Influence of Droplet Spectra on the Efficiency of Contact Fungicides and Mixtures of Contact and Systemic Fungicides

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Abstract

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The effects of droplet spectra, spray volume, and the addition of an adjuvant to the spray solution against *Phytophthora infestans* were evaluated using contact fungicides, mixtures of contact and systemic fungicides, and a contact fungicide + an adjuvant. Six droplet spectra, ranging from VMD = 183 µm to VMD = 939 µm, were used. The spray volumes were 300, 450 and 600 l/ha for the contact fungicides, and 300 l/ha was used for the mix of contact with systemic fungicides. No significant differences in efficiency were observed between different droplet spectra when used for the mix of contact with systemic fungicide treatments. However, the efficiency of treatments with a contact fungicide significantly increased with smaller droplet spectra. The larger droplet spectra required larger spray volumes for greater efficiency. The addition of the adjuvant (pinolene, 96%) to the spray solution of the contact fungicide caused the efficiency to be similar for all droplet spectra. The effect of droplet spectra is more pronounced in contact compounds. The translocation of the systemic compounds and the ability of the surfactant to improve the coverage with contact compounds may be the main mechanisms that counteract the effects of larger droplet spectra and lower leaf coverage.

Keywords: *Phytophthora infestans*; fungicides; water volume; droplet size; droplet density

The use of agrochemicals to control pests in agricultural crops is a widely accepted practice. Most of these products are applied on the stand as liquid spray droplets. The atomisation process of converting liquid into spray droplets and the fate of the droplets after their formation are dependent on the physical properties of the formula, spray volume, nozzle type, nozzle pressure, and ambient conditions at the time of application. The fate of these droplets, and especially of the pesticide contained in them, has caused significant environmental concerns related to air and water contamination. The small droplets produced in this process are recognised as a major contributor to off-target drift, resulting in environmental contamination (HANKS 1995; MILLER & ELLIS 2000; FAROOQ *et al.* 2001). On the other hand, many investigators reported that smaller droplets can improve efficiency of a treatment. The efficiency increases with smaller droplets and with a higher droplet density with fungicides containing a contact active substance (COHEN *et al.* 1995). The effect of droplet spectra was more pronounced in contact herbicides (bentazon) than systemic

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ones (clethodim). The translocation of systemic compounds may be the main mechanism that nullifies the effect of larger droplet size and lower leaf coverage (Prokop & Veverka 2003).

One of the criteria used to judge the efficiency of a fungicide application is the density of spray droplet deposits per unit of leaf area, usually expressed as droplets/cm^2. The recommendations for fungicide applications range from 50 to 70 droplets/cm^2 for ground application and > 70 droplets/cm^2 for low-volume aerial application to achieve an adequate distribution of the fungicide on the leaf surface, and, consequently, an effective disease control (Hislop 1987). But other results show that fewer droplets per unit leaf area may be sufficient. Washington (1997) found that 30 droplets/cm^2 achieved the same efficiency against *Mycosphaerella fijiensis* as the treatment with 70 droplets/cm^2.

Previous studies were focused on the examination of homologous droplet size or narrow droplet spectrum influence on the efficiency of foliage-applied systemic and contact fungicides without using any surfactant (Cohen *et al.* 1995; Grinstein *et al.* 1997; Washington 1997). Most of them dealt with aerially applied fungicides with low volumes of water or greenhouse experiments when droplets were created by disc atomisers or laboratory devices for creating monodisperse droplets, which are usually not used under field conditions.

Because a fungicidal treatment under field conditions is distinguished by wide droplet spectra and with greater spray volumes, the objective of this study was to examine the influence of different droplet spectra on the efficiency of five fungicides, especially on that of contact fungicides as compared to a mixture of a contact with a systemic fungicide. Also evaluated was the influence of the addition of an adjuvant (pinolene 96%) to the contact fungicides and its effect together with different droplet spectra.

MATERIAL AND METHODS

Droplet size verification and droplet deposit. Flat fan nozzles were used for creating different droplet spectra. Droplet size and droplet deposit were estimated by the silicon capture method. Droplets were captured, photographed and than measured and counted on the computer screen (Prokop & Kejklíček 2002).

Fungicide experiments. The influence of droplet spectra on fungicide efficiency against *Phytophthora infestans* (Mont.) deBary was determined in field trials. In both years, the potato cultivar Korela (Sativa Keřkov, a. s.) was used. The width of the plots was 3 m (four rows of potatoes) and the length was 8 m, with 32 plants per row. There were 18 variants, and each variant had four repetitions. Disease severity was determined on two rows in the middle of each plot and is represented by the percentage of the affected plant surface from the total plant surface. The plots were read in intervals from 5 to 8 days. The evaluation was analysed by analysis of variance. The data in percentage was transformed by arcsin transformation ($y' = \arcsin \sqrt{y/100}$).

