees, using one frame for each treatment. Craters (100) were measured on each slide and a spread factor of 1.15 assumed for all drops.

Charge to mass ratio. The charging efficiency was determined in the field with the system fitted to the Commandair sprayer. An insulated wire mesh grid (1.3 cm "Weldmesh", c. 1.8 m x 0.8 m) fitted with 80 sharp points was held 1 m from the outlet, and the current to earth measured as the spray passed through the grid.

Hop garden trial

Technical details of the modified sprayer

A Victair sprayer was modified in a similar manner to the Commandair. Air outlets were widened to accommodate the electrodes and give a satisfactory air supply. The air input was filtered. There were seven electrode-and-nozzle units on each side, with Delavan HC6 (45^{o}) nozzles operated at 690 kPa. The Victair sprayer used for the uncharged treatment had seven nozzles with size 6 discs on each side, and was operated at 390 kPa. This unmodified Victair had the advantage, for hop spraying, of a faster air speed (c. 14%). The measured tractor speed was 4.8 km/h.

Hop garden. The trial was conducted in 1989 on a commercial farm in Kent on cultivars Challenger (spaced 2.4 m x 0.8 m) and Northdown (spaced 2.4 m x 0.9 m) grown on 4.6 m high wirework. Two unreplicated plots of ten rows of 200 bines of each cultivar were treated using the modified or unmodified sprayers.

Spray programme

Ambush C (cypermethrin) for damson-hop aphid control was applied from June until harvest, in early September. The charged treatment applied 390 l/ha and the uncharged treatment, with the unmodified Victair sprayer, 1100 l/ha. Both applied Ambush C at 0.07%.

Records

Pests. At approximately weekly intervals aphids were counted on a lateral branch taken from each of ten bines in each row in each of the two plots.

Pesticide Deposition. As soon as the sprayed plants were dry, laterals were taken from ten bines per cultivar in each of the two plots, at heights of 1.2, 2.1 and c. 4.5 m (i.e. near the top wire). The insecticide was extracted from all the leaves on each lateral and the concentration was determined by gas chromatography.

Charge to mass ratio. This was determined as described above for the Commandair sprayer.

RESULTS

Apple orchard trial

Under normal spraying conditions the charge to mass ratio of the spray was 1.2 mC/kg. Checks at the start and end of each application day showed that this high level of charging was maintained throughout the season.

The mean deposit of nitrothal-isopropyl per unit area (on both upper and lower leaf surfaces) from all applications is shown in Table 1: the mean increase caused by charging was 29% on Cox leaves and 36% on Suntan. The difference between charged and uncharged mean spray deposits was significant on both Cox and Suntan (P=0.001), and this increase in deposit concentration due to charging was significant on 11 application dates. Generally, there was no interaction between treatments and cultivars.

Examination of fluorescent deposits under u.v. light clearly indicated that charging increased these on lower surfaces of leaves. It was also clear from these examinations that charged drops were spaced more evenly over the surfaces of the leaves. There was no indication of any decrease in deposits in the centre or other regions of the canopy as a result of the increase in deposition on young leaves.

The mean drop sizes are shown in Table 2. They were similar for both treatments (c. 90 μm) but appeared to decrease gradually after the first few weeks.

TABLE 1. Mean deposits (μg/cm^2) of nitrothal-isopropyl on the youngest unfurled leaves on Cox's Orange Pippin and Suntan apple cultivars sprayed on 13 dates.

	Cox		Suntan	
	Uncharged spray	Charged spray	Uncharged spray	Charged spray
Mean	1.01	1.29	1.05	1.45
SE	0.27	0.30	0.29	0.32
Increase		28.5%		35.8%

TABLE 2. Volume median diameter (μm) of drops in charged and uncharged sprays of Pallitop on 13 spray dates

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	SD
Charged	96	92	107	103	87	88	91	79	84	72	74	66	71	14
Uncharged	92	101	110	88	90	87	88	79	83	77	79	72	73	16

Disease levels are shown in Fig. 1; on all three cultivars charging lowered the incidence of mildew by c. 10%. This improvement in control was consistent throughout the season despite notable differences in the epidemic patterns between the cultivars.

Hop garden trial

The spray charge to mass ratio with the Victair sprayer was difficult to measure with precision because of the wide vertical angle of the spray. It was estimated to be 0.4 mC/kg.

Deposit data from two applications are shown in Table 3. The charged spray applied more cypermethrin at all three positions on the bines. The mean increases in deposit concentration on these dates were 3.5 and 2.2 fold, and on both dates the greatest improvement was at 2.1 m.

Counts of damson-hop aphid are also shown in Table 3 and they did not reflect the deposit levels. On most occasions until harvest the unmodified sprayer gave better control. The electrostatic sprayer provided adequate control on Challenger but not on Northdown.

TABLE 3. Cypermethrin deposits (μg/cm^2) on hop leaves sampled at three heights and aphid numbers on two cultivars.

		Deposit				Aphid numbers ($\log_{10}$ per lateral)	
Date	Treat-ment	Sample height (m) 1.2	2.1	3.7	Mean deposit	cultivar Challenger	Northdown
25 July	C	5.9	6.4	3.2	5.2	0.7	1.6
	UC	1.7	1.2	1.5	1.5	1.5	0.0
7 Aug	C	1.0	1.5	0.8	1.1	0.7	1.8
	UC	0.6	0.4	0.6	0.5	0.1	0.0
31 Aug#	C					0.6	1.01
	UC					0.0	0.01

C = charged spray; UC = uncharged spray from unmodified sprayer
# pre-harvest aphid count

DISCUSSION

Apple orchard

The charge to mass ratio of 1.2 mC/kg was achieved by progressive development of the shape and configuration of the nozzle and electrode in relation to the output of air and spray from the Commandair sprayer, and the spray rate. The system can be adapted to other types of mist-blower sprayer. Orchard experiments at East Malling in 1986 and 1987 showed that with similar spray volume rates and drop sizes to those used in this study, improved disease control of apple powdery mildew could not be obtained with a charge to mass ratio less than 1.2 mC/kg. However, absolute and unambiguous values for this ratio are difficult to specify, which is the reason why it is essential to describe the method of measurement. Values higher than 1.2 mC/kg are theoretically possible and could further improve deposition and disease control.

The relative importance of the three improvements derived from spray charging (i.e. increased total deposition, increased deposition on the undersides of leaves and more even distribution) is not known, and may vary with the extent to which the applied active ingredient is systemic and becomes redistributed. However, given the small size and the orientation of the youngest unfurled leaves, increase in total deposition is likely to be of particular importance.

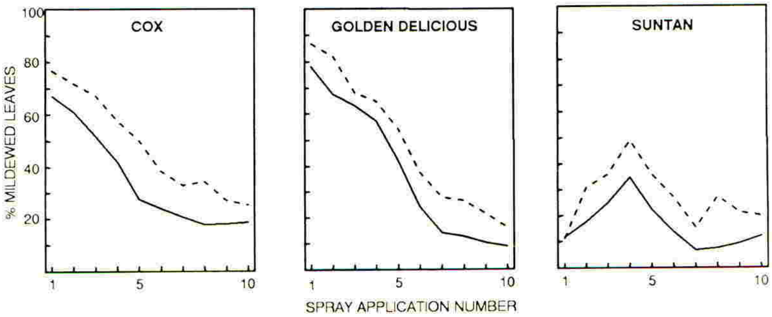
The reason for the greater deposit on Suntan on some dates is not known, but may be related to the denser canopy than that of Cox. This probably reduced the airflow more than Cox and allowed the force of attraction between drops and leaves to result in more effective deposition. Reducing the speed of the airflow may be helpful but this will eventually result in uneven spray distribution.

There is a direct relation between level of apple powdery mildew in commercial orchards and crop value (Butt et al., 1983). The enhanced mildew control observed in this study would be expected to improve crop value, particularly on Cox.

Hop garden

The relatively low charge to mass ratio (c. 0.4 mC/kg) was obtained without the opportunity for further development although this is clearly necessary. The volume and chemical rates from the electrostatic sprayer were only c. 35% of those applied by the unmodified sprayer (which were according to label recommendations). The remarkably high amount of deposit recorded, however, indicates the potential advantages of electrostatic charging in hops. Better aphid control may be expected with rates nearer to those used by the unmodified sprayer, or from a systemic aphicide.

Fig. 1. Incidence of powdery mildew during shoot growth on three apple cultivars treated with charged (__) and uncharged (----) fungicide sprays on ten dates.



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THE USE OF AIR ASSISTED HAND-HELD ULV SPRAYING FOR CONTROL OF COFFEE LEAF RUST IN COLOMBIA

R.P. ASTON, D.G. SHARP

T. L. Wiles and Associates Limited, 12 North Pallant, Chichester, West Sussex, PO19 1TQ

J.S. CLAYTON

Micron Sprayers Limited, Three Mills, Bromyard, Herefordshire, HR7 4HU

ABSTRACT

A systematic approach to the development of a control technique for coffee leaf rust has focused on three areas - finding the optimum formulation and deposit density in the laboratory for consistent control, designing equipment to meet this requirement in the field, and validating this system in field conditions. Laboratory bioassay work showed that sufficient biological effect could be achieved if a minimum of 8 drops/cm^2, of a 40% w/v copper in oil suspension could be deposited on the undersurface of the leaves. The most appropriate machinery for the conditions examined combined turbulent medium velocity air movement, with droplets produced by a spinning disc. A season-long field trial confirmed that the probability of leaf survival was significantly increased.

INTRODUCTION

Coffee leaf rust first reached the South American continent in 1970, and arrived in Colombia thirteen years later. Since then coffee leaf rust has spread to all the major coffee growing regions of the country (Fernandez 1987), Nutman and Roberts (1970) have discussed the biology of coffee leaf rust.

Coffee leaf rust is caused by the fungus *Hemileia vastatrix*, which can be controlled by the use of protectant copper fungicides applied to the trees at the appropriate times. In Colombia, using current techniques, the recommendation is for four applications annually. Application of copper in Colombia is by one of two methods, both requiring high volumes, typically 200-500 l/ha. One method employs semi-stationary pumps and long hoses using high pressure hydraulic nozzles, with the operator dragging the hose behind him. The second method uses pre-pressurised knapsack sprayers. However, the cultivation of coffee in Colombia presents two special problems for the application of pesticides, namely the density of planting and the steep slopes on which much of the coffee is grown. Tree density may be as high as 10000 trees per hectare, with the consequently intertwined branches forming a very thick canopy. With the very steep slopes (up to and exceeding 100%), movement through the coffee carrying a heavy sprayer is extremely difficult and slow. Under these conditions, typical work-rates of 0.20 ha/man day are achieved, and with an average farm size of 3 ha, timely application of fungicides is difficult (Fernandez 1987).

One of the added problems in the control of leaf rust is that copper fungicide applied to the upper surfaces of the leaves is rapidly removed by rain.

To overcome some of these problems, a programme to develop an Ultra Low Volume method of fungicide application was initiated between the National Federation of Colombian Coffee Growers (FNCC) and the Overseas Development Administration of the British Government (ODA). This paper covers three broad areas included in the project: defining the formulation and deposit density required for adequate leaf rust control for an acceptable period; development of equipment able to meet the deposit requirement under Colombian field conditions; and validation of the system for the control of coffee leaf rust under field conditions.

MATERIALS AND METHODS

Bioassay

The effect of varying deposit parameters of copper fungicides was determined using a bioassay technique. The formulation used was copper oxychloride, (PBI "Turbair" formulation) made up to 3 concentrations in oil (2.5, 5 and 10% [w/v] active ingredient). Coffee leaves were obtained from 6 month old plants grown under shelter. Droplets were applied to excised coffee leaves using a Micro Ulva (Micron Sprayers Ltd). Droplet size was altered by varying the speed of the spinning disc, with 2 speeds used - 15000 rev/min (small droplets) and larger droplets produced at 10000 rev/min. Droplets were applied to the lower leaf surface by passing the Micro Ulva over the leaves in still air conditions: the number of drops/cm^2 was altered by varying the speed at which the Micro Ulva was passed across the leaves. The number of drops/cm^2 was measured from cards placed next to the leaves during treatment. Four 20 micro-litre droplets of spore suspension (5000 spores/ml) were pipetted onto the undersurface of the treated leaves. The leaves were then placed in the dark at high humidity for 18 hours. After this time, any remaining water on the spore droplet was allowed to dry. The spores were removed using sticky tape, stained with lactophenol/cotton blue and viewed under a microscope. Spores were considered to have germinated if the length of the germ tube was greater than twice the diameter of the spore. For the treated leaves this was converted to % inhibition by comparison with germination on untreated leaves. For this bioassay, three leaves per treatment, with four counts per spore drop were used. Waller et al (in prep.) describes the bioassay in detail.

Droplet deposition studies on coffee

To achieve adequate cover of coffee leaves under the widely different conditions of planting density, slope and environmental conditions found in coffee plantations, three distinct application systems were examined. These are classified as 1) Natural Air Movement (i.e. Micro Ulva); 2) Medium Velocity Turbulent Air; 3) High Velocity Air.

Over one hundred and twenty field trials were conducted under different recorded conditions, with variables including slope, planting density, age of coffee, meteorological conditions and way of using the sprayer (e.g. above vs within the crop, and the method of movement of the sprayer). The methodology of these field trials was developed after a large scale replicated trial in 1987. Trials were carried out in coffee plantations subject to normal agricultural practices in Colombia. For natural air movement the plot size was 20 trees by 10 rows, with sampling taking place from 10 randomly chosen trees within the centre of the treatment area. For the other systems, plot size was 14 trees by two or three rows. For visualising the droplet deposit on the leaves, either saturn yellow or lumogen fluorescent tracers were used at concentrations varying from 1.5% (w/v) to 5% (w/v). Leaves were sampled from the trees at three heights (top, middle and bottom) and from the inside and outside of the tree. Two sides of the tree were sampled, making 12 samples per tree. Droplets were counted on the upper and lower leaf surfaces using UV light and a 10 or 20 times magnifier, from one or two fields of view per leaf surface. The results were subjected to a Log (X+1) transformation for analysis.

Biological field trial

In 1988, a large scale field trial was undertaken to test the practicality of an Ultra Low Volume air assisted sprayer for controlling leaf rust in field conditions. The trial site consisted of mature 2 stem coffee, 3-4 years after stumping with a mean height of 2.2-2.5 m, and with a leaf area index (measured from 5 trees) of 5.92. The trees were planted in a triangular pattern with an inter-tree distance of 1.5m. This particular site was chosen to try to ensure the presence of leaf rust.

Two blocks of coffee were used, each of 400 trees. One block was treated, the other served as the control. In both plots sampling was from the middle 100 trees. On the treated plot four applications of a 40% (w/v) experimental copper oxychloride oil formulation (supplied by Collag Corporation, Southampton) were applied at approximately two month intervals in line with current Colombian practice. Immediately before each application the amount of leaf rust was assessed. Two methods were used to assess the effectiveness of the treatment. The first of these, termed fixed sampling, followed the fate of leaves on eight trees. From these trees, initially selected at random from the two plots, six branches were marked (two each from the top, middle and bottom of the tree). For the assessments, the nodes on each marked branch were examined and leaf sites classified as follows: i) no leaves, ii) healthy leaves and iii) leaves showing rust pustules. This data was used to calculate the survival probability of the leaves.

The other sampling method involved the random selection of five trees within each plot at each sampling time. Six branches were selected on each tree, and the number of leaves with rust were recorded. With this method of rust assessment, leaves which have become rusted and fallen off the tree cannot be included in the analysis.

Application was by "Motax" (produced by Micron Sprayers), an axial flow air assisted sprayer. This machine produces droplets by spinning disc, driven either by a propeller or directly from the fan drive. The application rate was 5 litres/ha. Immediately after each application the number of droplets deposited in the trees was assessed using the same sampling methodology described above. Using the 40% (w/v) copper formulation the droplets were clearly visible without the need to use a fluorescent tracer.

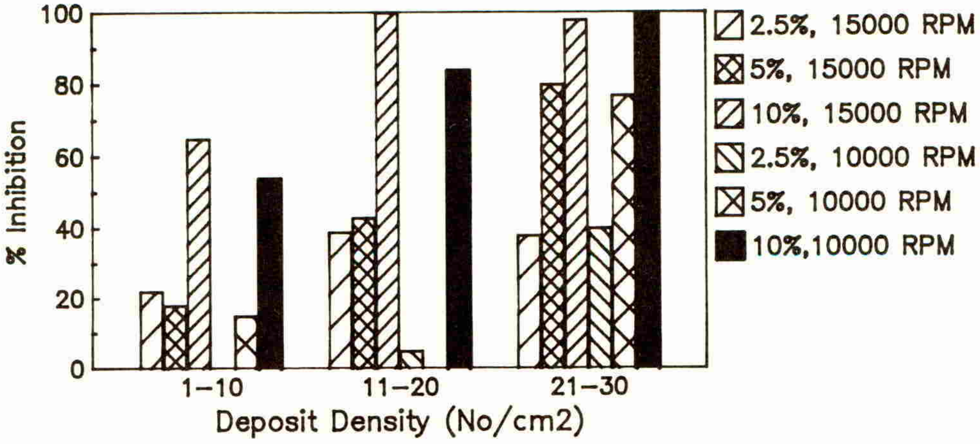
There were problems with the sprayer in applications one and two, resulting in low numbers of droplets being deposited per unit area. These technical problems were resolved before application three. In addition, it was found from other trials that moving the sprayer to each side of the line of travel increased the amount of copper deposited. This was adopted for applications three and four.

RESULTS

Bioassay

The results from this bioassay are shown in Fig. 1. For the smaller droplets, both increasing the deposit density and increasing the concentration significantly increased spore inhibition. Results for the larger drops are not complete due to missing values for 2.5% (w/v) concentration at 0-10 drops/cm^2 and 5% (w/v) at 11-20 drops/cm^2. However, for the 10% (w/v) concentration over a range of drop densities, there was no significant difference in the effectiveness of the two drop sizes. For droplet densities in the range of 21-30 droplets/cm^2, droplet size did not affect levels of inhibition at any of the concentrations tested. Thus it appears that smaller droplets were more efficient at delivering the toxic dose to the uredospores as, at 10% (w/v), smaller droplets were equally as toxic, despite containing less active ingredient. Fig. 1 shows that comparatively low deposit densities of the highest concentration reported here are able to give satisfactory uredospore inhibition. Using similar techniques to that described above, it was found from field applications that uredospores could be inhibited by as few as 8 drops/cm^2 up to 2 months after application from a field application of a 40% (w/v) oil based copper fungicide formulation when applied to the undersurface of the leaves. This was the level chosen as the target deposition in the field.

FIGURE 1. Effect of droplet size and droplet density on biological efficacy.

