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Deposition patterns by high and low pressure high volume spraying in glasshouse pot plant crops

Afsætning af sprøjtevæske i potteplantekulturer ved høj- og lavtryksprøjtning med store væskemængder

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Summary

The investigation comprised five pot plant gardeners who used different high and low pressure hydraulic equipment and different application technique. The distribution of spray liquid on the plants was invariably uneven with the least liquid deposited on the abaxial side of the leaves. Spraying into the crop in a horizontal direction gave a more even distribution than spraying from above in a sloping direction. The most uneven distribution was obtained by high pressure spraying solely applied from the middle pathway of the glasshouse up above the crop.

Key words: High pressure spraying, low pressure spraying, deposition, glasshouse.

Resumé

Fem potteplantegartnere, som benyttede forskelligt hydraulisk høj- og lavtryksprøjteudstyr og forskellig sprøjteteknik, indgik i undersøgelsen. Afsætningen af sprøjtevæske på planterne var i alle tilfælde uensartet med den mindste afsætning på bladundersiderne. Sprøjtning fra siden gav en mere ensartet fordeling af sprøjtevæsken end sprøjtning ovenfra i en mere eller mindre skrå vinkel. Den mest uensartede fordeling af sprøjtevæsken blev opnået ved højtryksprøjtning udført fra husets midtergang op over planterne.

Nøgleord: Højtryksprøjtning, lavtryksprøjtning, afsætning, væksthus.

Introduction

One of the main problems in application technique is to penetrate a dense crop and to obtain an adequate deposit of pesticide on the plant parts turning away from the liquid stream. Many approaches have been attempted to improve the application i.e. by use of low volume applicators applying very fine droplets (3, 8, 11, 16, 17) and electrostatic sprayers (1, 2, 12). Traditional high volume application with hydraulic sprayers however is still frequently used by Danish glasshouse gardeners. The aim of this investigation was to survey the quality of high volume applications expressed as the eveness of the deposition of spray liquid on the plants. Five pot plant gardeners using different spray equipment and technique were included in the survey. The intension is to use the results of the survey as a base for further improvement of the application technique.

Materials and methods

The experiments were carried out at five pot plant gardeners using their equipment and their application technique. It was the gardeners themselves who made the applications. The equipment was low and high pressure sprayers all equiped with cone spray nozzles. Tap water was always used as the carrying agent. The deposition of spray liquid in the crop was assessed by means of collectors with horizontally and vertically oriented surfaces representing plant parts as leaves and stems. The vertical surfaces were positioned toward the two house ends. Deposit on both surfaces was registered because differences could be expected when applications are made from each side of a bench or every second bench and the collectors are placed near one of the bench edges. In some experiments filter paper pieces were fastened directly to leaves. The paper pieces never exceeded the margin of the leaves.

Drops per area were registered by the magnesium oxide method (14) using 2 × 5 cm coated glass plates. The method can register drop diameters down to 10μm. The fluorescent dye uvitex (*Helios 010 EC,* Ciba-Geigy Ltd.) was added to the spray liquid with 4.5 mg uvitex per l. The fluorecent dye was not included in all the experiments however because of problems with possible phytotoxic effect to some of the plant cultures. The dye was collected on filter paper pieces 2 × 5 cm. The magnesium oxide coated glass plates and the filter paper pieces were fastened to the collectors. As uvitex is photo unstable the filter paper pieces were collected immediately after the spraying and stored in darkness and coolness at 4°C. The uvitex was extracted from the filter paper by isopropanol and the concentration was measured with a *Farrand Filter Ratio Fluoremeter – 2.* The plant heights were measured from the edge of the pots.

All in all seven experiments were carried out. An outline of the application equipment and technical parameters used is shown in Table 1 and further details of the experiments are given below.

