Droplet size spectrum of overhead irrigation sprinklers used for targeted apple scab control

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Abstract

The Research Centre Laimburg (South Tyrol, Italy) has been conducting trials on the use of plant protection products, applied via overhead irrigation, for apple scab control for more than 10 years. High levels of efficacy were achieved in several trials carried out in South Tyrol and in other fruit growing areas. However, in most countries it is still not clear whether a multi-functional overhead irrigation, developed for frost protection and irrigation, can also be used for plant protection. Different technical details such as pump pressure, sprinkler type, nozzle size, irrigation pipeline design and finally droplet size are under discussion.

It has not yet been established whether and to which extent (as during the application with conventional spray equipment) small driftable droplets are produced by using the overhead irrigation system. This study aimed at determining the droplet size spectrum of different circle sprinklers.

Keywords: overhead irrigation, plant protection, droplet spectrum, sprinklers, droplet size, drift

Introduction

In the orchards in South Tyrol, overhead irrigation systems have been used for decades not only for irrigation, but also for frost protection (Mantinger & Tinkhauser, 1978). Already in the 1950-ies and 1960-ies, overhead irrigation has been used in South Tyrolian orchards also for the application of plant protection products (Ramoser, 1966; 1971). Trials on the use of overhead irrigation systems for plant protection in fruit and especially grapevine production have been conducted also in Switzerland (Peyer, 1964) and Germany (Kümmerer, 1969; Goedecke, 1971; Müller, 1979). Depending on the target, results varied considerably, and for several agronomic and economic reasons the use of conventional foliar broadcast sprayers finally prevailed. In the 1990-ies the application of plant protection products via overhead irrigation was taken up again by the Research Centre Laimburg within the field of organic farming, in particular to improve scab control in organic orchards.

For scab control, many organic growers in South Tyrol rely on foliar applications directed onto the wet vegetation. Since these treatments must be carried out within a short period of time (Zemmer, 2001), their application via overhead irrigation is especially suitable, as already evidenced in several studies (Kelderer *et al*., 2000). In addition, the application via overhead irrigation proved to be effective in preventing phytotoxicity symptoms of lime sulphur (leaf burn) on the crop, which commonly occur when the product is applied as a conventional foliar broadcast spray (Kelderer *et al*., 2006).

According to the new Italian Regulation on Plant Protection, all systems that are used for the application of plant protection products, must be inspected, and information on technical details such as pump pressure, sprinkler type, nozzle size, irrigation pipeline design and finally droplet size must be provided.

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In this study we tried to overcome the lack of information concerning droplet size spectrum of overhead irrigation systems. „Pesticide drift is the movement of airborne spray droplets, vapors, or dust particles away from a target area" (Baker & Cordell, 1998). By using conventional foliar spray equipment, the spray drift of plant protection products from the target area onto adjoining crops, areas, and/or water is a major problem. Spray drift also results in the loss of part of the spray solution during application. Furthermore, spray drift can result in water contamination, health risk for animals and humans, and under- and/or over-application in small areas. Several factors, especially those of technical and meteorological origin, may result in drift of a spray solution, and droplet size is the major cause (Nuyttens *et al.*, 2011). "When a liquid solution is sprayed under pressure it is atomized into droplets of varying sizes: the smaller the nozzle size and the greater the spray pressure, the smaller the droplets and therefore the greater the proportion of driftable droplets. Other causes of spray drift are spray heights, operating speed during application, wind speed, temperature, humidity, spray volume and spray product (http://www.teejet.com, 07.07.2011). Concern exists that spray drift may occur also by using overhead irrigation for plant protection. The risk of drift is considered to exist for droplets below 250 µm in size (www.wysspumpen.ch, 2010). In this study, the droplet size spectrum of different overhead sprinklers was determined.

Material and Methods

The trials have been conducted in a sprinkler test station of the Research Centre Laimburg (South Tyrol, Italy). A digital pressure regulator was used to adjust pressure. The sprinkler types equipped with different nozzles and pressure setups and listed in Table 1 were tested.

