Influence of droplet spectra on the efficiency of contact and systemic herbicides

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ABSTRACT

The effect of droplet spectra on efficiency of contact and systemic herbicides was evaluated. As a model components were used: mixture of clethodim 240 g/l + surfactant (90% raps fluid, 10% polyetoxyl esters); bentazon 600 g/l and bentazon 480 g/l + Wettol LF 150 g/l. The effect of droplet spectra on *Elytrigia repens* (L.) Desv. was evaluated using systemic herbicide (clethodim 240 g/l + surfactant). No significant differences of the efficiency were observed between different droplet sizes at the treatments of mixture of clethodim + adjuvant between very different droplet size ranging from VMD = 193 µm to VMD = 929 µm. The effect of droplet spectra on *Chenopodium album* L. and *Galium aparine* L. was evaluated using contact herbicides (bentazon 600 g/l and bentazon 480 g/l + Wettol LF 150 g/l). Six droplet spectra, ranging from VMD = 183 µm to VMD = 911 µm, were used. The efficiency significantly increased with smaller droplet sizes. The worst results were achieved by droplet spectra of 586 µm and 911 µm for both bentazon 600 g/l and bentazon 480 g/l + Wettol LF 150 g/l. Effect of droplet spectra is more pronounced in contact compounds. Translocation of systemic compounds may be the main mechanism that nullifies the effect of the droplets size and lower leaf coverage.

Keywords: pesticide application; droplet spectra; *Elytrigia repens*; *Galium aparine*; *Chenopodium album*; clethodim; bentazon; raps fluid

The use of agrochemicals to control weed in agricultural crops is a widely accepted practice. Most of these products are applied on the stands as liquid spray droplets. The atomisation process of converting liquid into spray droplets and fate of the droplets after formation is dependent on physical properties of the formulation, spray volume, nozzle type, nozzle pressure, and ambient conditions at the time of application. Fate of these droplets, especially the pesticide contained in the droplets, has caused significant environmental concerns related to air and water contamination. The small droplets produced in this process are recognized as a major contributor to off-target drift, resulting in environmental contamination (Hanks 1995).

On the other hand, as some investigators reported, the smaller droplets may improve efficiency because they cover better, injure the target area less, and penetrate and translocate the active substance more (Merrit 1977, Ambach and Ashford 1982, Merrit 1982, Prasad 1985, Rogers and Kirkland 1985, Prasad and Cadogan 1992, Wolf et al. 1992). However, results from previous research on the relationship between droplet size and biological activity of herbicides are contradictory, because other scientists reported that large droplets are more effective than small droplets (Bode 1984, Cadogan et al. 1986). Still others found that droplet size did not influence weed control (Gebhardt et al. 1986, Liu et al. 1996).

Small droplets are more advantageous in providing good coverage on foliage than their larger counterparts for a given volume. Small droplets may be retained better on foliage surfaces and may penetrate more rapidly than large droplets, so that less active ingredient is needed (Lake and Marchant 1983).

The application of greater volumes with larger droplets in spray solution may improve herbicidal efficiency. On the other hand, phytotoxicity is also usually increased with greater herbicide concentration in spray solution (Cranmer and Linscott 1991). In addition, with greater spray volumes the herbicide concentration is decreased. Thus, spray volume selection requires a balance between herbicide concentration and the increased distribution of herbicide on leaf surface (Whisenant et al. 1993).

Previous studies were focused on examination of homologous droplet size or narrow droplet spectrum influence on efficiency of foliage applied systemic and contact herbicides (McKinlay et al. 1974, Merrit 1982, Western and Woodley 1987, Schaertl et al. 1988, Prasad et al. 1992, Liu et al. 1996). Most of them were focused on aerially applied herbicides with low volumes of water or on greenhouse experiments and droplets or droplet spec-

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Table 1.Overview of used herbicides

Herbicide	Active substance	Manufacturer
Select 2 EC-H	clethodim 240 g/l	American Cyanamid Co., US
Ekol	90% raps fluid, 10% polyetoxyl esters	JIZA a spol. v. o. s., Czech Republic
Basagran 600	bentazon 600 g/l	BASF Aktiengesellschaft, Germany
Basagran Super	bentazon 480 g/l, Wettol LF 150 g/l	BASF Aktiengesellschaft, Germany

tra were created by disc atomizers or laboratory devices for creating monodisperse droplets.

Because the herbicidal treatment in field condition 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 efficiency of three herbicides and to compare the response of systemic and contact herbicides to changing droplet spectra. Flat fan nozzles were used for creating different droplet spectra.