Low pressure sprayings

Experiment 1 and 2 were carried out in potted chrysanthemum *(Dendranthema morifolium)* 0.15 m high placed closely on 1.8 × 9.2 m benches. Fluorescent dye was added to the spray liquid and collectors were placed level with the top of the plants at four locations on each of two benches. Furthermore filter paper pieces were fastened to the adaxial and abaxial side of the leaves at the top and base of plants standing close to the collectors. Two types of equipment were tested. A boom which was 1,0 m long and equipped with six nozzles placed with equal distance from each other. The boom was used to apply growth regulators and it was held horizontal 0,25 m above the crop with the nozzles directed vertically down toward the plants. The other equipment was a nozzle head containing six nozzles placed in two parallel rows with the four outermost nozzles bent 10° outwards (Fig. 1A). It was used to apply insecticides and fungicides. The nozzle head was held 0,3 m above the crop and directed toward the plants at an angle of 30-40° to the horizontal plane.

Experiment 3 and 4 were carried out in closely placed hibiscus *(Hibiscus rosa-sinensis)* 0.15 and 0.9 m high, respectively. Fluorescent dye was added to the spray liquid. The low hibiscus were placed on a 1.8 × 9.2 m bench. Collectors were placed at six positions on the bench, three near the edge and three in the middle. Filter paper pieces were fastened to leaves at the top of six plants standing close to the collectors. The high hibiscus were placed on a 1.8 × 6.8 m bench with nine rows of pots transverse. Collectors were placed at six positions on the bench with three along the third and three along the fifth (the middle) row of pots. At each position three collectors

Table 1. The application equipments used in the survey. L.P. = low pressure sprayer. H.P. = high pressure sprayer. *Det anvendte sprøjteudstyr. L.P. = lavtryksprøjte. H.P. = højtryksprøjte.*

Exp. no. *Eksp. nr.*	Crop *Kultur*	Sprayer *Sprøjte*	Nozzles *Dyser*			Liquid pressure *Væsketryk MPA*	Capacity *Ydelse* 1 per min	Spray volume *Væskevolume* 1 per 1000 m^2
			Size *Str. mm*	No. *Nr.*	Cone *Kegle*			
1.	Chrysanthemum	L.P. with boom	1,2	6	Hollow	0,10	7,8	175
2.	Chrysanthemum	L.P. with head	0,8	6	Hollow	0,20	7,3	330
3.	Hibiscus, low	L.P. »Hardi 500-HT«	0,8	4	Hollow	0,13	4,4	228
4.	Hibiscus, high	L.P. »Hardi 500-HT«	0,8	4	Hollow	0,13	4,4	575
5.	Hedera	H.P. »Klinett«	1,6	2	Hollow	0,80	11,0	200
6.	Poinsettia	H.P. »Klinett«	1,2	1	Hollow	1,40	*	167
7.	Chrysanthemum	H.P. »Nord pump«	1,8	1	Full	0,80	*	200

* The capacity was not measured

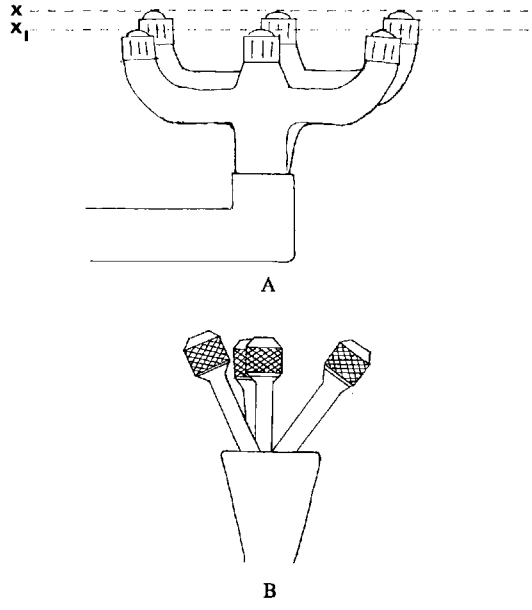

Fig. 1. A. The nozzle head used in experiment 2. X runs parallel to X_1. B. The nozzle head used in experiment 3 and 4.
A. Dysehovedet, der blev benyttet i eksperiment 2. X er parallel med X_1. B. Dysehovedet, der blev benyttet i eksperiment 3 og 4.