Table 1: Tested sprinkler types, nozzle sizes, pressure setups, spray radius and flow rates (data provided by manufacturers and/or obtained from separate measurements).

Sprinkler type	Nozzle size (mm)	Pressure (bar)	Spray radius (m)	Flow rate (l/min)
Kofler K 10	3.0	3.0	11.3	10.3
	3.0	4.0	12.2	11.9
	4.0	3.0	11.3	18.3
	4.0	4.0	12.1	21.1
Kofler K 16	3.0	3.0	10.9	10.3
	3.0	4.0	11.6	11.9
	4.0	3.0	12.6	18.3
	4.0	4.0	13.5	21.1
Perrot ZS30	3.5	3.0	13.5	12.5
	3.5	4.0	14.8	14.5
	4.0	3.0	14.5	16.5
	4.0	4.0	15.4	19.0
NetafimMeganet*	Blau 450	2.5	ca. 8	8.0
	Blau 450	3,0	ca. 8	8,5 l/min

* Data obtained from own separate measurements.

Droplet size spectrum

Strips of water sensitive paper (Syngenta water sensitive paper 52×76) were fixed onto wooden slats and deployed along a row at 1 meter distance one from the other starting from the sprinkler. The sprinkler was then turned on for one full rotation. As soon as the water droplets had dried, the paper strips were scanned and analysed on the computer.

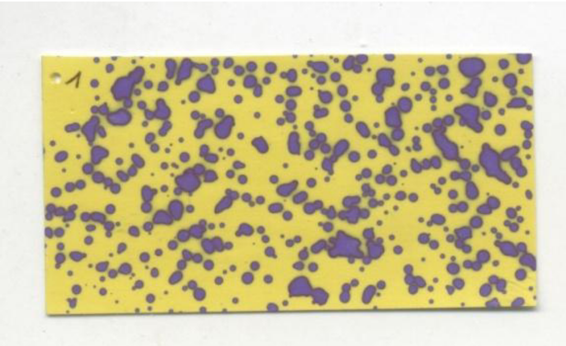

Fig. 1: water sensitive paper after one full rotation of a sprinkler.

Water distribution

Graduated jugs were placed along a row at 1 meter distance one from the other starting from the sprinkler. The sprinkler was then turned on for one hour and the water volume collected in each of the graduated jugs was then measured.

The weather station of the Research Centre Laimburg was used to determine wind speed and thus to decide whether to accept or repeat the measurement.

Computations

By using pipettes, samples of droplets of the following sizes on water sensitive paper were prepared: 100, 50, 10, 5, 2.5, 2, 1.5, 1, 0.9, 0.8, 0.7, 0.6, 0.5, and 0.4 µl. The paper strips were then scanned and the area covered by the droplets on the paper was determined by using the image processing and analysis program „Image Tool" (http://ddsdx.uthscsa.edu/dig/itdesc.html, 25.10.2011). The curves and functions relating the covered area to droplet size were obtained by using Excel software. To find the best data fit, two distinct functions, each plotting different droplet sizes, were compiled, one for droplets ranging from 2 to 100 µl in size ($y = -4e^{-24}x^3 + 3e^{-16}x^2 + 7e^{-7}x - 3{,}5589$), and one for droplets ranging from 0.4 to 2.0 µl in size ($y = 1e^{-28}x^4 + 4e^{-21}x^3 - 4e^{-14}x^2 + 2e^{-7}x$).

The following formula (source: Wikipedia „Droplet", 01.06.2010) was used to convert droplet volume (pl) in droplet diameter (µm):

Droplet diameter = $\sqrt[3]{\dfrac{Dropletvolume \times 6000}{3.14}}$

Droplet sizes obtained were then classified by using a scale such as the following (source: http://www.wysspumpen.ch/duesenrechner_feldbau.html, 01.06.2010):

>550 µm, especially big

400 – 550 µm, very big

350 – 400 µm, big

250 – 350 µm, medium

150 - 250 µm, small, risk of spray drift

< 150 µm, very small, not recommendable

By using the functions and formulas described above, the droplet size classes could finally be converted first in droplet volume, and then in droplet area.

