Project title:	The Bedding and Pot Plant Centre – new product opportunities for bedding and pot plant growers. Work Package 2. Spray application
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Project leader:	Dr Jill England, ADAS Boxworth
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AUTHENTICATION

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

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Contents

Grower Summary

Headline

- Reducing the applied volume with a spray pistol from a target of 1000 L/ha to 500 L/ha could result in a 30% increase in the quantity of active substance retained on the crop.
- Both spray pistols and nozzles affect flow rate hence the importance of calibrating each spray pistol and nozzle.

Background

The Bedding and Pot Plant Centre (BPPC) has been established to address the needs of the industry via a programme of work to trial and demonstrate new product opportunities and practical solutions to problems encountered on nurseries.

This is the Bedding and Pot Plant Centre report for:

Objective 2. Spray application.

This programme of work focuses on improving the application of plant protection products (PPPs) for bedding and pot plants through evaluating alternative approaches to existing hand-held high-volume systems, to improve the quantity, uniformity, and distribution of PPPs over plants.

Summary

Two case studies were agreed to base the project on: aphids on *Primula* and downy mildew on pansies. A review of the products used for these pests and diseases showed that an application of 200 – 400 L/ha using a medium spray quality would allow compliance with label recommendations and would be expected to give good efficacy.

An initial experiment at a host nursery evaluated the performance of a standard Ripa nozzle and spray pistol, in terms of the quantity deposited on plants and other spray collection materials, the uniformity of distribution over the beds and the speed of application. The bed width was 3 meters, and the target volume was 1000 L/ha.

Following this, some laboratory tests screened alternative approaches, including a battery-operated air-assisted knapsack sprayer, hydraulic off-set nozzles that are designed to deliver an even distribution over a defined width as well as a Ripa system with a lower flow rate. The potential for improvements of these approaches was considered, and equipment to be compared in a second field trial was identified.

The ‘OC nozzles (Teejet Technologies) did not allow an adequate distribution of spray to be achieved, compared with the current industry approach, without significant further work considering pressure, release height and angle, and technique for deployment. The Birchmeier A1200 with TeeJet AITXA 80-03 nozzle as tested delivered very large droplets and a very low flow rate so did not meet our application criteria and has the potential for very poor application.

The second field trial therefore aimed to compare the 1000 L/ha application with a Ripa system with one with a lower flow rate which would deliver a volume of around 500 L/ha. The Birchmeier A1200 was also included to gain some information about its practical usage under more realistic conditions.

During calibration of equipment for the second trial, it was found that the flow rate of the Ripa system was a function of both the nozzle size and the pistol itself. The host nurseries pistol had different dimensions from the one purchased for the project and gave a much higher flow rate (Figure 1), particularly when fully closed. While only changing the nozzle was anticipated (from 2.0 mm to 1.5 mm) to reduce the flow rate, in this case we changed only the spray pistol.

Figure 1. The two pistols for the Ripa nozzles – left hand, the original one used at the host nursery; right hand side, the newer one purchased by Silsoe spray application unit (SSAU)

This reinforces the need for calibration under the conditions that the spray pistol will be used, rather than relying on standard flow rate charts. The original Ripa flow rate was less repeatable, particularly in the closed position, so it is necessary to calibrate each time it is used.

It is well documented that high water volumes result in lower retention of applied spray by the crop. In this study we have shown that reducing the applied volume with a spray pistol from a target of 1000 L/ha to around 500 L/ha could result in a 30% increase in the quantity of active substance retained on the crop. This was achieved with a Ripa spray pistol with a 2.0 mm nozzle in the fully closed position, which gave a flow rate of 4.16 L/min resulting in a spray volume of 533 L/ha, compared with the original system which had a flow rate of 7.2 L/min and an applied volume of 918 L/Ha.

Ripa nozzles and pistols produce a good droplet size and offer a low-cost approach for those wishing to reduce volumes and improve their spray application. Reducing volume in this way could also improve the work rate slightly by reducing the filling time of the spray tank but would not speed up the application process.

Financial benefits

A typical spray programme applied to a pansy / *Primula* crop at 500 L/ha instead of 1000 L/Ha is likely to result in savings of £67/Ha per crop. Greater savings will be made where products that are applied at a rate per litre (e.g., Majestik) rather than a rate per hectare are used (e.g., Amistar (EAMU 3388/18).

Lower water volumes offer many benefits including reduced down time spent filling the spray tank.

Action points

- Spray booms are better able to deliver lower volumes more uniformly than handheld systems. Therefore, growers that cannot move away from handheld application should consider transitioning to small handheld booms where possible.
- Where booms are not a feasible option, we would recommend using a traditional handheld system to deliver no more than 500 L/ha.
- Aim to reduce water volumes to improve spray retention on the crop and the retention of active substance by the crop.
- Calibrate existing spray pistols and nozzles at various settings and pressures to determine how you reduce water volumes with existing equipment.
- Use lower flow rate Ripa systems (e.g., smaller nozzle sizes) if you want to reduce volumes.
- Increase your margins by reducing water volumes.

Science Section

Introduction

The Bedding and Pot Plant Centre (BPPC) has been established to address the needs of the industry via a programme of work to trial and demonstrate new product opportunities and practical solutions to problems encountered on nurseries.

This is the Bedding and Pot Plant Centre report for: Objective 2. Spray application.

Background

Application practice in the UK protected ornamentals industry remains generally poor, despite previous work highlighting the issues (**Talbot, 2014**). This was re-enforced in the Amber project (**Chandler, 2020; Butler Ellis *et al*, 2020**). Foqué (**2012**) also investigated the distribution of sprays for protected ornamentals and found that booms performed better than handheld application equipment. There are several barriers to growers making improvements to the equipment they use, including a lack of practical alternatives and a failure to demonstrate the economic benefit of investment (or the economic losses due to a lack of investment).

Current information available to growers seeking to improve their methods of spray application is limited. Two comprehensive factsheets were produced by the HDC (**Buxton and Hewson, 2007; Talbot and Basford, 2015**) but it seems that their recommendations have not been widely adopted.

Challenges associated with spray application in the production of protected ornamentals is well-documented. Whilst boom based systems are widely acknowledged to solve many of the challenges posed by handheld application, they are not a practical solution for all growers for various reasons including beds of varying width, vertical supports within growing structures, the difficulties in moving down rows without automation, particularly in manoeuvring between benches, as well as cost. Therefore, there is still a need for handheld application, as this application method gives growers the flexibility to treat small batches of stock and allows targeted application to hotspots of pest of pest or disease activity.

Opportunities for improvements have been identified for approaches used to apply plant protection products (PPPs) in the UK's protected ornamentals industry. Most of the industry typically applies PPPs with relatively large water volumes (of the order of 1000 l/ha) using a Ripa nozzle. Volumes as high as this are known to be inefficient, with significant losses and potentially lower quantities of active substances retained on plants. While we know that the best method of reducing volumes is by using automated booms, the aim of this study was to find manually operated equipment that could achieve increased plant deposits and improved uniformity.

This project focused on downy mildew on pansies and aphids on *Primula* as case studies, and considered how application could be optimised for these scenarios.

Manually operated spray pistols (such as the Ripa nozzle) have characteristics that are valuable in manual applications to protected crops, despite significant deficiencies:

- They can deliver a long throw, ensuring that spray can reach the furthest plants in the bed.
- At the same time, they can produce droplet sizes within the Medium and Fine range (**Talbot 2014**), which is likely to be required by many products used to control insect pests and diseases.

However, there are well-documented problems with the Ripa nozzle, primarily that droplet size and flow rate are variable (**Talbot, 2014**) making calibration difficult and application unrepeatable without care. Uniformity of deposit (i.e., the quantity of active substance. per plant) is likely to be poor with all manually-operated equipment, so a change in approach to application would benefit growers.

There are, potentially, alternative systems available that can deliver a greater throw than a conventional hand lance, but these have not been evaluated for use within protected crops and selecting an appropriate one for these purposes needs care.

It is accepted that higher volumes are associated with less active substance retained on plants for a very wide range of crops [e.g., Brusselman *et al* (**2012**), Butler Ellis *et al* (**2003**), Miller *et al* (**2010**), Butler Ellis *et al* (**2012**), Butler Ellis *et a*l (**2020**)]. Butler Ellis *et al* (**2020**) also showed that the distribution of spray over an individual plant was unaffected by volume, despite a common recommendation on product labels of increasing volume to improve distribution. These studies strongly support the assertion that a boom operated with lower volumes than the current UK practice in ornamental crops could deliver improved control compared with typical hand-held systems.

However, booms are not necessarily a practical option for many growers because of the reasons outlined above.

One option is to use a specially designed hydraulic "boomless nozzle". These are aimed at situations where a boom is not possible but are largely designed for use outdoors at much higher speeds than are possible with manual applications, and therefore they might not be able to meet our specifications for applied volume. They are made by at least four manufacturers, who provide some data and there are also some results from an independent laboratory (**Deveau, 2020**) which will be used as a baseline for selecting options for testing.

A second option is to use an air jet to carry droplets further. This is usually a high-energy option and requires a motorised knapsack airblast sprayer. New developments in rechargeable battery-operated equipment may bring benefits and open new practical options. A Birchmeier AS1200 (https://www.birchmeier.com/en/content/produkte/as_1200/index.php) battery-operated air-assisted sprayer was included in the experimental programme.

Published data showing a strong relationship between application technique and efficacy for any crop is limited, and this kind of experiment is costly and difficult to perform. We aimed instead to show how characteristics of the spray deposit (such as quantity retained on plants, distribution of spray over the treated area and over individual plants) that would be expected to correlate with PPP efficacy can be influenced by application technique.

In addition, some of the main benefits of improving application may be in improving the logistics (**Talbot, 2014**). This will enable the labour cost of application to be reduced, reduce operator exposure, and optimise timeliness of application and improve working conditions for the application operation.

Project objectives

1. To examine current information available to growers and recommendations for application.
2. To conduct a cost-benefit analysis for investment in new equipment, based on indicative costs and savings.
3. To develop an experimental protocol for measuring the performance of an application, which is likely to include volume used, speed of travel, time taken and spatial distribution of spray.
4. To use the protocol for an evaluation of the baseline performance of a typical application at a commercial site (Postponed to year 2 due to Covid 19).
5. To identify alternative approaches and conduct an initial laboratory evaluation.
6. To compare the performance of novel techniques compared with the baseline.
7. To provide updated guidance to growers

1. Review of information available to growers (Objective 1)

The products most likely to be sprayed in the selected scenarios were reviewed and label information relevant to application is summarised in Table 1. No other information was identified, apart from the previous HDC factsheets (**Buxton and Hewson, 2007**; **Talbot and Basford, 2015**). These do not provide information specific to these scenarios, however, but cover generic best-practice. As a result of this review, it was proposed that we should aim to identify equipment that can deliver in the range 200 - 400 L/ha with a droplet size no greater than ‘medium’. This would allow all the products in **Table 1** Table 1 to be sprayed legally, and at the lower end of the allowed range which we believe will be optimum.

It is recognised, however, that handheld equipment may not be able to deliver within this volume range and higher volumes might be a necessary compromise.