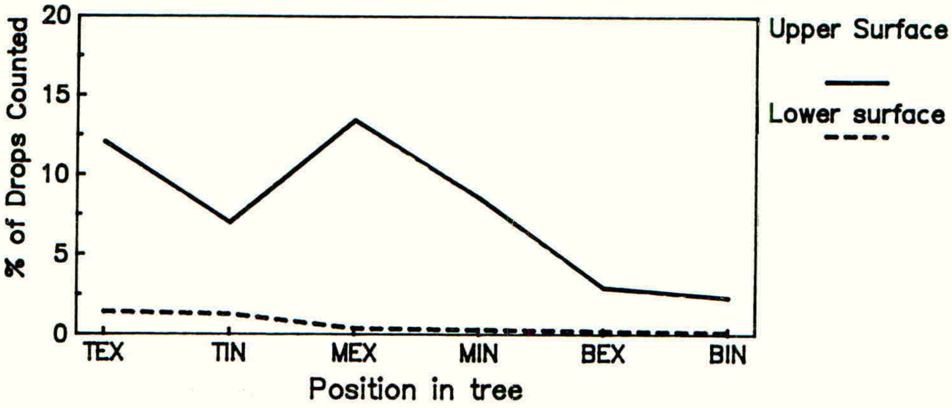


Droplet deposition studies on coffee

Natural air (Micro Ulva)

As is expected with this type of equipment under the conditions in which it was used, most of the deposit was on the upper surface of the top and middle leaves and there was little underleaf deposit. A typical result is shown in Fig. 2, with the results expressed as a percentage of the total drops deposited.

FIGURE 2. Droplet deposition within coffee trees. Natural air.

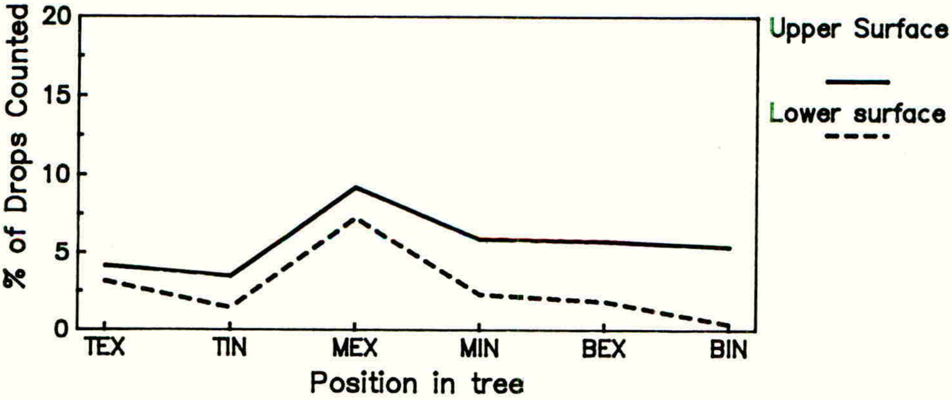


Key : T – Top, M – Middle, B – Bottom
EX – External, IN – Internal

Medium velocity air ('Motax')

Fig. 3 shows a typical deposit pattern achieved with this equipment under conditions comparable to those shown for the Micro Ulva. The data shows that this equipment is able to deposit droplets on the undersurface of the middle leaves (particularly the external ones) and there is also some deposit on the undersurface of top and bottom leaves. Sharp et al (1988) have reviewed the use of this equipment and discussed the deposit patterns obtained under various methods of use.

FIGURE 3. Deposition within coffee trees. Medium velocity air.

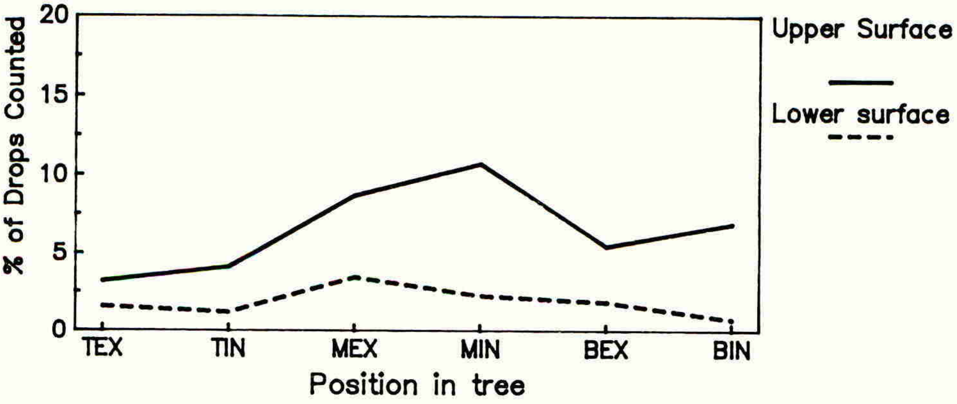


Key : T – Top, M – Middle, B – Bottom
EX – External, IN – Internal

High velocity directed air (Solo-Y)

Typical results obtained from this equipment are shown in Fig. 4. The conditions for this trial are slightly different from i) and ii) as this trial site was on a slope. This equipment had a Y-shaped outlet, directing spray to two rows at the same time. In addition, this equipment was moved up and down during application. However, the pattern is illustrative of the results obtained with this equipment. The data shows that there is a more even deposit in terms of the percentage of the total number of droplets deposited on the lower leaf surfaces throughout the trees. However, under conditions of steep slope this system gives a more variable deposit than the medium air velocity machine. In addition, the cost and complexity of this machine are further disadvantages. This equipment is discussed in more detail by Sharp et al (1988).

FIGURE 4. Droplet deposition within coffee trees; high velocity air.

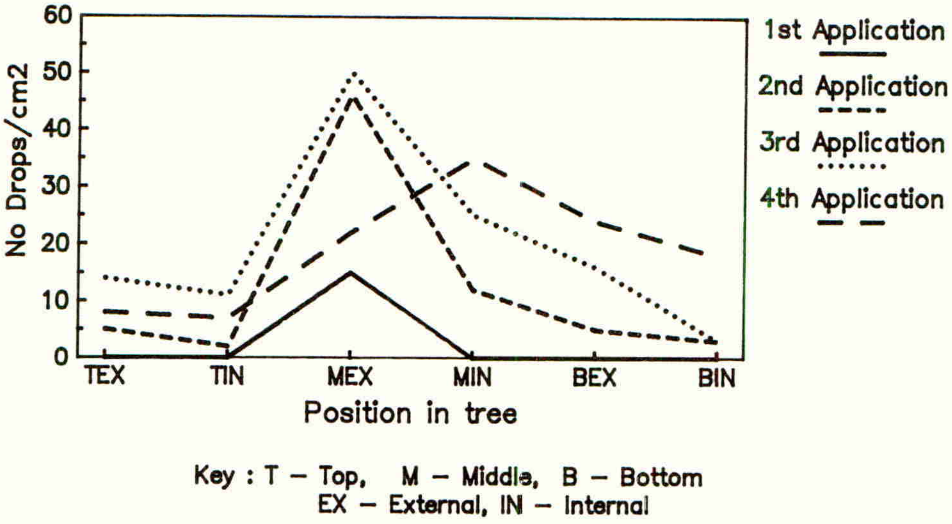


Key : T – Top, M – Middle, B – Bottom
EX – External, IN – Internal

Biological field trial

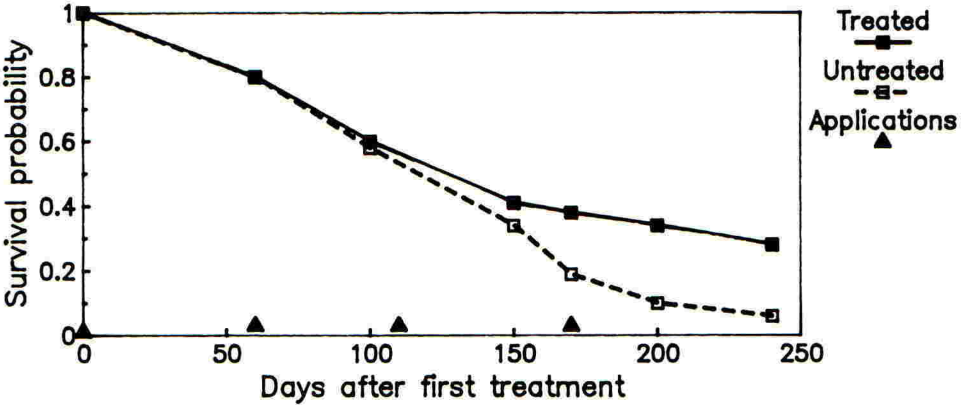
The coverage (drops/cm^2) from the four applications is shown in Fig. 5.

FIGURE 5. Number of drops/cm^2 deposited in the four applications.



There was no significant difference in the number of infected leaves in the treated and untreated plots from the randomly chosen trees until the final sample (231 days after the first treatment) when in the untreated plot 39% of the leaves were infected compared to 21% in the treated plot. Defoliation was high in both plots and the only significant difference was at the last sample time, when there was greater defoliation in the untreated plot (significant at p = 0.01). The effect of the treatment is clearer when the survival probabilities are considered (Fig. 6). Using this technique, there were significant differences (p = 0.01) between the treatment and the control resulting from both the third and fourth applications, with the differences first becoming clear 2 months (the time for the treatment to have a full effect) after the third treatment. At the end of the trial, the probabilities of leaves surviving in a healthy state were 0.26 in the treated plot and 0.06 in the untreated plot.

FIGURE 6. Survival probability for healthy leaves.



The results from the survival probabilities show that only treatments three and four were effective at influencing the progression of leaf rust. Fig. 5 shows that insufficient droplets were deposited in the correct place in applications one and two. When the minimum deposit criteria were met, in the last two applications, the survival probability data demonstrates that this system could be effective in reducing the progression of leaf rust.

CONCLUSIONS

The use of a relatively simple laboratory bioassay technique which allowed the effect of varying deposit parameters to be assessed rapidly, meant that the optimum deposit parameters for controlling coffee leaf rust could be defined. With this knowledge, it was possible to design and develop application equipment to meet these deposit criteria under Colombian field conditions.

The deposit data from the machinery field trials showed that under the conditions of cultivation and environmental factors studied, the most efficient method of meeting these criteria was with a machine producing a turbulent airstream of medium velocity, with droplets produced from a spinning disc rotating at 14000 rev/min. However, it is possible that alternative machinery may prove more efficient.

The season long biological field trial served to confirm the data obtained from the bioassay and deposition studies. Namely, if the minimum deposit criteria are met then the progression of coffee leaf rust can be reduced. In applications one and two, these deposit criteria were not met and it was not possible to detect any difference between the treated and the control plots. Conversely, when the appropriate deposit levels were met (applications three and four), then it was demonstrated, using the survival probabilities that the progression of the disease could be significantly reduced.

ACKNOWLEDGEMENTS

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CURRENT STATUS OF FOLIAR PESTICIDE APPLICATION TO CANE AND BUSH FRUIT CROPS IN EUROPE

S.C. GORDON, B. WILLIAMSON

Scottish Crop Research Institute, Invergowrie, Dundee DD2 5DA, United Kingdom

W.A. TAYLOR

Hardi International, Taastrup, Denmark

ABSTRACT

The development of air-assisted spraying technology for use in red raspberries (Rubus idaeus), black currants (Ribes nigrum) and other minor cane and bush fruits in Europe is reviewed. The effect of changing canopy structure and cultural practice on the location of major pests and diseases in these crops during the season is described in relation to spray application. Comparisons between traditional hydraulic sprayers and those using air-assistance have shown that in some situations there is potential for increased work rates and reduced volumes with equivalent or improved cover of target and efficacy of applied pesticide.

INTRODUCTION

The production of high quality cane and bush fruits in the UK and elsewhere in Europe is largely dependent on the use of insecticide and fungicide formulations sprayed in water to reduce damage by pests and diseases. Improvements in the performance of sprayers for foliar applied pesticides have occurred, but much of the current spray equipment has the same basic design as that used in the 1950s; it comprises a tank, a pump with regulatory valves and vertical, or near-vertical booms fitted with several nozzles. Penetration of the pesticide solution to potential targets within the crop relies largely on the kinetic energy imparted to the spray droplets when generated from simple nozzles, and to a lesser extent on the turbulence generated by the spraying process.

In the 1970s air-assisted sprayers became more widely used in cane and bush fruit plantations in England, but these sprayers were designed for application of pesticides in top (pome) fruit orchards.

The aim of this paper is to examine the development of several types of air-assisted sprayers for cane and bush crops and explore the possible benefits for pest and disease control. Emphasis is given to the effects of machine design and pesticide delivery methods on 'target' organisms. Control of weeds will not be considered because the primary concern here is the structure and surface characteristics of cane and bush fruits and the location of pests and diseases in the crop canopy in relation to application efficiency.

DEFINITION OF CANE AND BUSH FRUIT

The term 'cane fruit' usually refers to crop plants of the genus *Rubus*, particularly raspberry (*R. idaeus*), blackberry (*R. fruticosus*) and several hybrids between blackberry and red raspberry, notably Loganberry, Tayberry, Tummelberry, Sunberry and Boysenberry (Jennings, 1988). The term 'bush fruit' is loosely applied to fruits of the genus *Ribes*, such as black currant (*R. nigrum*), red currant (*R. rubrum*) and gooseberry (*R. grossularia*), but the term can perhaps be extended to include a range of small fruit crops of increasing importance, such as, sea buckthorn (*Hippophae rhamnoides*), *Rosa* spp. grown for hips and highbush blueberries (*Vaccinium corymbosum*) (Brennan & Cormack, 1989).

PESTS AND DISEASES

The prime target for any spraying system must be the site occupied by the pest or disease. In cane and bush crops there are three main locations, surfaces of leaves, stems, flowers and fruits, each requiring active pesticide in sufficient quantities to kill, or prevent the pest or disease spreading. The major pests and diseases of raspberry are listed in Table 1 and of currants in Table 2 to illustrate the diversity of targets for the spray designer.

TABLE 1. Pests and diseases of red raspberry: Major target sites and degree of difficulty for targeting spray application[†].

Target zone	Pest/Disease	Difficulty
Leaves	Aphids (*Amphorophora idaei*) (*Aphis idaei*)	***
	Raspberry leaf and bud mite (*Phyllocoptes gracilis*)	***
	Two-spotted spider mite (*Tetranychus urticae*)	***
	Rust (*Phragmidium rubi-idaei*)	***
	Powdery mildew (*Sphaerotheca macularis*)	*
Cane	Aphids (*A. idaei*/*A. idaei*)	*
	Raspberry cane midge (*Resseliella theobaldi*)	****
	Raspberry moth (*Lampronia rubiella*)	**
	Clay-coloured weevil (*Otiorhynchus singularis*)	*
	Cane blight (*Leptosphaeria coniothyrium*)	***
	Spur blight (*Didymella applanata*)	**
	Cane spot (*Elsinoe veneta*)	**
Flower/ fruit	Raspberry beetle (*Byturus tomentosus*)	**
	Raspberry moth (*L. rubiella*)	*
	Stamen blight (*Hapalosphaeria deformans*)	**
	Grey mould (*Botrytis cinerea*)	***

[†] Subjective assessment based on distribution of pests/diseases and cover of target by tracer dyes (see Gordon & Williamson, 1981).

TABLE 2. Pests and diseases of currants: Major targets for spray application and degree of difficulty in reaching target[†].

Target zone	Pest/Disease	Difficulty
Leaf	Aphids (*Hyperomyzus lactucae*) (*Cryptomyzus ribis*) (*Aphis schneideri*) (*A. grossulariae*)	**
	Black currant leaf midge (*Dasineura tetensi*)	****
	Black vine weevil (*Otiorhynchus sulcatus*)	**
	American gooseberry mildew (*Sphaerotheca mors-uvae*)	**
	Leaf spot (*Drepanopeziza ribis*)	*
	Rust (*Cronartium ribicola*)	**
Stem	Black currant gall mite/reversion (*Cecidophyopsis ribis*)	****
Flower/ fruit	Grey mould (*Botrytis cinerea*)	***

[†] Subjective assessment based on knowledge of biology of the pest/disease organism.

Organisms which largely occupy the undersides of leaves (e.g. rusts, mites and aphids), natural splits near the base of canes (raspberry cane midge) or infested buds in the centre of bushes (black currant gall mite) are given high ratings as targets.

CROP ARCHITECTURE/TARGETING PESTICIDES

The crop architecture of cane and bush fruits differs markedly, but both are woody perennials.

Cane fruits mostly have a biennial cane habit with vegetative primocanes growing each spring from the crowns and roots; these canes overwinter, produce lateral shoots and fruit in the second year, and then die. More recently autumn-fruiting cultivars which bear fruit on the upper half of the primocanes in the first year have been developed. A proliferation of sucker canes between the plants and in the inter-row space can overcrowd the plantation if unchecked. Many of the pests and diseases are host specific and their survival depends on the movement of these organisms between/from vegetative and fruiting canes. Most cane fruits are supported on trellis systems of posts and wires, with numerous systems devised to maximise yield, to protect primocanes from damage and offer ease of harvest (Pudwell *et al.*, 1982), but seldom with regard to ease of spraying. The distances between rows are dictated by cropping traditions, the trellis system adopted, and to some extent by the width of the tractor available to the grower. The maximum width of the plant rarely exceeds 1 m but in some regions primocane growth may reach a height of c. 1.8 m at the end of the period in which pesticides would normally be used. Although often desirable, post-harvest applications are rarely possible, except on the very widest row spacings because the unsupported primocanes fall into the alleys thus preventing access for machinery. However, to allow access for spraying and cultivation for a greater part of the growing season, narrow vine-yard tractors with an external width of 1.0 to 1.25 m are frequently used.

Bush fruits are free-standing plants which frequently self-propagate by rooting of low branches in soil, and when mature tend to sprawl into the inter-row spaces. Mature bushes may reach 1.5 to 2 m wide and c. 1.8 m high. The width of the inter-row spaces varies with local cultivation practice. The bush structure is maintained by regular pruning by hand, or by cutting down the entire branch system mechanically every few years. The latter leads to the proliferation of side shoots and the creation of an extremely compact canopy which is poorly ventilated, obscures light and restricts spray penetration.

The screening by a mass of broad-leaved foliage of stems, flowers and fruits and undersides of leaves where micro-organisms and pests reside is the most significant problem for spray technology in these crops. One consequence of the leaf 'screening' is that high volumes of spray solution are required (usually in excess of 1000 l/ha) for adequate control of pests and diseases, but a high proportion of the spray solution is intercepted by these outer leaves, coalesces on the upper leaf surfaces and runs down the veins and is lost on to the soil surface.

SPRAYER TYPES AND DEVELOPMENT

The hydraulic vertical boom sprayer is versatile and frequently can be modified to do a range of spraying tasks, including herbicide application. Nozzle size and type can be varied to the individual requirements of the grower. The work-rate of this type of sprayer is generally low, largely due to the high volumes of spray required to obtain a reasonable degree of cover and the need to spray each side of a row separately. In an attempt to increase work-rate by treating two rows simultaneously, 'up-and-over' booms were developed (Cole, 1979; Anon., 1980). The extra turbulence caused by the interaction of the spray patterns generated by nozzles on opposing sides of the rows increased the target cover on raspberry (Gordon & Williamson, 1981), but there is a reluctance by growers to adopt them in the UK, possibly due to difficulties in manoeuvring the booms in the narrow row spaces.

In the mid 1970s several growers in the UK realised that the work-rate of the existing high volume hydraulic sprayers was unsatisfactory and they began to evaluate various types of air-assisted sprayer, most of which were primarily designed for use in orchards. A comparison of the spray cover obtained in raspberry by one high air-velocity machine (Kinkelder Pony 3P50) with a conventional hydraulic sprayer showed that there was an overall improvement in deposit on leaf and cane surfaces (Gordon & Williamson, 1981). However, in the 2 m row spacing of the trial site, the air-flow severely buffeted the foliage and much of the spray appeared to be discharged into the air.

