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Effect of the spray distribution set-up of a cross-flow fan orchard sprayer on the spray deposition in a flat surface and in a tree

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Abstract

In a series of experiments the effect of sprayer set-up was assessed for spray deposit. A cross-flow fan sprayer was set-up to produce a uniform or a tree-shape liquid distribution on a vertical patternator. These distribution set-ups were used to quantify spray deposit stationary on the vertical patternator and also in a dynamic situation using a fluorescent tracer. Sprayer speeds of 0.6, 1.2 and 2.0 m/s were used. Also a comparison was made between the spray deposition on a flat surface and in a tree. Measurements were performed in artificial trees, therefore identical branch and leaf orientation was maintained throughout the experiments. In the trees a differentiation was made in five collection segments: top, middle and bottom (left, centre, right). Collectors in these segments of the tree were placed either in a horizontal or a vertical plane in order to assess leaf orientation on spray collection capability. Results show that with increasing speed the uniform distribution maintains its shape as of the stationary set-up. The tree shape distribution changes to a uniform distribution when passing the collection surface with increasing speed. In the tree a differentiation in spray deposition is seen because of the initial liquid distribution set-ups. In the top segment of the tree spray deposit of the uniform liquid distribution set-up is higher. In the middle and the bottom segment the tree shape liquid distribution has a higher spray deposit. Especially in the top, the middle and the bottom segments of the tree differences do occur in spray deposition ratio between horizontal and vertical placed collectors. The differences in spray deposition in an artificial tree are correlated with the initial liquid distribution set-up.

Introduction

Based on the experience with arable field-crop sprayers it is said that for a good crop protection the spray liquid distribution should be uniform. For field-crop sprayers this means that distribution in the horizontal plane on top of the crop canopy should be even. The evenness of the spray distribution is evaluated on a patternator. Based on the distribution on the patternator nozzle types, spacing of nozzles and sprayer boom height are adapted in order to come to an uniform distribution, within certain boundary conditions (e.g. coefficient of variation within limits). For orchard sprayers theory is more complicated. In fruit crop spraying the goal is to come to an uniform spray deposition all over the leaves in the tree. Losses to the soil underneath the tree and outside of the orchard through spray drift are to be minimised. Spray distribution measurements of orchard sprayers are measured in a vertical plane (MIRALLES *et al.*, 1996). However it is not clear what the relation is between a spray distribution measured stationary in a vertical plane and that in a dynamic situation, when driving through an orchard, and the spray deposition on the leaves in the tree. SCHMIDT & KOCH (1995) concluded that the requested distribution on a patternator depends on the type of sprayer and the shape and height of the trees to be sprayed. KOCH *et al.* (1998) found that with a cross-flow fan sprayer a fixed nozzle distance in combination

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with a uniform distribution on the vertical patternator was preferred to obtain a homogeneous spray distribution on the leaves of the tree. SIEGFRIED *et al.* (1995) prefer however a more canopy shaped spray distribution corresponding with leaf-mass and canopy-width in the tree.

In this paper we describe the research comparing a stationary and a dynamic measurement of spray distribution on a vertical measuring system for the spray output distribution of orchard sprayers (PORSKAMP *et al.*, 1993). Both a uniform and a tree canopy shaped (pyramid) spray distribution are compared. Dynamic measurements took place for three driving speeds. An evaluation was also made for both spray distributions and speeds on the spray distribution in different segments of an artificial apple tree. Spray deposition on collectors placed in different orientations in these tree-segments were compared with the offered spray as measured on the vertical measuring system.

Materials and methods

The experiments were performed using an axial fan orchard sprayer equipped with a cross-flow airflow device (Munckhof). Air-flow from the sprayer was in a horizontal direction and uniform in speed in the vertical plane for heights from 0.5m to 2.5m above soil surface. Liquid distribution in the vertical plane could be set by adapting nozzle-types and nozzle directions. In this way either a uniform and a tree-shaped distribution was set-up. A uniform liquid distribution means that spray distribution is equal for the different heights. With a tree-shaped liquid distribution spray volume is adapted to the amount of leaves in the tree. With this set-up spray volume changes with height of the tree and therefore is higher in the bottom of the tree and lower in the top of the tree.