were fastened at the top, the middle and the base of a plant, respectively. Filter paper pieces were fastened to the leaves next to collectors. The sprayer was equipped with a nozzle head containing four nozzles with one in the middle and the three others surrounding it and directed 25° outward compared to the middle nozzle (Fig. 1B). Both crops were sprayed from each side moving along the benches and the high hibiscus from the ends also. The low hibiscus were sprayed from above directing the nozzle head toward the plants at an angle of 30-40° to the horizontal plane. The high hibiscus were sprayed from the side by holding the nozzle head in a nearly horizontal direction and at the same time moving the nozzle head up and down from the top to the base of the plants.

High pressure sprayings

Experiment 5 was carried out in low ivy *(Hedera helix)* placed closely on a 0.85 × 8.4 m bench with collectors placed at four locations along the bench at the top of the canopy. The nozzle head contained two nozzles placed parallel with a distance of 18 cm. The plants were sprayed from each side of the bench moving along the bench. The nozzles were held 0,5 m above the crop and directed downward at an angle of 30-40° to the horizontal plane.

Table 2. Experiment 1. The distribution of drops/cm^2 and ng uvitex/cm^2 registered on collectors after low pressure spraying with a boom in a chrysanthemum crop.
Eksperiment 1. Afsat antal dråber/cm^2 og mængde uvitex/cm^2 på stativer i en krysantemum kultur efter lavtryksprøjtning med en bom.

Position of *Orientering af*		Drops/ cm^2	Uvitex		
			ng/cm^2	S.E.#	%
glass and paper *glas og papir*	coating *belægning*				
Horizontal *Horisontalt*	upward *opad*	*	47	4	64
Horizontal *Horisontalt*	downward *nedad*	693	1	0,2	1
Vertical *Vertikalt*	+	**	19	7	26
Vertical *Vertikalt*	+	**	6	1	8

S.E. = standard error of the mean.
\+ Towards the two house ends. *Imod de to gavle.*
* The coatings were soaked. *Belægningerne var gennemvædede.*
** The coatings were soaked in four out of eight stands. The average drops/cm^2 of the rest were 637 and 659 respectively.
Belægningerne var gennemvædede på fire ud af otte stativer. Det gennemsnitlige antal dråber/cm^2 på resten var henholdsvis 637 og 659.

Table 3. Experiment 2. The distribution of drops/cm^2 and ng uvitex/cm^2 registered on collectors after low pressure spraying with a nozzle head in a chrysanthemum crop.
Eksperiment 2. Afsat antal dråber/cm^2 og mængde uvitex/cm^2 på stativer i en krysantemum kultur efter lavtryksprøjtning med et dysehoved.

Position of *Orientering af*		Drops/ cm^2	Uvitex		
			ng/cm^2	S.E.#	%
glass and paper *glas og papir*	coating *belægning*				
Horizontal *Horisontalt*	upward *opad*	*	92	4	42
Horizontal *Horisontalt*	downward *nedad*	2285	3	0,7	1
Vertical *Vertikalt*	+	*	57	9	26
Vertical *Vertikalt*	+	*	67	13	31

S.E. = standard error of the mean.
\+ Towards the two house ends. *Imod de to gavle.*
* The coatings were soaked. *Belægningerne var gennemvædede.*

Experiment 6 was carried out in 0.3-0.4 m high rich branched mother plants of poinsettia *(Euphorbia pulcherrima)* placed closely on 2.0 × 9.2 m benches. Collectors were placed at the top and base of the plants at 12 positions with four lengthwise × three crosswise. The application technique used was to walk lengthwise every second bench holding the nozzle head in upwards stretched arm applying downward in a sloping direction.