In the late 1970s, work began at the National Institute of Agricultural Engineering (now the AFRC Institute of Engineering Research), Silsoe to improve the spraying of black currants by use of air-assisted sprayers. Studies were undertaken to optimise the air-flow and droplet characteristics for this crop. Initially the research concentrated on sprayers using axial flow fans to generate the air-flow, but they soon developed a sprayer which incorporated a novel design of fan, the cross-flow fan (Airwheels Ltd, Poole) (Sharp & Pottage, 1981a). Their investigations, on commercially grown black currants, revealed that the air velocity component of the spraying process was the single most important factor in obtaining satisfactory spray deposition. An air velocity of 12 to 13 m/s and spray droplets generated by Spraying Systems D2-23 nozzles gave the best deposition. Later studies by Sharp & Pottage (1981b) designed to quantify the spray deposits within the black currant bush were less successful, mainly due to decay of some samples prior to processing in a fluorimeter, but it was concluded that with the provision of a method to adjust the fan speed good penetration in black currant could be achieved and a prototype cross-flow sprayer was built and tested. Several commercial variants were developed and marketed e.g. 'Directair' (Drake & Fletcher Ltd, Maidstone) and 'Cross-flow Spraying Module' (Smallford Planters Ltd, St Albans). A similar type of sprayer, 'Holder QU 20' (Gebr. Holder GmbH & Co., Metzingen) was developed in Germany. Smallford's spraying panels were mounted in a self-propelled multi-purpose straddle frame (Smallford Mark II), used primarily as the motive power unit for a black currant harvester (Lovelidge, 1980; Anon., 1981).

In cross-flow sprayers, the fan assemblies are large, often 1 to 1.25 m tall. They can only direct air in one direction. Thus, in commercial practice, at least two such fans are required to permit both sides of a row to be treated in a single pass. The resultant sprayers tend to be bulky and more expensive than those with axial fans and because of their size, a trailed tank is often required. Cross-flow fans produce a uniform 'curtain' of air over the entire length of the fan, and provided that the spray solution can be incorporated satisfactorily, an even application should be possible over the desired target.

Several manufacturers continued to develop and further refine axial fan sprayers suitable for crops with similar growth habits e.g. vines and dwarf pome and stone fruits. The most widely used system involves the use of an axial fan driven from the tractor power take-off. In tractor-mounted sprayers, these fans are usually mounted below, or to the rear of the spray tank, drawing air through the fan and discharging it through a ducting system, incorporating the pesticide solution in the outlet. Because of the twisting, rotational forces generated by this design they have used baffle plates, flexible tubing or ducting to 'even-out' the air-flow. Altering the angle of attack of the air-flow relative to the crop i.e. at angles of 30-45° to the rear of the sprayer can influence the spray deposit and the level of drift (Gohlich, 1979, 1985).

EFFECT OF AIR-FLOW ON LEAVES

Cine and video recordings of leaf movements in black currants and raspberries have been employed to examine the effect of the air-flow generated by cross-flow sprayers (Sharp & Pottage, 1981b; Gordon & Williamson, 1988). In black currants, a cross-flow sprayer set to deliver an air velocity of 12.2 m/s at a forward speed of 6.9 km/h resulted in the bushes opening in a smooth manner as the machine passed. However, there was some evidence to suggest that at higher forward speeds, penetration was less effective. In raspberry cv. Malling Jewel, the leaf motion in response to an air-flow of 12.9 m/s to a stationary cross-flow sprayer indicated that two types of movement occurred, depending on the age of leaf examined. The larger and more 'mobile' leaves of the primocanes fluttered in the air-stream, whilst the smaller, rigid and slightly curved leaves, rotated about the petioles. When operated at a forward speed of 5 km/h, the raspberry plants were buffeted by the air, but no damage was observed.

SPRAY RETENTION IN RED RASPBERRIES

To quantify the effect of air assistance and reduced volume on spray retention by leaves and canes of raspberry cv. Glen Clova, a field trial in Scotland was sprayed with an aqueous solution of a mixture of non-ionic surfactant (PBI Spreader, Pan Britannica Industries Ltd) at 0.1% (V/V) and a fluorescent dye (fluorescein sodium, Merck) at 0.02% (wt/V) (W.A. Taylor & S.C. Gordon, unpublished). The spray was applied at two growth stages using two methods of application: at the first application (1 June 1988) the majority of the leaf canopy was formed by leaves of the fruiting laterals, but on the second application (28 June) most of the fruiting canes were obscured by rapidly growing primocanes. The spray solution was applied by an air-assisted Hardi SPV machine (Hardi Ltd., Nuneaton) delivering 630 l/ha from 10 nozzles (Hardi ceramic hollow cone jets 1999+0 with grey swirl jets 1554-1.5) operating at a pressure of 500 kPa, a forward speed of 4.7 km/h and a mean air velocity of 21.7 m/s at the orifice of the air ducts (equivalent to a mean air velocity of 16.1 m/s at crop interface), and a conventional hydraulic sprayer (Gordon & Williamson, 1988) delivering 1133 l/ha from eight fan nozzles (Spraying Systems 8006) operating at 325 kPa at 6.0 km/h as standard.

To quantify spray cover, ten leaf discs (20 mm diameter) were taken from each of the top, middle and lower zones of the canes on both sides of treated rows. The dye was extracted from the leaf and cane samples with a sodium hydroxide/non-ionic wetter solution, measured by fluorimetry and the figures expressed as a fraction of the application rate in l/ha (Taylor & Drouin, 1987). No account was taken of changes in leaf area index between the sample dates.

The results indicated that there were no significant differences ($\underline{P}>0.05$) in the level of spray deposit retained on the leaf surfaces after treatment by the conventional hydraulic sprayer compared with the air-assisted sprayer on both sampling occasions, although leaves treated by the air-assisted sprayer consistently tended to have a higher concentration of dye. Therefore, results from both sprayers are combined in Table 3 to show that at the second date the deposits on the leaves were consistently less than those of the first date.

EFFICACY IN TERMS OF BIOLOGICAL POTENCY

Most investigations of the efficiency of pesticide application have focused on the physical parameters associated with droplet penetration and deposition on target crops. Little work seems to have assessed the effect of different sprayers on biological target organisms. In cane and bush fruits this has been limited to observations in raspberry on the control of large raspberry aphid (Amphorophora idaei) by a contact insecticide (Gordon & Williamson, 1988). The biological efficacy of fenitrothion applied at three rates (0.55, 0.37 and 0.18 l a.i./ha) using a cross-flow air-assisted sprayer delivering 350 l/ha was compared with that achieved by a

TABLE 3. Spray deposits ($\mu l/cm^2$ deposited per 100 l/ha sprayed) of fluorescent dye applied by conventional hydraulic and air-assisted sprayers to fruiting cane leaves of red raspberry on two occasions.

Position in canopy		1 June	28 June	
Top (>1.2 m)	outer	0.138	0.066	**
	inner	0.130	0.080	*
Middle (0.6-1.2 m)	outer	0.169	0.091	n.s.
	inner	0.180	0.089	*
Bottom (0-0.6 m)	outer	0.185	0.073	***
	inner	0.173	0.105	*
Mean		0.160	0.084	**

*, **, *** Significantly different between spray dates at $P<0.05$, 0.01, 0.001 respectively.

conventional hydraulic boom sprayer applying fenitrothion (0.55 l a.i. 1/ha) at 2000 l/ha. The results are summarised in Table 4.

In 1980 and 1981 when high levels of infestation occurred in the unsprayed controls, the numbers of aphids detected in plots sprayed with fenitrothion at one third dose in 350 l/ha were substantially higher than in plots sprayed by either machine at the standard dose of 0.55 l/ha (Table 4).

No direct comparison between conventional hydraulic and air-assisted spraying in bush fruit crops has been reported. However, experiments in Denmark suggested that spray volume is an important factor influencing the effectiveness of an air-assisted sprayer for control of American gooseberry mildew and rust on black currants (Nielsen & Kirknel, 1986). An axial fan sprayer (Holder mist blower), fitted with three hollow-cone nozzles 'Holder D-10' on each side and operating at a range of spray volumes (200, 400, 800 and 1200 l/ha) at two pressures (800 and 2400 kPa), gave no differences in disease control with volumes of 400 l/ha or above; optimum deposition occurred at a rate of 400 l/ha.

DISCUSSION

Air-assistance has the potential to increase the droplet penetration during the spraying process to both cane and bush fruits. The differences in crop architecture between the bush and cane fruits suggests that optimum sprayer settings may have to differ between crops. At present there is insufficient data to provide precise settings for each crop but observations on retention of spray deposits in raspberry suggest that use of lower volumes with air-assistance results in more efficient transfer of spray to leaf and cane surfaces. Both these sites are important reservoirs of pests and diseases. The biological efficacy of the sprays has only been

TABLE 4. Numbers of raspberry aphids[†] on red raspberry canes after the application of fenitrothion by air-assisted and conventional hydraulic sprayers (after Gordon & Williamson, 1988).

Year		Conventional hydraulic	Air-assisted			Unsprayed control
	fenitrothion (l a.i./ha)	0.55	0.55	0.37	0.18	-
	volume (l/ha)	2000	350	350	350	-
Primocanes						
1980		5.2	9.3	8.2	16.5**	38.4***
1981		6.1	11.6***	16.7***	40.7***	60.8***
1982		4.7	4.9	5.2	-	14.3***
1983		4.7	3.3	3.9	-	8.6
Fruiting canes						
1980		2.5	14.0***	11.2***	21.4***	76.7***
1981		3.4	7.4*	24.3***	53.7***	86.7***
1982		2.2	1.5	1.4	-	6.5*

[†] Log$_e$ (n+1) transformed for analysis, detransformed for table.

*, **, *** Significantly different from conventional hydraulic sprayer at P<0.05, 0.01 and 0.001 respectively.

tested against raspberry aphids; although conventional hydraulic and cross-flow spraying systems reduced the numbers of aphids, the combination of a low spray volume with air assistance and the one third insecticide dose proved to be ineffective (Gordon & Williamson, 1988).

Air-assisted spraying has a role in improving foliar pesticide application in cane and bush fruits and in other low plantation crops and its use is likely to increase. With the development of more advanced 'nozzles' producing a narrower droplet spectrum and/or electrostatically charged spray solutions, air assistance, especially at relatively low velocities, may prove invaluable. The introduction of biological agents for control of pests and diseases of leaves, stems, flowers and fruit will require a continuing appraisal of spraying systems to give optimum delivery to the target and ensure minimum waste and maximum efficacy.

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ORCHARD GEOMETRY AND PESTICIDE PLACEMENT

F.R. HALL, J.A. COOPER

Laboratory for Pest Control Application Technology, The Ohio State University, Wooster, OH 44691, USA.

D.C. FERREE

Department of Horticulture, The Ohio State University, Wooster, OH44691, USA.

ABSTRACT

Orchard spraying is generally regarded as an inefficient, albeit usually effective, process. This paper describes findings from one aspect (orchard geometry) of a much larger project, designed to determine the major parameters governing in-canopy and off-target pesticide movement.

Calcium nitrate, used to mimic the application of a pesticide, was applied using an airblast sprayer to an apple orchard in full leaf.

Results from this application indicated that more spray passed through canopies of widely spaced trees compared to canopies of closely spaced trees, no significant differences were noted in spray penetration through either cultivar or management system. More chemical was deposited on leaves from wide than close spaced canopies, Smoothee than Lawspur when grown as a trellis system, and the deposits on both these cultivars and systems were higher than those on the leaves of freestanding Lawspur.

INTRODUCTION

Pesticides are expected to continue to play a major role for the foreseeable future in protection of most crop systems from insect and disease damage. Increased concern about pesticide pollution (drift and ground water contamination), development of pesticide resistance, recent advances in low volume spraying and integrated pest management (IPM) make it even more important than the correct amount of pesticide is applied to the target.

In the orchard, the target is complex; it may be an insect, pathogen, mite, or it could be the leaves or fruit etc. In addition, the target location within the canopy varies, eg. outside edges of canopy, or inside top centre. The tree size and shape changes during an individual growing season as well as during the span of tree age. Most sprays applied by traditional techniques produce a satisfactory biological result. However, a large proportion of the pesticide may never reach its intended target due to factors such as tree density, seasonal growth patterns, pruning/management characteristics, the differential retention properties of leaves from different cultivars, and improper calibration or "poor match" between sprayer operating parameters and plant geometry.

However, a poor match of sprayer to plant geometry often occurs where the operating parameters of the sprayer are set at the start of a growing season, and are seldom modified as the crop morphology changes (Giles, 1989). Additionally, a recent Agricultural Research Institute Report (ARI, 1985) also concluded that the current airblast sprayers are not flexible. Thus growers are not likely to change the "sprayer match" as they proceed into orchard blocks of different geometries. As a result, speed of travel is the only easily manipulated factor. Many scientists have shown that as the crop structure changes, the deposition rate of the material varies accordingly (Warman & Hunter, 1981; Byers et al, 1984; Byers et al, 1989). However, many studies have also noted little correlation between deposition patterns and biological effects. The research described below is part of a much larger project designed to evaluate the magnitude of such factors as plant geometry, (systems and seasonal change), cultivar variations (including specific leaf retention of pesticides), biological targeting, and the potential for practical and logistical adjustments by the orchard manager to aid such strategies as IPM, drift management and pest resistance. It provides some initial data on one phase of the project concerning the magnitude of the effect orchard geometry has on the within-canopy deposition and through-canopy penetration of pesticide.

EQUIPMENT AND MATERIALS

Trial layout

The orchard consisted of four blocks of apple trees, all the same age (nine years old) but containing an array of cultivars and management systems. Smoothee, Golden Delicious, Lawspur and Rome Beauty, were established either in a 4 wire trellis hedgerow trained as oblique palmettes on M.9 rootstock, or freestanding trained as a leader on M.7 rootstock. A three tree plot of each combination was established at the recommended spacing for that cultivar and rootstock (Smoothee - M.7, 4.5 m x 6M; M.9, 2.5 x 3.5 m. Lawspur - M.7, 3.5 x 5m; M9, 2 x 3.5 m) and two plots of three trees were established in each row at half the recommended in row spacing. Trees in the plots at half spacing (ie. close spacing) were either rootpruned (annually at full bloom) or mechanically hedged (annually in mid-August), to achieve additional tree size control. The cultivars Smoothee and Lawspur, the systems trellis and freestanding, and the treatments of wide and close spacings were compared.

Application details

An application of 1% calcium nitrate (used to mimic the application of a pesticide) at 748 litres per hectare was made using a Swanson airblast sprayer set up as for routine spraying of that orchard. Application was made from the west side of the canopy only, with the sprayer passing as close to each tree as possible without actually touching the canopy.

All three trees of each plot were sprayed, but only the centre tree was used for these assessments. Each plot was replicated once in each of the four blocks. Only the July (full-canopy) application is reported herein although data was recorded for pre-bloom and just prior to harvest.

Targets

Plastic tape

Tape (0.05 m wide and 2.4 m long) was placed in an aluminium holder on the east (non-spray) side of the canopy, behind the centre of the tree and the same distance as the radius of the widest canopy in the study. The centre of the tape was positioned at the same height as the centre of the tree ie. approximately 1.5 m for trellis, and 2 m for freestanding canopies. Tape was used to detect calcium nitrate passing through the canopy.

Leaves

Leaves were used as targets to measure within-canopy deposition. Three four-leaf samples, from each of four trees were taken at random from each of the west, middle and east third of each canopy, at approximately the same height as the centre of the tree.

All targets were removed after each spray pass, taken back to the laboratory after spray completion, and stored in a refrigerator until analysis.

Target analysis

Leaves

Each sample of four leaves were shaken together with 10 ml of tap water for twenty seconds, and the conductivity of the resultant solution measured using a hand-held conductivity meter. The amount of calcium nitrate per cm^2 leaf surface was calculated using the regression equation from a previoously obtained calibration curve, and from measuring the area of leaves, using a LI-3000 (LI-COR, Lincoln, NE.) portable area meter.

Tape

The conductivity of each tape was plotted as a trace using a "tape-washing machine" (developed by Krueger, Reichard and Collins, unpublished). This was converted into amount of calcium nitrate per cm^2 tape using a calibration curve.

RESULTS

Within-canopy deposition

Table 1 shows a decrease in spray deposit as the distance from the sprayer increases, with 50% less deposit on the east side of trellis canopies compared to 38% in the larger freestanding canopies.

TABLE 1. Within-canopy deposition of calcium nitrate (ug/cm^2) on apple leaves.[1]

		West[2]	Centre	East	mean
System/Cultivar					
Trellis	Smoothee	22.5a	16.6a	12.5a	16.9a
Trellis	Lawspur	21.8a	16.4a	10.9a	14.4ab
Freestanding	Lawspur	17.8a	13.4a	6.9a	12.1b
Spacing					
Wide		21.9a	16.9a	11.0a	16.2a
Close		19.3a	14.4a	8.1a	12.7b

[1] means within columns followed by a common letter do not differ significantly at the 5% level (Duncan's multiple range test)
[2] "sprayer-side" of canopy

More spray was deposited on leaves from trellis trees than freestanding, and on Smoothee leaves than Lawspur. This can be explained by the leaf area index data in Table 2 (Ferree, pers. comm.), which shows a higher leaf area index value (and thus a larger area of leaves to "capture" more spray) for both Smoothee and Trellis.

Significantly more spray was deposited on wide spaced trees than close spaced ones, but this does not follow the earlier trend of a canopy with a larger leaf area index capturing more spray.

TABLE 2. Leaf Area Indices per section

Cultivar	
Smoothee	0.98a
Lawspur	0.67b
System	
Trellis	1.02a
F/standing	0.79b
Spacing	
Wide	0.70b
Close	0.97a

TABLE 3. Mean canopy spread (cm)

Cultivar		
Trellis	Smoothee	210b
Trellis	Lawspur	180b
F/standing	Lawspur	300a
System		
Wide spaced		250a
Close spaced		220a

Through-canopy penetration

More spray passed through the wide-spaced canopies than the close spaced (Table 4). These results can be explained by the leaf area index values with less dense canopies resulting in a larger quantity of spray penetration. However, the trellis/freestanding result cannot be explained by leaf area index. It is possible that in this case, the size of the canopy affects spray penetration ie. the greater the distance from the atomizer to canopy centre, the greater the loss in deposition values (Hall et al., 1988). The freestanding canopies have fewer leaves per unit area compared to trellis, but the total number of leaves in the freestanding canopy is much higher because of the greater spread of the canopy (Table 3).

TABLE 4. Mean deposition of calcium nitrate on plastic tape (ug/cm^2) positioned 2m from centre, and on non-sprayer side, of canopy.[1]

System	Cultivar		Spacing	
Trellis	Smoothee	2.38b	Wide	3.00a
Trellis	Lawspur	2.59b	Close	1.81b
Freestandingh	Lawspur	2.07b		
Control[2]		8.78a		

[1] means within columns followed by common letter do not differ significantly at the 5% level (Duncan's multiple range test)

[2] control tapes positioned at same distance from sprayer as test tapes, but not shielded by any canopy.

There were no significant differences in the amount of spray penetrating either cultivar or system, although the trend was for more spray to penetrate Lawspur than Smoothee, and trellis than freestanding (Table 4).

An average of 28% of the spray fully penetrated the canopies when compared to the amount deposited on tape in the absence of a canopy. The correlation between spray deposit and penetration, leaf area index, and area of leaves per section is currently being investigated.