STATIONARY MEASUREMENTS

In the laboratory a series of measurements were performed to set-up the spray volume distribution in the requested uniform and tree-shaped way. To quantify spray volume with height a standard measuring system was used (PORSKAMP *et al.*, 1993). The measuring system consists of a vertical pole (3.0m high) mounted on a 4-wheel cart that moves at constant speed (0.15 m/s) over guiding rails at a pre-set distance (1.5m from the centre of the sprayer) alongside the sprayer. Spray distribution is measured on 30 vertical spray collectors that are attached to the pole at intervals of 100mm. The collectors are filter papers (100x125mm), quick-fixed to an adapter at the pole. The increase in weight of the spray collectors is measured with an electronic balance, and transferred to a computer. The computer processes the weight per collector and presents the distribution pattern as tables and diagrams. Measurements were executed in three replications.

Spray volume distribution is obtained by choice of nozzle size and nozzle direction. The total output of spray volume was intended to be equal for both distribution set-ups. Vertical nozzle height and spacing used was as set by the manufacturer. In table 1 nozzle spacing, nozzle type (Albuz hollow cone) and size (colour), nozzle flow rate (operated at 7 bar pressure) and direction (angling from horizontal plane) are given as used to produce a tree-shaped and a uniform spray distribution on the vertical measuring system.

TABLE 1

Characteristics of the sprayer and the sprayer settings for a uniform and a tree-shaped spray distribution on a vertical measuring system

Nozzle height (cm)	Tree shape distribution			Uniform distribution		
	nozzle	flow rate (l/min.)	angle [1])	nozzle	flow rate (l/min.)	angle [1])
50	Brown	0.59	15	Brown	0.64	17
67	Brown	0.56	8	Brown	0.56	-22
84	Brown	0.56	5	Brown	0.55	-13
102	Orange	1.18	-13	Lilac	0.41	-18
130	Lilac	0.42	-20	Brown	0.55	14
165	Lilac	0.41	-19	Lilac	0.42	12
200	Lilac	0.41	20	Lilac	0.41	-11
235	-	-	-	Brown	0.54	-15

[1])positive angle = upward direction

DYNAMIC MEASUREMENTS

To assess the effect of velocity on spray distribution the stationary measurements were repeated under dynamic conditions. In an outdoor experiment, vertical distribution was quantified (3 replications) on the same measuring system with the orchard sprayer passing at driving speeds of 0.6, 1.2 and 2.0 m/s. The quantification of the spray deposition on the collectors was in this case not performed by means of weighing spray liquid deposition but by fluorimetry. Therefore a fluorescent tracer (Brilliant Sulfo Flavine BSF, 0.5g/l) was added to the tank mix.

In order to evaluate the effect of spray volume set-up on leaf deposition in a tree, spray deposition measurements were performed passing a 'row' of three artificial apple trees. These trees were reconstructed from a semi-dwarf Elstar apple tree on M9 rootstock. Stem and main branches were reconstructed from aluminium. Shoots were established with artificial Ficus Benjamina leaves. Height of the tree was 2.2m, crown diameter was 1.5m The tree had 3000 leaves and total leaf area was 6.8 m^2. With a tree density of 3m row spacing and 1.25m tree spacing in the row leaf area index (LAI) is 1.8.

The orchard sprayer passed at driving speeds of 0.6, 1.2 and 2.0 m/s (3 replications) with both spray distribution set-ups. Spray deposition in the tree was quantified using paperstrip collectors (6x5 cm) placed in five sections of the leaf canopy. A distinction is made between vertical and horizontal placed collectors. Per canopy segment 2 papers were placed in each direction. Segments sampled were the top of the tree on 2m height, the middle section on 1 m height and the bottom section on 0.5m height both on the left and right-hand side of the tree and in the centre.

TABLE 2

Characteristics of the artificial apple trees used in the experiments.

Height [cm]	Tree		Leaves		
	Volume [cm^3]	Projection Area [cm^2]	Number	Area [cm^2]	Number/dm^3
30-75	794812	6750	1386	30603	1.7
75-150	772656	8438	1386	30603	1.8
150-225	110377	2812	210	4637	1.9

Number of leaves and leaf surface area are as measured from an orchard tree. In order to estimate a number density of leaves per segment the tree volume and projection areas per segment were estimated. Calculation basis was a cylinder for the bottom segment (1.5m diameter) of 0.30-0.75m height, and a truncated cone (base diameter 1.5m) with a height of 1.5m for the middle and the top section, respectively 0.75-1.50m and 1.50-2.25m height.

statistical analysis
A statistical analysis was executed on the results. Differences between means were assessed using analysis of variance at a 95% confidence interval with the GENSTAT software package (PAYNE, 1993).