Table 1. Plant protection products likely to be used for treating downy mildew and aphids on protected ornamentals and label recommendations for application

Downy Mildew	Based on ADAS presentation from 2020 on AHDB website: https://ahdb.org.uk/control-of-foliar-diseases-in-autumn-grown-bedding-plants						
			Volume range, L/ha				
Product	**EAMU**	**Systemic/contact**	**min**	**max**	**Max concentration**	**Spray quality**	**Other info**
Amistar	yes	Systemic	200				
Peros	yes	Systemic	100	1000		medium	
Fubol Gold	yes	Systemic	250			medium	Label has min vol 200 L/ha
Aphids	Based on ADAS Powerpoint presentation from 2021 supplied by D Talbot						
			Volume range, L/ha				
Product	**EAMU**	**Systemic/contact**	**min**	**max**	**Max concentration**	**Spray quality**	**Other info**
Spruzit	no	Contact		600		fine	Increase vol for taller crops. Achieve under-leaf coverage
Sequoia	no	Systemic	400	1200			
Mainman	yes	Systemic	200	1500			High vol probably relevant only to trees/v tall crops
Gazelle SG	no	Systemic		1500		fine/medium	for outdoor crops; thorough coverage
				1000		fine/medium	for protected crops; thorough coverage
Aphox	yes	Contact	300		50 g a.s./hl	medium	Label has 200-400 L/ha for other crops
Batavia	yes	Systemic					Label has 1000-1500 for protected strawberries. EAMU suggests 'sufficient volume'!

2. Cost-benefit analysis (Objective 2)

Applying plant protection products via handheld equipment at lower water volumes generates cost savings due to less down time (due to reduced time spent mixing and filling the tank) and lower water and energy use. We have calculated that a typical spray programme applied to a pansy / summer bedding crop at 500 L/ha instead of 1000 L/ha is likely to result in average savings of £488 per crop of pansies and £468 per crop of mixed summer bedding (**Table 2**).

A typical spray programme applied to a pansy / summer bedding crops at 500 L/ha instead of 1000 L/Ha (assuming three crops of pansies and three crops of mixed summer bedding as a typical annual cropping cycle on an average bedding nursery) is likely to result in savings of £2,870 /Ha per annum. Greater savings will be made where products that are applied at a rate per litre (e.g., Majestik) rather than a rate per hectare are used (e.g., Amistar (EAMU 3388/18)). Lower water volumes offer many benefits including improved retention on the crop.

The above costings are based on a typical pansy crop being sprayed with Majestik, Amistar (EAMU 3388/18), Percos (EAMU 0962/21), Switch and two applications of Bonzi. For mixed summer bedding, costs are based on crops being sprayed with Majestik, Mainman (EAMU 0045/13), Serenade ASO (EAMU 2364/18) and two applications of Bonzi.

Table 2. Costings for example spray programmes for pansy and summer bedding crops

		Inputs				Unit costs					Cost, £/ha					
		water vol, L/ha	dose, L/ha or KG/ha	Workrate, ha/h		water cost £/L	Pesticide £/L or £/KG	labour cost, £/h	Energy, £/h		Water	Pesticide	Labour	energy		Total cost, £/h
	Baseline															
Spray 1 Pansy		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Amistar		1				49					49.00				**49.00**
Spray 2 Pansy		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Majestik		25				12.9					322.50				**322.50**
Spray 3 Pansy		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Percos		0.8				52					41.60				**41.60**
Spray 4 Pansy		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Bonzi		1.25				115.26					144.08				**144.08**
Spray 5 Pansy		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Switch		0.8				182					145.60				**145.60**
Spray 6 Pansy		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Bonzi		1.25				115.26					144.08				**144.08**
										Total	120.00	846.85	196.94	2.89		1166.67
	Reduced volume															
	Baseline															
Spray 1 Pansy		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Amistar		1				49					49.00				**49.00**
Spray 2 Pansy		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Majestik		10				12.9					129.00				**129.00**
Spray 3 Pansy		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Percos		0.8				52					41.60				**41.60**
Spray 4 Pansy		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Bonzi		0.5				115.26					57.63				**57.63**
Spray 5 Pansy		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Switch		0.8				182					145.60				**145.60**
Spray 6 Pansy		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Bonzi		0.5				115.26					57.63				**57.63**
										Total	60.00	480.46	136.16	1.63		678.25
											Savings per ha per crop before benefits of improved control					488.42

		Inputs				Unit costs					Cost, £/ha					
		water vol, L/ha	dose, L/ha or KG/ha	Workrate ha/h		water cost £/L	Pesticide £/L or £/KG	labour cost, £/h	Energy, £/h		Water	Pesticide	Labour	energy		Total cost, £
	Baseline															
pray 1 summer bedding		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Majestik		25				12.9					322.50				**322.50**
pray 2 summer bedding		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Serenade ASO		10				20.25					202.51				**202.51**
pray 3 summer bedding		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Bonzi		1.25				115.26					144.08				**144.08**
pray 4 summer bedding		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Mainman		0.14				240					33.60				**33.60**
pray 5 summer bedding		1000		0.457		0.02		15	0.22		20.00		32.82	0.48		**53.30**
	Bonzi		1.25				115.26					144.08				**144.08**
										Total	100.00	846.76	164.11	2.41		1113.28
	Reduced volume															
	Baseline															
pray 1 summer bedding		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Majestik		10				12.9					129.00				**129.00**
pray 2 summer bedding		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Serenade ASO		10				20.25					202.51				**202.51**
pray 3 summer bedding		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Bonzi		0.5				115.26					57.63				**57.63**
pray 4 summer bedding		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Mainman		0.14				240					33.60				**33.60**
pray 5 summer bedding		500		0.661		0.02		15	0.18		10.00		22.69	0.27		**32.97**
	Bonzi		0.5				115.26					57.63				**57.63**
										Total	50.00	480.37	113.46	1.36		645.20
											Savings per ha per crop before benefits of improved control					468.08

3. Development of experimental protocol (Objective 3)

While well-established methods of measuring deposits on plants and uniformity of distribution are available for boom sprayers (**International Standards Organisation, 2015**), there were challenges to be overcome in making similar measurements in protected ornamental crops:

- The volumes applied are significantly higher than used in typical boom-sprayer applications.
- The need to conduct the work within a commercial glasshouse placed considerable constraints upon what could be achieved.
- Two different methods for determining the applied volume were included in the original protocol because we had concerns that our usual methodology would not cope with volumes of around 1000 L/ha.

The original protocol is given in **Appendix 1**.

4. Experiment 1. Evaluation of baseline performance (Objective 4)

Materials and methods

Measurements of the performance of an application on a commercial nursery were made. This was undertaken by an experienced spray operator using his own standard equipment, i.e., a 2.0 mm Ripa nozzle at approximately 12 bar, with the aim of applying 1000 L/ha.

The protocol in **Appendix 1** was followed. A single bay in a glasshouse was made available. Dimensions were approximately 16 m x 3 m.

An array of four different collectors were distributed across the area to be treated (**Figure 3** and **Table 3**).

Paper strips mounted on plastic battens are our usual method to determine the applied volume but there was concern that they would not cope with the high volumes and high liquid velocities and there could be significant losses. Plastic boxes were therefore used as an alternative – selected to have sufficient height to prevent spray splashing or bouncing off.

Two plants were placed at each ‘P’ location, one to be used for evaluating the total quantity on the plant, and one had four stickers (2 x 1.5 cm) placed underneath the leaves as randomly as possible to evaluate the quantity underneath the leaves.

Artificial targets were plastic labels, placed at an approximate 45-degree angle to the vertical.

Measurement of nozzle flow rate was made prior to the experiment.

The application was timed to determine the applied volume.

A solution of approx. 0.05% sodium fluorescein was mixed in the spray tank and samples taken before and after spraying. This allowed spray solution to be recovered from the collectors.

Table 3. Sampling layout

	0 m	1 m	2 m	3 m				
1	V1	P5	B9	A13		**P**	Plants (pelargonium)	
2	A1	V5	P9	B13		**V**	Volume (boxes)	
3	B1	A5	V9	P13		**B**	Battens	
4	P1	B5	A9	V13		**A**	Artificial targets	
5	V2	P6	B10	A14				
6	A2	V6	P10	B14				
7	B2	A6	V10	P14				
8	P2	B6	A10	V14				
9	V3	P7	B11	A15				
10	A3	V7	P11	B15				
11	B3	A7	V11	P15				
12	P3	B7	A11	V15				
13	V4	P8	B12	A16				
14	A4	V8	P12	B16				
15	B4	A8	V12	P16				
16	P4	B8	A12	V16				

A known quantity of tank mix was spiked onto examples of each of the collectors to establish if there were any losses across the duration of the experiment (sodium fluorescein is known to photodegrade in some circumstances).

The spray operator was asked to perform the application as if the area in **Figure 3** was covered with plants at the normal density. The grey areas in **Table 3** show the walkways. The spray operator opted to start at the back wall (16 m along the length) and walk forward, spraying to the right, as he is right-handed (**Figure 3**).

Following the application, the lids were replaced on the boxes which were collected and placed in a black sack. The other collectors were observed and photographed while drying.

The stickers were removed from the plants and placed in labelled pots. The other plants were cut off at ground level, placed in bags and weighed. They were washed in a known quantity of water, samples of the liquid taken, then plants disposed of.

Paper strips on the battens and artificial targets were placed in plastic bags. These were all placed in a black sack, taken back to the laboratory at SSAU and analysed to determine the quantity of spray liquid deposited on each collector type at each location.

Figure 2. Examples of the different collection materials, clockwise from top left: box, plant labels, batten, Pelargonium

Figure 3. Application in progress

Results

Calibration

- Flow rate: 7.2 L/min.
- Duration of the spray application: 36 seconds.
- Dimensions of the area to be treated: 15.68 x 3.0 m.
- The calculated application volume over the area was therefore 918 L/ha.
- Speed along the bed: 0.44 m/s or 1.57 km/h.

Measurement of applied volume

Two collectors were used to determine applied volume – the battens with paper strips of dimensions 0.5 x 0.05 m, and plastic boxes of dimensions 0.116 x 0.116 m.

The mean recorded quantity on the paper strips was 244 L/ha. This is considered too low to be of any value and therefore these data were discarded from any further analysis.

The plastic boxes had a mean recorded quantity of 619 L/ha. While this was only 67% of the calculated applied volume, this would be considered acceptable to be able to evaluate the variability of the applied dose over the area. The calibrated volume would however be considered as the most 'accurate' figure. Further consideration of this is given in the discussion.

Measurement of deposits on plants, artificial collectors, and the underside of leaves.

The mean values of deposits for all collectors are given in **Table 4**. There are no comparative values for assessing deposit on plants, under leaf collectors and the artificial targets at this stage as these will be used to evaluate the equipment that will be tested in a future experiment.

Table 4. Mean values of deposits for all collectors, standard deviation, and coefficient of variation (CV)

	units	mean	st. dev	CV (%)
Boxes	L/ha	619.1	381.1	61.6
Paper strips	L/ha	244.3	83.7	34.3
Plants	ul/g	22.9	9.4	41.2
Under leaf	ul	14.3	15.6	109.2
Artificial	ul	60.2	17.7	29.4

A high level of recovery from the spiked collectors showed that there was no degradation over the course of the experiment.

