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TOMATOES - AN EXAMINATION OF THE EFFICIENCY OF SPRAY APPLICATION TO COMMERCIAL CROPS

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedure described herein and that this report represents a true and accurate record of the results obtained.

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TOMATOES - AN EVALUATION OF THE EFFICIENCY OF SPRAY APPLICATION TO COMMERCIAL CROPS

SUMMARY

The efficiency of spray application was assessed on nine commercial tomato crops growing in Southern England. A flourescent tracer (Tinopal CBS-X) was used and applied with the grower's equipment and using his normal procedures. Some variations from the normal which included different nozzles, nozzle positions and spray pressure were examined on some sites. When the spray was dry the plants were sampled by removing leaves from the base, the middle and the tops of the plants (ten in each position) and those facing outwards (nearest to the spray source) were separated from those facing inwards (furthest from spray source). The leaf area covered was assessed in the laboratory under near UV light by examination of the distribution of the deposit.

There was considerable variation in the type of spray equipment used varying from a hand held lance with a single large nozzle to a twenty nozzle trolley sprayer. Of the nine growers visited five used trolley sprayers, three hand lances and one used both. Nozzle types also varied with size growers using hollow cones, two flat fans and one both. The individual nozzle output varied from 0.5 l/minute (grower 1) to 10 l/minute (grower 5). Spray pressure was more consistent throughout at between 10-15 bar. The spray volume applied per unit area ranged from 767 l/ha (grower 1) to 347 l/ha (grower 7). The condition of the nozzles varied from those which appeared to be regularly maintained (similar output for each noxxle on a boom) to little maintenance (large variations between nozzles and bits missing). At one site the variation between nozzle output was up to a litre/minute. Most of the trolley sprayers gave better coverage of the inner leaves although one grower using a hand lance achieved similar results. Generally the sprays with cone nozzles gave a slightly better performance than those with hollow cones but because of many factors, most importantly bad nozzle maintenance, it was not possible to draw firm conclusions on nozzle type.

There was, no clear relationship between spray volume and cover. By dividing the mean cover achieved by the volume used, it was possible to calculate the theoretical volume needed for every 1% cover achieved.

This varied from 23 to 109 litres. The difference in volumes used in relation to cover achieved means that much of the spray is lost by run-off on some nurseries. Also pesticide costs for those where the recommendation is based on a concentration (chlorothalonil for instance) can vary from £15-£120/hectare/application. Where nozzles were pointed upwards the undersides of the leaves were better covered although this was not the case with the grower using the lowest volumes.

On none of the nurseries was it possible to relate sprayer performance to biological efficacy. Also, as a tracer was used the crops could only be sprayed after the last pick and in this respect they were not the same as a mid-season crop.

There is a clear need for further in depth studies of spray application to maximise efficiency and reduce pesticide use. As a first step growers should make sure that their spray equipment is properly maintained.

INTRODUCTION

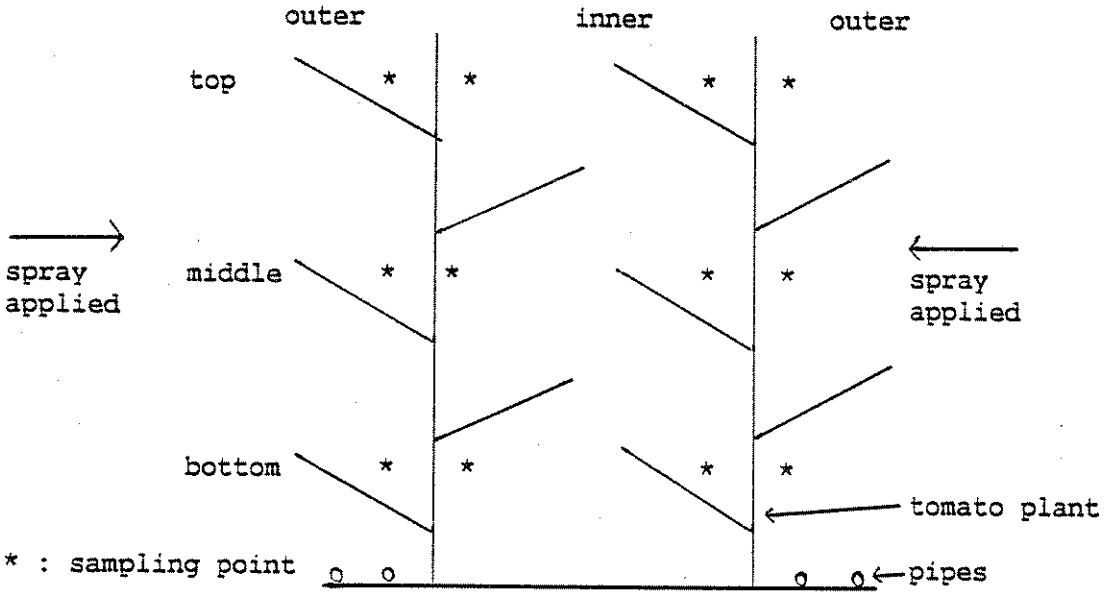
Most growers use high volume systems of pesticide application for the control of both pests and diseases. Information from field crops generally supports the view that the higher the spray volume the more effective the control but much of the earlier work did not clearly differentiate between volume and amount of product applied. With good systemic materials it should be possible to reduce the volume and still achieve a satisfactory level of control. There are indications that this may be possible for the control of some glasshouse pests but no such indications are available for diseases. There is now an increasing interest in fogging or misting methods of application to glasshouse crops but so far no evidence of the biological efficacy of such means of application.