Results

UNIFORM AND TREE-SHAPE SPRAY DISTRIBUTION

By choosing nozzle types and nozzle direction on a cross-flow sprayer (Table 1) an uniform and a tree-shaped spray distribution could be generated in a stationary measuring situation. Spray pressure was 7 bar. Lowest nozzle was at 0.5m height and highest nozzle was at 2.35m height. Total flow rate of the nozzles was 4.2 l/min. Results of this sprayer set-up, on the vertical measuring system on 1.5m distance from the centre of the sprayer, was as shown in Figure 1. Spray distribution is expressed as percentage of the total spray volume.

STATIONARY AND DYNAMIC SPRAY DISTRIBUTION

The stationary spray distribution was measured under laboratory conditions and obtained by weighing the deposited spray on the collectors. In the dynamic situation measurements were performed outdoors, influenced by the weather conditions. Spray deposition was quantified by means of fluorimetry. A comparison of the stationary and dynamic situation is made for the 0.6m/s velocity, and shown for both distribution set-ups in figs. 2 and 3 for the tree-shaped and the uniform spray distribution respectively.
Both the tree-shape (fig. 2) as the uniform (fig. 3) spray distribution show a good resemblance between the stationary and the dynamic measurement when driving speed is low (0.6 m/s).
When in the dynamic situation sprayer velocity changes from 0.6 to 1.2 and 2.0 m/s the spray distribution measured on the vertical measuring system changes as can be seen in figures 2 and 3 for respectively the tree-shaped and the uniform distribution. Because of the increase in driving speed spray deposition on the upper half of the measuring system increases. In table 3 the average spray deposition discriminated in the zones 0-100, 100-200 and 200-300 cm height on the spraying system are presented for the three sprayer speeds and two spray distribution set-ups.

TABLE 3
Effect of sprayer speed and spray distribution setting on spray deposition (% total spray deposition) differentiated to height segments on a vertical measuring system

Distribution setting	Segment	Height [cm]	Sprayer speed [m/s]		
			0.6	1.2	2.0
Tree-shape	Top	200-300	7[a]	11[b]	19[c]
	Middle	100-200	35[a]	41[a]	39[a]
	Bottom	0-100	58[a]	48[b]	42[c]
Uniform	Top	200-300	26[a]	27[a]	35[b]
	Middle	100-200	35[a]	35[a]	30[b]
	Bottom	0-100	39[a]	38[a]	34[b]

same letter for speeds means no significant difference $\alpha<0.05$

For the tree-shaped spray distribution it is shown (Table 3) that with increasing speed from 0.6 m/s to 2.0 m/s spray deposition changes with height. On the bottom segment of the measuring system spray deposition reduces significantly ($\alpha<0.05$) from 58% to 42% of the applied volume. In the middle segment no differences are found. In the top segment spray deposition more than doubles from 7% to 19% when speed increases from 0.6 m/s to 2.0 m/s. With the uniform spray distribution the same trends do occur. The changes in spray deposition are however less pronounced for the uniform than for the tree-shaped distribution. With increasing speed both spray distribution settings tend to change therefore toward a more uniform distribution with height.

However when the spray deposition data on the measuring system are not evaluated on a relative basis, as deposition from total (Table 3), but on an absolute basis of spray deposition expressed as $\mu l/cm^2$ other conclusions can be drawn from the same (measured) deposition results (Table 4). Expressed as spray liquid amount per unit area, spray deposition in the bottom segment of the measuring system was for all sprayer speeds higher for the tree-shaped distribution than for the uniform spray distribution. In the middle segment spray deposition was equally high for both distribution settings for the 0.6 m/s speed, and higher for the tree-shaped distribution for the 1.2 m/s and the 2.0 m/s driving speed. For the top segment the tree-shaped distribution gave a lower deposition for the 0.6 and 1.2 m/s sprayer speeds and no difference in deposition was found for both distribution settings for the 2.0 m/s sprayer speed.