Variability of application and deposits

The coefficient of variation (CV) given in **Table 4** gives an indication of the variability of each target over the whole area. Note that a boom sprayer is designed to have a CV of around 10% (although in outdoor conditions it might be closer to 20%)

Further analysis of the data has been undertaken, both by collector type and using all collectors combined, except the battens and under leaf collectors, across the whole area.

The deposit on each collector in the graphs below (**Figure 4**, **Figure 5**) is expressed as a percentage of the average value for each collector type.

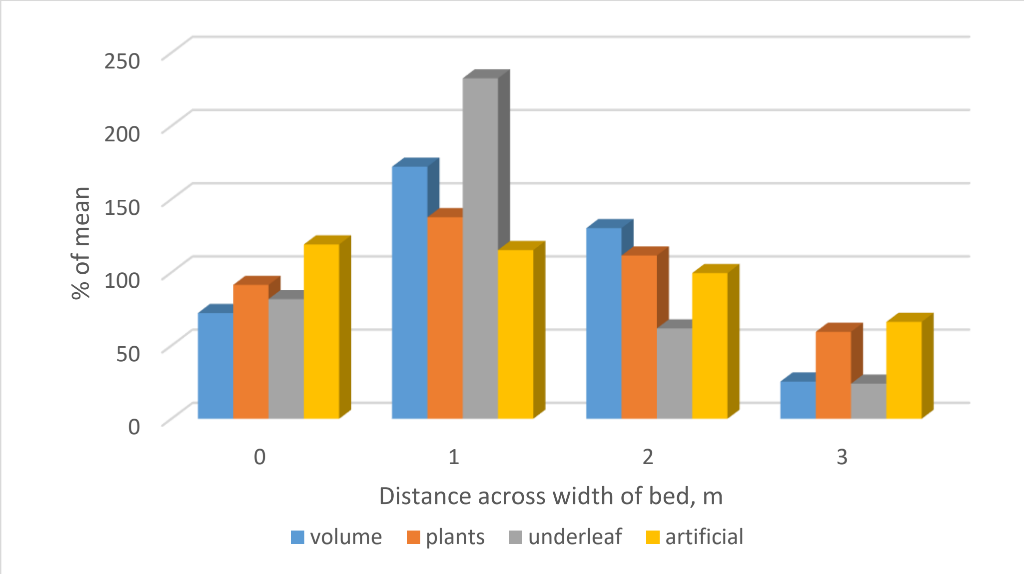


Figure 4. Mean deposit as a function of position across the width of the bed

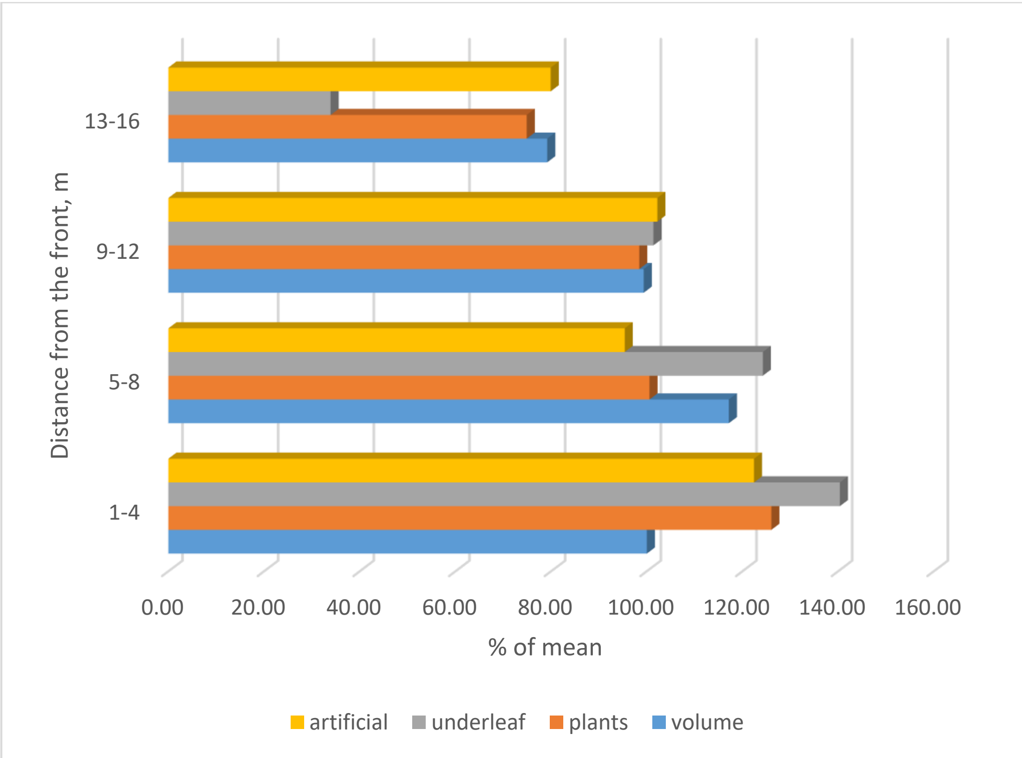


Figure 5. Mean deposit as a function of average distance along the length of the bed (16 m is the back wall of the bed)

5. Lab evaluation of alternative approaches (Objective 5)

Identifying techniques for consideration

The objectives for identifying alternative manual techniques that might be able to deliver improvements in performance were to:

- Reduce the variability of the application (as measured by the coefficient of variation).
- Improve the work rate.
- Increase the quantity deposited on the plants or the distribution over the plants.

Boomless nozzles

The 'boomless' nozzles had been initially proposed as a potential method of achieving the first two of the above objectives. These are designed to distribute spray evenly over an area, in the same way as a boom, but from a single central nozzle. It is known that their uniformity can be poor compared with a boom, but it was hoped that it would be better than a manual application.

The droplet size of these nozzles is also likely to be larger than ideal – for example, the TeeJet XPBoomJet nozzles are noted as ultra coarse in the manufacturer's catalogue. However, operating these at higher pressures might enable the droplet size to be reduced without compromising the distance they would travel.

In addition, a boomless nozzle could be operated more quickly than other handheld devices as movement in only one dimension is needed. Effectively, the operator can walk quickly (up to 3 km/h) along the path adjacent to the bed and hold the nozzle in a static position.

Boomless nozzles are designed to give spray widths in the region 3 – 6 m. However, the bed width available for our experimental work was a maximum of 3 m and therefore these larger capacity nozzles were not ideal, particularly if we intend to increase the operating pressure. TeeJet also sell nozzles that they call 'off-centre' spray tips which are similar but have smaller capacities and shorter widths. No information about the droplet size produced by these nozzles is available, but because of their smaller capacity, it was anticipated that they would produce a finer spray than the XP BoomJet.

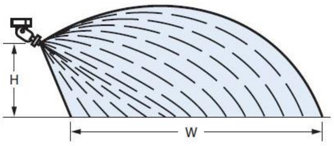
The TeeJet OC12 was selected for further laboratory tests (**Figure 6**).

TeeJet® Off-Center Flat Spray Tips — Smaller Capacities

TeeJet Off-Center spray tips are commonly installed in double and single swivel nozzle bodies. Because these bodies are adjustable for angular position, a wide spray swath is easily obtained.

See page 71 for swivels and hose drops.

How to order:
Specify tip number and material.
Example: OC-02 – Brass
OC-SS06 – Stainless Steel



Tip	bar	CAPACITY ONE NOZZLE IN l/min	HEIGHT = 45 cm "W" cm	HEIGHT = 45 cm l/ha 4 km/h	6 km/h	8 km/h	10 km/h	HEIGHT = 60 cm "W" cm	HEIGHT = 60 cm l/ha 4 km/h	6 km/h	8 km/h	10 km/h
OC-01 (100)	2.0	0.32	147	32.7	21.8	16.3	13.1	165	29.1	19.4	14.5	11.6
	3.0	0.39	152	38.5	25.7	19.2	15.4	170	34.4	22.9	17.2	13.8
	4.0	0.45	157	43.0	28.7	21.5	17.2	175	38.6	25.7	19.3	15.4
OC-02 (50)	2.0	0.65	172	56.7	37.8	28.3	22.7	190	51.3	34.2	25.7	20.5
	3.0	0.79	177	66.9	44.6	33.5	26.8	195	60.8	40.5	30.4	24.3
	4.0	0.91	182	75.0	50.0	37.5	30.0	198	68.9	46.0	34.5	27.6
OC-03 (50)	2.0	0.96	195	73.8	49.2	36.9	29.5	203	70.9	47.3	35.5	28.4
	3.0	1.18	203	87.2	58.1	43.6	34.9	210	84.3	56.2	42.1	33.7
	4.0	1.36	208	98.1	65.4	49.0	39.2	215	94.9	63.3	47.4	38.0
OC-04 (50)	2.0	1.29	231	83.8	55.8	41.9	33.5	236	82.0	54.7	41.0	32.8
	3.0	1.58	236	100	66.9	50.2	40.2	238	99.6	66.4	49.8	39.8
	4.0	1.82	238	115	76.5	57.4	45.9	241	113	75.5	56.6	45.3
OC-06 (50)	2.0	1.94	251	116	77.3	58.0	46.4	274	106	70.8	53.1	42.5
	3.0	2.37	256	139	92.6	69.4	55.5	279	127	84.9	63.7	51.0
	4.0	2.74	259	159	106	79.3	63.5	281	146	97.5	73.1	58.5
OC-08 (50)	2.0	2.58	254	152	102	76.2	60.9	279	139	92.5	69.4	55.5
	3.0	3.16	259	183	122	91.5	73.2	284	167	111	83.5	66.8
	4.0	3.65	264	207	138	104	83.0	287	191	127	95.4	76.3
OC-12	2.0	3.87	259	224	149	112	89.7	287	202	135	101	80.9
	3.0	4.74	264	269	180	135	108	292	243	162	122	97.4
	4.0	5.47	266	308	206	154	123	294	279	186	140	112
OC-16	2.0	5.16	335	231	154	116	92.4	360	215	143	108	86.0
	3.0	6.32	350	271	181	135	108	370	256	171	128	102
	4.0	7.30	363	302	201	151	121	375	292	195	146	117

Note: Always double check your application rates. Tabulations are based on spraying water at 70°F (21°C).
See pages 136–157 for useful formulas and other information.

Figure 6. Specification for TeeJet OC nozzles

Air-assisted sprays

AHDB requested that a specific manually operated air-assisted sprayer was included in tests. Air assistance can help deliver finer sprays over longer distances than conventional nozzles and therefore may be able to match the Ripa nozzle. In addition, the air assistance can, if appropriately configured, help with improving the deposit and distribution over plants, by ruffling leaves and penetrating the canopy. The plant species selected as our case studies – pansy and *Primula* – are small plants with leaves growing close to the growing media surface and therefore the air movement is unlikely to help significantly with deposit or distribution (which in our experiments is measured only by considering deposit under the leaves). It is anticipated that such equipment would have greater potential for improvement in taller crops, where there is space around the leaves for the air jet to disperse the spray.