Preliminary work in 1990 on three tomato nurseries, all using similar spraying equipment and methods of application, showed considerable variation between the three in the amount of cover achieved (measured with fluorescent tracer). Generally, the undersides of the leaves, those facing inwards, and those at the bottom of the plants were poorly covered. This could have important implications where non-systemic products are applied. For example, with powdery mildew control, the non-systemic protectant fungicides chlorothalonil and sulphur are recommended as part of a programme to combat the possibility of resistance developing to the systemic materials fenarimol and bupirimate. On one site in 1990, tomato powdery mildew developed on the underside of the leaves where the cover was a fraction of that on the upper surface. In the work described here, comparisons were made of the spray cover achieved by the application methods of nine tomato nurseries in southern England. Where possible, a number of variations were also examined, including pressure, nozzle type and spraying technique.

METHOD

On nine tomato nurseries in southern England a number of rows of plants were left after the last harvest for use in this work. A ten per cent suspension of the UV fluorescent tracer Tinopal CBS-X was made up on each nursery and applied using the equipment as set up by the grower for normal spray work. The spray was usually applied to a 20 metre length of the double row. On some nurseries applications were also made to rows in other parts of the house to study variations such as nozzle type, pressure, and spraying technique.

After the spray had dried, leaf samples were taken at random in the row from various heights and distributions in the crop canopy. Within a row, samples were taken from the top, middle and bottom of plants. Distinction was also made between leaves on the outside of the row (closest to the sprayer) and those facing inward. 10 leaves were taken from each sample position. The positions are shown in the diagram below.



As the fluorescent tracer can break down rapidly if exposed to daylight, the sampled leaves were returned to the laboratory protected by black plastic bags. In the laboratory the leaves were examined under a near UV light, causing the tracer to fluoresce. Estimates of percentage cover were made for both the upper and lower surfaces of each leaf.

Detailed records were made at each site of the type and dimensions of the sprayer, and the number and type of nozzles. Measurements of nozzle output were taken by collecting the spray from individual nozzles in a measuring cylinder for a period of thirty seconds or one minute, depending on speed of output. From these measurements the sprayer output in litres/minute could be estimated. The pressure at which the spray was applied was noted, and mean travelling speed of the sprayer or spray operator recorded. From these measurements a cross-site comparison of spray volume applied per unit area could be made. Details of the sprayed crop were also recorded.

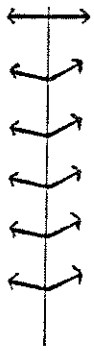
RESULTS

1) Details of Spray Equipment and Crop

These are given for each of the nine nurseries on pages 4-15. Table 1 summarises the more important points and gives values for sprayer output and spray volume per unit area.

GROWER 1

Sprayer

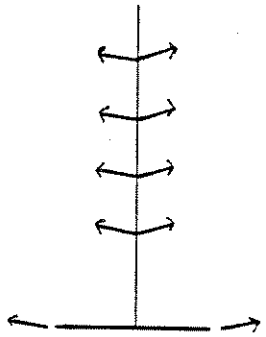
Type of Sprayer:	nurseries own sprayer. Self-contained, petrol-driven sprayer, running on pipes.
Number of nozzles:	6 pairs
Distance from ground to bottom nozzles:	30.5 cm
Nozzle spacing:	30.5 cm
Angle of nozzles:	top pair horizontal, all others angled upwards at 45°.
Diagram of spray boom:	
Nozzle type:	Teejet no. 4 hollow cone.
Operating pressure:	12 bar