TABLE 4

Effect of sprayer speed and spray distribution setting on spray deposition ($\mu l/cm^2$) differentiated to height segments on a vertical measuring system

Distribution setting	Bottom 0-100 cm			Middle 100-200 cm			Top 200-300 cm		
	Sprayer speed [m/s]			Sprayer speed [m/s]			Sprayer speed [m/s]		
	0.6	1.2	2	0.6	1.2	2	0.6	1.2	2
Tree-shaped	4.07[a]	2.11[a]	1.37[a]	2.44[a]	1.82[a]	1.29[a]	0.50[a]	0.51[a]	0.63[a]
Uniform	2.47[b]	1.20[b]	0.74[b]	2.26[a]	1.12[b]	0.65[b]	1.63[b]	0.88[b]	0.75[a]

same letter for speeds means no significant difference $\alpha<0.05$

SPRAY DISTRIBUTION IN A TREE

In an artificial tree spray deposition is assessed on five canopy sections. The offered spray amount on the canopy sections is known from the corresponding segment heights on the measuring system. Results of the deposition measurements in the artificial apple tree are summarised in Table 5. Results for the left-hand and right-hand side bottom sections are averaged. Deposition measurements are presented for the horizontal and vertical collectors in the canopy sections, three sprayer speeds and two spray distribution settings.

TABLE 5

Effect of sprayer speed and spray distribution setting on spray deposition
differentiated to canopy segments in an artificial apple tree measured on horizontal
and vertical placed collectors (μl/cm^2)

Sprayer speed [m/s]	Section in tree	Tree-shaped distribution		Uniform distribution		Tree-shaped distribution	Uniform distribution
		Horizontal	Vertical	Horizontal	Vertical	Total	Total
0,6	Top	1,49 [a]	1,11 [b]	3,44 [a]	1,86 [b]	1,30 [a]	2,65 [b]
	Middle	3,14 [a]	1,92 [b]	2,55 [a]	0,58 [b]	2,53 [a]	1,57 [b]
	Bottom-centre	0,61 [a]	0,22 [b]	0,39 [a]	0,48 [a]	0,41 [a]	0,44 [a]
	Bottom-out	1,19 [a]	3,82 [b]	0,96 [a]	3,36 [b]	2,50 [a]	2,16 [a]
	Average	1,52	2,18	1,66	1,93	1,85	1,80
1,2	Top	0,92 [a]	0,49 [b]	1,66 [a]	1,01 [b]	0,70 [a]	1,33 [b]
	Middle	1,19 [a]	0,68 [b]	1,18 [a]	0,30 [b]	0,93 [a]	0,74 [a]
	Bottom-centre	0,19 [a]	0,14 [a]	0,24 [a]	0,15 [a]	0,17 [a]	0,19 [a]
	Bottom-out	0,88 [a]	1,99 [b]	0,37 [a]	1,44 [b]	1,43 [a]	0,91 [b]
	Average	0,81	1,06	0,76	0,87	0,93	0,87
2,0	Top	0,43 [a]	0,33 [a]	0,87 [a]	0,88 [a]	0,38 [a]	0,88 [b]
	Middle	0,88 [a]	0,61 [b]	0,94 [a]	0,24 [b]	0,74 [a]	0,59 [a]
	Bottom-centre	0,07 [a]	0,06 [a]	0,15 [a]	0,16 [a]	0,07 [a]	0,16 [b]
	Bottom-out	0,26 [a]	0,80 [b]	0,26 [a]	0,92 [b]	0,53 [a]	0,59 [a]
	Average	0,38	0,52	0,50	0,62	0,45	0,56

same letter for section and direction or distribution means no significant difference $\alpha<0.05$

For a driving speed of 0.6 and 1.2 m/s spray deposition in the top and middle section
of the tree is higher on the horizontal than on the vertical collectors (Table 5). In the
bottom-out section of the tree spray deposition is higher on the vertical placed
collectors. In the bottom-centre of the tree spray deposition is very low and no
differences were found between horizontal and vertical collector deposition, except
for the 0.6 m/s tree-shaped distribution. No difference was found between distribution
set-ups.
Effect of sprayer speed and spray distribution setting on the total spray deposition
differentiated to canopy segments in an artificial apple tree and the on equal heights
offered spray volume assessed on a vertical measuring system are compared in Table
6. Spray deposition in the bottom-centre of the tree is for all situations lower than
measured on the same height on the vertical measuring system.