The Birchmeier AS1200 (**Figure 7**) and knapsack was loaned to us to include in our experimental work. It has two different nozzle types – one very fine, effectively behaving as a mist blower, and the other (probably) very coarse, although no manufacturer's information on droplet size was provided. The very coarse nozzles are agricultural air-induction hollow cone nozzles and deliver very low flow rates compared with the Ripa nozzle flow rates, and so applied volumes are likely to be very low. We selected the largest nozzle size but could not use the highest pressure without using the highest air flow rate, which would be extremely noisy, inefficient and project the spray too far for a 3 m bed width (2.5 – 13 m). We chose the setting of airflow 2 with a pressure of 3 bar as the optimum out of those available.

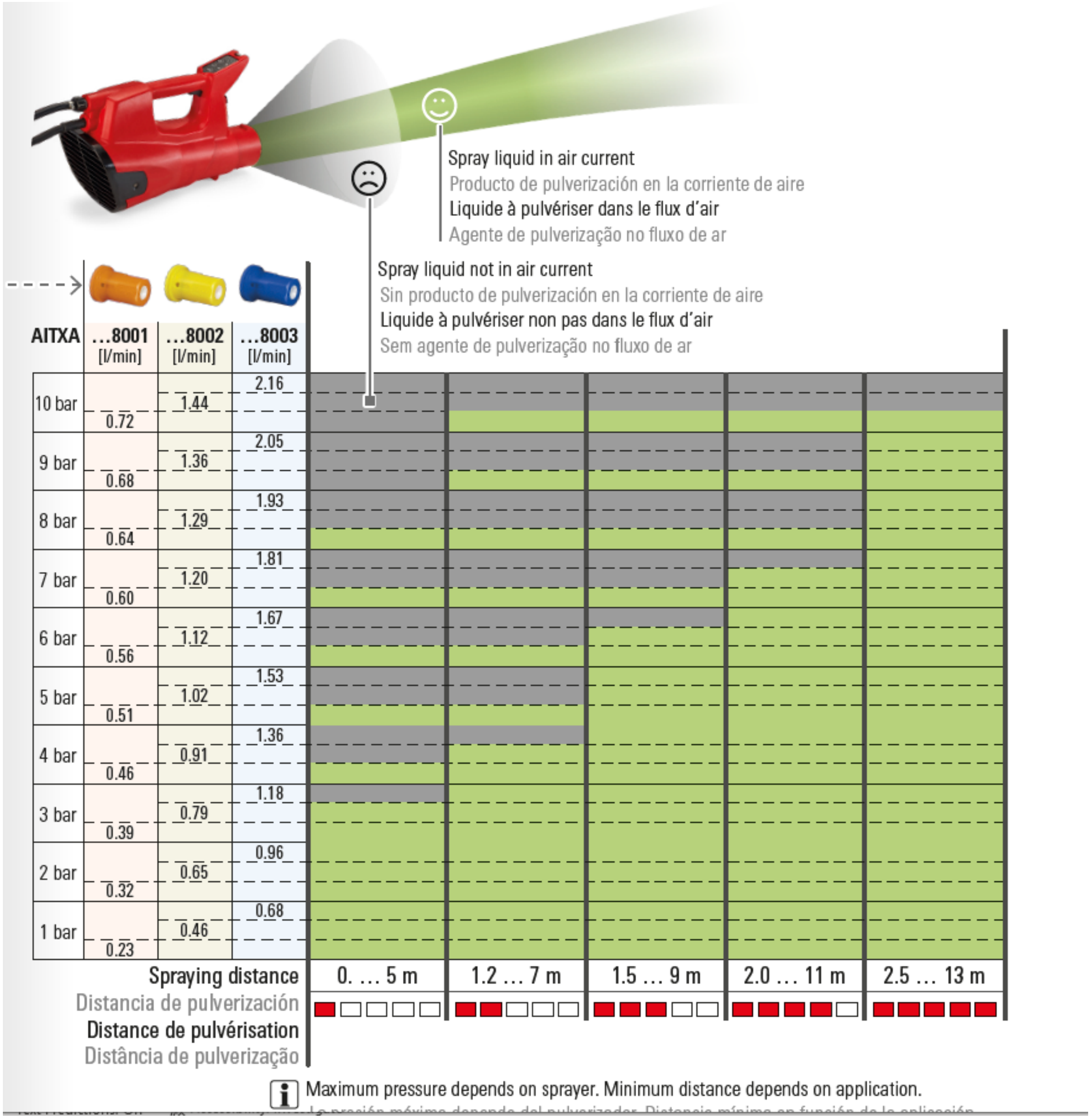


Figure 7. Specifications for Birchmeier AS1200 air assisted handheld sprayer

Alternative Ripa nozzle

A third option was to replace the Ripa nozzle with a smaller size, to reduce the flow rate. This would have no impact on the variability, providing the spray operator behaved identically with the different sized nozzles. It could improve the work rate slightly by reducing the filling time of the spray tank but would not speed up the actual application process. However, it is known that 1000 L/ha, which is the target volume for the spray operator at the host nursery, is likely to deposit a lower quantity of active substance than if the volume can be reduced. Most growers seem to use the largest Ripa nozzle, with the 2 mm diameter. Smaller nozzles (1.2 and 1.5 mm) are available. We therefore obtained a spray pistol together with a 1.5 mm nozzle and a 2.0 mm nozzle for comparison.

Flow rate and droplet size tests

Figure 8 shows the flow rate of the AS1200 with the TeeJet AITXA 80-03 nozzle as a function of pressure. This is not consistent with the manufacturer's charts, which suggests that either the pressure gauge of the AS1200 is inaccurate or the pump is unable to cope with pressures much above 3.0 bar. We suspect a combination of both factors.

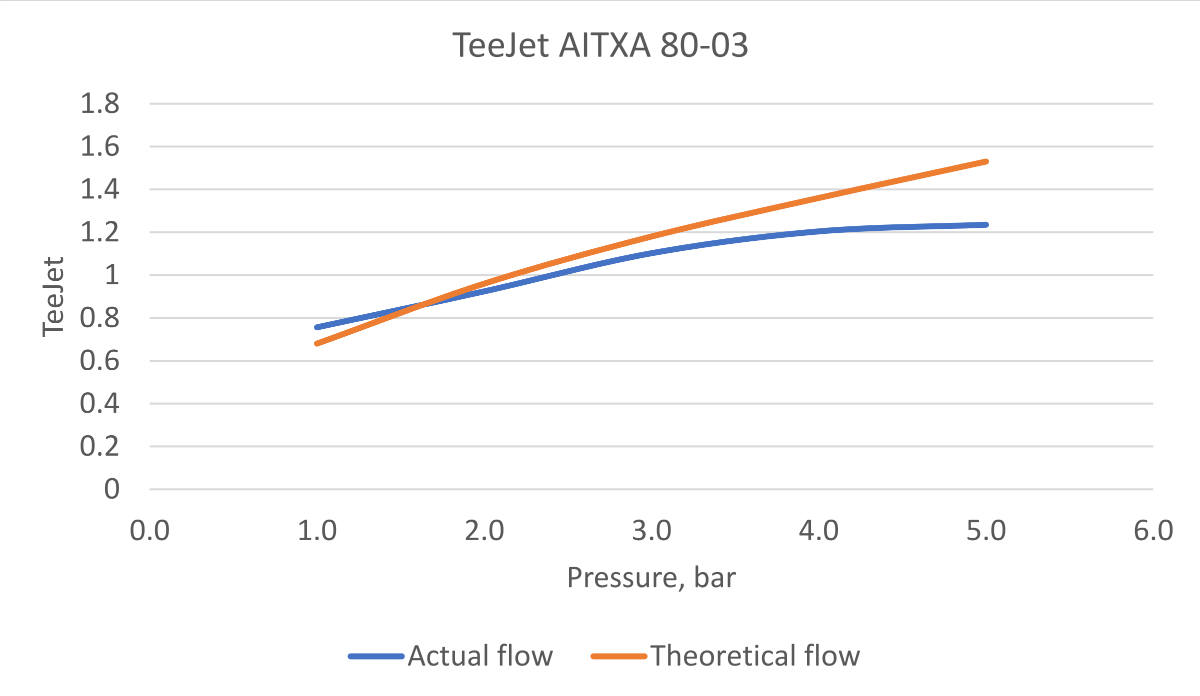


Figure 8. Flow rate of the TeeJet AITXA 80-03 nozzle in the Birchmeier AS1200 air-assisted knapsack sprayer

Droplet size was measured with the nozzle operating at a nominal pressure of 4.0 bar (giving a flow rate of 1.2 L/min) using laser diffraction which resulted in a Volume Median Diameter (VMD) of 437 µm, probably close to the boundary between Extra Coarse and Ultra Coarse.

TeeJet OC nozzle

Table 5 shows the calculated applied volumes for a 3 km/h speed of delivering different flow rates across a 3 m bed width. For our stated requirement of an applied volume between 200 and 400 L/ha, that requires a flow rate of between 3 and 6 L/min. We selected a flow rate of 4.5 L/min to be in the middle of this range. Our starting point was therefore the OC12 nozzle at 3.0 bar.

Table 5. Calculated applied volumes for different flow rates with 3 km/h speed over 3.0 m width

Speed	**3 km/h**
Swath width	**3.0 m**
Flow, l/min	**L/ha**
2.5	167
3.0	200
3.5	233
4.0	267
4.5	300
5.0	333
5.5	367
6.0	400
6.5	433
7.0	467
7.5	500

Figure 9 shows the droplet size of the OC12 nozzle across the pressure range, measured with laser diffraction. At 3.0 bar, the Volume Median Diameter (VMD) was 367 µm, which is probably close to the boundary between Very Coarse and Extra Coarse, and therefore is finer than the Ultra Coarse spray that the manufacturer suggests is produced by the larger XP BoomJet nozzles. Using the nozzle at pressure of 6.0 bar would potentially bring the spray quality down to the middle of the Coarse range, with a VMD of 300 µm.

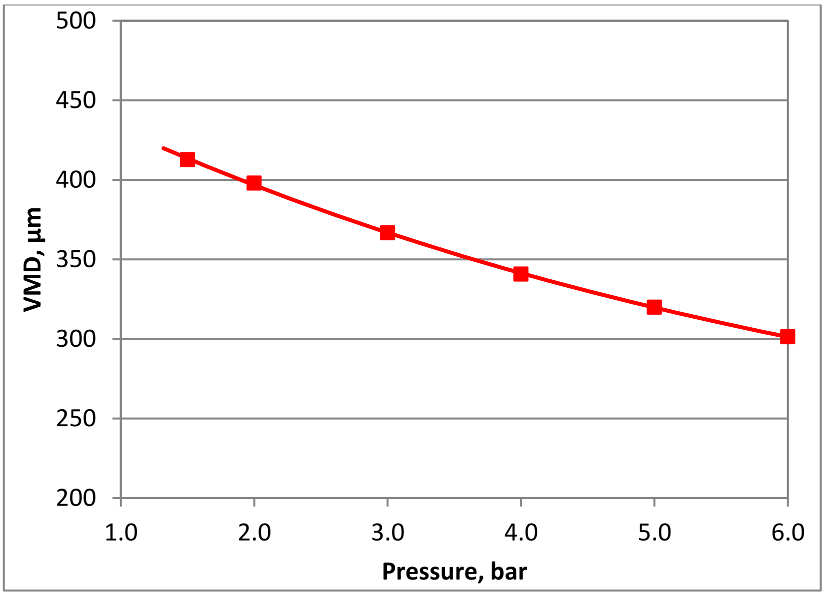


Figure 9. VMD (µm) produced by the OC12 nozzle

Ripa nozzles

Previous work (**Talbot, 2014**) measured flow rates and droplet sizes from Ripa nozzles and therefore only a small amount of confirmatory work was undertaken in this study. The Ripa 2.0 mm nozzle size had been shown to produce a medium quality spray across most of the pressure range when the nozzle was fully closed (as used in Experiment 1).