DISCUSSION

The current trend in many U.S. apple orchards is towards higher density plantings of small trees (Hall et al, 1988). The change to smaller trees has been accompanied by some grower confusion about pesticide rates and specific spray volumes for various orchards, with phytotoxicity and variable biological response problems not uncommon.

Previous studies showed high density systems to differ in spray capture efficiency by up to six fold of that received in standard trees (Ferree & Hall, 1980). The following parameters appear to play a key role in spray deposition:- tree height, nozzle to tree row distance, nozzle to canopy edge, tree shape, cultivar, crop management and row spacing (Hall et al, 1988). It was also identified that one of the practical approaches for improving spray application, and hence success of an IPM strategy, would be to map the orchard by block and to plan the crop protection strategy for each block by cultivar, tree density and production potential.

The study described in this paper looked at two cultivars (Smoothee and Lawspur), two planting densities (wide and close spaced) and two management systems (freestanding - chosen to be representative of a large, wide canopy - and trellis, representative of a smaller tree) and the differences in spray deposition within-canopy and spray penetration through these canopies. Results from this full-foliage application indicate that more spray penetrated a wide-spaced canopy than a close spaced canopy, no significant differences were noted in spray penetration through either cultivar or management system. More chemical was deposited on leaves from:- wide than close spaced canopies, Smoothee than Lawspur when grown as a trellis system and the deposits on both these cultivars and systems were higher than those on the leaves of freestanding Lawspur.

This study is part of an on-going project in which both seasonal changes of the canopies (and effects on spray deposition) and the change in liquid retention properties of apple leaves are being monitored. Followed by on-going studies at LPCAT on pesticide deposit characteristics (size, concentration, density and formulation) and leaf to leaf (and surface) variation in deposits, the role of deposit on biological efficacy, depending on target pest, can be more clearly defined for delivery modifications. When all the findings are considered together, it is hoped that it will enable individual strategies to be developed so that the appropriate adjustments can be made in spray delivery - thereby increasing the precision of pesticide application.

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EVALUATION OF KNAPSACK MISTBLOWERS FOR THE CONTROL OF COFFEE LEAF RUST IN PAPUA NEW GUINEA

P.JOLLANDS

Harrisons Fleming Advisory Services, Currie Street, Duns, Berwickshire,
TD11 3DL.

ABSTRACT

Field evaluations of knapsack mistblowers for control of Hemileia vastatrix on coffee in Papua New Guinea in terms of fungicide and tracer deposits and performance characteristics indicate widely differing machine suitability.

Comparison of high volume applications using standard air shear nozzles, with low volume applications using different restrictors on the air shear nozzles and spinning disc attachments indicate no significant difference in deposition of cuprous oxide (ug/cm^2) applied at 2.1-2.8 kg/ha at 560, 53 and 44l/ha.

Tank pressurisation was inadequate on all machines tested, resulting in large variations in flow rate. For low volume applications a pump is essential to maintain constant pressure and adequate agitation of the spray suspension.

INTRODUCTION

Coffee rust,caused by Hemileia vastatrix, has been a major problem for many years in most coffee producing countries (Waller,1982). The first recorded outbreak of the disease in Papua New Guinea in 1965 was eradicated (Shaw, 1968) and only recently has it become of economic importance following a further outbreak in 1986 .

Initial recommendations for control in Papua New Guinea (Anon, 1987) have been based on experience in other countries. For general control using knapsack mistblowers, the recommendation is for application of 0.5l of 0.3-0.5% copper product per tree. Assuming a typical planting density of 3010 trees per hectare, a 0.3% suspension of cuprous oxide involves application of 4.5kg/ha product in 1,500l/ha, though this will vary widely as coffee planting density varies.

To investigate the possibility of reducing spray volumes using commercially available equipment, initial field deposits of copper obtained from high volume knapsack mistblower applications of Copper Sandoz (560g/kg cuprous oxide) were compared with deposits from low volume applications using both a smaller restrictor on the standard air shear nozzle and a spinning disc attachment. The advent of coffee rust was followed by the influx of a wide variety of machines. As suitable machine characteristics are a vital prerequisite for successful fungicide application, a range of motorised knapsack mistblowers was considered in terms of their suitability for widespread use.

METHODS

Machine suitability

Well defined guidelines exist for evaluation of motorised knapsack mistblowers at various levels (Sutherland,1979; Thornhill, 1982) and these were used to determine suitability. It was not possible to measure air flow or droplet characteristics.

Initial tests indicated that there were large variations in flow rate on all machines during field applications as nozzle position was changed. This suggested inadequate tank pressurisation and this was checked by attaching a clear tube to the flow control valve and measuring the height of the water in the tube held vertically at maximum engine revolutions. This was repeated with different levels of liquid in the spray tank. A further check on adequacy of pressurisation was made by measuring variations in flow rate at different nozzle heights.

Fungicide application

A randomised complete block design with five blocks was used to compare the deposit achieved with two different flow rates on the standard Solo 423 machine and the Solo Turbo ULV attachment using different concentrations of cuprous oxide to achieve broadly similar product application rates (Table 1).

The coffee used (var. Arusha, 3yrs old) had been unsprayed for >2 months. Each side of each row was treated separately, with the nozzle moved up and down as the operator walked along the row. Spray times for each bush were measured.

The Solo 423 was fitted with a diffuser screen for treatments 1 and 2 and with a booster pump for treatment 3. No booster pump was used for treatments 1 and 2 as these treatments were intended to represent the accepted standard and a possible rapid improvement respectively, despite the potential for large variations in flow rate.

Each treatment replicate consisted of 12 bushes (3 rows of 4 bushes), with one guard row. The centre row was sampled by taking 10 leaves at approximately 1.5m high from each bush, 1-2 h after application. A subsample of 5 leaves was then selected at random from each sample for analysis of copper deposits on both upper and lower leaf surfaces.

Copper deposit analysis

Copper deposits were removed separately from upper and lower leaf surfaces by scrubbing with cotton wool soaked in 50 ml 0.06M HCl (Mabbett and Phelps , 1983) and then drying with tissue. Containers of acid, cotton wool and tissue were left for a minimum of 1h to ensure complete solution of the copper. Samples were filtered and assessed for copper content (Cu^{++} ug/ml) using a Varian 875 atomic absorption spectrophotometer, and results converted to ug/cm^2 leaf surface.

For a rapid estimate of leaf area, twenty leaves from v.Arusha were checked for consistency with a formula used by Park and Burdekin (1964) .The mean deviation from actual measurements for this predictor (area = 0.65L x B + 0.48, where L=leaf length and B= leaf breadth) was an unsatisfactory 10.14% . An simple alternative predictor of leaf length x width gave a mean deviation from area measurements of 3.6% . The regression equation used was y=5.09 + 0.576X, where X = length x width of leaf.

Interactions between deposit and application rate were statistically analysed by analysis of variance.

Table 1. Fungicide application treatments

Treatment	Nozzle Type	Restrictor (orifice mm)	Flow rate (ml/min)*	Cuprous oxide (%)	Mean spray time (s)	Volume application rate** (l/ha)	Cuprous oxide (kg/ha) ***
1.	air shear	Black 4 (6.2)	2376	0.5	4.7	560	2.8
2.	air shear	Red 2 (1.5)	170	5.0	6.2	53	2.7
3.	Turbo ULV	In-line (0.58)	143	5.0	6.0	43	2.2

* measured with nozzle held horizontally

** assuming 3010 bushes per hectare

*** both sides of each bush

RESULTS

Machine suitability

No machine completely satisfied the ideal criteria (Table 2), though on some, variations were minimal. The variable nature of the flow restrictors of the Silvan, Maruyama and Stihl machines, ie. a single large orifice which is rotated to increase or decrease flow rate, make it impossible to duplicate flow rates. In addition, the Echo, Maruyama and Silvan machines had very high minimum flow rates giving minimal working time per tank.

No machine had adequate pressurisation (Table 3) to maintain a constant flow rate at different nozzle positions and at different levels of spray solution in the tank. The Solo 423 gives reasonable results on the simple pressurisation test, but when flow rates are measured (Table 4) large variations in flow rate occur. There was no apparent leakage of air from the tank lid on any machine. All machines were fitted with gaskets as standard.

Table 2.Knapsack mistblower characteristics

	Ideal	Solo 423	Solo 410	Maruyama MD300	Echo DM9	Silvan M14	Stihl SG17
General							
Weight empty (kg)	<10.0	11.6	8.5	10.5	10.0	9.8	8.2
Strap width (cm)	> 3.5	3.3	3.3	3.6	3.7	3.8	1.8
Strap material	Non-absorbent	No	No	Yes	Yes	Yes	Yes
Engine							
Ignition	Electronic	Yes	Yes	Yes	No	No	Yes
Fuel system							
Time taken for full tank(mins)	>60	42.0	60.0	61.0	81.0	75.0	73.0
Pesticide delivery system							
Tank opening(cm)	>13.0	10.6	10.6	16.1	14.1	14.2	10.4
Time(min)/tank at minimum flow rate	>30.0	53.6	27.3	19.4	12.3	22.5	32.2
Pesticide tank(l)	>10.0	12.0	12.0	13.0	10.0	12.0	12.0
Flow restrictor	Single	Single	Multiple	Multiple	Multiple	Multiple	Multiple
Cut off valve							
-location*	Separate	Yes	Yes	Yes	Yes	No	Yes
-action	Positive	Positive	Positive	Variable	Variable	Variable	Positive
Pump	Standard	Option	None	Option	None	None	None
Tank pressurisation	Adequate in absence of pump	No	No	No	No	No	No

*separate from flow restrictor

Table 3. Tank pressurisation(cm)at maximum nozzle elevation*

Tank level	Solo 423	Solo 410	Maruyama MD300	Stihl SG17
Full	+12.0	+ 3.5	+ 1.0	+ 9.5
1/2	+13.5	- 7.5	- 4.5	- 8.4
1/6	- 2.5	- 5.0	-11.5	-10.0

*level in tube relative to nozzle height

Table 4. Variations in flow rate(ml/min)* with different nozzle positions

Machine	Restrictor	Nozzle position(angle to horizontal) +45°	horizontal	-20°
Solo 423	Black2	250	360	500
Solo410	Black2	260	440	672
Maruyama MD300	2	475	1400	1600
Echo DM9	1	260	820	930
Silvan M14	3	1384	1650	1776
Stihl SG17	1	365	865	1700

*mean of three replicates

The commercially available Solo ULV Turbo attachment produces ligaments from the centre of the disc assembly at all flow rates. This obviously affects the total droplet spectrum produced.

Copper deposits

The results (Table 5) suggest that there is no significant difference ($p>0.05$) in deposits achieved on both upper and lower leaf surfaces at different volume application rates,though in all treatments, deposits on lower surfaces were lower than those on upper surfaces.

Table 5. Mean copper deposits(ug/cm^2) on upper and lower leaf surfaces

Treatment	Volume application rate(1/ha)	Leaf surface	Mean deposit* Cu^{++} (ug/cm^2)	95% confidence interval
1	560	Upper	32.8 a	5.84
2	53	Upper	26.6 a	5.28
3	43	Upper	27.0 a	5.24
Untreated		Upper	0.02 b	0.01
1	560	Lower	28.2 a	6.62
2	53	Lower	21.2 a	6.66
3	43	Lower	24.2 a	6.62
Untreated		Lower	0.01 b	0.02

*Results are means of 5 replicates and figures followed by the same letter are not significantly different ($p>0.05$)

DISCUSSION

Machine suitability

Despite the well established and widespread use of motorised knapsack mistblowers, various design characteristics of machines tested will affect accuracy of application.

The design of flow control valves on some machines and the likelihood that they will be altered in the field will give large variations in application rates. A further major problem with all machines is the variation in flow rate as the nozzle position changes. Minimum flow rates occur when the nozzle is directed upwards and this has implications for the initial deposition pattern and redistribution of the copper. Sharp et al.(1986) suggested that a greater concentration of copper at the top at the bush could be expected to lead to a more effective use of the a.i. as it is redistributed. A pump, together with appropriate restrictors, is essential to achieve consistent flow rates for both standard air shear and spinning disc attachments. It has the added advantage of providing agitation of the spray suspension.

A major variable influencing initial distribution is the operator, and training is vital and usually overlooked. Work in South America on experimental machines (Sharp.ibid) has suggested that the most efficient application method is a high velocity spray, operating from a central position behind the operator, implying that the operator has no control over the direction in which the nozzle is pointing. Such machines are not however commercially available and in this case, where rapid large scale applications were required to limit the impact of a disease outbreak, the majority of applications in the plantation sector have been by knapsack mistblower , and in the smallholder sector by lever operated knapsack pressure sprayers, with all their limitations.

The inherent inefficiency of motorised knapsack mistblowers has led some plantations to move towards tractor mounted or trailed air blast machines, usually applying high volumes. Use of this type of system is governed by terrain and planting densities and little consideration has been given to the possible effects of soil compaction.

Copper deposits

Deposit levels achieved on both upper and lower leaf surfaces were comparable at all volume application rates. Similar results were obtained by Park and Burdekin (ibid) comparing 1350l/ha and 80l/ha in West Africa. This suggests that a reduction in spray volume from the recommendation of 1500l/ha is feasible.This would give increased spray time per tank,less downtime and logistic advantages in water supply, though further field trials with assessment of disease control levels would be required to confirm this. Work on degradation of copper deposits applied by lever operated knapsack pressure sprayers using a spore bioassay (Jollands, unpublished results) suggests that initial deposit levels of 20-30 ug/cm^2 are adequate for control , as breakdown of control occurs only at levels below 2-3 ug.Cu^{++}/cm^2 reached after 3-4 weeks weathering.

Spinning disc attachments offer the potential for accurate, low volume applications, though the design problems in the attachment tested need to be overcome and detailed work is required on droplet size/deposition interactions for control of coffee leaf rust.

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COMPARISON OF DIFFERENT MISTBLOWERS AND VOLUME RATES FOR ORCHARD SPRAYING

U. RAISIGL, H. FELBER
Ciba-Geigy Ltd., Application Technology AG 8.11, CH4002 Basle, Switzerland.

W. Siegfried, Ch. Krebs.

Swiss Federal Research Station for Fruit-growing, Viti-, and Horticulture CH-8820 Wadenswil, Switzerland

ABSTRACT

At a spray volume of 400l/ha, qualitatively the same cover of leaves and fruit is obtained from both the Holder QU 41 cross-flow sprayer and the Viromax axial -fan sprayer from Fischer. With modern spindle-pruned trees, spray volumes of between 300 and 500l/ha of insecticides and fungicides are adequate for effective pest and disease control. Spray volumes of more than 600l/ha result in increased losses through run-off. The Holder QU 41 is easy to manage and set. It is particularly useful for spindle-pruned trees on flat terrain. The Viromax is extremely versatile, but needs greater care when targeting the foliage. The use of rotary Micron X1 atomisers cannot be recommended for practical purposes. With the equipment currently available and tested, optimal settings result in a maximum of 45-55% of the spray volume used being deposited on fruit and leaves.

INTRODUCTION

Modern application technology places great demands on users and equipment. Inadequacies in application techniques mainly become apparent in years when diseases and pests are difficult to control.

Figure 1. Viromax with flat fan nozzles.

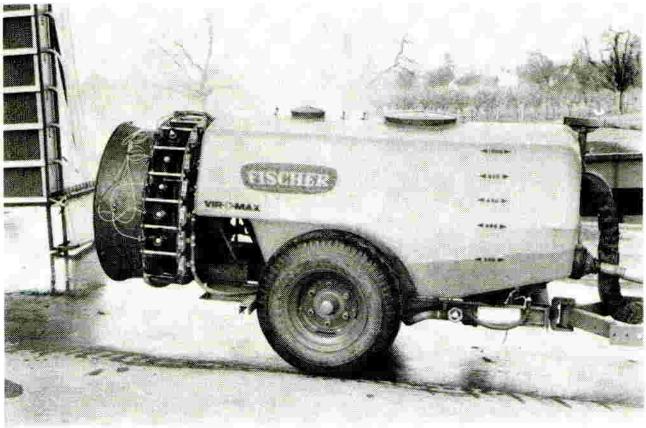
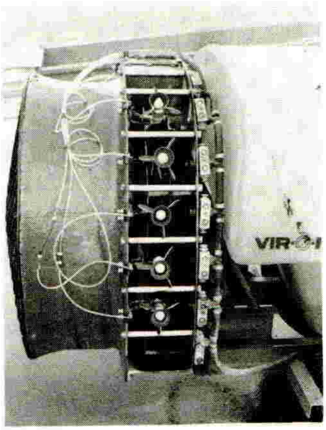


Figure 2. Viromax with spinning discs



In recent years, equipment manufacturers in Switzerland and abroad have been working intensively on new developments and on improvements to already commercially available equipment. Improved air conduction in axial-fan and cross-flow sprayers has been of particular interest.

In connection with the development of new equipment, there is also a good deal of discussion about reducing pesticide dose rates. The Micron X1 spinning disc atomiser has generated a much interest in this respect. It is claimed that use of this atomiser, which produces very fine drops, can reduce pesticide dose rates of up to 50%. As far as new equipment is concerned a number of questions need to be answered for both user and consultant. Has the equipment been adequately developed technically, and is it suitable for practical use? Whar differences do various spray volumes and types of sprayer make to the control of apple scab (Venturia inaequalis) and apple powdery mildew (Podosphaera leucotricha)? What are the advantages and disadvantages of each machine?

MATERIALS AND METHODS

Sprayers

Data of equipment and volume rates used for the trials in 1988 and 1989 used are given in Tables 1 and 2.

TABLE 1. Summary of volume rates, and technical data of Axial- fan sprayer applications.

Model		Fischer Viromax	
Application vol l/ha	84	400	80
Nozzles	Albuz orange flat fan	Albuz yellow flat fan	Micron X1 spinning discs
No. of nozzles	14 (7 right, 7 left)	14 (7 right, 7 left)	10 (5 right, 5 left)
Location of nozzles	In front of air stream	In front of air stream	In air stream
Flow rate per nozzle 1.9l/min	0.8l/min	0.28l/min	
Pressure	18 bar	12 bar	2 bar
Quantity of air	Level 1 30,200m^3/h	Level 1 30,200m^3/h	Level 2 34,600m^3/h
Discharge velocity	21.5m/s (calculated)	21.5m/s (calculated)	24.6m/s (calculated)
Direction of discharge	Right angles to direction of travel	Right angles to direction of travel	Right angles to direction of travel
Spraying speed	5km/h	5km/h	5km/h

TABLE 2. Summary of volume rates and technical data of cross-flow fan sprayer applications.

Model	Holder QU41	Fischer Turbo-six
Application vol. l/ha	330	330
Nozzles	Albuz purple hollow cone	Fischer 07 flat fan
No. of nozzles	20 (10 right, 10 left)	12 (6 right, 6 left)
Location of nozzles	In the air stream	Spinning with fan
Flow rate per nozzle	0.58l/min	0.8l/min
Pressure	10 bar	15 bar
Quantity of air	40,000m^3/h	4,800m^3/h
Discharge velocity	29.6m/s (calculated)	16.9m/s (calculated)
Spray speed	5km/h	5km/h

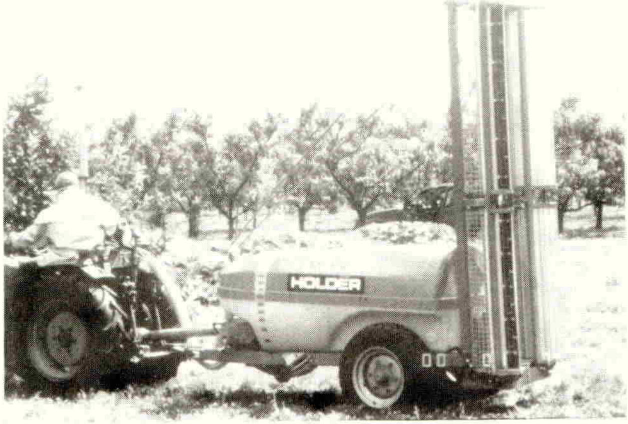


Figure 3. Holder Qu 41 cross flow fan sprayer.