A totally different application technique was used in experiment 7, which was carried out in a 23 × 65 m glasshouse with potted 0.15 m high chrysanthemum placed closely on benches on each side of a middle pathway. The application was made from the middle pathway while the spray operator was moving through the house with the nozzle head held 0.5 m above the plants and raised 30° above the horizontal level and spraying to both sides of the middle pathway. Collectors with coated glass plates were placed in one half of the glasshouse with seven positions covering the lengthwise × three positions covering the crosswise distribution, i.e. all in all 21 position.

Results

The deposition of spray liquid registered on collectors in experiment 1 and 2 is shown in Table 2 and 3, and the deposition of fluorescent dye on leaves at 2 heights from experiment 2 is shown in Table 4.

Table 4. Experiment 2. The deposit of uvitex/cm^2 registered on leaves at the top and base of chrysanthemum plants after low pressure spraying with a nozzle head.
Eksperiment 2. Afsat mængde uvitex/cm^2 på blade fra top og basis af krysantemumplanter efter lavtryksprøjtning med et dysehoved.

Leaf position *Bladets placering*	Side of leaf *Bladside*	Uvitex ng/cm^2	S.E.#	%
Top *Top*	Adaxial *Overside*	154	22	95
	Abaxial *Underside*	8	4	5
Base *Basis*	Adaxial *Overside*	25	8	86
	Abaxial *Underside*	4	2	14

S.E. = standard error of the mean.

The deposition of spray liquid registered on collectors and leaves in experiments 3 and 4 is shown in Table 5 and 6.

Table 5. Experiment 3. The distribution of drops/cm^2 and ng uvitex/cm^2 on collectors and leaves after low pressure spraying in low hibiscus.
Eksperiment 3. Afsat antal dråber/cm^2 og mængde uvitex/cm^2 på stativer og blade i lave hibiscus efter lavtryksprøjtning.

Position of *Orientering af*		Drops/cm^2 *Dråber/cm^2*	Uvitex					
			Collectors *Stativer*			Leaves *Blade*		
glass and paper *glas og papir*	coating/leaf *belægning/blad*	Collectors *Stativer*	ng/cm^2	S.E.#	%	ng/cm^2	S.E.#	%
Horizontal *Horisontalt*	upward/adaxial *opad*	*	70	11	35	53	14	77
Horizontal *Horisontalt*	downward/abaxial *nedad*	2434	4	0,4	2	16	8	23
Vertical *Vertikalt*	+	*	62	9	31			
Vertical *Vertikalt*	+	*	65	17	32			

S.E. = standard error of the mean.
\+ Towards the two house ends. *Imod de to gavle.*
* The coatings were soaked. *Belægningerne var gennemvædede.*

Table 6. Experiment 4. The distribution of drops/cm^2 and ng uvitex/cm^2 at 3 heights: Top, middle and base of the plants after low pressure spraying in high hibiscus.
Eksperiment 4. Afsat antal dråber/cm^2 i 3 højder i høje hibiscus efter lavtryksprøjtning.

Measuring height *Registre-ringshøjde*	Position of *Orientering af*		Drops/cm^2 *Dråber/cm^2*	Uvitex			
				Collectors *Stativer*		Leaves *Blade*	
	glass and paper *glas og papir*	coating/leaf *belægning/blad*	Collectors *Stativer*	ng/cm^2	S.E.#	ng/cm^2	S.E.#
Top *Top*	Horizontal *Horisontalt*	upward/adaxial *opad*	*	41	6	69	22
	Horizontal *Horisontalt*	downward/abaxial *nedad*	4404	13	7	34	21
	Vertical *Vertikalt*	+	*	53	17		
	Vertical *Vertikalt*	+	6443	10	3		
Middle *Midte*	Horizontal *Horisontalt*	upward/adaxial *opad*	*	43	5	71	17
	Horizontal *Horisontalt*	downward/abaxial *nedad*	3680	13	7	30	23
	Vertical *Vertikalt*	+	*	92	9		
	Vertical *Vertikalt*	+	4400	8	4		
Base *Basis*	Horizontal *Horisontalt*	upward/adaxial *opad*	*	57	10	76	22
	Horizontal *Horisontalt*	downward/abaxial *nedad*	2517	2	0,4	6	1
	Vertical *Vertikalt*	+	*	56	13		
	Vertical *Vertikalt*	+	7417	26	9		

S.E. = standard error of the mean.
\+ Towards the two house ends. *Imod de to gavle.*
* The coatings were soaked. *Belægningerne var gennemvædede.*

The results in table 6 show that there were no filtering effects of the canopy from the top to the base.