Table 6 shows measured flow rates for the 1.2 and 1.5 mm nozzles based at SSAU, and the 2.0 mm nozzle based at the host nursery.

Table 6. Measured flow rates for Ripa nozzles, L/min, for nozzle sizes 1.2, 1.5 and 2.0 mm

	1.2 mm (SSAU)	1.5 mm (SSAU)		2.0 mm (SSAU)		2.0 mm (Host nursery)
	10 bar	10 bar	12 bar	10 bar	12 bar	11 bar
closed	1.92	2.47		3.9	4.3	7.2*
3/4 open	2.16	2.73	3.08†			
Fully open				8.7		

*Measured on site in Experiment 1. †VMD 183 µm, (medium – fine quality) measured with laser diffraction

Our aim was to approximately half the flow rate of the nozzle used in Experiment 1, i.e., of the order of 3.6 L/min, for which we assumed that the 1.5 mm nozzle would be appropriate. It became clear that the 2.0 mm nozzle at SSAU gave lower flow rates than the one at the host nursery, despite being the same specification. None of the flow rates were consistent with those measured in Talbot (**2014**), and it seems likely that the flow rate of the host nurseries nozzle was higher than that in the equipment manufacturer's specification.

Footprint tests

It was not possible to test the uniformity of spray distribution in the laboratory because there was insufficient area available and two of the techniques – the Ripa nozzle and the AS1200 need an experienced spray operator. The OC nozzle could, however, be attached to a track sprayer and the potential for a more even distribution over a smaller area could be assessed. The other two were assessed in a stationary mode to evaluate the distance that the spray could be projected.

The OC16 nozzle was initially included because it was felt that the throw from the OC12 might be inadequate – the higher flow rate and larger droplet expected from the OC16 nozzle would potentially travel further.

At this stage in the tests, we were expecting the 1.5 mm nozzle to give the target applied volume and so this was used in the Ripa pistol rather than the 2.0 mm.

Figure 10 shows the general set up used in the wind tunnel at SSAU. The spray generator is mounted at the back of the wind tunnel on a workbench at approximately 0.5 m above the floor. A series of boxes (the same as those used in Experiment 1) were placed down the centre line of the spray plume at 0.5 m intervals. The boxes were pre-weighed. The spray was operated for a period of time for sufficient water to collect in the boxes so that they could be weighed again, and the quantity of water in each one determined.

The OC nozzle was also mounted on a transporter and moved at a speed of 3 km/h across the wind tunnel.

Figure 11 shows the relative quantity of spray in each of the boxes. These data are presented as a fraction of the total volume collected. There were different absolute quantities in each box because of the different flow rates and spray durations of the different systems.

The AS1200 had a throw that was relatively consistent with water pressure, depositing most of the spray between 2 and 6 m from the nozzle. The distribution is most even for the highest pressures, suggesting that 3 bar upwards will give optimum spray patterns.

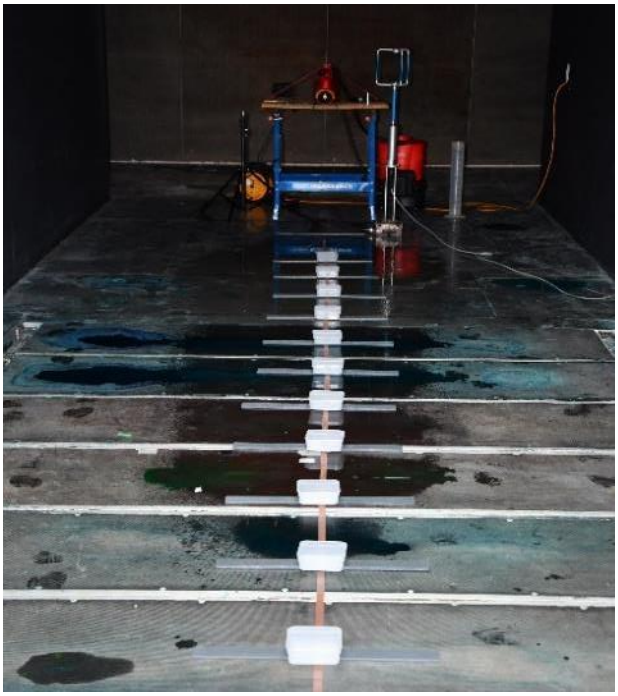


Figure 10. General setup for measurement of the throw of the spray generated with each system

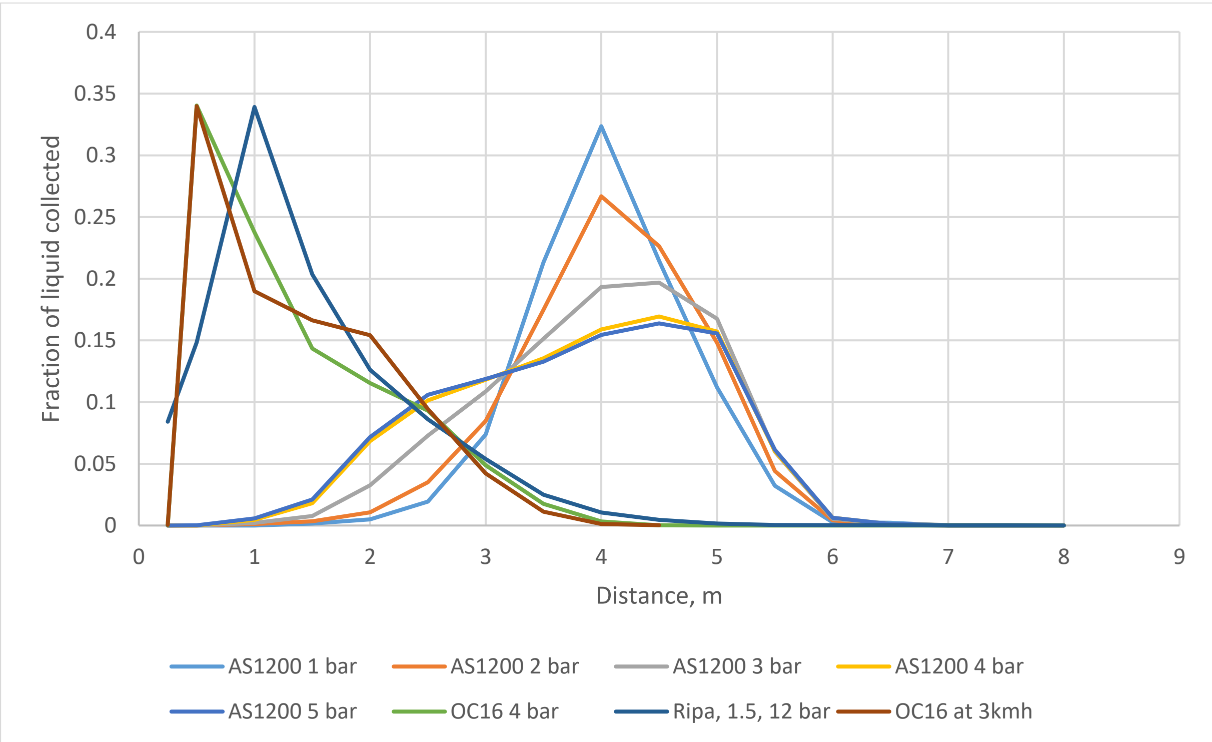


Figure 11. Relative quantity of spray along the centre line of each spray plume for three systems, the Ripa nozzle, the AS1200 (air flow setting 2) and the OC16 nozzle. All were stationary apart from one measurement with the OC nozzle moving laterally at 3 km/h

The OC16 gave a surprisingly poor performance, with the majority of spay falling within 2 m of the nozzle. A moving nozzle improved this slightly, but not sufficiently. The Ripa nozzle gave a similar performance, suggesting that the OC nozzle would not provide any advantage over the Ripa in terms of distribution and would still require some level of human intervention to achieve uniformity.

Figure 12 shows the spray plume from the Ripa 1.5 mm, with the droplets falling out of the plume within a short distance clearly visible.

Figure 12. Spray plume from the Ripa 1.5 mm nozzle at 12 bar

These results were unexpected, and further work would have been beneficial to try to improve performance of all the equipment. It is likely that adjusting the angle and height of the nozzles could have changed the distributions, and extended the throw and reduced the sharp peak at 0.5 m for the TeeJet OC12 nozzle.

Other observations made during tests

TeeJet OC12 nozzle

- Spray angle quite narrow to achieve an even throw, approx. 90°
- Most of the spray was in the 0.5 to 1.5m area, knocking the sample pots away initially.
- Using book settings, the spray could achieve the 3 to 3.5 m required BUT very uneven distribution.
- Unlike the Ripa or Birchmeier, the nozzle would be in a fixed position and not "waved" about meaning that the distribution would also be fixed.
- A medium spray quality could be achieved at some nozzle/setting combinations, but flow rates were compromised along with horizontal throw.

Birchmeier A1200

- Pump struggles at 1 bar pressure and hunts. 3 flow rates for 3 reps: 0.793, 0.729 and 0.746 l/min.
- Nozzles are recommended at 4 to 20 bar; sprayer gives pressures of 1 to 6 bar.
- Pump appears to flatten out at higher pressures – 4 bar maximum with this nozzle.
- Sprayer does not comply with international standard for hand-held airblast sprayers.
- Ergonomically poor:
    - High air flows result in significant noise - ear defenders required at air setting 3 and above.
    - Handheld lance quite heavy and unbalanced, weight is to the back. Hard on the wrist if using for any length of time.
    - A lot of backpressure (kickback) on the handheld lance on 4 and 5 air settings (5 max) adding to the potential for wrist strain.
    - Care is required not to block the air inlet with loose coveralls, they are sucked in.
    - Pressure cannot be changed once the knapsack is on your back.
    - Cannot see the pump warning indicator light to show battery power is being lost.
- Droplets too large. Smaller droplet nozzles are available but have too wide an angle combined with too high a droplet velocity so that the spray escapes the air flow.
- Maximum volume that could be applied without slowing down the application is 143 L/ha
- In practice, the application would almost certainly be slower.
- Combination of large droplet and very low volume would not be advisable for contact-acting PPPs.
- Position of battery on the back of sprayer makes it heavy, unbalanced, and tricky to put onto operator's shoulder. When fully loaded its very heavy; Handheld blower plus pipe and lead = 3.97 kg, knapsack plus batteries = 7.28 kg, capacity of knapsack = 15 l. total weight full 26.25 kg.

Conclusions and options to take forward to experiment 2.

TeeJet off-centre nozzles moved in one dimension.

- Adequate droplet size and flow rate.
- Currently inadequate distribution of spray compared with current approach.
- Potential for improving this with more work but insufficient resources were available within this project.

Birchmeier A1200

- Very large droplets combined with very low flow rate has the potential for very poor application.
- Throw good – but different from current approach so would need practice to get a good distribution.
- Many design flaws – much of which could be improved on but currently would be very difficult to recommend.