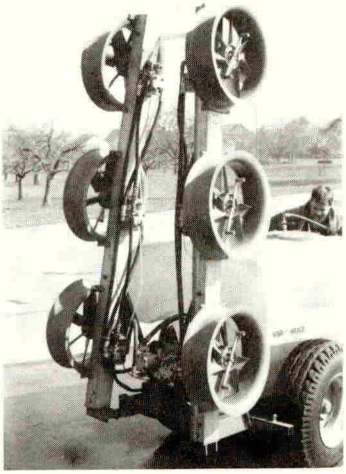


Fig 4. Fischer Turbo-six cross flow fan.

Trial orchards

The trials were carried out on two adjacent orchards (4 rows X 13 trees per method), which had been planted with Golden Delicious (M9 rootstock) and Idared (M26 rootstock) in 1979.

Tree spacing:	Golden Delicious	3.5 X 1.8m = 1485 trees/ha
	Idared	3.5 X 2.0m = 1330 trees/ha

Disregarding the trees at the edge, the two middle rows with 15 trees each were taken for assessment and measurement of cover. The spindle-pruned, skittle-shaped trees had a maximum height of 3 m. The bases of the crowns were 1.8-2.0 m wide.

Fungicides and tracer

The filler material of the products (Topas C® and Orthozid®) used was coated with the fluorescent tracer HELIOS (70 g/ha). The solids in the spray thus contained active ingredient and tracer in the same phase. The treatment at bud-burst was with Delan® WP (75% dithianon) at a rate of 0.75 kg/ha. Six treatments against scab and apple powdery mildew were with Topas C® (47.5% captan+2.5% penconazole) at a rate of 1.6 kg/ha. For the two concluding treatments Orthozid® (83% captan) was used at a rate of 2.5 kg/ha.

Machine settings

The travelling speed and the flow rate were set precisely with the "**CALISET**"(see also "Caliset: Safety and Ecology in a Holdall" in these proceedings) at the beginning of the experiment. Using plastic tape and tent poles, the air stream was targeted directly into the crop, at the exact height of the foliage. The baffles were spaced out evenly, and the nozzles set such that the spray plumes overlapped uniformly.

Measuring deposits and cover

Nine hundred leaf and 120 fruit samples per sprayer were analysed. These were taken from 4 different parts of the tree (heights 0-1 m; 1-2 m, from both near the trunk and from the tree periphery; 2-3 m).

Deposit of active ingredient (tracer)

Out of the 225 leaves per tree sector, 50 were photographed on both sides under UV light using a CU-5 polaroid camera with a 667 black and white film. These leaves were then individually washed using diethylene glycol monoethylether, and the marking substance content determined by photofluorometry and converted to ng/cm^2 per g per ha sprayed. The remaining leaves were sorted into 5 subsamples of 35 leaves each and washed. The amount of deposit on them was then determined by photofluorometry.

The apples were individually weighed and cut up into 8 segments of equal size. The peel from 20-30 pieces of apple was removed from every position - eg the foremost and hindmost sides - and photographed under UV light. Further processing was carried out as for the leaf samples.

Degree of cover

The black and white photographs of the leaves and apple peel were evaluated using an "Optomax V" image analyser. Both the percentage cover and the number of spots of product per cm^2 were measured.

Meteorological data and periods of scab infection

Meteorological data from the automatic weather station at the trial site was available throughout the entire experimental period. The periods of scab infection were recorded directly at the orchard using KMS-P (A Paar, Graz) scab warning equipment.

Assessment of scab and mildew infection

The development of the scab and mildew attacks was monitored periodically on untreated trees. The evaluation of the scab on leaves was carried out at the end of shoot growth in mid-August. A total of 2,000 leaves was checked in the same tree sectors as described for the measurement of deposits.

Assessment of scab on fruit was carried out at the end of September, shortly before harvesting. A total of 1,000 pieces of fruit per mistblower was evaluated. These were again taken from the tree sectors described above.

Storage experiments

From each tree sector, 4 cases of Golden Delicious (= 16 cases per mistblower) were placed in cold storage at +2°C and 92% relative humidity. The degree of storage scab that occurred (also Gloeosporium spp. and other storage disorders) was assessed in spring.

RESULTS

Deposits and distribution of product

The results for 1988 are presented in Table 3. For all four mistblowers, only 42-53% of the mixture sprayed was deposited on the leaves, despite optimal setting. The Holder Qu 41 tended to give the best recovery rate (53%). The high spray volume used by the axial-fan Viromax (840 l/ha) leads to higher losses through run-off than with the other mistblowers. The axial-fan sprayer equipped with Micron X1 spinning disc nozzles deposits the least on the soil (14%). No exact results can be given for deposits on branches and trunks.

The foliage was photographed and the pictures were analysed using the Optomax image analyser. The results are presented in figure 5 and show, that with optimally set equipment, the losses correspond fairly closely to the unoccupied spaces in the foliage. With traditional axial-fan or cross-flow equipment, further improvements in the deposit are to all intents and purposes unattainable.

There are no significant differences between the mistblowers as far as average amount sprayed over the whole of the foliage is concerned. In the top part of the tree (2-3 m in height), however, up to 40% more active ingredient is deposited by the Holder Qu 41 and Turbo-six cross-flow sprayers. The horizontal direction of the spray, coupled with the short distance to the target, allows cross-flow equipment to deposit the mixture evenly.

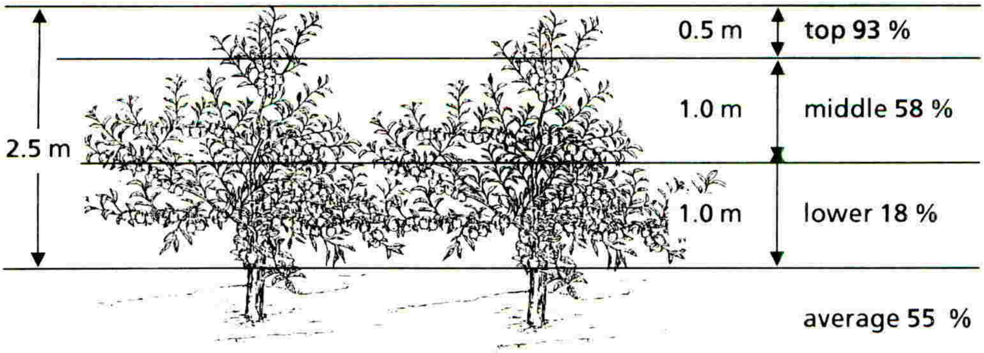
Leaf cover 1988

The amounts deposited are more or less the same, but are distributed on the leaves very differently from machine to machine. The underside of the leaf is always better covered than the topside. The best cover was obtained using the Holder Qu 41 and Viromax with Micron X1 nozzles. The Viromax at 840 l/ha gave the lowest degree of cover. The large spray volume of 840 l/ha means that the numerous drops coalesce. As there are practically no leaves which lie horizontally, the particles of product deposit themselves at the lowest point of the leaf, where they are concentrated in a small, sickle-shaped area.

TABLE 3: Güttingen 1988: deposits and distribution of product on fully developed foliage

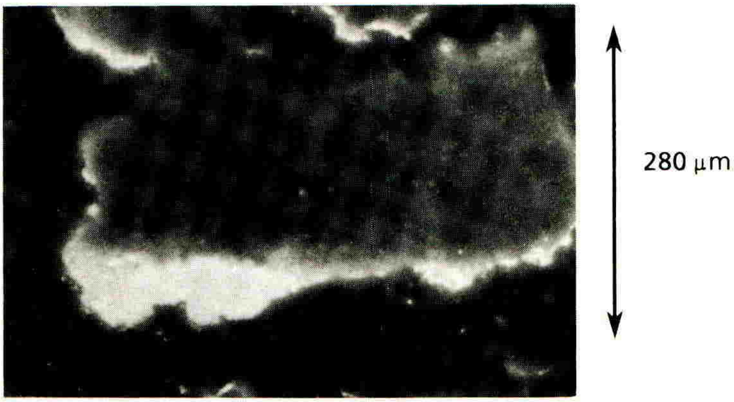
Criterion	Viromax axial-fan	Viromax Micron X1	Turbo-six cross-flow	Holder Qu41 cross-flow
Spray volume l/ha	840	80	330	330
Topas C® per ha	1,6 kg	1,6 kg	1,6 kg	1,6 kg
Concent. of mixture	2 x	20 x	5 x	5 x
Recovery rate				
Percentage on leaves	**42**	**48**	**46**	**53**
Percentage on fruit	2	4	2	2
Percentage on soil	21	14	19	16
Total measured in %	**65**	**66**	**67**	**71**
Trunk,branches,drift (remainder to 100 %)	35	34	33	29
Deposit on leaves ng/cm2/g/ha				
Tree height 0-1 m	2,1	2,3	2,2	2,4
Height 1-2 m, outside	2,2	3,4	2,5	2,3
Height 1-2 m, inside	1,7	2,3	1,8	2,4
Tree height 2-3 m	1,6	1,7	2,1	2,5
Average	**1,9**	**2,4**	**2,2**	**2,4**
Degree of cover of leaves in %	leaf side upper/under	leaf side upper/under	leaf side upper/under	leaf side upper/under
Tree height 0-1 m	9,1 8,4	17,4 26,1	4,5 13,8	8,1 15,6
Height 1-2 m, outside	6,9 10,4	8,4 28,9	3,5 17.3	5,7 29,6
Height 1-2 m, inside	4,4 6,3	10,7 27,8	4,7 9,6	12,2 22,1
Tree height 2-3 m	6,3 12,3	5,2 13,3	4,0 20,8	5,7 34,0
Average	**6,7 9,4**	**10,4 24,0**	**4,2 15,4**	**7,9 25,3**

FIGURE 5: Unoccupied spaces in the fully developed foliage, measured (photograph / Image analyser) at the experimental site.



Large drops give inadequate cover of the leaves after drying. The same axial-fan with Micron X1 nozzles achieves double the cover with 80 l/ha of spray.

FIGURE 6: With high spray volumes (840 l/ha), only a small area is covered with product after the drops have dried

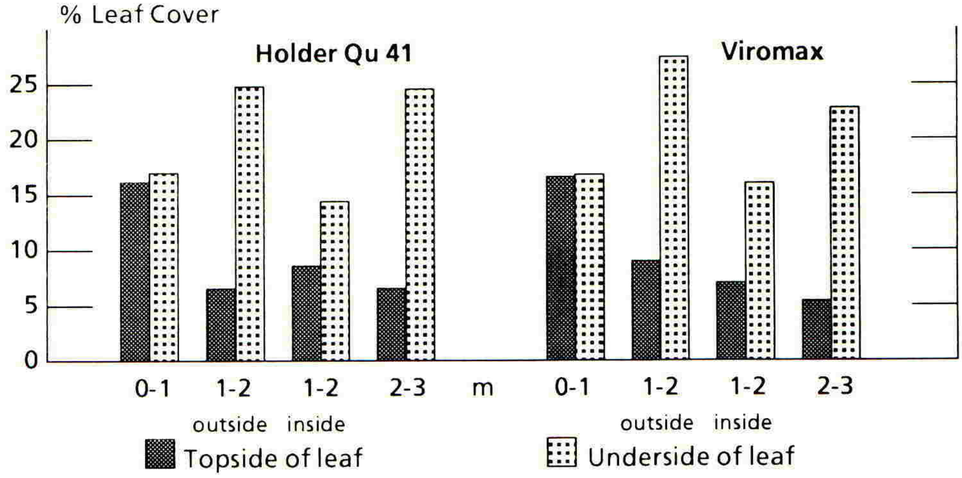


<u>Leaf cover 1989</u>

The previous year's results showed that spray volumes above 800 l/ha are clearly too high for modern spindle-pruned orchards where trees are planted 3.5-4 m apart.

For the 1989 experiments, therefore, we reduced the spray volume for the Viromax axial-fan sprayers from 840 to 400 l/ha. This resulted in a far better leaf cover. Holder Qu 41 and Viromax axial achieved equivalent leaf cover with spray volumes of 400 l/ha. Figure 7 shows the leaf cover average from Golden Delicious and Idared in 1989 experiments:

Figure 7: Holder Qu 41 (Albuz purple hollow cone jets) and Viromax (Albuz yellow fan jets) achieve equally good leaf cover at 400 l/ha



Product deposits on apples

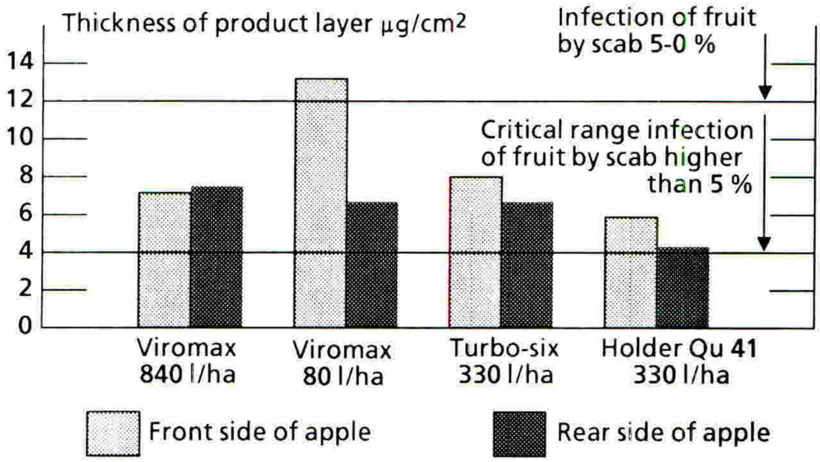
A turbulent air stream with fine drops achieves optimal deposits. The axial-fan sprayer with Micron X1 nozzles has a recovery rate on the fruit of 4%, double than that of the other methods (Table 3). It gave at the hindmost part of the apple the highest deposit. The fine drops can float around obstacles and are thus better able to reach parts which are not directly accessible. The foremost part of the apple had more or less the same deposit no matter which machine was used. The turbulent air stream of the Turbo-six sprayer achieves an extremely even deposit of both the foremost and the hindmost parts of the apple.

Cover and thickness of product (captan) layer on apples

All four mistblowers produced less cover on the hindmost part of the apple than on the foremost; the Holder Qu 41 achieved the best average cover on the foremost part. The axial-fan sprayer at 840 l/ha achieved less cover at a height of 2-3 m than the other machines, both on the foremost and the hindmost parts of the apple. The thickness of the product layer can be calculated from the amount of product and the cover measured.

The Micron X1 nozzles give by far the thickest layer (figure 8). In the 1989 comparison the Holder Qu 41 and the Viromax axial-fan (400 l/ha) achieved equivalent results in both cover and thickness of layer.

FIGURE 8: The thickest product layer is achieved using Micron X1 nozzles at 80 l/ha



Incidence of scab and mildew

In 1988 and 1989, we found above-average incidence of apple scab infection. The first attacks came early, at bud-burst. Frequent infection periods together with occasional heavy periods of rain created a constant threat of scab during the months of May and June. For scab it was possible to compare the mistblowers under conditions of high disease pressure. Apple powdery mildew on the other hand remained at low level. Infections of only 3-6% were found on untreated trees. It is thus not possible to draw conclusions about the effect of application methods on apple mildew.

Table 4 shows scab infection levels for 1988 in Golden Delicious on leaves, fruit in the orchard and stored apples. In the middle and top parts of the tree, the Holder Qu 41 (330 l/ha) performed better than the axial-fan machine (840 l/ha). At tree heights of 2-3 m, around 4 times as much scab occurred with the axial machine than with the Holder Qu 41. Scab infection on the leaves in the top part of the tree considerably increases the risk of fruit and storage infections. When it rains, the conidia easily reach the fruit below. In spite of final treatment being carried out at the correct time, the greater scab infection on leaves with the axial machine led to heavy scab infection during storage. The reduction of the spray volume in the axial machine from 840 l/ha to 400 l/ha in 1989 gave better cover, which was distributed more evenly over the various tree sectors. This had a positive effect on the success of control. In 1989, untreated trees had a scab infection level of 60%, but with the Holder Qu 41 and the Viromax axial-fan (400 l/ha), a nearly 100% control of scab was achieved.

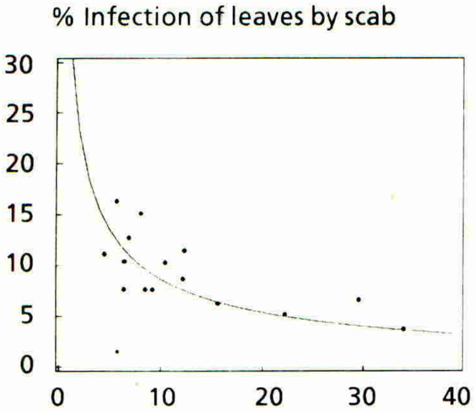
TABLE 4: Scab infection of Golden Delicious in 1988 (average infection of the top- and underside of the leaf)

Equipment	**Infection of leaves by scab (%) in various tree sectors**			
	0-1 m	**1-2 m, outside**	**1-2 m, inside**	**2-3 m**
Holder Qu 41, 330 l/ha	10,8	11,6	7,0	2,8
Viromax axial, 840 l/ha	7,6	11,6	9,4	11,0
	Infection of fruit by scab (%) in various tree sectors			
Holder Qu 41, 330 l/ha	7,2	2,0	7,2	0,4
Viromax axial, 840 l/ha	4,0	2,8	11,2	2,4
	Scab infection during storage (%) on apples from various tree sectors			
Holder Qu 41, 330 l/ha	13,5	12,1	10,9	1,4
Viromax axial, 840 l/ha	18,3	22,3	22,4	20,7

Relationship between Degree of Cover and Infection of Leaves by Scab

Studies of the Topas® C coating were carried out in the same tree sectors as for the assessment of scab infection. Figure 9 shows the relationship between scab infection and degree of cover clearly. The higher the degree of leaf cover, the lower the extent of infection.Under the difficult weather conditions of 1988, even the best degree of cover did not give complete protection against scab. Treatment at the right time and the curative and preventive properties of the active ingredients are also decisive for good control. Systemic fungicides are usually add-mixed with the protective contact component captan. The systemic active ingredient can only be taken up by the leaf as long as the drops are wet.

FIGURE 9: A higher degree of Topas C® (47.5% captan + 2.5% penconazole) cover improves the effect against scab in the 1988 experiment



% infection of leaves by scab (effect)

$$= \frac{1}{1+\text{Exp.}(b1+b2 \times \%\ \underset{\text{(rate)}}{\text{leaf cover}})}$$

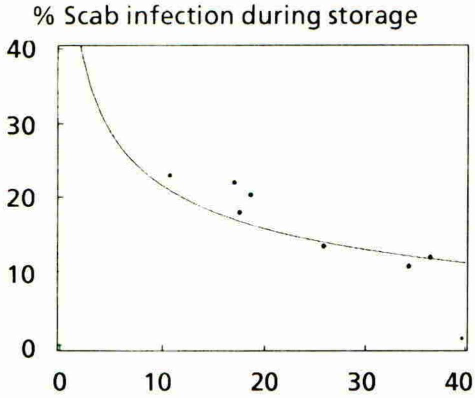
$b1 = 0.699$
$b2 = 0.721$

Greater cover guarantees rapid penetration of the systemic active ingredient. With low volume applications (eg 80 l/ha) in warm and dry weather, there is a danger of the systemic active ingredient drying on the leaf before it can penetrate. Spray volumes of 300-500 l/ha are preferable to both extremely low and high spray volumes.