The deposition of the spray liquid of the high pressure sprayings in experiments 5, 6 and 7 is shown in Table 7, 8 and 9.

In experiment 7 all the upwards directed coatings were soaked so there were no problems in covering the plants placed near the trempler from the middle pathway with the high pressure sprayer.

Discussion

In all the experiments irrespective of the equipment and the spray technical parameters used the horisontal upwards directed magnesium oxide coated surfaces and sometimes also the vertical surfaces were soaked, while less spray liquid was deposited on the downwards directed surfaces. Quantification of the deposit then had to be based on experiments where fluorescent dye was included. They comprise only the low pressure sprayings. The spray liquid was invariably depo-

Table 7. Experiment 5. The distribution of drops/cm² on collectors after high pressure spraying in ivy.
Eksperiment 5. Afsat antal dråber/cm² på stativer efter højtryksprøjtning i vedben.

Position of *Orientering af*		Drops/cm² *Dråber/cm²*
glass and paper *glas og papir*	coating *belægning*	
Horizontal *Horisontalt*	upward *opad*	*
Horizontal *Horisontalt*	downward *nedad*	820
Vertical *Vertikalt*	+	*
Vertical *Vertikalt*	+	1021**

\+ Towards the two house ends. *Imod de to gavle.*
* The coatings were soaked.
Belægningerne var gennemvædede.
** Based on three replica. The fourth was soaked.
Baseret på tre gentagelser. Den fjerde var gennemvædet.

sited very uneven as seen by the very high standard errors found in al experiments. In the low pressure spraying experiments 1, 2 and 3, where the applications were made from above the plants, only 1–2% of the total registered deposit was found on the downwards directed surfaces. The uneven deposit masks any difference in the deposit in the crysanthemum crop in experiments 1 and 2, where a boom and a nozzle head held at different angles to the plants were compaired. In the high hibiscus in experiment 4 a much higher deposit was registered on the downwards directed surfaces probably because the spray liquid was applied horizontal into the plant canopy instead of from above. The low deposit registered on the downwards directed surfaces of both collectors and leaves at the base of the high hibiscus is due to that the base of the plants mainly received the spray liquid from above even though the application as so was made from the side.

Table 8. Experiment 6. The distribution of drops/cm² on collectors at two heights after high pressure spraying in poinsettia.
Eksperiment 6. Afsat antal dråber/cm² registreret på stativer i to højder i poinsettia efter højtryksprøjtning.

Position of *Orientering af*		Plant height *Plantehøjde*			
glass *glas*	coating *belægning*	Top *Top*		Base *Basis*	
		drops/cm²	S.E.#	drops/cm²	S.E.#
Horizontal *Horisontalt*	upward *opad*	*		**	
Horizontal *Horisontalt*	downward *nedad*	233	60	41	19
Vertical *Vertikalt*	+	*		380[1]	134
Vertical *Vertikalt*	+	*		235[2]	77

\# S.E. = standard error of the mean.
\+ Towards the house ends. *Imod de to gavle.*
* The coatings were soaked. *Belægningerne var gennemvædede.*
** In nine of the measuring points the coatings were soaked. The average drops/cm² at the remaining three points was 1692.
I ni af målepunkterne var belægningerne gennemvædede. Det gnst. antal dråber/cm² i de resterende tre punkter var 1692.
1) In one of the measuring points the coating was soaked. The average of the other 11 is given in the table.
I ét af målepunkterne var belægningen gennemvædet. Det gnst. antal dråber/cm² i de resterende 11 målepunkter er angivet i tabellen.
2) In three of the measuring points the coatings were soaked. The average of the other nine is given in the table.
I tre af målepunkterne var belægningerne gennemvædede. Det gnst. antal dråber/cm² i de resterende ni målepunkter er angivet i tabellen.