TABLE 6

Effect of sprayer speed and spray distribution setting on spray deposition
differentiated to canopy segments in an artificial apple tree and the offered spray
volume assessed on a vertical measuring system (μl/cm^2 and %)

Sprayer speed [m/s]	Height on Measuring system [cm]	Section in tree	Tree-shaped distribution			Uniform distribution		
			Offered μl/cm^2	Deposition μl/cm^2	Deposition of offered %	Offered μl/cm^2	Deposition μl/cm^2	Deposition of offered %
0.6	150-225	Top	0.90	1.30	144	2.56	2.65	104
	75-150	Middle	3.89	2.53	65	2.38	2.16	66
	30-75	Bottom-centre	4.90	0.41	8	2.73	0,44	16
	30-75	Bottom-out	4.90	2.50	51	2.73	2.16	79

1.2	150-225	Top	0.97	0.70	72	1.26	1.33	106
	75-150	Middle	2.33	0.93	40	1.14	0.74	65
	30-75	Bottom-centre	2.58	0.17	7	1.32	0.19	14
	30-75	Bottom-out	2.58	1.43	55	1.32	0.59	69
2.0	150-225	Top	0.86	0.38	44	0.77	0.88	114
	75-150	Middle	1.60	0.74	46	0.68	0.59	87
	30-75	Bottom-centre	1.61	0.07	4	0.82	0.16	20
	30-75	Bottom-out	1.61	0.53	33	0.82	0.59	72

With the tree-shaped distribution spray deposition in the bottom-centre and the bottom-out of the tree is lower than on the vertical measuring system. In the top of the tree more spray deposition is measured in the tree than on the same height at the measuring system. With a sprayer speed of 1.2 and 2.0 m/s spray deposition in the tree is on all other sections lower than on the vertical measuring system with the same speeds. For the 2 m/s speed this is less than 50% of what is collected on the vertical measuring system.

For the uniform distribution set-up spray deposition in the top section of the tree is comparable with the deposit on the vertical measuring system. In the middle and bottom-out section spray deposition is on average 75% of the amount measured on the vertical measuring system.

Discussion

KAUL et al. (1996) concluded that there is no good relation between the spray distribution on a vertical patternator and the spray distribution in a tree canopy. It was suggested that a vertical patternator only allows the description of vertical distribution patterns at low forward speed of the sprayer in the orchard, as can be seen from figure 2 and 3. They advocated the need for dynamic measurements of vertical spray distribution and showed the effect of speed on a paper strip wall when passing with a speed of 6 km/h. They also showed a good resemblance between spray deposition on the paper strips with in tree deposit. Because of speed they found also a higher deposit at higher heights coinciding with the top of the tree (1.75-2.50m).

Spray distribution on the vertical measuring system had on average a recovery of 55% to 94% of total sprayed volume. When recovery on the vertical patternator is in the range of 80-90% of sprayed volume distribution over height will in general have a good correlation with the offered flux over height (μl/cm^2). If the recovery is lower than it will not be clear whether differences in sprayer distribution can be attributed to the sprayer settings or to the differences in collector efficiency. When the volume distribution on the vertical measuring system is presented on the different heights as percentage of total captured volume it is assumed that spray recovery for the collectors on these heights is identical for all speeds. If results are presented as μl/cm^2 the difference in collector efficiency for height and speed are implicitly in the results. These differences can influence the presentation of the results and the conclusions drawn. The results presented in Table 3 and 4 show these differences. Based on Table 5 it can be concluded that more spray deposition is found in the top of the tree with increasing sprayer speed (for 0.6 m/s 7% spray deposition, for 1.2 m/s 11% spray

deposition, for 2.0.m/s 19% spray deposition). Based on Table 5 these values are respectively 0.5, 0.51 and 0.63 μl/cm^2.When spray deposition is normalised for differences in sprayer speed (spray volume) relative increase of spray deposition with increasing speed is respectively 1 : 1.6 : 2.7 according to spray distribution data (Table 3) and 1 : 2 : 2.2 to spray deposition data (Table 4). The recovery of the vertical measuring system was with increasing speed respectively 60%, 76% and 90%, and apparently influences presented results and conclusions. It must be emphasised that when spray deposition measurements are performed in trees, also measurements should be carried out on the same collector types in identical situations without a tree to quantify collector efficiency.