Alternative Ripa nozzle

- Good droplet size and optimised volume.
- Would probably not deliver huge improvements – technique rather than equipment.
- Low-cost approach
- No difficulties implementing for operators used to existing Ripa nozzles.

For experiment two, it was possible to include three treatments. It was decided to include the original Ripa nozzle so that the baseline assessment could be made on pansies, and we could evaluate how repeatable the results were. Thus, two alternatives were possible and the Birchmeier AS1200 and a lower flow rate Ripa were selected.

6. Experiment 2: Evaluation of alternative approaches (Objective 6)

- A second field experiment took place on 26th October 2021 on the host nursery. A similar approach was taken to the previous experimental protocol, with some modifications.

Materials and Methods

Three application methods were evaluated:

1. Lower flow rate Ripa
2. Birchmeier AS1200 with TeeJet AITXA-03 nozzle operated with air flow setting 2 and 3 bar pressure.
3. Original Ripa

Selection of Ripa nozzle

- The initial tests involved comparing the flow rate of the different Ripa nozzles in order to select one that had approximately half the flow rate of the standard equipment used in Experiment 1, i.e. 3.6 L/min. **Table 7** shows the measured flow rates from the different pistols, nozzle sizes and settings.

Table 7. Measured flow rates from calibration of Ripa nozzles

				Flowrate L/min				
Applicator	**Nozzle size (mm)**	**Pressure, bar**	**Setting**	**R1**	**R2**	**R3**	**Mean**	**SD**
Nursery Ripa pistol	2.0	11.5	Closed	7.3	7.29		7.30	0.01
Nursery Ripa pistol	2.0	11.5	Open	7.52	7.53		7.53	0.01
Nursery Ripa pistol	2.0	11.5	Closed	6.92	6.76	6.88	6.85	0.08
Nursery Ripa pistol	2.0	11.5	Open	7.76	7.8		7.78	0.03
SSAU Ripa pistol	2.0	11.5	Closed	4.16	4.16		4.16	0.00
SSAU Ripa pistol	2.0	11.5	Open	7.72	7.72		7.72	0.00
SSAU Ripa pistol	2.0	11.5	3/4 open	5.8	5.8		5.80	0.00
SSAU Ripa pistol	1.5	11.5	3/4 open	4.00	4.00		4.00	0.00

- It was established that the model of Ripa in use at the host nursery was subtly different from the new one purchased for testing at SSAU which is why the flow rates were different. However, there was no information available on this from Royal Brinkman and there is an assumption that the nozzle tip defines the flow rate, not the pistol into which it is inserted. The SSAU pistol was labelled as '*Nitto'* and therefore may have been from a different manufacturer than the host nurseries pistol.
- The new and old pistols gave similar values when fully open. However, when operated fully closed (which was standard practice at the host nursery) the flow rate of the original Ripa pistol did not fall as much as the new one did. Swapping the nozzle itself between the two pistols did not change the behaviour – it was a characteristic of the pistol, not the nozzle tip.
- The pressure gauge setting was measured at the pump, not at the nozzle, and the flow rate was consistent with a pressure at the nozzle of approximately 9 bar.
- This reinforces the need for calibration under the conditions that the spray pistol will be used, rather than relying on standard flow rate charts. The original Ripa flow rate was less repeatable, particularly in the closed position, so it is necessary to calibrate each time it is used.
- The low flow rate Ripa was selected as the SSAU pistol with the 2.0 nozzle in the fully closed position, which gave a flow rate of 4.16 L/min.

Modifications to experimental protocol

- Following experiment 1, some modifications were made to the experimental protocol.

- None of the treated areas were adjacent to a wall, as this potentially caused a change of behaviour by the spray operator in Experiment 1, which for small plots could impact on the results.
- Slightly smaller plots were used (12 m long instead of 16 m).
- The paper strips were included only as visualisation of spray and were not part of the array of collectors.
- Pansies were used as the test plant, as originally proposed as one of the case study plants, but some of the Pelargonium plants which had been retained from experiment 1 were also used in the low flow rate Ripa treatment.

Experimental set up

Two long bays were made available in a commercial glasshouse. Three 12 m long areas were marked out with sufficient gap to prevent cross contamination. An array of three different collectors were distributed across the area to be treated (**Figure 13**).

Spray path

	0 m	1 m	2 m
1	V1	P5	A9
2	A1	V5	P9
3	P1	A5	V9
4	V2	P6	A10
5	A2	V6	P10
6	P2	A6	V10
7	V3	P7	A11
8	A3	V7	P11
9	P3	A7	V11
10	V4	P8	A12
11	A4	V8	P12
12	P4	A8	V12

P	Plants (pelargonium and/or pansies)
V	Volume (boxes)
A	Artificial targets

Figure 13. Layout of collectors

Both plant species, *Pelargonium,* and pansies, were positioned at the 'P' location for the low volume Ripa nozzle to compare whole plant volumes retained across the two testing events. Only pansies were used for the applications with the high-volume Ripa and AS1200. Pansies were provided in trays of 9 plants where 6 plants were assessed for whole plant spray retention and four stickers (2 x 1.5 cm) were placed underneath the leaves of the remaining 3 plants, as randomly as possible, to evaluate the quantity underneath the leaf blades.

Figure 14 shows the low volume Ripa application in progress, with the two sets of plants. Two other plots are in the background and to the left.

Figure 14. Application with lower volume Ripa spray pistol in progress

Results

Table 8. Calibration data for both Experiments 1 and 2

Sprayer type	Flow rate (L/min)	Spray width (m)	Length of spray run (m)	Area (m^2)	Time to spray area (s)	Calculated vol (L/ha)	Speed (m/s)
High flow rate Ripa (Experiment 1)	7.20	3	15.7	47.0	36	918	0.44
Low flow rate Ripa (Experiment 2)	4.16	3	11.6	34.8	27	533	0.43
High flow rate Ripa (Experiment 2)	7.30	3	11.6	34.8	25	872	0.47
AS 1200 (Experiment 2)	1.20	3	11.6	34.8	26	151	0.44

The calculated applied volume is an approximation because it depends on the treated area. When small 'plots' are sprayed, as in this work, the 'edge effects' can be significant. There was no defined boundary marked, and the spray operator made a subjective judgment as to where the bed edges are. However, relative volumes between the treatments in Experiment 2 are consistent as all plots were the same size.

The speed of application of the spray operator was remarkably consistent, and his accuracy in delivering the required volume was good, although averaged more than 10% less than the target 1000 L/ha for the two high volume Ripa experiments. This could be affected by the small plots – he was closer to 1000 L/ha with the larger plot used in Experiment 1 – so does not necessarily indicate that this would occur in normal practice.

Measurement of applied volume

Table 9 shows the applied volume determined from the quantity deposited in the plastic boxes. There was a very low quantity recovered from the boxes compared with that calculated from the calibration. Some of this would be expected because no collection method is 100% effective, but the data suggest that the losses are significant for all equipment. However, the use of the boxes to determine the quantity of spray volume to the treated area is debatable as overall recoveries are so low.

Table 9. Application volumes, L/ha, determined from quantity deposited in plastic boxes

	Low flow rate Ripa	High flow rate Ripa	AS1200	High flow rate Ripa Experiment 1
Nominal*, L/ha	533	872	151	918
Mean, L/ha	384	463	79	619
% nominal	72	53	53	67
St dev, L/ha	224	133	36	381
CV	58	29	45	62

*from calibration, Table 7

Measurement of deposit on artificial collectors.

An alternative relative measure of performance is to consider the deposit on artificial targets, as this eliminates the biological variability between treatments, but provides a more realistic structure than the plastic boxes used for determining applied volume. The measurements of deposit are normalised for volume, so **Table 10** shows the quantity of spray liquid deposited per 1000 L/ha applied.

Table 10. Quantity of spray liquid deposited on artificial collectors, ul per 1000 L/ha applied

	Low flow rate Ripa	High flow rate Ripa	AS12000	High flow rate Ripa Experiment 1
Mean, ul	127.0*	99.9	126.0	65.6
CV	43.9	29.7	36.8	29.4

*significantly different from the high flow rate Ripa at the 10% level

These data suggest that the lower flow rates can increase the mean normalised deposit but might also result in increased variability. The CV between the two high flow rate Ripa experiments is close to identical, unlike the measurement with the boxes where the CV was much higher in the first experiment than the second.

Measurement of deposit on plants.

Deposit on pelargonium were measured for the two Ripa treatments, but not in the same experiment. These are shown in **Table 11**, normalised to the nominal volume. As expected, the normalised deposit was higher for the low volume treatment, statistically significant at the 10% level. The variability of the low volume treatment is similar to the high-volume treatment.

Table 11. Deposit on pelargonium plants, ul/g per 1000 L/ha

	Low flow rate Ripa (Experiment 2)	High flow rate Ripa (Experiment 1)
Mean	33.4*	25.0
sd	14.3	10.3
CV	42.7	41.2

*statistically significant from the high flow rate Ripa at the 10% level.

The equivalent data for the pansy plants, obtained in Experiment 2, is given in **Table 12**. The lower volume treatment again results in a higher level of deposit. The very low volume treatment with the AS1200 does not further increase deposit, however.

Table 12. Deposit on pansy plants, ul/g per 1000 L/ha

	Low flow rate Ripa	High flow rate Ripa	AS1200
Mean	41.39*	31.56	31.68
sd	15.56	14.13	11.21
CV	37.59	44.78	35.39

*significantly different from the high flow rate Ripa at the 5% level

Measurement of deposit underneath plant leaves

Table 13 shows the quantity deposited underneath the leaves. Note that the value from Experiment 1 relates to *Pelargonium*, and therefore would be expected to be different due to the different plant structures.

Table 13. Quantity deposited under leaves, ul/cm2 per 1000 L/ha

	Low flow rate Ripa	High flow rate Ripa	AS1200	High flow rate Ripa (Experiment 1) *
Mean	0.52	0.90	0.51	1.30
sd	0.36	1.17	0.64	1.41
CV	70	131	125	109

*Note the Experiment 1 measurements were made with *Pelargonium* and so are not directly comparable.

The variability of this measurement is very large and there were no significant differences between treatments. This is expected because of the very low levels recorded on the underside of leaves.

Uniformity across the treated area

The coefficient of variation (CV) given in the tables above gives an indication of the variability of each target over the whole area. Note that a boom sprayer is designed to have a CV of around 10%.

Variability of hand-held systems is known to be high, and that is one of the reasons why switching to a boom wherever possible is recommended. The CVs depend on the collector, but when evaluated over all collectors, there are only relatively small differences between treatments and no big improvements to be seen (**Table 14**).

Table 14. Coefficient of variation for all collectors for each equipment type

	Low flow rate Ripa	High flow rate Ripa	AS1200	High flow rate Ripa (Experiment 1)
CV	47	34	41	45

Table 15 shows the relative values of each measure for the three measurement positions across the bed, with 'near' being closest to the spray operator. The mean value for each collector type over the whole bed was obtained, then the mean value for each of the three locations within the bed. The mean quantity measured at each location is then expressed as a percentage of the mean across the whole bed.