Relationship between Cover and Scab Infection during Storage

Figure 10 shows the results of the assessment of scab for 1988. A close correlation exists between both infection of leaves and infection during storage, and the degree of leaf cover and infection during storage. **Effective control of leaf scab is essential for good control of scab on fruit and during storage**. Inadequate protection of leaves creates primary sources of infection for later infection of fruit during storage.

FIGURE 10: A high degree of Topas C® (47.5% captan + 2.5% penconazole) leaf cover ensures good protection against scab infection during storage



% scab infection during storage (effect)

$$= \frac{1}{1+\text{Exp.}(b1+b2 \times \%\ \underset{\text{(rate)}}{\text{leaf cover}})}$$

$b1 = 0.0264$
$b2 = 0.548$

Field experience and conclusions

Table 5 summarises the findings from the practical experimentation. Frequency of repairs, ease and possibilities of use in various fruit crops are important criteria for the end user.

TABLE 5: Summary from the practical experimentation with the 5 application methods

Assessment criteria	**Viromax axial-fan 840 l/ha**	**Viromax axial-fan 400 l/ha**	**Viromax Micron X1 80 l/ha**	**Holder Qu 41 330 l/ha**	**Turbo-six cross-flow 330 l/ha**
Ease of use	very good reliable	very good reliable	not ready for field use	very good reliable	difficult, limited
Application angle on sloping ground	good	good	good	poor, centre of gravity high, danger of overturning	not so good, centre of gravity higher than Axial machine
Need for repairs	normal, slight	normal, slight	high with Micron X1 nozzles	normal, slight	ball races/oil leads may be prone
Power requirement	normal	normal	high	normal	high
Spraying performance	normal, satisfactory	normal, satisfactory	high discharge velocity needed, might damage fruit	normal, satisfactory	normal, satisfactory
Application height	by choosing and setting appropriate nozzles, may be used with partically all varieties of fruits			limited to 3 m	limited to 3 m
Adjustment to the crop	**more care necessary.** The air stream can be set to the foliage by adjusting the baffles.			very easy, height set by individually adjustable jets	easy, but little possibility of adjustment higher up
Cover on leaves and fruits	coalescence of drops, poor cover	even cover	even cover	even cover	even cover
Overall assessment	versatile machine that has proved its worth		Micron X1 nozzles (propeller drive) unsuitable	very good for flat terrain and modern crops	limited usefulness for fruit

The Holder Qu 41 is especially suited to modern spindle-pruned orchards on flat ground. The machine is easy to use and adjust to the foliage and has a low maintenance requirement. As the centre of gravity is relatively high, sloping ground causes stability problems. Undulations lead to large rocking movements, resulting in the possibility of gaps in the distribution of the spray mixture. Only orchards with a maximum height of 3 m can be treated.

After years of use in the field, the Fischer Viromax axial-fan mistblower has stood the test of time well. The machine is versatile and can be adjusted to different crops by setting the nozzles and baffles. The low centre of gravity allows use in sloping orchards too. In practice, adjusting axial-fan sprayers to the crop can often be an extremely arduous task. The experiments have shown that optimal adjustment to various crops is possible with minimum effort. With the nozzles available today, spray volumes of 300-500 l/ha can be applied without difficulty.

The Micron X1 nozzles fitted onto the axial machine need frequent repairs. Despite careful cleaning after use, problems were encountered with the ball races. After a time, they spun very irregularly, and feed pipes and jets often became clogged by the highly concentrated spray mixture. Precise setting of the flow rate is very difficult. The propeller drive requires a high air discharge velocity from the sprayer, which could cause damage to the fruit. Micron X1 nozzles in their present state of development cannot be recommended for practical use.

The Turbo-six is more suitable for use in viticulture. Application height is restricted to 3 m. Power requirements are very high due to the sprayer's hydraulic drive. It left a lot to be desired as far as ease of use was concerned. The high centre of gravity means that its usefulness is limited for sloping orchards.

ACKNOWLEDGEMENTS

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Many thanks also to Dr. S. Lander for the translation of the paper from German to English.

COVER/CONCENTRATION/CONTROL CORRELATIONS (C.C.C.C.). WHAT ARE THE IMPLICATIONS?

M.C.D. RAS

Department of Agricultural Development, Directorate of Mechanisation,
Stellenbosch 7600, South Africa

ABSTRACT

Quality of spray cover on tree and bush fruits is defined by an index calculated from the percentage of the leaf surface covered with spray spray deposit divided by the product of the coefficients of micro- (leaf to leaf) and macro- (plant to plant) variation. The relationship between this index, the concentration of spray applied and the resulting efficacy of control powdery mildew, Uncinula nicator, on vine, and of Fusicladium (asexual stage of apple scab Venturia inaequalis) and two spotted spider mite, Tetranychus urticae, on apple is investigated and discussed. The importance of a knowledge and understanding of these relationships (termed here as Cover/Concentration/Control Correlations (C.C.C.C.)) in obtaining optimum efficiency of spray application and agrochemical use is highlighted.

INTRODUCTION

Poor pest and disease control in agriculture poses the second highest risk of economic losses to non-irrigated crops and the greatest risk of losses to irrigated crops.

High value crops such as decidious and sub-tropical fruits are especially prone to financial losses resulting from pest or disease damage. On the other hand, the fruit producer incurs high input costs when performing pest control operations. The average figure for the apple and pear industry in South Africa amounts to some $625 per hectare per year.

When following an Integrated Fruit Production (IFP) strategy, it is of the utmost importance to use the minimum amount of agrochemical for the maximum degree of control.

The only way to succeed in minimising input costs whilst still retaining a low risk factor, is to know the quality of cover with a given concentration of active ingredient required to achieve control.

Three aspects discussed are:

- Definitions of effective control.
- Concentration of active ingredient.
- Definitions of effective cover.

EFFECTIVE CONTROL

This is an economy related subject and might best be described as the degree of control necessary to obtain and sustain the maximum economic result.

It is thus a parameter related to crop value and risk of loss in yield and quality. For example, to control *Uncinula nicator* in table grapes, the amount of infection at harvest must be limited to 5%, (De Clerk, 1989). *Fusicladium* on apples should be controlled to a 95% level (Schwabe, 1988). The maximum allowable infestation level of *T. urticae* is two adult females per leaf, (Pringle, 1987). Herbicides applications may also be evaluated in the same way.

Another important aspect is the degree of infection before application. This could either be a fixed reference value or comparative.

CONCENTRATION

The registered concentration for a given chemical is referred to here as the IX concentration. In South Africa *acephate* is registered for *Cydia pomonella* control at a concentration of 50g/100l. This is termed the 1X concentration, doubling and redoubling the concentration thus being called 2X and 4X, equating to 100g/100 litre, 200g/100 litre, etc.

EFFECTIVE COVER

Effective cover is that *quality of coverage* with spray at a *given concentration* that would result in *effective control* of a given ailment.

The quality of coverage is dependant upon:

- The level of coverage (droplets/cm^2 or % cover)
- The coefficient of micro-variation of coverage (ie. leaf to leaf variation)
- The coefficient macrovariation of coverage (ie. plant to plant variation).

The micro-variation describes the consistency of cover within a tree structure, whilst macro-variation describes the consistency of application in an orchard between trees.

Here a quality index is defined by the following formula

$$\text{Quality index} = \frac{100 \times \%\ \text{cover}}{\%\ \text{Microvariation} \times \%\ \text{Macrovariation}}$$

This index gives equal weight to all three factors for control. Maximizing the index will enhance the quality of application.

MATERIALS AND METHODS

Glossy, self prepared water sensitive cards were used to evaluate the coverage obtained in the centre of trees by attaching the cards to poles erected in the tree. Where dwarf trees were investigated, cards were stapled to the leaves.

Vines were also assessed by stapling cards to the leaves in the densest part of the bush.

A minimum of sixteen samples were taken per replicate and four or five replicates were used per treatment.

Field calibrations, where applicable, were done using standard methods (Ras, 1986). This included measurement of parameters such as air capacities, ground speeds, tree row volume requirements and VMD of droplet spectra.

The results are comparative and not absolute. Spread factors of the water sensitive cards were not used in calculation.

RESULTS

Table 1 overleaf shows some of the results obtained. The results showed that there are vast differences between the optimum characteristics necessary for vine and tree spraying. Efficacy trials in vines were thus restricted to investigation of only one machine type. Orchard spraying was done with a greater variety of machines.

DISCUSSION

Vine Powdery Mildew (Uncinula nicator)

If these comparative correlations were accepted as criteria by which to evaluate application equipment, it is found that additional input cost reductions are possible by using certain equipment in specific ways.

Table 2 overleaf shows the spray volume needed to obtain the desired levels of cover with different application techniques. Over or under supply of air energy resulted in worse cover with the same spray volume.

TABLE 1. Relative cover and concentration levels giving similar control of various target pests or diseases. (Cover/Concentrate/Control Correlations)

CROP TYPE	PEST OR DISEASE	ACTIVE INGREDIENT	CONCENTRATION	AVERAGE % COVER	% VARIATION MICRO	MACRO
VINES	*Uncinula nicator* (56% infested)	Pyrifenox/ nuarimol	1X	50	75	NA
			2X	30	85	NA
			4X	18	110	NA
APPLES	*Fusicladium* (Infection: 101000 cnidia/cm^2	Bitertanol *(Curative)*	1X	95	NA	NA
		Mancozeb (Preventative)	1X	90	NA	NA
			4X	20	NA	NA
			8X	8	NA	NA
APPLES	*T. urticae* (Infestation: 20 Motile stages per leaf)	Azocyclotin	1X	65	60	30
			2X	50	85	45
			4X	20	110	45

TABLE 2: Spray volume rate required for different applicators to obtain required cover as given in Table 1 for vines.

MACHINE TYPE	AIR VOLUME (m^3/hr)	OUTLET SPEED (m/s)	TRAVELLED SPEED (km/h)	LITRE/HA REQUIRED FOR COVER		
				50%	30%	18%
A1	4140	167	3.8	500	250	125
A2	4140	167	5.1	-	500	250
B	35000	?	3.8	850	500	250
C	27000	42	5.2	-	600	400
D	26000	32	5.2	-	600	400

A high air speed coupled with a low air volume, when used at the correct ground speed, appears to be the bests suited to vertically trellised veins. Too high a travelling speed resulted in a dramatic deterioration in the quality of cover, or an increased spray volume necessary for the same cover. This results in increased amounts of active ingredient needed per hectare when too high a ground speed is used.

Over supply of air energy also resulted in a marked deterioration of cover. This was a result of the high amount of energy of air, breaking through the tree taking spray liquid into the open row and resultant loss of cover.

The balance between available air energy and speed of travel during application is thus one of the most prominent factors affecting the successful deposit of spray liquid.

Droplet sizes used were similar throughout, and in the 100-175 Micron VMD range. The main physical variables were thus the balance of air energy to ground speed and the spray volume rate.

Orchards

In orchards comparative tests with different types of airblast sprayer used within set standards (Ras, 1986) revealed no statistical differences in the quality indices obtained, except for one machine that was designed to project more air energy to the upper half of the tree.

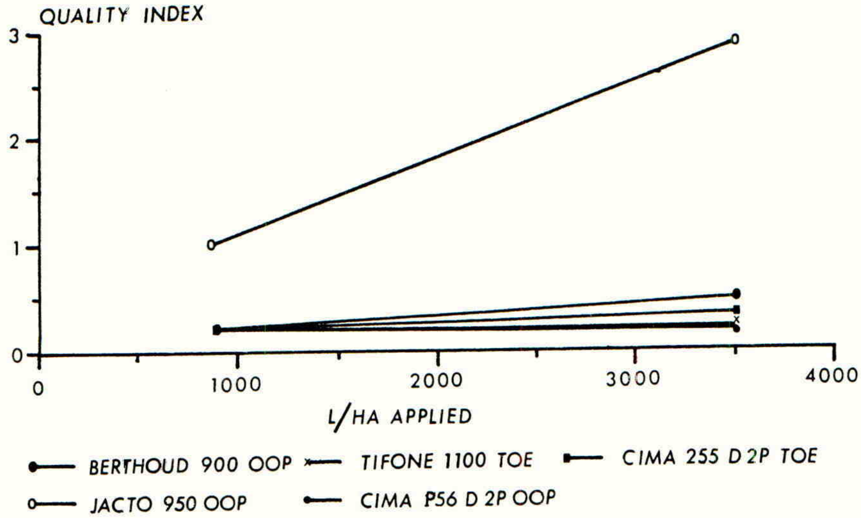
Figure 1 illustrates the difference in the quality index which could be interpreted as indicating lower spray volumes sufficient to obtain the same level of control. This however, was not verified by efficacy trials.

SUMMARY

The value of C.C.C.C. are still not recognised by manufacturers of spray equipment, growers and the agrochemical industry who might draw benefits by researching and applying these principles. The concept is a way of minimising both the risk of losses due to poor application and input costs.

Optimum use of chemicals minimises environmental pollution and health risks due to operator and bystander contamination. Proper design and use of air in machinery design is clearly the most single prominent factor affecting good or bad cover.

FIGURE 1: Comparative quality indices obtained with different air assisted sprayers at varying volume rates.



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DEVELOPMENT AND EVALUATION OF ROTARY CAGE ATOMISER CONVERSION FOR ORCHARD SPRAYER

T.P.Y. SANDER

Micronair Limited, Bembridge Fort, Sandown, Isle of Wight, PO36 8QS, England

ABSTRACT

Rotary atomisers employing a cylindrical cage for droplet production are widely used on agricultural aircraft. A similar atomiser has now been developed for installation in the air duct of conventional airblast type orchard sprayers. Field trials have shown that this approach achieves significantly better coverage than conventional hydraulic nozzles and can allow a 50% reduction of the volume of water applied.

INTRODUCTION

Rotary atomisers employ spinning discs or cylinders to break a liquid into droplets. Atomisers based on a rotating woven wire cylinder or cage have been used on agricultural aircraft for over 35 years. They are often chosen in preference to conventional hydraulic nozzles because of their wide operating flow range and narrow spectrum of spray droplet size.

The same design principles have now been applied to an atomiser suitable for installation in place of conventional nozzles in radial and axial fan airblast sprayers.

PRINCIPLE OF OPERATION

Fig. 1 shows a cross-section of a typical rotating cage atomiser.

The atomiser is placed in an airstream so that the fan blades rotate the hub and cage about a fixed spindle.

Spray liquid is delivered to the atomiser by a feed tube connected to the hollow spindle. The liquid flows through the spindle and emerges through a series of holes aligned with a rotating spray deflector. This distributes the liquid inside a perforated drive tube, which is also rotating. The liquid passes through the holes in the drive tube and is thrown against the inside surface of the cylindrical cage.

The cage is made from either woven wire or expanded metal with 25 - 100 apertures per cm^2.

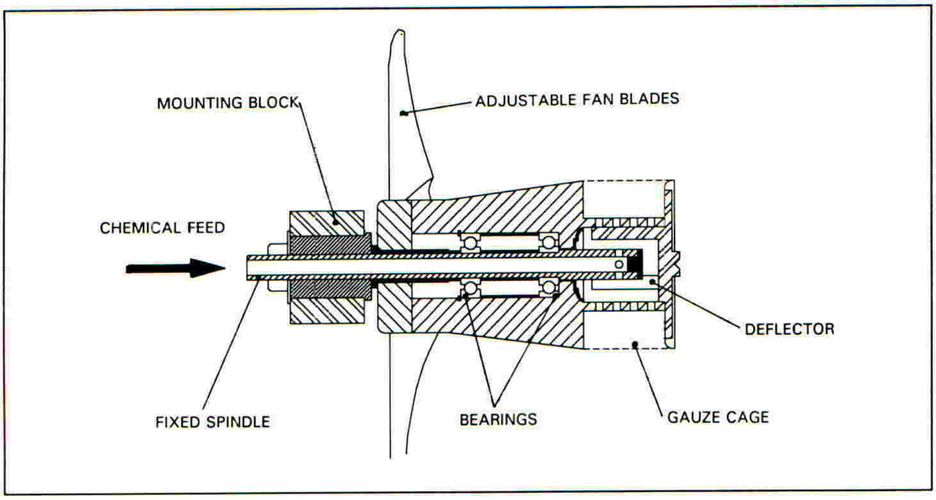

Fig. 1 - Cross-section of rotary cage atomiser

Liquid reaching the inside of the cage flows radially outwards through the mesh and streams off the individual wires as ligaments. The combined effect of centrifugal energy and the airflow over the atomiser causes the ligaments to disrupt into droplets.

This mechanism of droplet production remains effective until the flow rate per unit area of mesh reaches a point where the process of ligament formation breaks down and the cage 'floods'. This is analogous to the transition from ligament to sheet formation at the edge of a spinning disc.

The onset of flooding is dependant upon liquid viscosity and rotational speed but typically occurs at 15-20 ml/cm^2 of cage area for low viscosity liquids at 6000 rev/min.

The mean size of droplets produced by an atomiser is a function of the rotational speed of the cage and the properties of the liquid. The higher the rotational speed of the cage, the greater will be the centrifugal energy disrupting ligaments at the surface and the smaller will be the droplets. Similarly, liquids with a low viscosity and surface tension will form droplets with low surface energy and will therefore disrupt into a larger number of smaller droplets than a liquid with high surface tension.

In order to vary the droplet size for a given liquid, it is necessary to change the rotational speed of the atomiser. This is achieved by varying the pitch (angle of attack) of the fan blades which drive the atomiser in the airstream.

Fig. 2 shows the relationship between droplet size (V.M.D.) and rotational speed when spraying water.

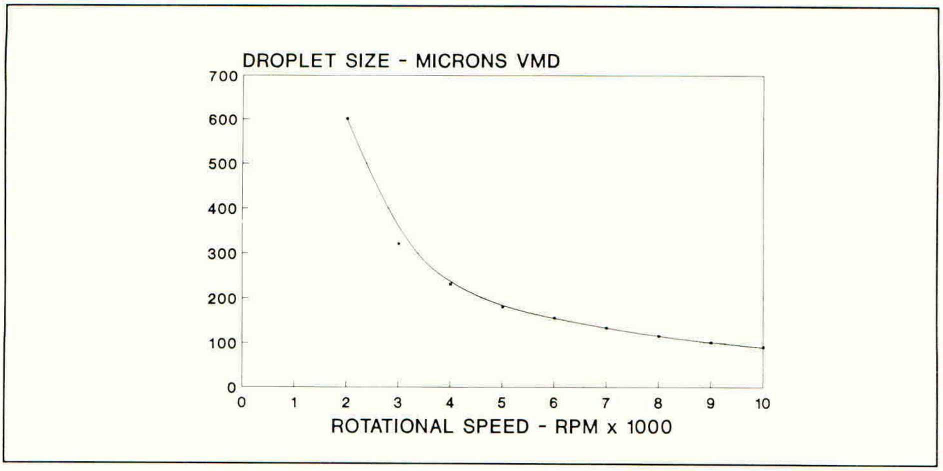

Fig. 2 - Relationship between droplet size and revs/min.