The beginning of the treatment was determined by the critical value of the negative prognosis (150). The following treatments were performed in accordance with the weather in intervals from 7 to 15 days. In total, six treatments were performed in the year 2000 and four treatments in 2001 for each variant.

The weather conditions in the two years differed. In 2000, the symptoms of late blight appeared 3 weeks later because of dry and warm weather during May and June. But rainfall at the end of July and at the beginning of August created ideal conditions for infection. In 2001, ideal weather conditions existed for infection by late blight from the beginning of the growing season on. There was an early infection by late blight and epidemic development through the whole growing season.

Three experiments were done with mixtures of systemic and contact fungicides: benalaxyl + mancozeb; metalaxyl + oxychloride-Cu and dimethomorph + mancozeb. Fully randomised plots with six droplet spectra of VMD = 183, 267, 389, 484, 568 and 911 µm, and a spray volume of 300 l/ha were replicated four times. The fungicides used are listed in Table 1, results in Tables 2, 3 and 4.

Two experiments were done with the contact fungicides oxychloride-Cu and folpet. One experiment with a contact fungicide and a surfactant: folpet + pinolene. Randomised, complete blocks including six droplet spectra of VMD = 183 (193), 267 (275), 389 (383), 484 (528), 568 (616) and 911 (939) µm, and three spray volumes of 300, 450 and 600 l/ha were replicated four times. The numbers in brackets are those for the mixture fungicide + adjuvant (Tables 5 and 6).

Table 1. Overview of fungicides used

Fungicide	Dosage	Active substance	Manufacturer
Acrobat MZ	2.5 kg/ha	dimethomorph (90 g/kg), mancozeb (600 g/kg)	BASF AG, DE
Folpan 50 WP	3 kg/ha	folpet (50%)	Makhteshim Chemical Works, Beer-Sheva, Izrael
Galben M	2 kg/ha	benalaxyl (8%), mancozeb (65%)	Isagro, Italy
Kuprikol 50	4 kg/ha	oxychlorid-Cu (50%)	Spolana, CZ
Ridomil Plus 48 WP	2.5 kg/ha	oxychlorid-Cu (40%), metalaxyl (8%)	Syngenta Crop Protection AG, CH
Agrovital	0.05%	pinolene (96%)	Agrovita, CZ

RESULTS

Mixtures of systemic and contact fungicides

In both 2000 and 2001, different droplet spectra that ranged from VMD = 183 µm to 911 µm had no significant influence on the efficiency of treatments containing both systemic and contact active substances (Tables 2–4).

Contact fungicides

Oxychloride-Cu 50%. The differences in efficiency between the tested variants after oxychloride-Cu 50 treatment against *Ph. infestans* are shown in Table 5. The efficiency ranged from 20.54% to 53.32% in 2000, and from 14.58% to 58.96% in 2001. The variants with large droplets and with a spray volume of 300 l/ha had the lowest efficiency. The variants with small droplets or with larger spray volumes gave the best results. Still, the efficiency of oxychloride-Cu 50% was very low in both years. No differences were found between the untreated control plot and variants 6 (VMD = 911 µm/300 l/ha) and 5 (VMD = 568 µm per 300 l/ha) on the statistical level of 95% in 2001. Larger spray volumes improved the efficiency for the large droplet spectra. The spray volumes in the range of 300, 450 and 600 l/ha had no influence on the efficiency of sprays with VMD 183 µm (Variants 1, 7, 13).

Folpet 50%. The influence of different droplet spectra on the efficiency of folpet 50% is shown in Table 6. The efficiency ranged from 26.12% to 63.37% in 2000 and from 25.26% to 56.02% in 2001. The worst results were obtained with variants 6 (VMD = 911 µm/300 l/ha), 5 (VMD = 568 µm/300 l per ha), 4 (VMD = 484 µm/300 l/ha) and 3 (VMD = 389 µm/300 l/ha). Larger spray volumes improved the efficiency for large droplets.