Table 15. Quantity of spray liquid as a percentage of the mean for that collector type for three positions across the bed

	Low flow rate Ripa			High flow rate Ripa			AS1200		
Nominal volume (L/ha)	533			872			151		
	near	**centre**	**far**	**near**	**centre**	**far**	**near**	**centre**	**far**
Volume	80.58	163.78	55.64	105.56	121.05	73.39	78.77	119.01	77.65
Artificial	105.17	145.51	49.32	113.11	112.04	74.84	84.94	101.84	113.22
Pansies	77.50	141.89	80.60	94.70	130.64	74.65	96.15	105.30	98.55
Underleaf	65.91	108.56	125.54	34.75	229.68	35.57	179.77	79.36	40.87

In almost every situation, the centre of the bed received noticeably more than the edges, and this is illustrated in **Figure 15**.

By determining the measured value as a percentage of the mean for each collector, the data can be combined to compare and visualise the variability of the three treatments (**Figure 15)**.

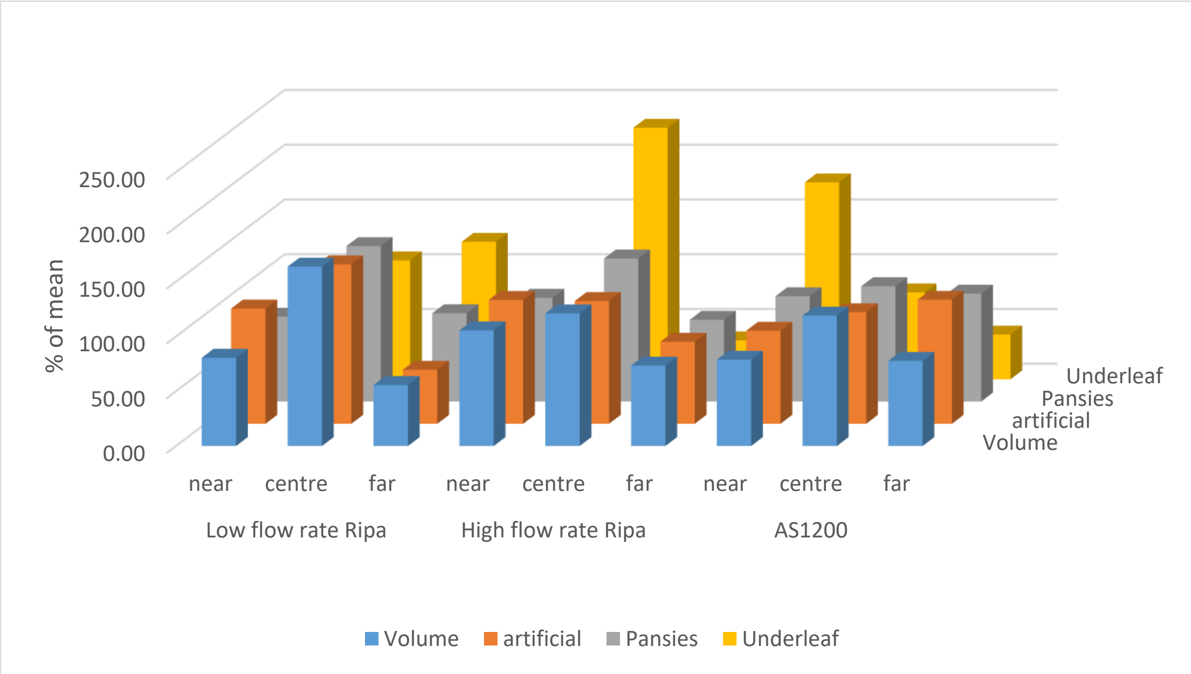


Figure 15. Distribution of spray deposits across the bed for the different treatments and spray collectors

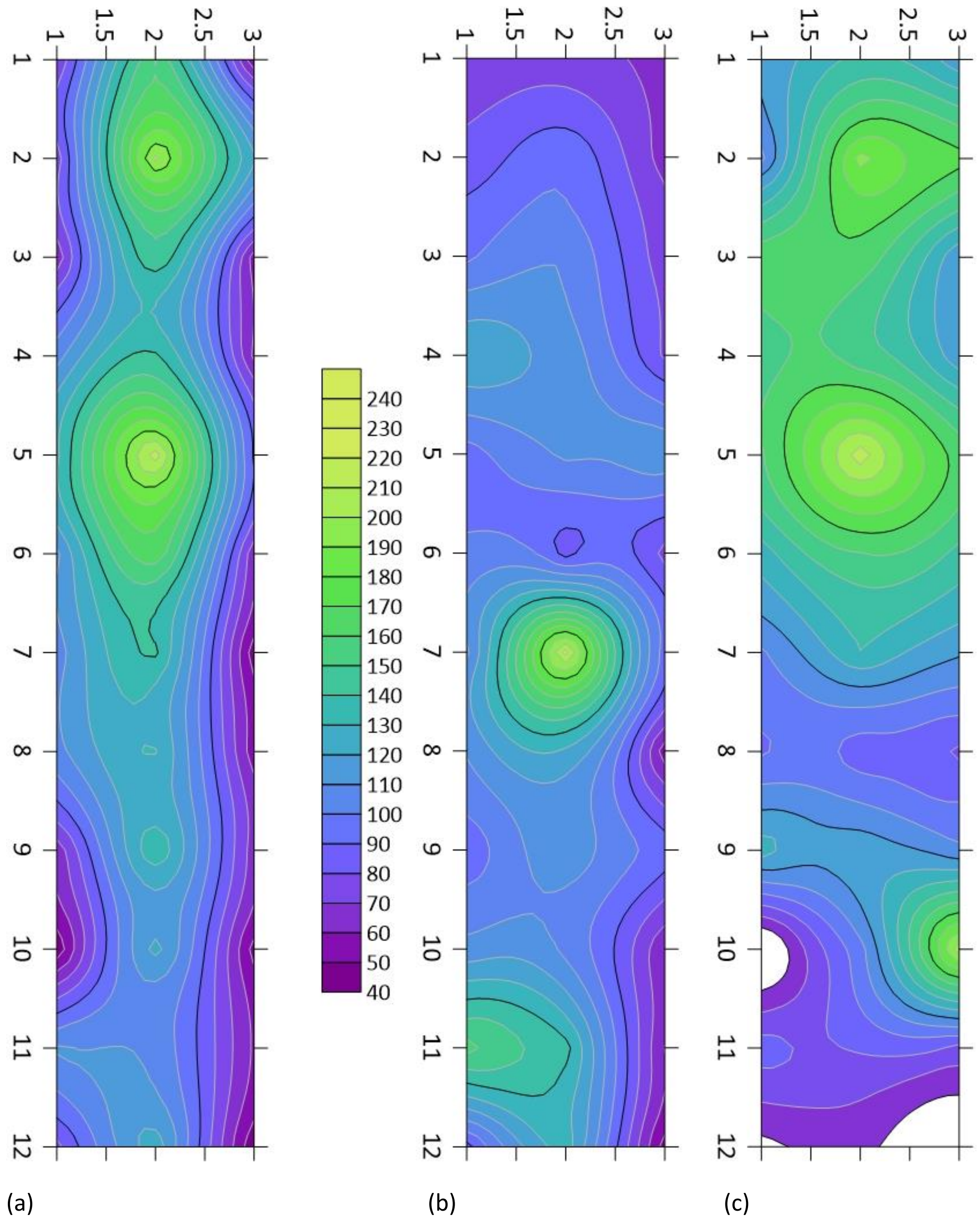


Figure 16. Contour plot of deposits over the treated area for the three treatments. (a) Low flow rate Ripa, (b) High flow rate Ripa, (c) AS1200

Discussion

Although the data obtained in the field experiments were very variable, resulting in few statistically significant differences, we have shown that it is very likely that using a lower volume application will result in a greater quantity of active substance retained on small ornamental plants, as expected, with no change in the uniformity of application or reductions in the quantity on the underside of leaves.

The technique for measurement of the quantity underneath plant leaves was also novel and could be refined with the experiences obtained for this work. The method had some advantages in that the under leaf stickers could be removed and taken back to the laboratory for subsequent analysis. Previous work using the SSAU track sprayer took a more rigorous approach of sampling whole leaves and washing off each side individually. This would have been too time-consuming and difficult on site, with no clean laboratory facilities available. Another common technique is to attach paper underneath leaves with a paperclip or similar, but this adds weight to the leaves and potentially causes them to behave differently. The stickers had a minimal effect on the leaves but were probably smaller than ideal (although could not be larger for the pansies) and were difficult to find and recover after the application was completed.

We found no clear technique for improving the logistics of the application. The speed of application remained the same for the three treatments, although the lower volumes would result in reduced filling time. An analysis of the data generated in this study, combined with data from Talbot (**2014**) shows that the speed of spraying appears to be largely uncorrelated with bed width (**Figure 17**), and therefore work rate during the application is highest for wider beds (**Figure 18**).

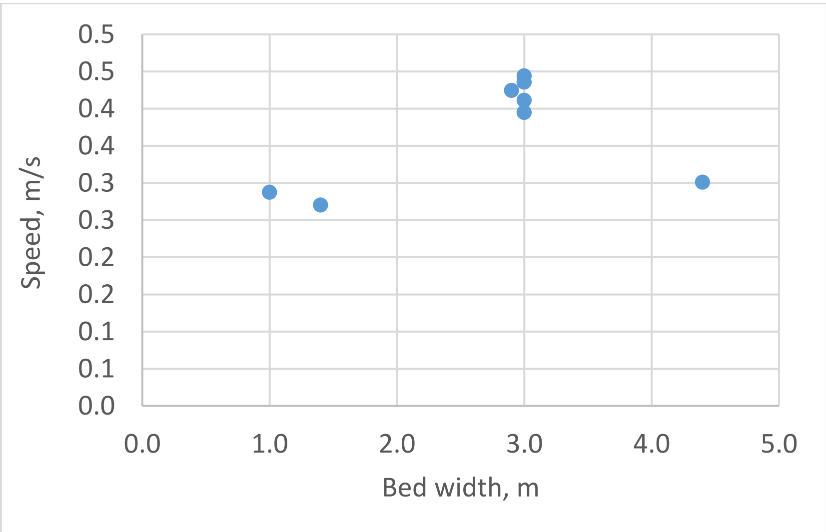


Figure 17. Data from this study combined with data from AHDB project PO 008 – correlation between speed of application and bed width (**Talbot, 2014**)

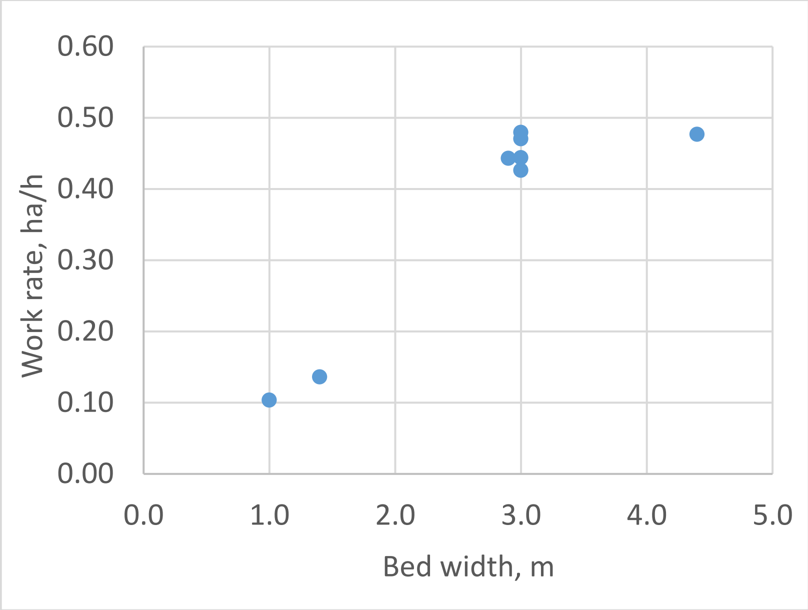


Figure 18. Data from this study combined with data from AHDB project PO 008 – correlation between work rate and bed width with handheld application equipment (**Talbot, 2014**)

We cannot necessarily conclude that using wider beds would be better because the distribution over wider beds may be poorer. Further work on wider beds would be beneficial to identify the optimum layout for the equipment currently available.