MATERIAL AND METHODS

Droplet size verification and droplet deposit

The 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 and Kejklíček 2002).

Herbicides experiments

Influences of droplet size spectra on herbicide efficiency were estimated in field trials. Their effect on the activity of the mixture of clethodim 240 g/l + surfactant (90% raps fluid, 10% polyetoxyl esters) on *Elytrigia repens* (L.) Desv. was studied in full randomized plots with six droplet spectra of 193, 282, 387, 536, 614, 929 µm and the spray volume of 200 l/ha.

The effect of contact herbicides bentazon 600 g/l and bentazon 480 g/l + Wettol LF 150 g/l was studied in randomised, complete blocs including six droplet spectra of 183, 267, 389, 484, 586, 911 µm for each herbicide and spray volumes of 300 l/ha. Trials in 1999 and 2000 were replicated four times. The overview of used herbicides is shown in Table 1.

The crop was potatoes. The width of the plots was 3 m (4 rows of potatoes) and the length was 8 m. The plots estimation was done on the two rows in the middle of the plots.

Table 2. Comparison of variants 1999, *Elytrigia repens* (L.)

Variant	Droplet spectra VMD (µm)	Before treatment (g/0.5 m^2)	After treatment (g/0.5 m^2)	Efficiency (%)	95%
3	387	27.45	4.17	84.81	A
1	193	30.36	4.83	84.09	A
2	282	29.32	4.84	83.49	A
5	614	25.99	4.33	83.34	A
4	536	24.71	4.14	83.25	A
6	929	26.51	4.52	82.95	A
7	untreated variant	27.30	44.11	0.00	B

Table 3. Comparison of variants 2000, *Elytrigia repens* (L.)

Variant	Droplet spectra VMD (µm)	Before treatment (g/0.5 m^2)	After treatment (g/0.5 m^2)	Efficiency (%)	95%
6	929	34.53	4.64	86.56	A
3	387	36.66	5.13	86.01	A
4	536	34.41	5.01	85.44	A
1	193	36.10	5.28	85.37	A
5	614	33.40	4.90	85.33	A
2	282	37.28	5.61	84.95	A
7	untreated variant	36.12	53.66	0.00	B

Table 4. Comparison of variants 1999, *Galium aparine* L.

Variant	Herbicide	Droplet spectra VMD (µm)	Before treatment (number of weed)	After treatment (number of weed)	Efficiency (%)	95%
10	Basagran Super	484	40.25	3.50	93.92	A
2	Basagran 600	267	33.25	4.25	91.00	AB
7	Basagran Super	183	31.75	3.50	90.85	AB
3	Basagran 600	389	49.25	4.00	93.05	AB
8	Basagran Super	267	42.00	4.00	92.10	AB
4	Basagran 600	484	40.25	4.50	91.17	AB
1	Basagran 600	183	42.00	5.00	90.10	ABC
9	Basagran Super	389	49.25	3.25	87.93	ABC
5	Basagran 600	586	45.00	11.25	78.72	ABCD
11	Basagran Super	586	37.00	10.50	75.20	BCD
12	Basagran Super	911	37.25	12.75	67.35	CD
6	Basagran 600	911	38.75	15.25	64.36	D
13	untreated variant		45.50	51.75	0.00	E

The absolute values of weed plants on plots were noted, e. g. number of *Chenopodium album* L. plants on 1 m^2 large parts of plots in 1999, number of *Ch. album* plants on the two rows in the middle of the plots in 2000 and number of *Galium aparine* L. on the two rows in the middle of plots in 1999 and 2000.

The weight of *E. repens* L. on 0.5 m^2 was noted and then compared with the untreated plots. Finally the ratio of treated to untreated plots was counted.

Application was made with a back sprayer F 320 (FOX MOTORI, Italy) with the mash of 1.5 m, nozzles LURMARK.

The plots evaluation were analysed using analysis of variance. The percentage values were transformed by arcsin transformation ($y' = \arcsin. \sqrt{y/100}$). Lowest significant differences were calculated according Tukey.

RESULTS

Clethodim + surfactant

The droplet size ranges from 193 µm to 929 µm did not have a significant influence on the efficiency of the tested mixture of clethodim 240 g/l + surfactant (90% raps fluid, 10% polyetoxyl esters). No significant differences were found between the treated plots in years 1999 and 2000 against *E. repens* (Tables 2 and 3). The sequence of variants is shown in the first column, second column shows initial state (before treatment) of weed weight on plots and their comparison with the untreated plots (weight on untreated plots equals 100%). The following columns show terminal state (five weeks after treatment) on the variants and their comparison with the untreated plots, then the percentage of decrease and the last column shows differences between variants.