Folpet 50% + 0.05% pinolene. Pinolene (Agrovital®) is a surfactant which polymerises and cre-

Table 2. Comparison of variants 2000 and 2001, benalaxyl 8% + mancozeb 65%

2000					2001				
Variants	VMD (µm)	Droplets/cm^2	Efficiency (%)	95%	Variants	VMD (µm)	Droples/cm^2	Efficiency (%)	95%
C			0.00	A	C			0.00	A
4.	484	3.60	48.30	B	2.	267	19.86	37.13	B
6.	911	0.48	49.33	B	4.	484	3.60	42.08	B
3.	389	5.62	49.33	B	3.	389	5.62	44.25	B
5.	586	2.04	57.14	B	1.	183	55.42	44.87	B
1.	183	55.42	57.42	B	6.	911	0.48	45.74	B
2.	267	19.86	58.84	B	5.	586	2.04	48.70	B

C = untreated control; VMD = volume medium diameter

Table 3. Comparison of variants 2000 and 2001, oxychlorid-Cu (40%) + metalaxyl (8%)

2000					2001				
Variants	VMD (μm)	Droplets/cm^2	Efficiency (%)	95%	Variants	VMD (μm)	Droplets/cm^2	Efficiency (%)	95%
C			0.00	A	C			0.00	A
1.	183	55.42	44.61	B	5.	586	2.04	42.60	B
6.	911	0.48	48.39	B	2.	267	19.86	45.81	B
3.	389	5.62	48.81	B	6.	911	0.48	48.90	B
5.	586	2.04	49.43	B	4.	484	3.60	49.01	B
4.	484	3.60	49.85	B	1.	183	55.42	49.53	B
2.	267	19.86	55.87	B	3.	389	5.62	49.53	B

C = untreated control

ates an elastic semi-permeable membrane which extends the time of the pesticide efficiency. The droplet size ranging from VMD = 193 μm to VMD = 939 μm did not have a significant influence on the efficiency of the contact fungicide folpet with the adjuvant pinolene. No significant differences were found between the treated plots in the years 2000 and 2001 (Table 7).

Droplet deposit density (droplets/cm^2) and fungicide efficiency

The droplet deposit density depends on the droplet size and water volume. Though with treatments containing a systemic active substance and a contact active substance the droplet deposit density ranged from 0.48 to 55.42 droplets/cm^2, it did not have a significant influence on efficiency (Tables 2–4). Similar results were found for the treatment with the mixture of contact fungicide + adjuvant (folpet 50% + 0.05% pinolene 96%), while droplet density ranged from 0.4 to 107 droplets per cm^2. The results are shown in Table 7.

A higher droplet density increased the efficiency of the contact fungicides. For example, the variants with the droplet size of VMD = 389 μm and the droplet density of 5.62 droplets/cm^2 (spray volume = 300 l/ha) reached the efficiency of 42.75% in 2000. This droplet spectrum with a droplet deposit of 8.42 droplets/cm^2 (spray volume = 450 l/ha) increased the efficiency to 53.73%, and a droplet deposit with 13.34 droplet/cm^2 (spray volume = 600/ha) reached the efficiency of 61.41%. This improvement in efficiency applies to the variants with larger droplet sizes (Tables 5 and 6).

This droplet spectrum with the droplet deposit of 8.42 droplets/cm^2 (spray volume = 450 l/ha) increased the efficiency to the level of 53.73%,

Table 4. Comparison of variants 2000 and 2001, dimethomorph (90 g/kg) + mancozeb (600 g/kg)

2000					2001				
Variants	VMD (μm)	Droplets/cm^2	Efficiency (%)	95%	Variants	VMD (μm)	Droplets/cm^2	Efficiency (%)	95%
C			0.00	A	C			0.00	A
4.	484	3.60	56.29	B	3.	389	5.62	58.77	B
6.	911	0.48	57.06	B	2.	267	19.86	59.02	B
1.	183	55.42	60.15	B	6.	911	0.48	59.14	B
3.	389	5.62	62.09	B	1.	183	55.42	59.28	B
5.	586	2.04	64.25	B	5.	586	2.04	62.56	B
2.	267	19.86	65.95	B	4.	484	3.60	63.98	B