Crop

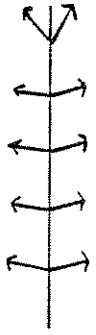
Plant spacing:	50 cm
Training method:	layering
Height to top of plants:	2 m
State of crop:	leaves turgid but tending to hand downwards, with much curling of individual leaflets. Many side-shoots at the base of plants.
Variations studied in addition to growers method:	i) Teejet no. 2 hollow cone nozzles (finer spray) ii) Teejet 8002 flow fan nozzle

GROWER 2

Sprayer 1

Type of sprayer:	trolley sprayer running on pipes
Number of nozzles:	5 pairs
Distance from ground to bottom nozzles:	20 cm
Nozzle spacing:	40 cm
Angle of nozzles:	upwards at 45^0
Diagram of spray boom:	
Nozzle type:	Teejet 80015 VK flow fan
Operating pressure:	15 bar

Sprayer 2

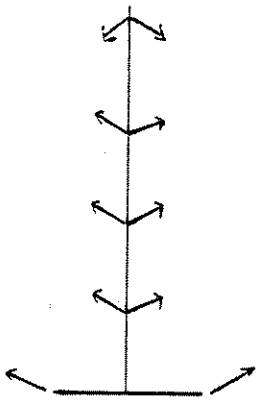
Type of sprayer:	wheeled trolley sprayer
Number of nozzles:	5 pairs
Distance from ground to bottom nozzles:	15.2 cm
Nozzle spacing:	30.5 cm
Angle of nozzles:	top nozzles almost vertical, others angled upwards at 45^0
Diagram of spray boom:	
Nozzle type:	ceramic '00' hollow cone

GROWER 2 (cont'd)

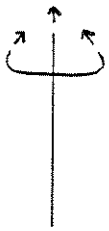
Operating pressure:	15 bar
Crop	
Plant spacing:	55 cm
Height to top of plants:	2 cm
State of crop:	as grower 1. Rows used for sprayer 2 were on either side of the glasshouse structure, therefore these rows were more open in the middle.

GROWER 3

Sprayer 1

Type of sprayer:	trolley sprayer running on pipes
Number of nozzles:	5 pairs
Distance from ground to bottom nozzles:	20 cm
Nozzle spacing:	40 cm
Angle of nozzles:	top nozzles angled slightly downwards. All other nozzles angled upwards at 45°
Diagram of spray boom:	
Nozzle type:	unmarked ceramic hollow cones
Operating pressure:	10-12 bar

Sprayer 2

Type of sprayer:	hand lance
Number of nozzles:	3 in fork-like arrangement
Diagram of spray boom:	
Nozzle type:	unmarked brass hollow cones
Operating pressure:	10-12 bar

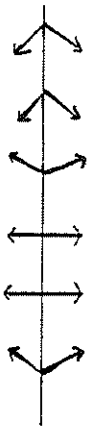
SPRAYER 3 (cont'd)

Crop

Plant spacing:	50 cm
Training method:	layering
Height to top of plants	1.5 m
State of crop:	as grower 1

GROWER 4

Sprayer

Type of sprayer:	trolley sprayer running on pipes
Number of nozzles:	6 pairs
Distance from ground to bottom nozzles:	35 cm
Nozzle spacing:	35 cm
Angle of nozzles:	angled variously upwards and downwards at about 45° (see diagram)
Diagram of spray boom:	
Nozzle type:	D3 hollow cones
Operating pressure:	13 bar

Crop

Plant spacing:	55 cm
Training method:	layering
Height to top of plants:	2.5 m
State of crop:	leaves turgid but tending to hang downward. High proportion of leaves curled. Numerous side shoots.
Variations studied in addition to growers method:	Teejet 8502 flat fan nozzles at 5 bar.

GROWER 5

Sprayer

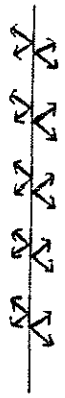
Type of sprayer:	hand lance
Number of nozzles:	1
Diagram of spray boom	
Nozzle type:	'0' flat fan
Operating pressure:	15 bar

Crop

Plant spacing:	55 cm
Training method:	layering
Height to top of plants:	2 m
State of crop:	as grower 1, but plants less turgid.