Table 9. Experiment 7. The distribution of drops/cm^2 on collectors after high pressure spraying in a chrysanthemum house.
Eksperiment 7. Afsat antal dråber/cm^2 på stativer i et krysantemumhus efter højtryksprøjtning.

Position of *Orientering af*		Drops/cm^2 *Dråber/cm^2*
glass and paper *glas og papir*	coating *belægning*	
Horizontal *Horisontalt*	upward *opad*	*
Horizontal *Horisontalt*	downward *nedad*	63
Vertical *Vertikalt*	+	**
Vertical *Vertikalt*	+	***

\+ Towards the two house ends. *Imod de to gavle.*
* The coatings were soaked. *Belægningerne var gennemvædede.*
** The coatings were soaked in 11 out of 21 collectors. The average drops/cm^2 of the rest was 635. *Belægningerne var gennemvædede på 11 ud af 21 stativer. Det gnst. antal dråber/cm^2 på resten var 635.*
*** The coatings were soaked in 8 out of 21 collectors. The average drops/cm^2 of the rest was 747. *Belægningerne var gennemvædede på 8 ud af 21 stativer. Det gnst. antal dråber/cm^2 på resten var 747.*

The deposit on the abaxial side of the leaves was invariably much higher than found on the downwards directed collector surfaces. This is probably due to the fact that leaves are never positioned absolutely horizontal, they often curve and they are flexible. *Ganzelmeier* and *Lüders* (6) sprayed two artificial broad leaved crops 0.48 and 1.40 m high from above with cone spray nozzles ∅ 1.0 and 1.5 mm delivering 30 and 90 l per 1000 m^2 respectively. The deposit on the abaxial side of the uppermost leaves at both heights amounted to 2–3% of total deposit registered on the leaves. This distribution is close to the one registered on stands in the present investigation while the deposits registered on the abaxial side of leaves were much higher.

A filtering effect of the leaves was – not surprisingly – observed in the experiments, where the applications were made from above and the deposition was registered at the top and base of the plants. This is in accordance with *Cooke et al.* (4), *Ganzelmeier* and *Lüders* (6), *Göhlich* (7) and *Jegatheeswaran* (9).

According to *Drouin* (5) and *Lerch* (10) a coverage of 20–70 drops per cm^2 by folia sprays ensures an adequate control of pests and diseases. This coverage was highly exceeded on the downwards directed surfaces at the top of the canopy in all the experiments except experiment 7. Whether the coverage will be sufficient at the base of the plants will, among other things, depend on the leaf area index, the spray volume, the drop size and the application technique used. In experiment 7 the application was made above the plants instead of into the canopy, so much of the deposition must have taken place by sedimentation, which explains the very low deposit found on the downwards directed surfaces.

The growers were all satisfied with the result of their applications judged by the control of pests and diseases usually obtained. The very uneven deposition of spray liquid on the plants observed in all the experiments shows that the adequate control of pests and diseases living on the abaxial side of the leaves or at the base of the plants is obviously obtained at the expense of an enormous overdose on the other parts of the plants. An improvement might be obtained by spraying in a more horizontal direction as indicated by the experiment with the high hibiscus. *Jarrett et al.* (8) obtained a deposition on the abaxial side of leaves as high as 32% of the total deposit on the leaves by low pressure spraying in 0.6 m high chrysanthemum plants »by spraying the plants from the side of the beds ensuring that the spray was directed from ground level up toward the underside of the leaves and also from above«.

Use of air assistance might be a way to increase the deposition on the abaxial side of the leaves and increase the penetration into broad leaved crops (13, 15, 18) but apparently not into narrow leaved crops (7, 9).

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