C = untreated control

Table 5. Comparison of variants with oxychloride-Cu (50%), 2000 and 2001

Variants	VMD (μm)	Water volume (1/ha)	Droplets/cm^2	2000		2001	
				efficiency (%)	95%	efficiency (%)	95%
C	–	–	–	0.00	A	0.00	A
6.	911	300	0.4	20.5	AB	14.5	AB
5.	568	300	2.0	24.2	. BC	18.1	ABC
12.	911	450	0.8	25.5	. BC	24.4	. BCD
3.	389	300	5.6	27.6	. BC	31.5	. BCDEF
4.	484	300	3.6	31.9	. BCD	30.1	. BCDE
18.	911	600	1.1	36.6	. BCDE	36.4	. BCDEFG
11.	568	450	3.0	37.4	. BCDE	38.6	. . CDEFGH
17.	568	600	4.3	37.4	. BCDE	50.9	. . . . EFGH
10.	484	450	4.8	37.7	. BCDE	45.6	. . . DEFGH
9.	389	450	8.4	39.4	. BCDE	41.4	. . . DEFGH
2.	267	300	19.8	39.4	. BCDE	46.8	. . . . EFGH
16.	484	600	6.6	40.8	. BCDE	51.0	. . . . EFGH
13.	183	600	123.5	42.9	. . CDE	58.9	. . . . H
14.	267	600	45.7	43.2	. . CDE	52.8	. . . . . FGH
7.	183	450	84.7	44.5	. . CDE	53.5	. . . . . . GH
8.	267	450	30.8	49.3	. . . DE	54.6	. . . . . . GH
15.	389	600	13.3	51.3	. . . DE	54.6	. . . . . . GH
1.	183	300	55.4	53.3	. . . . E	52.0	. . . . EFGH

Variants in Tables 5, 6, and 7: droplet spectra ranging from 183 μm to 911 μm; variants 1–6 with water volume of 300 l/ha, variants 7–12 with water volume of 450 l/ha, variants 13–18 with water volume of 600 l/ha
C = untreated control

and the droplet deposit with 13.34 droplet/cm^2 (spray volume = 600/ha) reached the efficiency of 61.41%. This improvement in efficiency applies to the variants with larger droplet sizes (Tables 5 and 6).

DISCUSSION

The application of larger volumes of a spray solution may improve the pesticide efficacy, but it also increases treatment costs. Smaller droplet sizes increase the drift potential, but may improve pesticide efficacy. Another important factor of fungicide efficiency is the ability of droplets to penetrate into the middle and lower parts of the plants. This attribute is especially important for the treatment of dense crops with a high LAI (leaf area index). Akesson and Yates (1986) reported the best droplet size to be between 200 μm and 400 μm.

Grinstein *et al.* (1997) examined the influence of droplet density and droplet size on the efficiency of two kinds of fungicides against *Botrytis cinerea* on roses. The active substances were pyrimethanil – 300 g/l and tank-mix prochloraz-Zn – 150 g + folpet – 600 g/l. The pyrimethanil efficiency was not influenced by droplet size and density. In contrast, the efficiency of tank-mix prochloraz-Zn + folpet was increased by smaller droplet size and higher droplet density.

Similar results were reached by Washington (1997) who tested the influence of droplet size and density on the efficiency of chlorothalonil and mancozeb to control *Mycosphaerella fijiensis*

Table 6. Comparison of variants with folpet (50%), years 2000 and 2001

Variants	VMD (µm)	Water volume (1/ha)	Droplets/cm^2	2000		2001	
				efficiency (%)	95%	efficiency (%)	95%
C	–	–	–	0.00	A	0.00	A
6.	911	300	0.4	26.1	. B	25.2	. B
5.	568	300	2.0	30.0	. BC	27.4	. BC
12.	911	450	0.8	34.4	. BCD	31.6	. BCD
3.	389	300	5.6	42.7	. BCDE	44.7	. . CDE
4.	484	300	3.6	45.0	. BCDEF	42.4	. BCDE
11.	568	450	3.0	46.9	. BCDEF	49.5	. . . DE
18.	911	600	1.1	47.0	. BCDEF	47.7	. . . DE
10.	484	450	4.8	50.2	. . CDEF	52.7	. . . . E
17.	568	600	4.3	50.9	. . CDEF	51.0	. . . . E
16.	484	600	6.6	50.9	. . CDEF	54.5	. . . . E
2.	267	300	19.8	53.7	. . . DEF	53.0	. . . . E
9.	389	450	8.4	53.7	. . . DEF	53.0	. . . . E
8.	267	450	30.8	56.3	. . . . EF	55.9	. . . . E
13.	183	600	123.5	57.6	. . . . EF	56.0	. . . . E
7.	183	450	84.7	57.9	. . . . EF	54.8	. . . . E
15.	389	600	13.3	61.4	. . . . EF	54.5	. . . . E
14.	2267	600	45.7	62.27	. . . . EF	54.9	. . . . E
1.	183	300	55.4	63.37	. . . . . F	55.8	. . . . E

Legend to the table see in Table 5

on banana leaves. When both droplet size and droplet per cm^2 varied while the spray volume was constant, the efficiency reached 100% with 10 droplets/cm^2 (VMD = 602 µm) for both fungicides. With lower densities (2–5 droplets/cm^2, VMD = 989 µm and 804 µm, respectively), the efficiency was significantly lower.