GROWER 6

Sprayer

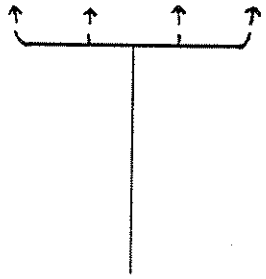
Type of sprayer:	trolley sprayer running on pipes
Number of nozzles:	5 pairs of twin nozzles = 20
Distance from ground to bottom nozzles:	50 cm
Nozzle spacing:	50 cm
Angle of nozzles:	one nozzle in each 'twin' angled upwards, the other downwards at about 45°
Diagram of spray boom:	
Nozzle type:	Teejet flat fan
Operating pressure:	5 bar

Crop

Plant spacing:	45 cm
Training method:	layering
Height to top of plants:	2.5 m
State of crop:	leaves turgid but tending to hang downwards. Canopy quite thin - very few side shoots. Bottom leaves about 60 cm above the ground.

GROWER 7

Sprayer

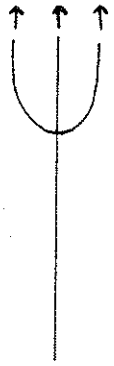
Type of sprayer:	hand lance
Number of nozzles:	4 in fork-like arrangement
Diagram of spray boom:	
Nozzle type:	'40' hollow cone
Operating pressure:	19 bar

Crop

Planting spacing:	45 cm
Training method:	layering
Height to top of plants:	2 m
State of crop:	as grower 1. Long side shoots on most plants.
Variations studied:	i) Growers technique for spider mite control:- nozzle held sideways, boom vertical, figure of eight movements
	ii) Growers technique for powdery mildew control:- nozzle held sideways, boom vertical, upward sweeping movements

GROWER 8

Sprayer

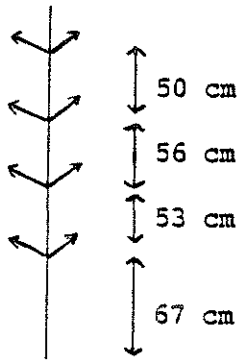
Type of sprayer:	hand lance
Number of nozzles:	3 in fork-like arrangement
Diagram of spray boom:	
Nozzle type:	Allman No. 4 hollow cone
Operating pressure:	20 bar

Crop

Plant spacing:	45 cm
Training method:	layering
Height to top of plants:	2 m
State of crop:	leaves turgid and held more or less horizontally, but long side shoots on many plants
Variations studied:	nozzles pointing either up or down

GROWER 9

Sprayer

Type of sprayer:	trolley sprayer running on pipes
Number of nozzles:	4 pairs
Nozzle spacing:	see diagram
Diagram of spray boom:	
Nozzle type:	Brinkman hollow cone
Operating pressure:	10 bar

Crop

Plant spacing:	50 cm
Training method:	layering
Height to top of plant:	2 m
State of crop:	still turgid but some plants with leaflets slightly wilted. Some side shoots lower down stem but not too leafy.
Variations studied:	nozzles pointing either up or down.

TABLE 1 Details of Spraying Equipment and Output

Grower Number	Sprayer Type	Nozzle Type	No. of nozzles	Pressure (bar)	Sprayer Output (l/min)	Travelling Speed (kph)	Spray Volume (l/ha)*
1(a)	Trolley	Teejet No.4 hollow cone	12	12	6.3	2.7	767.4
+ 1(b)	"	Teejet No.2 hollow cone	12	12	3.0	2.7	365.4
+ 1(c)	"	Teejet 8002 flat fan	12	12	18.0	2.7	2192.5
2(a)	"	Teejet 80025 VIC flat fan	10	15	11.9	2.2	1752.5
2(b)	"	'00' ceramic hollow cone	10	15	20.1	2.1	3101.1
3(a)	"	unmarked ceramic hollow cone	10	10-12	12.6	2.4	1701.1
3(b)	Hand lance	unmarked brass hollow cones	3	10-12	10.4	1.3	2592.0
4(a)	Trolley	D3 hollow cone	12	13	10.8	2.6	1345.8
+ 4(b)	Trolley	Teejet 8002 flat fan	12	5	4.4	2.6	548.3
5	Hand lance	'0' flat fan	1	15	10.0	1.8	1800.0
6	Trolley	flat fan	20	5	26.3	2.8	3043.3
7	Hand lance	'40' hollow cone	4	19	15.0	1.4	3471.4
8	Hand lance	Allman No.4 hollow cone	3	20*	10.0	1.4	2314.3
9	Trolley	Brinkman hollow cone	8	10	?	3.60	1950.6

*based on a hypothetical 1 ha glasshouse with 118 rows, 46 m long, row width 1.7 m.
+experimental variation. In all other cases equipment was used as set up by the grower.