DESIGN CONSIDERATIONS

An atomiser for use in a conventional airblast sprayer must meet the following criteria:

- Be small enough to fit into an existing air duct
- Must achieve the required rotational speed with the available air velocity.
- Must be capable of handling a sufficient liquid flow rate to achieve an adequate application rate (in l/ha) from the sprayer.

The critical dimension in this application is the effective diameter of the fan blades. The maximum diameter is determined by the dimensions of the duct but the minimum diameter is determined by the available air velocity, maximum speed required and power absorbed at maximum liquid flow rate.

Fig. 3 shows the relationship between minimum fan diameter and air velocity for operation at 6000 rev/min with a flow of 1 l/min water.

In order to provide maximum flexibility, the atomiser must be suitable for as wide a range of application rates as possible.

For an orchard sprayer applying 200 l/ha at a speed of 7 Km/hr and a swath of 3.5 m, the output will be 8.2 l/min. This corresponds to a flow of 1.4 l/min per atomiser if six are fitted to the sprayer.

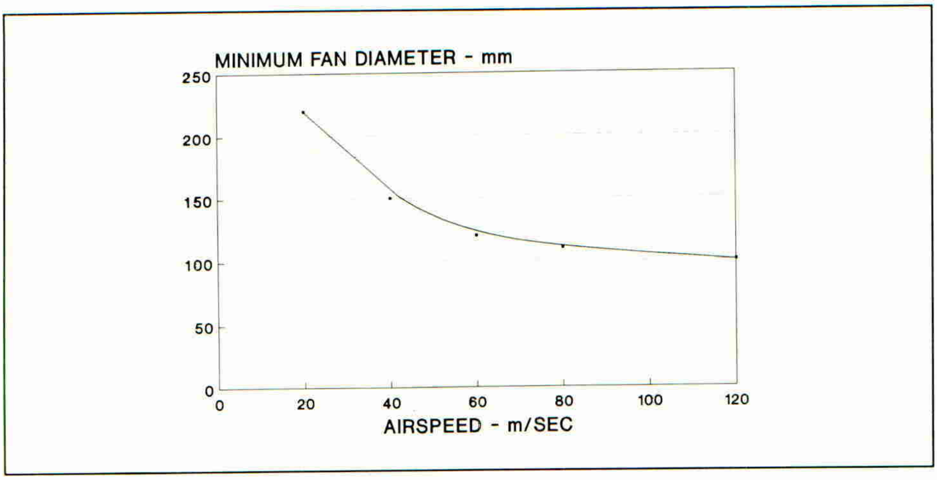

Fig. 3 - Required fan diameter against air velocity

This maximum flow rate determines the minimum cage area of the atomiser. As the mechanism of atomisation remains substantially unchanged as the flow rate is decreased, the same cage configuration can be used for all lower application rates, including ultra low volume if required.

The flow range of a rotary cage atomiser is considerably wider than for a rotating disc atomiser. This greatly increases the versatility of the sprayer as it can be used for both conventional application rates and low and even ultra low volumes when these are advantageous.

The 'Micronair' AU8000 atomiser has been designed to meet these criteria. It is fitted with woven wire gauze cage 7 cm diameter and 4 cm long. This allows a maximum flow rate of 1.5 l/min with typical insecticide and fungicide formulations (including solids in suspension). The atomiser is fitted with four twisted aerofoil section fan blades which can be adapted to have an effective diameter of between 10 and 22 cm.

INSTALLATION ON SPRAYER

Six AU8000 atomisers were installed on a 'Berthoud' Arbo 480 radial airblast orchard sprayer. This is a 3 point linkage sprayer with a power take-off driven fan delivering approximately 14 m^3/minute of air at 38 m/sec.

The atomisers were mounted between flange plates bolted to

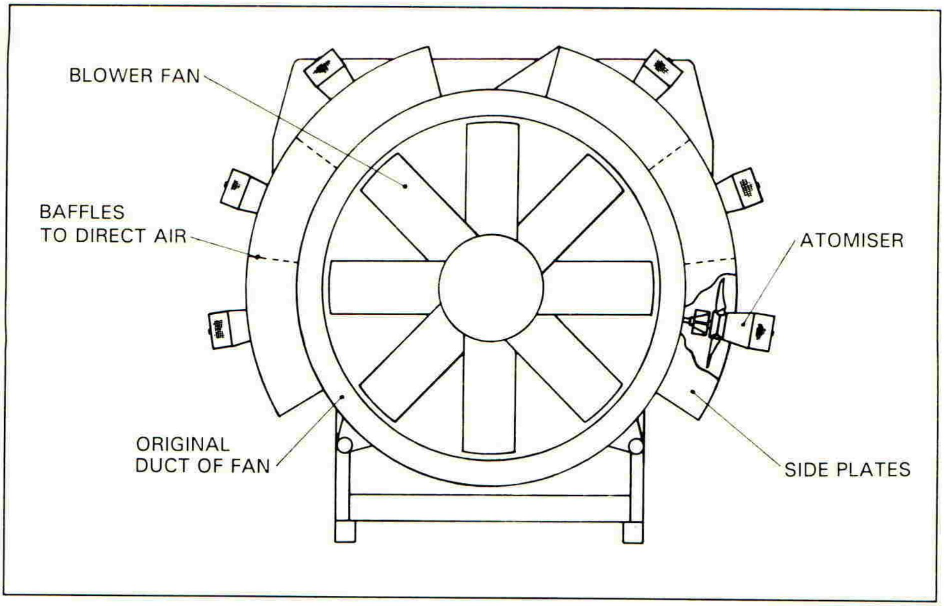

Fig. 4 - Configuration of sprayer with rotary atomisers

The radial air velocity from the air duct of axial fan sprayers is not consistent around the periphery. In general, the air velocity increases from lower left to lower right with a clockwise rotating fan as viewed from the rear. A constant air velocity is necessary to achieve consistent atomiser speed and spray distribution. It was, therefore, necessary to fit a series of baffles between the fan and atomisers to deflect the air (see Fig 4). These were adjusted to achieve an even velocity distribution around the periphery of the sprayer. Air velocity was measured with an anemometer and verified by measuring the rotational speeds of the atomiser with a tachometer.

Atomiser fan blades were adjusted so that all units ran at 7000 rev/min +/- 200 rev/min at the normal operating speed of the blower fan.

Liquid was fed to the atomisers from a manifold via individual restrictor orifices. Liquid pressure at the manifold (and hence flow to individual atomisers) was controlled and regulated by an electronic application controller.

EVALUATION OF SPRAYER

After initial calibration, the converted sprayer was used for the application of fungicides and insecticides in trial blocks of an orchard at Glabbeek in Belgium.

The orchard was planted as single rows of 5 year old Conference Pear trees grown in pyramid (centre leader) shape. Trees were planted 1.5 m apart with a row spacing of 3.5 m. Tree height varied between 2 - 2.5 m.

For comparison, a 10 ha section of the orchard was sprayed with the converted sprayer and the remaining 30 ha with a 'Munckof' airblast sprayer fitted with 'Albuz' 210 Brown nozzles with Maroon swirl plates operating at a pressure of 7.5 bar. The application rate with this machine was 200 l/ha for all treatments.

Because of the unusually dry weather during the 1990 season and the lack of pest pressure, a meaningful biological comparison of the sprayers was not possible. However, the machines were compared on the basis of spray coverage. This was assessed by means of water sensitive cards stapled to the leaves of sample trees chosen at random in each trial block.

Cards were placed at the top (2.5 m above ground level), middle (1.5 m) and bottom (0.75 m) of sample trees on both the top and bottom surfaces of leaves. At the middle level, cards were placed at the front, centre and back of each tree to assess penetration of the thickest section of the foliage.

In order to estimate the amount of spray passing through a tree and deposited on the next row, cards were also placed on the upper leaf surfaces at the top, middle and bottom of trees immediately behind the sprayed row. These cards were only placed on the side of the tree facing the sprayer.

Results

Droplet numbers were counted on each card by taking the average of counts from 4 random 1 cm squares. An average of all cards for each location was then taken to give the figures presented here.

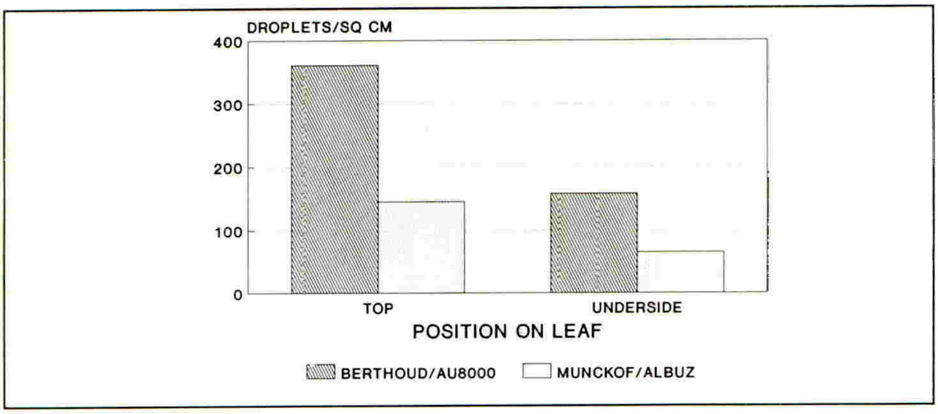

Fig. 5 - Coverage at top of trees

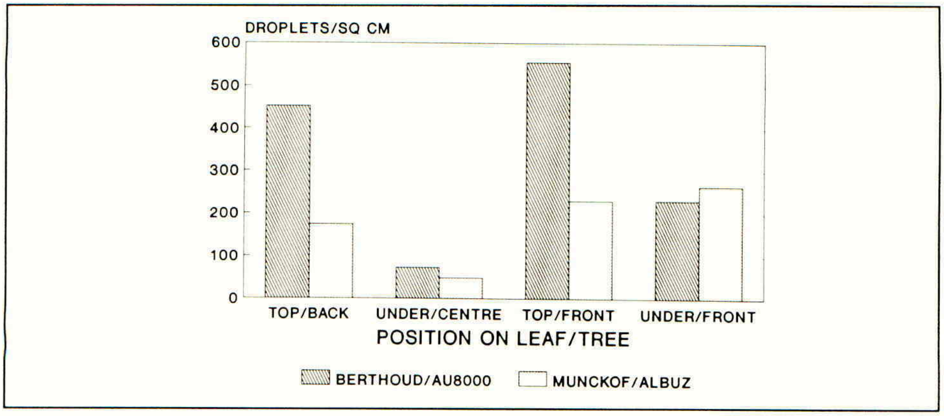

Fig. 6 - Coverage at middle of trees

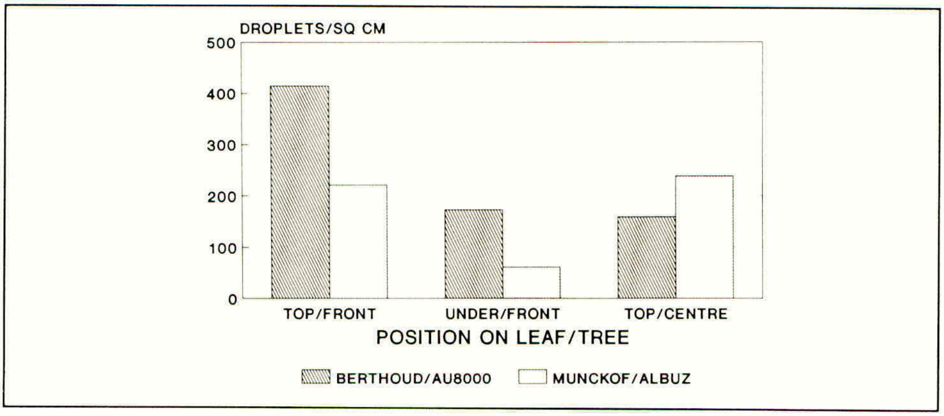

Fig. 7 - Coverage at bottom of trees

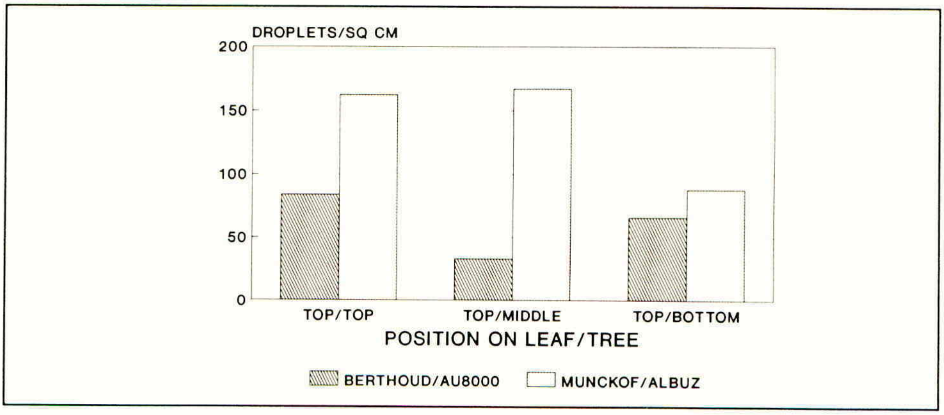

Fig. 8 - Deposit on leaves of trees behind sprayed row

A comparison of droplet numbers for rotary atomisers and conventional nozzles is shown in Figs 5, 6 and 7 for the top, middle, and bottom of the trees respectively. The droplet density was significantly higher with the rotary atomisers in all cases except the underside of middle front leaves and the top of leaves at the bottom of the trees. However, the coverage on these exceeded 150 droplets/cm^2.

Fig. 8 shows numbers of droplets collected on upper leaf surfaces of trees immediately behind the sprayed row. All samples showed lower droplet numbers with the converted sprayer as compared with hydraulic nozzles. This is believed to be for the following reasons:

- Rotary atomisers impart a swirling turbulent motion to the airstream, causing disturbance of foliage and increasing collection efficiency.
- The presence of atomisers in the outlet duct reduces the volume of air emitted and consequently the tendency for spray droplets to be blown through a tree.

Droplets not collected on foliage and passing through a tree can be prone to drift. Because of this, the reduction in droplet numbers found behind the sprayed trees could be significant and deserves further study.

CONCLUSION

The work carried out during the 1990 season has shown the feasibility of installing rotary cage atomisers in a conventional orchard sprayer. An initial assessment of droplet deposits has indicated coverage at 100 l/ha which is superior to that from conventional hydraulic nozzles at 200 l/ha.

THE DEVELOPMENT OF AN UNMANNED AIR ASSISTED TUNNEL SPRAYER FOR ORCHARDS

J. VAN DE WERKEN

Institute for Agricultural Engineering (IMAG), P.O. Box 43, 6700 AA
Wageningen, The Netherlands.

ABSTRACT

The development and use of a fully automated air-assisted tunnel sprayer for use in apple orchards by IMAG is described. The machine incorporates the unmanned transport of the sprayer through the orchard, recycling spray not deposited on the target (a Closed Loop Spraying system). The machine has been tested, and its development and perfection are continuing.

INTRODUCTION

Conventional spraying machines used in fruit growing produce large losses of chemicals which pollute the environment during spraying. Also their safety for the operator is poor. At the Institute for Agricultural Engineering 9IMAG) in Wageningen, a spraying robot, called OOSEF, is being developed. The aim is to spray orchards without polluting the environment and with maximum safety for the operator. Improved deposition may result in reduction in chemical use. Ideally this means no losses of chemicals to the ground or the air, and a fully unmanned spraying operation. The name "OOSEF" means (translated from Dutch) unmanned optimised spraying in fruit growing. OOSEF was originally designed to automatise the spraying operation for the IMAG seven row bed orchard system. This is a narrow plantation with a row width of approximately two meters, and with a distance between the beds of 3.5 m. OOSEF can be used in any single row planting system providing an alley way of at least one half meter path is available between the rows. Photographs of the machine developed are shown in figures 1 and 2.

PRE-STUDY

Before the design of OOSEF was started a pre-study of the spraying operation was made, covering the following aspects:

- Correct deposition of spray droplets on the leaves
- Eliminating the emission of chemicals to the air and the ground
- Reduction of the use of chemicals
- Unmanned transport of the sprayer through the orchard

The plantation

At IMAG an experimental high density seven row bed orchard has been established. The row width is 2 m and the bed width is 15.5 m. The plan was to design a complete mechanisation system for this type of orchard. Some years ago a mechanical picking aid was developed for this type of orchard at IMAG. At first a number of different ideas for transferring the chemicals to the trees, with air assistance were explored:

1. Spraying one half of the bed at the time using four pipes to duct air each with its own fan.
2. A similar design to (1) for spraying the whole seven row bed.
3. One big central fan with a pipe construction for spraying half the bed at a time.
4. As (3) but spraying seven rows at the time.
5. Using the support carriage of the picking aid.
6. Rails in the orchard, including a number of alternative arrangements.
7. A straddle tractor as carrier for the spraying unit.
8. OOSEF.

For various reasons the single row treatment (OOSEF) was chosen as follows:

low investment
low power consumption
easy cover of the tree
sufficient capacity for spraying 15 ha
easier automatisation of the transport operation through the orchard

Analysing the spraying process

The time to spray the IMAG seven row orchard was calculated as follows:

Orchard area 15 ha, row length 200 m, bed width 15.5 m. Per ha there are 340 rows. The calculated spraying speed was 1.25 m/sec.

Required transport time in the row is (200/1.25 x 340) = 15.1 hours
Required transport time from row to row is 60 x 340/3600 = 5.6 hours
Required total spray volume at a volume rate of 150 1/ha for 15 ha is this 2250 1.
Tank volume 4001 = 6 tank fillings required = 1.0 hour

TOTAL 21.7 hours

The time for spraying 15 ha is about 22 hours, this was considered low enough to achieve the demanded work rate. The calculations showed it was theoretically possible to spray an orchard of 15 ha with a single row treatment unit.

OOSEF is a unique combination of spraying and unmanned transport through the orchard. The chosen way of automatic motion of the machine has had an effect on the design of the sprayer equipment. For this reason the design of the automatic operation of OOSEF will first be explained.

Description of the unmanned operation of OOSEF

There are many different ways to guide a vehicle through an orchard, each with its advantages and disadvantages. We have tried to find a solution that needs least alteration to the orchard and which is not too complicated.

Wheeldrive

OOSEF has two driven wheels on one side of the tree row and two swivel wheels on the other. When the machine has reached the end of the row, it does not turn in the normal way but the two driven wheels are turned at right angles and the machine makes a cross movement to the next row. Then the drive is reversed and the sprayer moves backwards along the next row. This means the machine is bi-directional, it does not have a particular front or rear.

How does it work

Automatic transport of OOSEF through the orchard can be divided into two parts.

A) unmanned steering in the row.
B) unmanned steering from row to row.

Unmanned steering in the row

The machine has two driven wheels on one side and two swivel wheels on the other. Both driven wheels have three different positions:

1. - fixed position, wheel in line with the tree row.
2. - steering position approximately 20 degrees to both sides of the tree row line.
3. - ninety degrees turned left in comparison with the tree row line.