Conclusions

For low sprayer speeds (0.6 m/s) there is a good correlation with a stationary spray distribution measurement on a vertical measuring system. With increasing speed the uniform distribution maintains its shape as of the stationary set-up. The tree shape distribution changes toward a more uniform distribution when passing the collection surface with increasing speed. For higher sprayer speeds (1.2 m/s and 2.0 m/s) the spray deposition in the top section on the measuring system increases and decreases in the lower section, compared to stationary.

With a tree-shaped spray distribution set-up, spray deposition in the artificial apple tree was lower as for the comparable heights on the vertical measuring system. This was especially the case in the bottom-centre of the tree. For the 0.6 m/s sprayer speed spray deposition in the top of the tree seems to be higher than offered on the same height on the vertical measuring system. For the 2.0 m/s sprayer speed spray deposition in the tree was only half of the amount on the vertical measuring system.

With a uniform spray distribution set-up the spray deposition on the vertical measuring system and on the same heights in the artificial apple tree are much more (75%-100%) of the same level. Except also for the bottom-centre of the tree.

Spray deposition on horizontal placed collectors in the tree were for both distribution set-ups higher than on vertical placed collectors in the top and the middle sections of the tree. In the bottom section of the tree more spray liquid was deposited on the vertical placed collectors.

If the recovery of applied measuring techniques is getting low, the accuracy of conclusions drawn can be discussed. The way results are presented, e.g. % of spray distribution or μl/cm^2, can influence than the conclusions.

Acknowledgements

Samenvatting

VLOEISTOFVERDELING VAN EEN BOOMGAARDSPUIT IN EEN PLAT VLAK EN IN EEN BOOM

Bij de gewasbescherming is het belangrijk dat de spuitvloeistof regelmatig over het doelobject wordt verdeeld. Ook op de bladeren van bomen is het streven op elk blad dezelfde hoeveelheid vloeistof aan te brengen met zo weinig mogelijk verliezen naar de bodem en zo weinig mogelijk drift naar buiten het perceel. Verdelingsmetingen aan fruitteeltspuiten worden veelal uitgevoerd in een plat verticaal vlak. Niet duidelijk is wat de optimale verdeling in het verticale vlak is en hoe de relatie is tussen de verdeling in het verticale vlak en de verdeling op de bladeren in de boom. In dit onderzoek wordt allereerst een vergelijking gemaakt tussen een stationaire en een dynamische verdelingsmeting op een verticale meetmast. Bij dynamische metingen is voor een boomvormige en een vlakke afstelling van de spuit de invloed van de rijsnelheid op het verdelingspatroon op de meetmast bepaald. Op meerdere plaatsen in een kunstboom is tenslotte de op horizontaal en verticaal geplaatste collectoren gemeten vloeistofhoeveelheid bepaald en vergeleken met de aangeboden vloeistof gemeten op de meetmast. Bij het bepalen van de vloeistofverdeling van een dwarsstroom fruitteeltspuit op een verticale meetmast is er weinig verschil in verdelingsvorm tussen een stationaire meting en een dynamische meting bij een rijsnelheid van 0,6 m/s. Door het verhogen van de rijsnelheid van 0,6 naar 2,0 m/s wordt er minder op het onderste deel van de meetmast gemeten en meer op het bovenste deel. Dit is zowel het geval bij een afstelling met een boomvormige als met een vlakke verdeling. Bij een boomvormige afstelling van de spuit wordt op collectoren in een kunstboom per cm^2 minder vloeistof opgevangen dan op de meetmast wordt aangeboden. Bij een vlakke afstelling liggen de op de mast aangeboden en in de boom gemeten hoeveelheden veel dichter bij elkaar.