ii) Assessment of Spray Cover

Mean percentage leaf cover (upper and lower surfaces) for the ten leaves taken from each sample position on the plants is given in Appendix 1. However, a summary table (Table 2) enables direct comparisons to be made and the main points of interest to be viewed with more ease.

a) Height of leaves in the crop canopy

With one or two exceptions, leaves at the bottom of the plants had less spray cover than those in the middle or at the top. Some sprayers gave similar levels of cover on leaves in all three positions (eg. grower 6), whereas others gave wide variation in the amount of cover achieved according to the height of the leaves (eg. growers 2 and 3, table 2). There did not appear to be any one sprayer type or nozzle configuration which gave a more uniform distribution than the rest.

b) Leaf surface

In all cases the cover achieved on the lower leaf surface was inferior to that on the upper surface. Comparisons were made at growers 8 and 9 between spraying with the nozzles pointing either upward or downward. As might be expected, spraying with the nozzles pointing upwards resulted in a better coverage of the lower leaf surface, whilst coverage of the upper leaf surface was also satisfactory. When spraying with the nozzles pointing downwards, coverage of the lower leaf surface was poor. There was a particularly high discrepancy between upper and lower leaf surfaces when grower nine's trolley sprayer was used with the nozzles pointing downwards (upper surface 81.3% covered, lower surface 9.4%).

c) Distance of the leaf from the sprayer

Leaves positioned on the inside of the row (and therefore furthest from the nozzles of the sprayer) often received similar coverage to those on the outside. This was particularly the case with trolley sprayers. Leaves on the outside of the plants receive the majority of their spray cover when the sprayer is used on the side of the row nearest to them. Although leaves on the inside are likely to receive less spray from a single pass, they should receive spray when either side of the row is sprayed. This could lead to a total spray cover which is comparable to outside leaves.

Use of hand lances tended to result in less spray cover on the inner leaves, although grower 7 achieved similar cover on both outer and inner leaves.

Table 2 Mean Percentage Leaf Cover (Summary Table)

Grower Number	Sprayer	Additional Comments	Spray Cover						
			Leaf height			Leaf surface		Leaf position	
			Top	Middle	Bottom	Upper	Lower	Outer	Inner
1(a)	T, C, 12, 12, 767.4	Teejet No. 4	26.7	37.7	12.9	44.5	7.1	27.3	24.3
+ 1(b)	T, C, 12, 12, 365.4	Teejet No. 2	18.7	13.3	15.3	29.1	2.5	18.9	12.6
+ 1(c)	T, F, 12, 12, 2192.5		27.1	40.8	20.9	51.4	7.8	23.8	35.4
2(a)	T, F, 10, 15, 1752.5		38.5	49.8	36.3	57.7	25.3	40.1	42.9
2(b)	T, C, 10, 15, 3101.1		52.8	47.7	34.8	67.4	22.8	45.0	45.2
3(a)	T, C, 10, 10-12, 1701.1		42.6	37.0	29.9	40.2	32.8	32.2	40.7
3(b)	H, C, 3, 10-12, 2592.0		29.2	40.1	26.1	34.9	28.6	38.0	25.6
4(a)	T, C, 12, 13, 1345.8		30.0	32.0	13.9	41.6	9.1	25.3	25.4
+ 4(b)	T, F, 12, 5, 548.3		15.8	12.5	10.6	18.6	7.3	11.9	14.1
5	H, F, 1, 15, 1800.0		19.5	26.2	25.2	32.6	14.6	33.0	14.3
6	T, F, 20, 5, 3043.3		36.2	37.0	40.3	58.8	16.8	37.3	38.3
7(a)	H, C, 4, 19, 3471.4	Spider mite technique	31.1	35.5	29.2	39.7	24.1	31.1	32.7
7(b)	H, C, 4, 19, 3471.4	Powdery mildew technique	38.3	43.4	35.1	54.9	22.9	41.9	35.9
8(a)	H, C, 3, 20, 2314.3	Nozzles up	51.6	51.1	29.0	55.8	31.9	56.5	31.2
8(b)	H, C, 3, 20, 2314.3	Nozzles down	55.8	39.2	22.3	61.8	16.4	41.9	31.3
9(a)	T, C, 8, 10, 1950.6	Nozzles up	52.9	48.3	21.6	58.2	23.6	49.7	32.1
+ 9(b)	T, C, 8, 10, 1950.6	Nozzles down	44.4	47.2	44.5	81.3	9.4	46.4	44.3

+Experimental variation. In all other cases equipment was used as set up by the grower.
Sprayer description: (sprayer type, nozzle type, number of nozzles, pressure (bar), spray volume (l/ha))
Abbreviations: sprayer type T = trolley H = hand lance nozzle type C = cone F = flat fan

DISCUSSION

i) Spraying equipment

One of the most notable features of this work was the wide range of spraying equipment used by growers to combat pests and diseases. This varied from a hand lance with a single large nozzle to a twenty-nozzle trolley sprayer. Of the nine growers visited, five used trolley sprayers, three used hand lances, and one used both.