Each area covered by the droplets on the paper strips used in the trials (which had been previously scanned and analysed by using the program „Image Tool“) could thus be assigned to one of the different classes.

Since neither visually nor with image analysis an exact distinction between blurry, overlapping droplets could be made, these were considered as one single droplet in all calculations.

Results

For each combination sprinkler type-nozzle size-pressure setup, a table reporting water distribution (in mm/h and %), and the percentage of water per droplet size class at different distances from the sprinkler was prepared (see Table 2 as example). The total percentage of water within each droplet size class for all tested sprinkler type-nozzle size-pressure setup combinations is reported in Table 3.

Table 2: Droplet size spectrum of sprinkler type Kofler K10 with nozzle of 3 mm in size at a pressure setup of 3 bar.

Distance (m)	**Water distribution (mm/h)**	**Water distribution (%)**	**Percentag (%) of water within each droplet size class (µm Ø)**					
			<150 (%)	**150-250 (%)**	**250-350 (%)**	**350-400 (%)**	**400-550 (%)**	**>550 (%)**
1	2.99	15.44	0.04	0.50	4.17	5.02	16,41	73,86
2	2.26	11.66	0.01	0.06	1.11	2.03	12,19	84,60
3	1.69	8.72	0.03	0.09	0.49	1.36	3,96	94,08
4	1.87	9.66	0.05	0.09	0.49	0.31	9,32	89,74
5	1.71	8.82	0.04	0.28	0.45	0.10	0,75	98,38
6	1.95	10.08	0.04	0.35	0.54	0.20	1,08	97,79
7	1.93	9.98	0.10	1.60	4.93	4.79	6,00	82,58
8	1.32	6.83	0.04	0.32	0.72	0.83	1,53	96,56
9	1.14	5.88	0.03	0.16	0.23	0.00	0,28	99,30
10	0.91	4.73	1.85	4.82	6.82	11.12	32,97	42,42
11	0.81	4.20	0.08	0.34	0.46	0.56	1,53	97,03
12	0.53	2.73	0.02	0.11	0.13	0.13	0,65	98,95
13	0.24	1.26	1.28	0.45	0.00	6.94	17,35	73,97
Mean percentage of water in each droplet size class			**0.14**	**0.60**	**1.86**	**2.36**	**7.96**	**87.08**

For the combination sprinkler type-nozzle size-pressure setup described in Table 2, the highest amount of small droplets (< 250 µm) was found at a distance of 10 (1.85% + 4.82%) and 13 m (1.28% + 0.45%).

Table 3: Percentage of water within each droplet size class for the tested sprinkler type-nozzle size-pressure setup combinations

Sprinkler-nozzle-pressure	Percentage (%) of water in droplet size class					
	<150 µm	150-250 µm	250-350 µm	350-400 µm	400-550 µm	>550 µm
K10 3mm 3bar	0.14	0.60	1.86	2.36	7.96	87.08
K10 3mm 4bar	0.04	0.27	0.73	0.66	2.46	79.06
K10 4mm 3bar	0.06	0.56	1.09	0.83	3.28	94.18
K10 4mm 4bar	0.03	0.23	0.62	0.50	1.39	97.23
K16 3mm 3bar	0.05	0.46	1.74	1.78	4.96	91.06
K16 3mm 4bar	0.06	0.22	0.60	0.55	1.68	96.90
K16 4mm 3bar	0.04	0.44	0.85	0.78	3.29	94.61
K16 4mm 4bar	0.04	0.20	0.44	0.64	2.22	96.46
Perrot ZS30 3.5mm 3bar	0.02	0.11	0.17	0.12	0.28	99.31
Perrot ZS30 3.5mm 4bar	0.03	0.12	0.18	0.14	0.82	98.70
Perrot ZS30 4mm 3bar	0.09	0.55	1.87	0.81	3.64	93.04
Perrot ZS30 4mm 4bar	0.04	0.20	0.69	0.70	1.89	96.47
Netafim 2.5bar	0.21	0.84	1.15	0.72	1.31	95.76
Netafim 3bar	0.02	0.16	1.15	1.78	10.63	86.26