Equally, our experiments with *Phytophthora infestans* in 2000 and 2001 showed that droplet size and droplet density are very important factors for fungicide application. But such a dependence between fungicidal treatment and these factors was found only with contact fungicides. The fungicidal treatment with oxychloride-Cu (50%) and folpet (50%) showed that the lowest efficiency was achieved with the droplet spectra of VMD = 911 µm and droplet density of 0.48 droplets/cm^2. The droplet spectra of VMD = 568 µm, 484 µm and 389 µm (2.04, 3.60 and 5.02 droplets/cm^2, respectively) followed. Efficiency increased with higher spray volumes, especially in the treatments with larger droplets, when a higher droplet density was reached.

On the other hand, the addition of the adjuvant pinolene (96%) to the contact fungicide folpet (50%) resulted in a similar efficiency with six droplet spectra (from VMD = 193 µm to VMD = 939 µm). Pinolene (96%) is an adjuvant which decreases the surface tension and positively influences the active substance coverage on the leaf surface. The addition of this adjuvant apparently compensated for differences in the droplet density on the leaf surface between different droplet spectra so that efficiency was similar for all variants.

Equally, the experiments with the fungicides containing mixtures of a contact and a systemic

Table 7. Comparison of variants with folpet (50%) + 0.05% pinolene (95%), years 2000 and 2001

Variants	VMD (μm)	Water volume (1/ha)	Droplets/cm^2	2000		2001	
				efficiency (%)	95%	efficiency (%)	95%
C	–	–	–	0.00	A	0.00	A
6.	939	300	0.4	21.1	. B	31.6	. B
5.	616	300	1.6	21.2	. B	40.1	. B
18.	939	600	0.9	21.5	. B	32.9	. B
12.	939	450	0.6	23.2	. B	31.8	. B
3.	383	300	6.8	24.2	. B	41.8	. B
9.	383	450	9.4	24.2	. B	45.0	. B
2.	275	300	16.7	25.3	. B	44.6	. B
11.	616	450	2.1	25.3	. B	37.8	. B
4.	528	300	2.4	25.4	. B	44.3	. B
16.	528	600	5.4	26.7	. B	44.7	. B
10.	528	450	3.5	28.1	. B	43.2	. B
8.	275	450	24.0	29.9	. B	52.2	. B
7.	193	450	72.4	29.9	. B	47.7	. B
17.	616	600	3.3	29.83	. B	43.8	. B
13.	193	600	107.2	30.9	. B	54.7	. B
14.	275	600	37.8	35.74	. B	45.3	. B
15.	383	600	13.5	37.4	. B	52.0	. B
1.	193	300	47.6	38,3	. B	48,6	. B

Legend to the table see in Table 5

active substance showed no differences between the droplet spectra. The droplet spectra ranging from VMD = 183 μm to VMD = 911 μm did not influence efficiency of the fungicide, regardless that the contact active substance was the essential part of this mixture.

The results of the experiments in 2000 and 2001 showed that the droplet spectra and droplet density can influence the efficiency of fungicide treatment, especially with contact active substances. A mixture of contact + systemic active substances or a mixture of a contact fungicide + a suitable surfactant equalises the differences between different droplet spectra and droplet deposit. The translocation of systemic compounds and the ability of the surfactant to improve the coverage with contact compounds may be the main mechanisms that counteract the effects of the larger droplet spectra and a lower leaf coverage.

CONCLUSIONS

The data presented here and in the previous paper (Prokop & Veverka 2003) support the following conclusions:

– Poor leaf coverage after using large droplet spectra substantially decreases the effectiveness of contact compounds. The performance of systemic compounds is not affected as their uneven distribution is compensated for by their translocation in plant tissues.
– Poor leaf coverage by large droplets can be only partly compensated by higher spray volumes. The compensation is more adequate with medium droplet sizes (VMD 389 μm and 484 μm) than with the largest one (VMD 911 μm).
– The addition of the surfactant pinolene to the contact fungicide increased the effectiveness of

variants treated with large droplets, compensating for the low leaf coverage.

The described effects of the droplet spectra can be substantially changed by weather conditions, by the wettability of the leaf waxes, by redistribution of the deposits by rain, and by other factors.

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