The majority of sprayers used high-capacity pumps which were normally mains powered and remained in the central isle, although the sprayer of grower 1 was a completely self-contained, petrol-driven model of lower capacity.

Nozzle types also varied, with six growers using hollow cones, two using flat fans, and one using both. There was also a tremendous variation in individual nozzle output, from 0.525 l/min by the low volume sprayer used by grower 1, to 10.0 l/min from the single flat fan used by grower 5. Most growers sprayed at a pressure of 10-15 bar, although there were also variations on this figure (grower 6, five bar, grower 8, twenty bar).

Calculation of spray volume applied per unit area again revealed an enormous variation, from 767.4 l/ha used by grower 1 to 3471.4 l/ha by grower 7 - nearly a five-fold difference.

A final aspect which differed between growers was the condition of the nozzles themselves. Whilst in some cases individual nozzles on a sprayer had similar output, indicating regular maintenance and replacement of nozzles, in others there was a large difference in output, and it was clear that the nozzle had not been replaced for several years. At one site, the variation in output between individual nozzles was up to 1 litre per minute. On one nursery, many of the nozzles had filters missing, leading to blockage. Regular maintenance of the sprayer itself must be a prerequisite to obtaining more uniform spray coverage, whichever type of sprayer or nozzle is used.

ii) Limitations of this work

Fruits sprayed with the fluorescent tracer used in this work cannot be marketed. This meant that all the work was carried out in the few days between the end of picking in October and removal of the plants. The plants encountered at this time were somewhat atypical for a number of reasons. Many of the leaves on the plants, particularly near the base, were quite old and whilst remaining turgid had become twisted. This meant that in some cases part of the lower leaf surface (the adaxial surface) was actually facing upwards, and as such would have intercepted the majority of the spray. Such leaves will have distorted the figures quoted for the upper/lower leaf surface cover.

On all the nurseries normal removal of side shoots had ceased and many plants had quite long shoots which would not normally be present. These side shoots made the canopy more crowded and intercepted spray that may, under more normal circumstances, have found its way onto leaves attached to the main stem.

On two nurseries the plants had also begun to wilt slightly as the water supply had been turned off prior to removal of the plants.

All of the above factors were present to differing degrees on the various nurseries, and these, together with others such as differences in plant spacing and height, make it very difficult to make precise comparisons between nurseries, although where variations were made in spraying equipment on the same nursery, comparisons are valid.

Bearing in mind the above comments, it is possible to draw some conclusions with regard to the various types of equipment used.

iii) Trolley sprayers versus hand lances

The main difference noticed between the two types of sprayer was that most of the trolley sprayers gave coverage of the inner leaves which was comparable to that of leaves on the outside of the plant. However, as grower 7 showed, this can be achieved with a hand lance.

One aspect which was not studied in this work is the effect that a prolonged period of spraying would have on an operator using a hand lance. One would expect that tiredness may result in less attention to detail and consequently more variation in the amount and type of cover achieved. Provided a trolley sprayer is regularly maintained the only variation will be speed of movement of the trolley itself, and even this can be kept constant on sprayers which are drawn in automatically.

A further advantage of trolley sprayers is their speed of operation, at about 2.6 kph compared with 1.5 kph for operators with hand lances.

iv) Cone nozzles versus flat fan nozzles

It is difficult to draw conclusions here due to the sheer range of nozzles, particularly cones, which were used. As mentioned previously, individual nozzle output for cone nozzles on the various nurseries ranged from 0.525 l/min for grower 1 to 10.0 l/min for grower 5. Grower 2 used both flat fan and cone nozzles in different sprayers. The sprayer with cone nozzles achieved slightly better cover, but used a much higher spray volume than the flat fan sprayer (3101.1 l/ha compared with 1752.5 l/ha). In contrast, when the low volume cone nozzles of grower 1 were replaced with flat fans, little difference in spray cover was achieved whilst spray volume increased from 767.4 l/ha to 2192.5 l/ha.

v) Spray volume

Table 3 lists the growers in a rank order according to the percentage cover achieved (mean of the top, middle and bottom figures given in Table 2), together with the respective spray volumes applied.