Since droplets of both 150-250 µm and <150 µm in size are considered driftable. These two classes were combined in one single droplet size class of <250 µm (Table 3). The percentage of water within this class was very low for all sprinkler types. In fact, it exceeded 1% only for the sprinkler type Netafim at a pressure setup of 2.5 bar, while lowest values (0.13%) were recorded for the sprinkler type-nozzle size-pressure setup combination Perrot ZS30-3.5 mm-3 bar. Contrary to what assumed, the percentage of driftable droplets was always higher at low pressure than at high pressure, except for the combination sprinkler type Regner Perrot ZS30 - nozzle size 3.5 mm. In this case, the percentage of driftable droplets was comparable at both tested pressure setups, and amounted to 0.13% at 3 bar and 0.15% at 4 bar. For the sprinklers of the company Kofler an increased percentage of small, driftable droplets was recorded when these were used in combination with small nozzles, but no similar trend was observed for the sprinkler type Perrot ZS30.

Discussion

The use of overhead irrigation systems for the application of plant protection products, especially for products against apple scab, seems to be a valuable alternative to the use of conventional foliar broadcast sprayers, because it enables the grower to safe time and money. In addition, the applications can be conducted within a very limited period of time, which positively affects targeted apple scab control. In South Tyrol, growers have been using overhead irrigation systems for decades, primarily for frost protection. The entire area cultivated with apple is therefore equipped with overhead irrigation, thus favouring its use also for plant protection.

The Department for Organic Production of the Research Centre Laimburg has been evaluating the application of plant protection products, and especially of lime sulphur for targeted scab control, via overhead irrigation for 10 years (Kelderer. *et al.*, 2000). Within these studies, also the efficacy of different lime sulphur-based products was tested (Kelderer. *et al.*, 2006).

Overhead irrigation systems are supposed to have an average water consumption of 4 mm/h/m2. However, the actual amount of water may vary considerably depending on the structure of the entire irrigation system. In order to establish the water use per sprinkler and thus mean water consumption, pressure setup, friction loss in relation to irrigation pipeline length and diameter, and sprinkler height must be taken into consideration. The manufacturers of the sprinklers tested in our studies declare flow rates ranging from 10.3 l/min (Kofler K10. nozzle size 3 mm. pressure setup 3 bar) to 21.1 l/min (Kofler K10 and K16. nozzle size 4 mm. pressure setup 4 bar).

Since almost no information concerning the droplet size spectrum of overhead irrigation systems exists, we decided to determine the droplet size spectrum and the proportion of small driftable droplets of different sprinkler types. Except for sprinkler type Netafim at a pressure setup of 2.5 bar, for all the other tested combinations sprinkler type-nozzle size-pressure setup, the percentage of driftable droplets was below 1%. The time period required for the application of plant protection products via overhead irrigation amounts to 5 minutes, and 5 additional minutes are necessary for rinsing (Kelderer. *et al.*, 2000). The amount of water applied by each sprinkler in 5 minutes ranges from 52 l (Kofler K10, nozzle size 3 mm, pressure setup 3 bar) to 106 l (Kofler K10 and K16, nozzle size 4 mm, pressure setup 4 bar). Considering a percentage of driftable droplets of 1%, 0.5 to 1 l water are at risk of drift at each treatment application. An average irrigation system consists of approximately 50 sprinklers per hectare. Thus the amount of driftable water per hectare corresponds to 25-50 l per treatment application. According to the statement of a nozzle producing company, nozzles for a five times concentrated spray volume (300 l per meter crown height), 90% of the droplets have a diameter smaller than 250 µm and are so classified as driftable droplets. As visible in the experiment on hand, the overhead irrigation systems produce less than 1% of droplets in the driftable size range and can so be considered clearly less at risk of drift.

To clearly prove the drift potential of overhead irrigation, in addition to this experiment, spray drift trials should be carried out. It has to be considered that the proportion of small droplets prone to drift is relatively low, but all the irrigation heads are positioned above the canopies, where natural wind may easily pick up the smaller droplets below 250 µm, possibly depositing a significant fraction of those outside the orchard on non-target areas.

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