In the automatic mode the front wheel is standing not quite in line with the tree row, but it is turned an adjustable angle towards the tree row. An outside spring keeps the wheel in this position. The rear wheel is then in the fixed position. When OOSEF receives the command "go forward", then the front wheel is steered towards the centre line of the tree row. On the front of the machine to the drive wheel side an electro-mechanical sensor is mounted to detect the tree trunks. If the sensor is operated by a trunk, then an hydraulic cylinder steers the front wheel back as long as the sensor is in contact with the stem, this against the outside spring force. If the back steering-signal is interrupted, the spring retracts the front wheel into the start position. The steering speed can be adjusted in both directions. This effects the amplitude and wavelength of the steering line of the front wheel in the orchard. A correction can be made at every tree. When the machine has reached the end of the row it does not turn in the usual way, but both wheels are turned through ninety degrees and the machine moves across to the next row of trees. When it has just reached the centre of that next row the machine stops, the wheels are turned back, the drive is reversed. The machine moves backwards into the new row. The previous rear wheel becomes the new front wheel and vice-versa. The rear wheel is then in the fixed position and the front wheel is in the automatic steering mode (pointed to the centre of the tree row). On reaching the end of the row the whole turning operation is repeated until the machine reaches the third row. The machine then stops if one cycle is programmed, or starts again if more than two tree rows are programmed.

Necessary alteration to the orchard to make the unmanned operation possible

Each tree normally has a stake. The first and last stake of each tree row must be about 250 mm longer than the others. OOSEF has sensors, two in the middle on the top on the front side and two on the rear side. These sensors are operated by the long stakes, which affects the built-in electronic control unit. The programmable control unit receives signals from the trunks and the first and last stakes of the tree row and gives a voltage supply to the electronic-hydraulic valve for all the hydraulic activities. The automatic steering is done by hydraulic cylinders including the ninety degree turning on the drive wheels. The fan has its own hydraulic motor and the spray pump is also hydraulically driven. In the automatic control program, timers are set to make the turning operation at the end and beginning of each row possible. Switching on and off of the spray is also controlled electronically.

Power supply

A 24 HP diesel engine drives a hydraulic pump directly. This pump supplies the electronic-hydraulic valve with oil. The system is provided with a load sensing device. Each section of the valve is controlled by the electronic sequence controller. Step by step the conditions for the inputs and outputs can be programmed. It is also possible to programme the number of tree rows that are to be sprayed.

Spraying equipment

The concept of the automatic transport of the machine through the orchard has an important effect on the design of the spraying equipment. The straddle frame is covered on the inside with a canopy or tent construction to avoid spray mist reaching the environment. On both sides of the tent there are trays to collect the surplus liquid running down the tent walls (Figure 4). The collected liquid is filtered. Spraying is air assisted. The spray nozzles are located to the left and right, just in the middle of the tent construction (Figure 3). The spray nozzles are mounted on air pipes, one on each side. The airstream comes from a fan which is mounted on the top, in the middle of the tent. The fan sucks its air out of the tent space. In this way a circulation system of air and chemicals is obtained more or less. We have called this the Closed Loop Spraying system (CLS). The air pipes can pivot around their axis. In this way it is possible to spray in the direction of travel. In order to avoid the spray mist leaving, the tent cover can be provided with plastic sheets and strips.

The automatic operation

OOSEF is placed exactly in front of the first tree row manually. Then it is switched on in the automatic mode. The number of trees to be sprayed are set and after starting the cycle, OOSEF starts moving. After a predetermined time the spraying valve is opened and the fan rotates. The front trunk sensor is switched on. OOSEF sprays at high speed (1.25 m/sec). Coming to the end of the row, the speed is reduced to avoid high breaking forces. At low speed (0.3 m/sec) the machine moves to the next tree row, then again at high speed it goes to the end of the row. Arrived there, the spraying action stops, the machine moves at low speed out of the row and stops. Then it moves across to the next row.

Testing OOSEF

The experimental machine was ready for testing in the orchard in May 1989. The automatic operation was tried and tested first. We started at low speed and found that the automatic steering design worked. Although the opening between the liquid collecting trays is 400 mm and sometimes the trunk diameter is 150 mm, OOSEF searched for the centre of the row. Maximum driving speed tested with automatic steering was 1.1 m/sec. It seems likely that the calculated speed of 1.25 m/sec can be achieved. Moving from row to row was a little more difficult. The drive wheels are connected in parallel in the hydraulic circuit via a flow divider. At first it was a problem to keep the machine straight during cross movement. The solution was to use two fixed line wheels mounted on lift cylinders between the two swivel wheels on the other side of the construction. Before the drive wheels are turned ninety degrees they are also lifted in order to avoid making holes in the orchard. The wheels always turn on the same spot.

Testing the top sensors

When the test was started OOSEF was equipped with sensors which were provided provisory. During testing it was discovered that cross detection is very important. Therefore a special cross detection device was designed to stop the machine at the correct position in front of each new row independent of the machine's position right after leaving the former row (place or angles).

OOSEF spray concept test

The first spray test was done using seven nozzles on each side, the machine moved at low speed, to determine the expulsion of spray mist out of the tent cover. However, with too high a spray volume, no exhaust of spray mist out of the tent cover could be seen. Measurements were not made. Later in the 1989 season, attention was paid to the deposition of the droplets on the leaves. Using a UV lamp it was possible to obtain an impression of the deposition of the droplets in the tree. In comparison with former tests the OOSEF spraying system gave a perfect deposition pattern. The number of spray nozzles was reduced to three nozzles on each side. This gave a volume rate of 225 l/ha (1m/sec). In the same season some spray drift measurements were also done. For the 1990 season a measuring system was designed and developed in order that a mass balance for OOSEF could be done. (Design Ing. H. Porskamp, IMAG).

RESULTS

In 1990 a number of measurements were made. It was found that 90% and more of the sprayed liquid was deposited on the tree. The tent cover was at that particular time not fitted with any inside filling. It is clear that these percentages change with the leaf area index. So there will be a difference between early and later in the season. The OOSEF concept makes automatic transport of the sprayer possible. The development and perfection of the system are continuing.

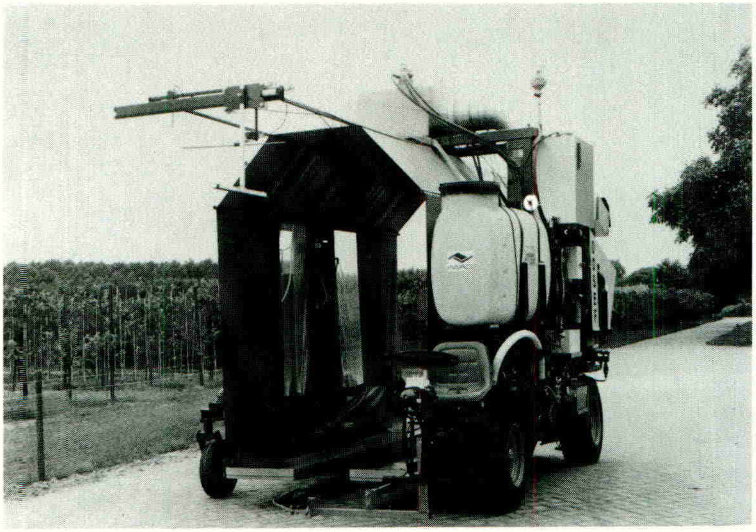

Fig. 1. OOSEF EXPERIMENTAL SPRAYING ROBOT (1990 model)

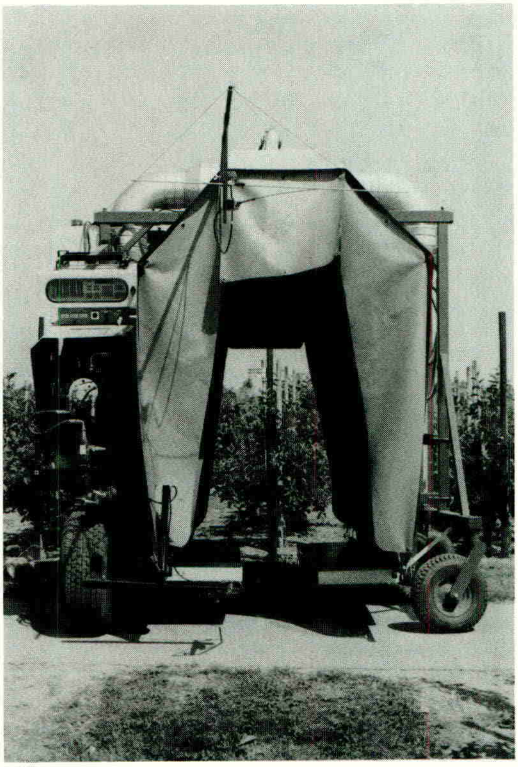

Fig. 2. Front view of OOSEF

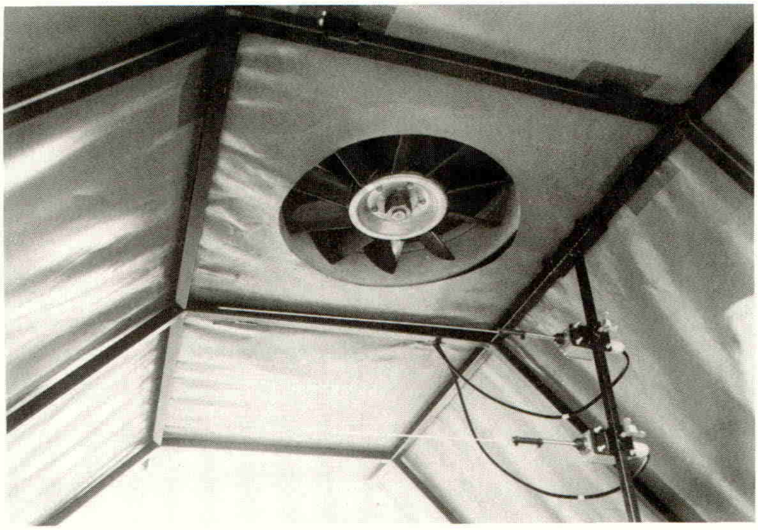

Fig. 3 Top ventilator inside the tent cover of OOSEF

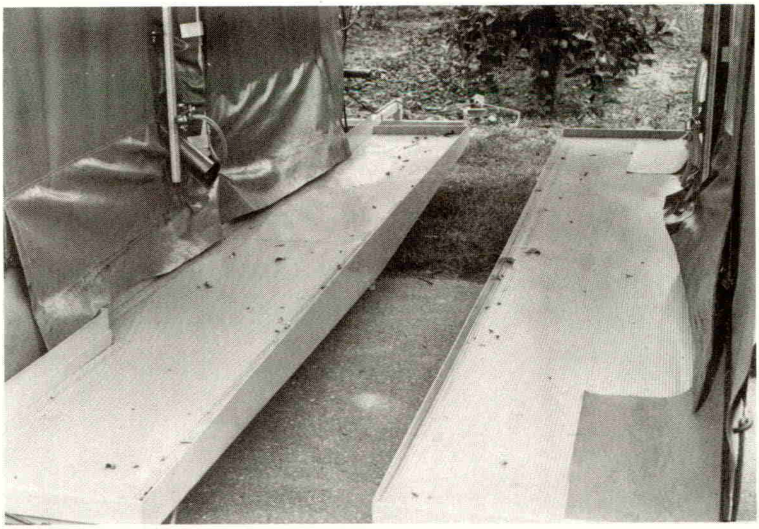

Fig. 4. Liquid collecting trays with trunk sensor

OPTIMISATION OF SPRAYING METHODS FOR FRUIT TREES WITH REDUCED USE OF CHEMICALS

H. WIEDENHOFF

Horticultural Mechanisation Specialist, Drumptselaan 29, 4003 HA, Tiel, The Netherlands.

ABSTRACT

Traditionally, radial-flow air-assisted sprayers, incorporating axial or centrifugal fans, were used for spraying fruit trees in The Netherlands. These designs are poorly suited to modern intensive orchards and cause significant environmental pollution. Significant improvements in efficiency have been achieved by using cross-flow spraying techniques coupled with small orifice hollow cone hydraulic nozzles. Careful attention to design results in a greater proportion of pesticide spray being deposited, with a better distribution on the target. Pesticide use has been reduced by about 50% and volume rates reduced from approximately 1000 litres per hectare to 150 litres per hectare, resulting in a marked improvement in work rates. Further improvements in fruit tree spraying efficiency will result from the commercial adoption of air-assisted tunnel sprayers, where the spray is enclosed in a canopy carried by the sprayer and spray not deposited on the tree collected and re-cycled.

Sprayer design

Until recently, radial flow mist-blower sprayers utilising either axial or centrifugal fans were used almost exclusively for fruit tree spraying in The Netherlands. These machines were well suited to more traditional orchards with large, tall trees on vigorous rootstocks with an overhanging canopy. The designs were simple in order to keep manufacturing costs low, and allowed flexibility for use in different types of orchard. However, with the almost universal use of dwarfing rootstocks and higher planting densities, tree size has been greatly reduced and shape dramatically altered (mostly to the slender spindle shape) over the past decades. Radial flow sprayers are not suited to modern orchards. The spray impinges on the tree target at an angle which varies with height, the air output is often grossly excessive and a large proportion of the spray is emitted into the atmosphere above the top of the tree target, even if nozzles are carefully positioned (Cross, 1991). For these reasons, in recent years, cross-flow mist-blower sprayers, have found general acceptance in The Netherlands. With these sprayers the spray is blown almost horizontally from tall vertical air outlets. Cross-flow sprayers have several distinct advantages.

1. The spray does not rise significantly above the tree tops, thereby reducing environmental pollution by spray drift.

2. The distance travelled by the spray to the most distant parts of the tree target is minimised so reducing losses by evaporation.

3. Careful control of the angle of emission enables optimisation of deposition of spray on leaves. In slender spindle trees a slight upward angling of about 12° is optimal.

A further development now being tested is enclosure of the spray in a canopy carried by the sprayer. Spray not deposited on the tree is collected and re-cycled. Spray drift is considerably reduced.

Optimising droplet size

It has long been recognised that smaller droplets give a more even covering. The reason for the improved spreading efficiency of smaller drops is shown in Table 1 (Porskamp *et al*, 1985).

TABLE 1. Effect of spray volume and drop size on percentage cover in orchards

Spray volume (litres deposited per hectare of surface)	Droplet diameter (microns)	Number deposited per cm^2	% cover	Distance between drops (mm)
40	400	12	1.5	2.5
	200	96	3.0	0.8
	100	764	6.0	0.3
400	400	119	15	0.5
	200	995	30	0.1
	100	7639	60	0.01

Dividing the droplet diameter by two generates eight times as many droplets and, if all these are deposited, they cover twice the surface area with the same spray volume rate.

Reducing the droplet diameter improves the spreading efficiency. However, it cannot be reduced indefinitely because smaller droplets are progressively more prone to drift, loss by evaporation, and do not impact so efficiently on the target. As a compromise, a droplet diameter of 50 to 150 microns is advised in The Netherlands.

Spray atomisation

Dutch growers almost exclusively use hollow-cone hydraulic nozzles. Air atomisation is no longer preferred, because it is unreliable, difficult to control and produces a wide spectrum of drop sizes. Traditionally, large orifice hydraulic hollow cone nozzles were used, producing drops of large average size (VMD = *circa* 200-300 microns). In order to achieve smaller droplet sizes, small orifice types are widely used. Table 2 shows pressures and flow rates for a homologous series of small orifice hollow cone nozzles to produce drops in the required size range of 50 to 150 microns.

TABLE 2. Examples of nozzle pressure combinations which give the required drop size characteristics for a homologous series of nozzles manufactured by Albuz, France

orifice diameter (mm)	0.8	1.0	1.2	1.5
pressure (Bar)	7.5	9.5	10.0	10.5
Flow rate (l/minute)	0.45	0.66	1.06	1.43

Ceramic nozzles are preferred because they are very resistant to wear and are not attacked by pesticides. Flat fan nozzles, widely used for spraying arable crops are not advised, partly because they are more prone to blockage and partly because they produce a less even cover of the foliage. Spinning disc nozzles widely used for orchard spraying in Southern England, but hardly at all elsewhere, have a number of disadvantages that make them less than ideal. They are comparatively expensive, prone to breakage, spin unevenly, readily become fouled with pesticide and are difficult to check for correct operation when spraying. Furthermore they are inflexible as only about 300 ml of spray liquid can be atomised per minute. They cannot readily be used with cross-flow sprayers (Wiedenhoff, 1989), and have performed poorly in efficacy trials (Beeke et al, 1984).

Boom orientation and nozzle positioning

Ideally the spray boom and air orifice should be shaped to match the profile of the tree target. For tall, slender, spindle trees widely grown in The Netherlands, the straight vertical booms and ducting of cross-flow sprayers are ideal. The lowest part of the tree contains most leaves and branches, gradually tapering to the top. Nozzles should be more closely spaced on the bottom of the boom, with increasingly wide spacing towards the top.

Nozzles should not be placed in the air orifice. The spray cone should be allowed to spread to its optimal width before entrainment in the air, to avoid streaking. This is especially important with small orifice nozzles. Apart from streaking, building spray nozzles into the air orifice is complicated and disrupts the airflow.

Advice on spray volume rates

Traditionally high spray volume rates of 1000 to 1500 litres per hectare or more were used in conjunction with large orifice hollow cone nozzles. Following efficacy trials and extensive commercial experience, much lower spray volume rates (and small orifice hollow cone nozzles) are advised of 150 litres per hectare for single row plantings up to 300 litres per hectare for five row bed orchards. This reduction in volumes has led to a marked improvement in work rates.

Techniques for spraying bed systems.

Cross-flow sprayers are very effective for spraying single-, double- or three-row orchard systems. However, at the present stage of technology, bed systems of more than three-rows cannot be properly sprayed. In these orchards specialist air-blast sprayers with raised outlets are used (termed tower sprayers). The spray is emitted both sideways and at a downwards slant from above. The undersides of the leaves in the centre of the bed, however, are insufficiently covered. Figure 1 shows the suitability of different types of sprayer for different orchard systems.

Pesticide use reductions

The more efficient spraying methods described above have led, in part, to a substantial reduction in pesticide use, averaging over 50% per season, as shown in table 3 below.

TABLE 3. Pesticide use (kg per ha of active ingredient) in The Netherlands for spraying fruit trees in 1985 and 1990

Agrochemical class	1985	1990
fungicides	11.4	6.4
insecticides	1.05	0.75
herbicides	1.65	0.50
growth regulators	0.90	0.25
TOTAL	15.00	7.90

Enclosed spraying with tunnel-sprayers

The first research into spraying tree rows underneath a trailed cover (termed here as a tunnel sprayer) was done many years ago by N G Morgan at Long Ashton Research Station, England (now the Institute of Arable Crops Research, Long Ashton, Bristol) (Cook *et al*, 1976). These early designs were not air-assisted. More recently an unmanned, air-assisted tunnel sprayer has been developed at the Institute of Agricultural Engineering (IMAG), Wageningen, The Netherlands (v.d. Werken, 1991). Spray not deposited on the target is captured by the canopy, collected and recycled. More recently, a tractor drawn, air-assisted tunnel sprayer has been developed jointly by John and Company, Achern, West Germany and Noric, Tongeren, Belgium. The sprayer incorporates four hydraulically driven Noric rotary atomisers of a new design. This machine can operate at very low volumes. Recent field measurements of spray deposit and cover are very favourable and a further 25 to 30% saving of chemicals appears possible. These savings are likely to more than compensate for the higher cost of this type of equipment compared to simpler radial flow sprayers, which pollute the environment.

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