Table 3 Rank Order of Growers According to Spray Cover

Grower	Percentage cover achieved	Spray Volume (l/ha)	
+ 9(b)	45.4	1950.6	
2(b)	45.1	3101.1	
8(a)	43.9	2314.3	
2(a)	41.5	1752.5	
9(a)	40.9	1950.6	
+ 8(b)	39.1	2314.3	
7(b)	38.9	3471.4	
6	37.8	3043.3	
3(a)	36.5	1701.1	
7(a)	31.9	3471.4	
3(b)	31.8	2592.0	
+ 1(c)	29.6	2192.5	
1(a)	25.8	767.4	
4(a)	25.3	1345.8	
5	23.6	1800.0	
+ 1(b)	15.8	365.5	+ Experimental
+ 4(b)	13.0	548.3	treatments

Clearly it is not true that the higher the volume applied, the greater the cover achieved. Other factors such as nozzle type, configuration, direction and spraying technique are all affecting the amount of spray cover achieved. This can be clearly seen for growers 7, 8 and 9, where the same spray volume is applied but different overall cover is achieved according to nozzle direction or spraying technique.

If the spray volume is divided by the percentage cover achieved, this will give some indication of the efficiency of the sprayer (the theoretical volume in litres needed to achieve 1% cover). A rank order of these values is given in Table 4.

Table 4 Rank Order of Growers According to Sprayer Efficiency

Grower	Spray Volume (Litres) Required to achieve 1% Cover	Spray Volume
+ 1(b)	23.1	365.5
1(a)	29.7	767.4
+ 4(b)	42.2	548.3
2(a)	42.2	1752.5
+ 9(b)	43.0	1950.6
3(a)	46.6	1701.1
9(a)	47.7	1950.6
8(a)	52.7	2314.3
4(a)	53.2	1358.8
+ 8(b)	59.2	2314.3
2(b)	68.8	3101.1
1(c)	74.1	2192.5
5	76.3	1800.0
6	80.5	3043.3
3(b)	81.5	2592.0
7(b)	89.2	3471.4
7(a)	108.8	3471.4

The order in table 4 is very different to that in Table 3. In order to achieve the highest percentage cover, in most cases a lot of the spray is lost, presumably as run-off from the plants. At low volume more of the spray is retained on the plant, but is the spray cover achieved enough to provide adequate pest and disease control? This could only be ascertained by working with individual pests and pathogens and both systemic and non-systemic fungicides.

The above differences in spray volume could also lead to large variations in the amount of active ingredient applied per hectare. For example Repulse (chlorothalonil, 500 g/l) has a recommended rate for tomatoes of 200 ml in 100 litres of water, applied to achieve 'complete crop cover'. It can be seen from the spray volumes applied that grower 1 would be applying 0.85 litres a.i. per hectare at a cost of approximately £15.00, whereas grower 7 would apply 6.94 litres a.i. per hectare at a cost of approximately £120.00. This would not be the case for products applied on an area basis rather than according a dilution rate, for example the off-label approval for Rubigan (120 g/l fenarimol) quotes a rate of 72 ml product/hectare, so in theory all growers would apply 86.4 g a.i. per hectare. Obviously with the most efficient sprayers more of the product would actually reach the plant rather than being lost as run-off.

vi) Nozzle direction

As we have already seen, spraying with the nozzles pointing upwards results in increased coverage of the underside of the leaves. This may be important where non-systemic products are being used, for example chlorothalonil for the control of powdery mildew. Most of the growers did indeed have their equipment set up with the nozzles pointing upwards. An exception to this rule is the low volume sprayer used by grower 1, where despite having the nozzles pointing upwards, cover on the undersides of the leaves is poor. It is possible that the small droplets produced by the low volume nozzles do not impact on the undersurfaces down to a low impaction efficiency. Work with fungal spores has shown that the impaction efficiency decreases with a decrease in spore size. It also decreases with an increase in the diameter of the obstacle (ie., leaf laminae are not very efficient at intercepting spores). Is this also the case with spray droplets?

vii) Further work

This work is of significant value in highlighting the large differences in methods used by tomato growers to combat pests and diseases, and in indicating the effect of factors such as nozzle position and spray volume. But it is only a beginning, and further useful information could be allowed by:-

a) Working with crops which are more representative of a normal growing crop in mid season or earlier. This could be done by using a specific crop in which the sprayed fruit is discarded or by using a different method of spray tracing which does not depend upon a UV tracer.

b) In depth studies need to be made of spraying systems including low and high volume and detailed studies on one site used to identify all of the factors which can be optimised to give the best possible cover and pest and disease control.

c) Having identified the relevant factors involved in the best possible cover and use of pesticides, work would be necessary on the efficacy of such a system for the control of a range of pests and pathogens.