Table 5. Comparison of variants 1999, *Chenopodium album* L.

Variant	Herbicide	Droplet spectra VMD (µm)	Before treatment (number of weed)	After treatment (number of weed)	Efficiency (%)	95%
9	Basagran Super	389	56.75	5.25	92.72	A
8	Basagran Super	267	77.50	8.75	91.55	A
10	Basagran Super	484	81.50	12.50	89.20	A
3	Basagran 600	389	74.25	8.50	90.43	A
1	Basagran 600	183	82.25	11.00	88.91	A
7	Basagran Super	183	78.75	11.50	87.70	A
2	Basagran 600	267	65.00	9.75	87.69	A
4	Basagran 600	484	80.50	10.00	87.60	A
5	Basagran 600	586	93.00	15.50	85.49	A
11	Basagran Super	586	68.00	15.50	77.88	AB
12	Basagran Super	911	100.50	53.00	50.06	BC
6	Basagran 600	911	73.50	48.25	41.67	C
13	untreated variant		92.25	102.75	0.000	D

Table 6. Comparison of variants 2000, *Galium aparine* L.

Variant	Herbicide	Droplet spectra VMD (µm)	Before treatment (number of weed)	After treatment (number of weed)	Efficiency (%)	95%
7	Basagran Super	183	23.00	3.25	95.28	A
2	Basagran 600	267	30.75	3.50	95.54	A
1	Basagran 600	183	23.75	3.25	93.42	A
9	Basagran Super	389	25.75	3.75	93.69	A
8	Basagran Super	267	25.25	3.75	93.65	A
3	Basagran 600	389	25.00	4.00	92.06	A
10	Basagran Super	484	22.75	4.50	92.06	A
4	Basagran 600	484	19.75	4.00	90.75	A
11	Basagran Super	586	25.00	7.00	86.97	AB
5	Basagran 600	586	24.25	7.50	85.30	AB
12	Basagran Super	911	23.50	12.75	74.64	B
6	Basagran 600	911	19.00	10.00	73.79	B
13	untreated variant		22.00	45.00	0.000	C

Bentazon and bentazon + Wettol LF 150

The efficiency differences between tested variants after herbicide treatment are shown in the Tables 4–7. We can see the sequence of variants, initial state (number of weed plants before treatment), terminal state (number of weed plants four weeks after treatment) and percentage of decrease in the tables. The last column shows differences between variants level 95%. The efficiency for *G. aparine* ranged from 64.36 to 93.92% in 1999 and from 73.79 to 95.28% in 2000. The efficiency for *Ch. album* ranged from 41.67 to 92.72% in 1999 and from 60.70 to 97.27% in 2000. The variants with course droplets spectra had the worst efficiency. The best results were achieved by the variants with fine droplets spectra. The results for both weed plants are similar in both years. The worst efficiency was found at variants 6 (bentazon, 911 µm), 12 (bentazon + Wettol LF, 911 µm), 5 (bentazon, 586 µm) and 11 (bentazon + Wettol LF, 586 µm). No significant differences were found between both herbicides.

DISCUSSION

Previous reports showed that droplet size is very important for efficiency of herbicidal treatment. Many scientists were engaged in testing of droplet size influence on foliage applied systemic herbicides but the results were different. Prasad et al. (1992) found that small droplets of glyphosate were more phytotoxic than larger droplets. Test showed also greater penetration and translocation by leaves when an adjuvant was used. Similar result was reported by Schaertl et al. (1988). They found that small droplets were more effective than larger droplets regardless of delivery volume. The small droplets and reduced carrier rates increased control with gly-

Table 7. Comparison of variants 2000, *Chenopodium album* L.

Variant	Herbicide	Droplet spectra VMD (µm)	Before treatment (number of weed)	After treatment (number of weed)	Efficiency (%)	95%
7	Basagran Super	183	217.00	6.75	97.27	A
3	Basagran 600	389	220.50	6.75	97.28	A
8	Basagran Super	267	210.75	7.00	97.06	A
1	Basagran 600	183	220.75	8.50	96.61	A
2	Basagran 600	267	210.25	8.75	96.23	A
9	Basagran Super	389	213.75	9.50	96.07	AB
10	Basagran Super	484	215.50	12.50	94.86	ABC
4	Basagran 600	484	208.00	13.50	94.31	ABC
11	Basagran Super	586	215.75	25.75	89.49	BC
5	Basagran 600	586	221.75	29.00	88.18	C
12	Basagran Super	911	216.75	88.25	63.46	D
6	Basagran 600	911	193.00	81.75	60.70	D
13	untreated variant		211.00	236.25	0.000	E