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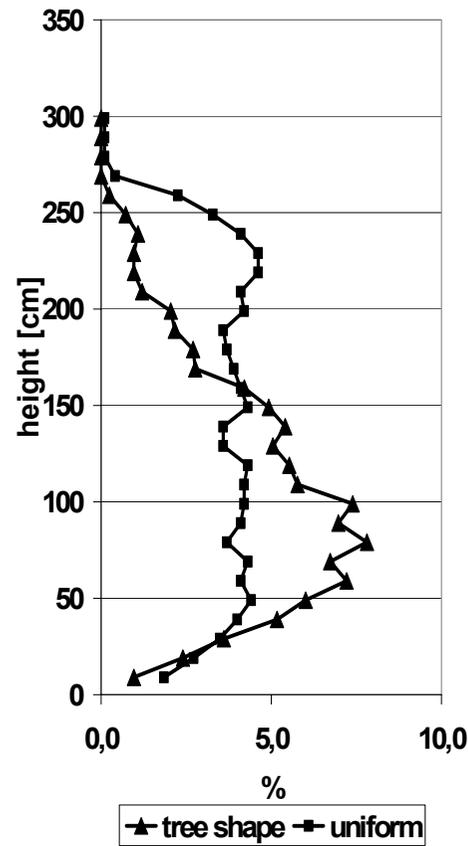
Figure 1. Stationary measured distribution of a tree-shape and a uniform distribution setting of a cross-flow orchard sprayer
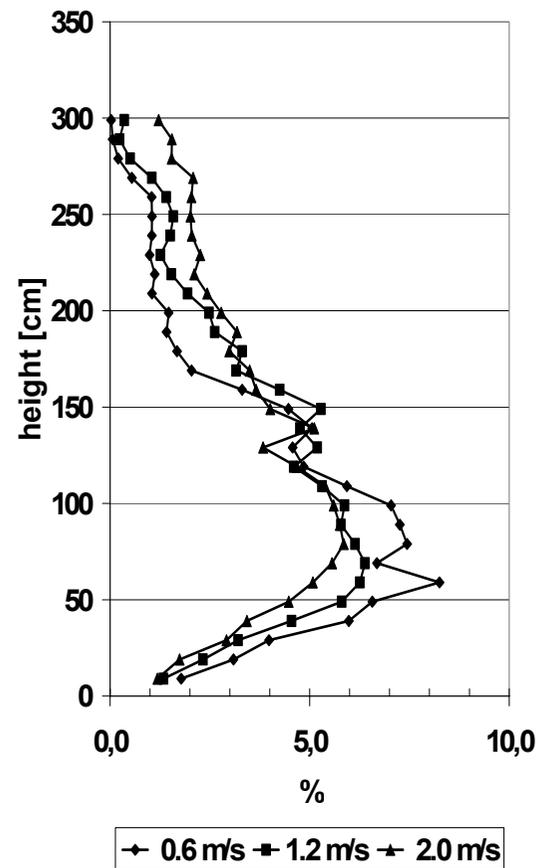
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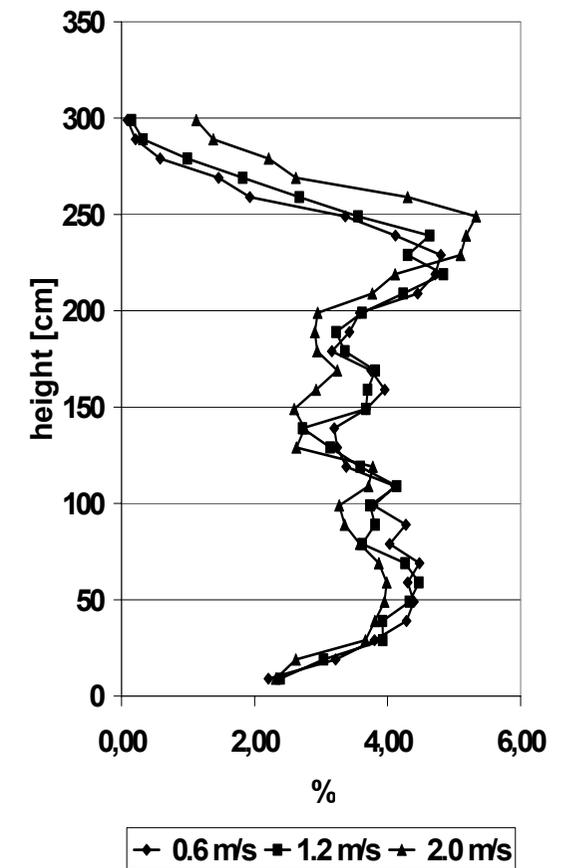
Figure 3. Dynamic measurements of spray distribution of an uniform distribution setting of a cross-flow orchard sprayer with different speeds