APPENDIX 1: Mean Percentage Leaf Cover

Grower	LEAF POSITION AND SURFACE											
	Top				Middle				Bottom			
	Inner		Outer		Inner		Outer		Inner		Outer	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
1(a)	52.6	9.1	38.0	7.2	58.4	9.4	71.9	11.1	14.2	1.9	31.6	3.8
1(b)	25.3	0.4	48.1	1.0	14.8	0.4	33.8	4.1	26.6	8.1	25.7	0.9
1(c)	42.3	18.8	44.0	3.2	82.8	15.1	62.6	2.5	46.9	6.3	29.7	0.8
2(a)	52.7	30.0	39.0	32.1	78.5	29.3	69.0	22.3	57.0	10.2	50.1	27.8
2(b)	71.5	23.7	75.3	40.6	73.2	25.1	74.0	18.4	61.6	16.0	48.5	12.9
3(a)	56.3	43.8	30.1	40.0	41.1	22.9	42.9	41.2	47.9	32.4	22.9	16.3
3(b)	21.5	26.8	33.5	34.8	42.5	26.5	49.0	42.3	18.1	17.9	44.9	23.4
4(a)	40.9	6.4	45.4	27.4	70.8	3.2	48.6	5.5	22.7	8.1	20.9	4.0
4(b)	23.7	6.3	19.5	13.8	24.0	6.1	14.6	5.4	16.3	8.1	13.6	4.3
5	16.1	2.2	21.8	37.8	28.6	0.5	49.6	26.0	38.0	0.4	41.7	20.8
6	58.0	17.3	58.0	11.4	57.4	13.7	46.8	29.9	74.4	9.1	58.3	19.4
7(a)	55.5	9.3	34.0	25.6	47.5	22.2	30.0	42.1	46.1	15.5	25.0	30.1
7(b)	54.5	19.6	50.5	28.5	66.0	18.6	51.5	37.5	51.6	5.0	55.5	28.1
8(a)	58.6	23.1	57.0	67.5	56.7	8.3	63.6	75.6	39.6	0.9	59.5	16.0
8(b)	75.5	6.8	73.0	68.0	75.0	2.4	65.5	13.8	26.0	2.3	55.5	5.3
9(a)	77.6	17.8	78.0	38.0	65.5	6.7	74.5	46.5	23.2	1.9	30.5	30.6
9(b)	75.5	9.9	74.5	17.6	81.5	12.1	89.0	6.2	83.0	3.8	84.5	6.6

APPENDIX II : EFFICIENCY OF SPRAY APPLICATION TO HEBE

For several years downy mildew of hebe has been one of the most important diseases of nursery stock. Many growers have stopped growing the species as they are unable to keep the disease under control. Whilst growers can use systemic materials containing metalaxyl at their own risk under the current interim pesticide arrangements, in order to prevent fungicide resistance occurring it is important that non-systemic materials from other fungicide groups are used. As with spraying tomatoes, when using non-systemic materials on hebe coverage of the undersides of the leaves becomes particularly important.

On grower eight's nursery, comparisons were made of different techniques for spraying hebe. The equipment used was as described on page 13. The plants were sprayed with horizontal sweeping movements of the lance, with the nozzles pointing either up or down. The plants were situated in a block at the side of a pathway. Plants at the back of the lock were approximately two metres from the pathway. The operator remained on the pathway whilst spraying the plants.

Forty leaves were sampled from plants at the front, middle and back of the block. Upper and lower leaf surfaces were scored for percentage cover. Results are shown below:-

Mean Percentage Spray Cover (40 leaves)

	Position of plant and leaf surface							
	Front		Middle		Back		Mean	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Nozzles up	82	53	77	14	82	18	80.3	28.3
Nozzles down	82	25	84	9	64	3	76.7	12.3

The results obtained are similar to those with tomato plants. Spraying with the nozzles pointing upwards resulted in better coverage of the lower leaf surface. This did not occur at the expense of poorer coverage of the upper surface. More of the spray also reached plants at the back of the block with the nozzles in this position.