phosate, diclofop-methyl, fluazifop-butyl, and sethoxydim (Rogers 1989). On the other hand, Liu et al. (1996) found that droplet size between 177 µm and 1589 µm did not influence glyphosate efficiency. Similar results were reported by Merritt (1982) and Kudsk (1988). For efficiency of herbicides, the droplet size is not the only important parameter. It can be influenced by other factors such as: the ability of the leaves to intercept spray droplets, drying up of the droplets in air or on a surface of the leaves, the leaking droplets from the leaves or penetration of the droplets into a canopy of the plants. It is difficult to say which of these factors are most important and it required other examinations to find which factor is more or less important, especially under different weather conditions.

Our experiments with mixture of clethodim 240 g/l + surfactant (90% raps fluid, 10% polyetoxyl esters) against *E. repens* compared the efficiency of six wide droplet spectra, which were produced by flat fan nozzles. This experiment demonstrated that droplet size, expressed by VMD (Volume Median Diameter), ranging from 193 µm to 929 µm did not influence the herbicide efficiency.

In addition, experiments with foliage applied contact herbicides were reported by many scientists. Douglas (1986) found that different droplet sizes influenced paraquate efficiency. The small droplets were more efficient than larger ones. Similar results were published by other reseachers (McKinlay et al. 1972, 1974, Merritt 1982, Reichard and Triplett 1983). These studies reported on the influence of uniform droplet size or narrow droplet spectrum on efficiency of contact herbicides.

The results of our experiments with bentazon 600 g/l and bentazon g/l + Wettol LF in 1999 and 2000 demonstrated the dependence of the efficiency of herbicides on droplet spectra. Flat fan nozzles were used for herbicidal treatment, which produced wide droplet spectra and droplet size was expressed by VMD (Volume Median Diameter). There were no differences in efficiency between droplet sizes ranging from 193 µm to 484 µm but the variants with the course droplet spectra (VMD = 586 µm and VMD = 911 µm) showed significantly lower efficiency.

The experiments with systemic and contact herbicides showed different effect of the droplet size on herbicide efficiency. While the efficiency of the systemic herbicide was not influenced by droplet spectra ranging from 193 to 929 µm, the efficiency of the contact herbicides was influenced and the variants with courser droplet spectra showed lower efficiency. The experiments also showed that the efficiency of the contact herbicides can be influenced by course droplet spectra containing both larger and smaller droplets and not only by uniform large droplets as the previous results show.

The experiments showed that good coverage provided by fine droplet spectra is a prerequisite of high efficiency of contact compound bentazon. On the contrary, movement of systemic compound clethodim compensates for the poorer distribution of the active compound. Those relationships may be of different importance under influence of various speed of drying of droplets, different structure of canopy or redistribution of spray coverage by rain etc.

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ABSTRAKT

Vliv velikosti kapkových spekter na účinnost kontaktních a systémových herbicidů

Byl sledován vliv velikosti kapkových spekter na účinnost kontaktních a systémových herbicidů. Jako modelové účinné látky byly vybrány: clethodim 240 g/l + povrchové aktivní látky (90% řepkový olej, 10% polyetoxylované estery); bentazon 600 g/l a bentazon 480 g/l + Wettol LF 150 g/l. Ošetření proti pýru plazivému (*Elytrigia repens* L.) bylo provedeno systémově působící směsí clethodim + povrchově aktivní látky. Výsledky neprokázaly žádný vliv různých kapkových spekter na účinnost tohoto přípravku, a to v rozmezí kapkových spekter od VMD =193 µm do VMD = 929 µm. Ošetření pokusných parcelek proti merlíku bílému (*Chenopodium album* L.) a svízeli přítule (*Galium aparine* L.) bylo provedeno kontaktními účinnými látkami bentazon 600 g/l and bentazon 480 g/l + Wettol LF 150 g/l. Šest velikostních spekter pohybujících se v rozmezí od VMD = 183 µm do VMD = 911 µm mělo statisticky průkazný vliv na účinnost zkoušených herbicidů. Nejhorší výsledky byly dosaženy u varianty s velikostmi kapek 586 a 911 µm. Velikost kapkového spektra ovlivňuje především účinnost kontaktní látky. Translokace systémově účinné látky zřejmě eliminuje vliv různé pokryvnosti listů dosažené různým kapkovým spektrem.

Klíčová slova: aplikace herbicidů; velikost kapek; pýr plazivý; svízel přítula; merlík bílý; clethodim; bentazon; řepkový olej

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