The width of the beds in the host nurseries glasshouses were, anecdotally, at the lower end of those used commercially although they were consistent with the sites included in Talbot (**2014**). This led to us defining specifications for alternative equipment which might be different from that needed for wider beds. Both the boomless nozzle approach and the air-assisted sprayer might perform differently over a wider bed. Further work is possible to refine the use of boomless nozzles for a range of bed sizes. We cannot at this stage conclude that they offer no benefits, but we were unable to demonstrate any in the initial tests we undertook.

Similarly, the smaller bed sizes included in Talbot (2014) could also potentially be more appropriate for some of the alternatives (particularly the boomless nozzles) where a long throw becomes less important. However, one of the reasons for not using booms is that these are not possible to use where there are upright structures, yet smaller beds are much less likely to have stanchions in the way of a boom.

The use of air-assistance was not initially thought to be of benefit to small plants where penetration into a canopy, its main potential benefit, was unlikely to be affected. However, the distribution of spray in **Figure 11** shows some promise, and in fact the AS1200 gave close to the kind of distribution that we were trying to achieve with the OC nozzles. The very low volume was expected to give much higher variability, but this was not evident from the Coefficient of Variation. However, the combination of low volume and large droplet size would be inappropriate for many plant protection products, and other aspects of the AS1200 were less than satisfactory. It is possible that future developments in handheld air-assisted sprays might lead to some benefits for ornamentals, but currently they are more suited to larger, denser crop canopies.

A better assessment of the optimum approach to application is needed in relation to the bed sizes and layouts used in commercial organisations. Ideally, a willingness to change the layout to allow optimisation of application with existing equipment would be a major step forward.

We were unable to undertake any efficacy assessments as that was outside the scope of this project. We have therefore relied on measurement of quantity of spray liquid as a proxy for efficacy, but this clearly is making assumptions. The recommended doses will have been determined from experiments using similar equipment and are therefore designed to be effective despite relatively poor distribution. In addition, humidity at the edges of beds is likely to be lower than in the centre of the bed which may result in lower disease pressure for diseases such as *Botrytis* that require high humidity. This, combined with the relatively short crop cycles may be one of the reasons why higher incidence of disease is not seen at the edges of the bed.

However, reducing the water volume and improving the uniformity of application would allow a reduction in dose where products are applied at a rate per litre of water rather than a rate per Ha, since there would be a reduced risk of underdosing some plants, and could result in significant savings. The 1.5mm nozzle delivered too low a flow rate given that our aim was to approximately half the flow rate of the 2.0mm nozzle used by the host nursery (experiment 1). More work is required to determine how to get the best out of the 1.5mm nozzle.

The main benefit we identified was the increase in the normalised deposit achieved by moving to a lower flow rate Ripa nozzle, giving a lower applied volume. Over the three collectors we used (artificial targets, *Pelargonium,* and pansy) the lower flow rate Ripa gave an <u>average 30% increase</u> in deposit compared with the higher flow rate Ripa. This result is likely to apply to other plant species too as there is a wealth of data relating to a very wide range of crops that show lower volumes increase normalised deposit.

No adverse impacts of this change, in terms of uniformity or under leaf coverage, were measured or observed, however crop safety was not assessed. We can therefore recommend this simple and cost-effect approach to improving spray application.

Conclusions

The distribution of spray over 3 m-wide beds was shown to be poorer with a range of handheld systems than is likely to be achieved with a boom system, as expected, with more spray being delivered to the centre of the bed than the sides and significant variability along the length of the bed.

None of the alternative equipment tested within this programme of work proved to be any better than spray pistols in terms of uniformity of deposit.

However, we have shown that reducing the applied volume from a target of 1000 L/ha to 500 L/ha could result in a 30% increase in the quantity of active substance retained on the plant. In the case of the equipment used in the commercial glasshouse where the work was conducted, this was achieved with a reduced Ripa nozzle output resulting from a change in the pistol rather than the nozzle size. However, in other situations this could also be achieved by reducing the nozzle size or potentially changing the setting from 'open' to 'closed'.

Spray booms are better able to deliver lower volumes more uniformly than handheld systems. Therefore growers that cannot move away from handheld application should consider transitioning to small handheld booms where possible. Otherwise, we would recommend using a traditional handheld system to deliver no more than 500 L/ha.

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Appendix 1

Application to pot ornamentals

S0284 – Experiment protocol 13th July 2021

Investigation of the quantity, uniformity and distribution of PPPs over plants – baseline measurements

Introduction

Opportunities for improvements have been identified for approaches used to apply PPPs in the UK's protected ornamentals industry. The experimental site, like most of the industry, typically applies PPPs with relatively large volumes (of the order of 1000 l/ha) using a Ripa nozzle.

This project is focusing on downy mildew on pansies and aphids on *Primula*, and considering how application could be optimised for these scenarios.

The first step is to identify the performance of the equipment currently used at the experimental site so that future work can be compared against this baseline.

Performance measures that could be addressed include:

- Calibration and quantifying the applied dose.
  - Uniformity of PPP distribution over the treated area.
  - Quantity of PPP retained on plants.
  - Logistics of the application process.
  - Ease of use of the equipment.
  - Operator safety.
  - Initial and running costs.

An additional factor that could be considered for some product/pest or disease combinations is the quantity of spray depositing on the underside of leaves. There are challenges to measuring this on-site, and so a possible methodology will be tested.

Objectives

To determine the spray delivery performance of the standard equipment at the experimental site

Nozzle flow rate and applied dose.

  - Uniformity of applied dose.
  - Quantity of spray retained on plants.

    - Quantity of spray on artificial targets.
    - Quantity retained underneath leaves (if possible).
- To obtain qualitative and quantitative information on logistical and other parameters
    - Time taken to calibrate, prepare for spraying and time taken to spray experimental area.
    - Any other relevant observations.

Procedure

The spray operator will set up the application system according to their usual procedures, with SSAU/ADAS observing and timing.

Nozzle flow rate will be measured using a jug test.

A tank mix of 0.1% fluorescein will be prepared in tap water and mixed thoroughly before taking a subsample at the nozzle prior to spraying.

Collecting media will be laid out according to Figure A1. The area to be treated is 3.2 m wide x 21 m long.

There will be four types of collection media:

1. Plastic boxes for determining the variability of the applied dose.
2. Strips of chromatography paper for visualising and quantifying the variability (an alternative approach that might be needed when lower volumes are used in subsequent experiments).
3. Plants for determining (a) the total quantity deposited on plants and (b) the quantity deposited underneath the leaf with an adhesive collector (each 20 x 15 mm) attached to the underside.
4. Artificial collectors (based on plastic plant labels) to reduce variability and allow consistency across experiments.

A sub-sample of the tank mix will be taken from the nozzle immediately prior to spraying and used as a reference to quantify the extracted deposits using spectrofluorescence.

Some samples will be spiked with a known quantity of tank mix and recovered to check for any degradation.

The host nurseries spray operator will conduct the spray application, which will be timed.

A final sample of the spray liquid will be taken from the nozzle.

Figure A1 Sampling plan

	0 m	1 m	2 m	3 m
1	V	P	B	A
2	A	V	P	B
3	B	A	V	P
4	P	B	A	V
5	V	P	B	A
6	A	V	P	B
7	B	A	V	P
8	P	B	A	V
9	V	P	B	A
10	A	V	P	B
11	B	A	V	P
12	P	B	A	V
13	V	P	B	A
14	A	V	P	B
15	B	A	V	P
16	P	B	A	V
17	V	P	B	A
18	A	V	P	B
19	B	A	V	P
20	P	B	A	V
21				

P	Plants (pansies)
V	Volume (boxes)
B	Battens
A	Artificial targets

Sampling

Volume applied/artificial targets.

- Lids will be placed on the boxes and the outside wiped.
- Paper strips will be removed from battens and placed into plastic bags.
- Artificial targets will be placed in plastic bags.

Retention of applied spray on plants

The six pack trays of plants will be positioned as detailed in Figure A1. Four of the plants in each tray will be bulked. The two other plants will each have four collectors fixed to the underside of leaves.

Plant 1 - whole	Plant 2 - whole
Plant 3- whole	Plant 4- whole
Plant 5 – under leaf	Plant 6– under leaf

After spraying is complete the plants will be left to dry while other collectors are dealt with.

Whole plants will then be excised above the soil and placed in pre weighed bags before reweighing to measure the quantity of plant material. A known volume of 0.01M NaOH will be added to the bag and the fluorescent tracer removed with agitation. The rinsate will be decanted into screw-top test-tubes.

All lower leaf collectors from each plant tray will be sealed in a container

All samples will be placed in black bags and stored out of sunlight and in as cool a location as possible and then transported to SSAU for analysis.

Summary of samples numbers:

Application rate samples (boxes)	= 20 (labelled V1 – V20)
Application rate (battens)	= 20 (labelled B1 – B20)
Whole plants	= 20 (labelled P1 – P20)
Lower leaf samples	= 20 (Labelled L1 – L20)
Artificial targets	= 20 (labelled A1 – A20)

Roles

Silsoe Spray Applications Unit will:

- Provide the expertise and equipment to measure all application parameters.
- Assess the effectiveness of the spray application.
- To analyse samples and report the findings.

The host nursery will:

- Provide facilities, spray equipment, spray operator and plants to support the experimental plan.

ADAS will:

- Liaise with the staff at the host nursery.
- Agree this protocol.
- Attend and provide support to the experiment.

Timing: 10th August 2021.

Things to consider/take with us

Logistical equipment:
Measuring jugs, stop watches, tape measures.
Cameras

Lab materials:
2 containers for tank samples.
0.01 M NaOH for washing off (Waste will need to be collected. Alternative is to wash with water then dilute extracts into buffer for analysis).
Balance 2 dp plus power extension – or battery-operated?
Small folding table
Pre-cut under leaf stickers based on Avalon Plus
20 plastic boxes
20 labelled bags (artificial targets)
20 labelled, weighed bags (whole plants)
20 labelled containers (under leaf stickers)
20 test tubes and funnels
20 containers for mounting artificial targets (cups/boxes with oasis)
Extra containers & samplers for spiking.
Paper roll.
Pipette (10ml)
Smaller pipettes for spiking
Cool box/ice blocks and boxes/trays for transport.