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LEAVES COVERAGE OF SPRAY LIQUID AND INFLUENCE ON HERBICIDE EFFICACY

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Abstract

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The effect of spray liquid leaves coverage on efficacy of herbicides was investigated. Five nozzles sizes were used to reach different percentage coverage. The effect of leaves coverage on *Elytrigia repens* (L.) Desv. was evaluated using systemic herbicide (clethodim 240 g/l + surfactant) and the effect of leaves coverage on *Chenopodium album* L. and *Galium aparine* L. was evaluated using contact herbicides (bentazone 600 g/l and the mixture of bentazone 480 g/l + activator 150 g/l). No significant differences of the efficacy were observed between different percentages of leaves coverage in case of systemic herbicides. Vice versa the efficacy significantly increased with higher percentage of leaves coverage in case of contact herbicides.

pesticide application, leaves coverage, herbicides, clethodim, bentazone

Direct control of weed in agricultural crops is nowadays realized in two main ways. The fist approach uses the mechanical control of weed and the second means chemical control by using of herbicides. The second approach is widely accepted but may cause significant contamination of environment. This fact forces users of plant protection product to use more saving methods preferably at remaining of sufficient efficacy level.

Drift of spray droplets, especially the pesticide contained in the droplets, is the most important factor which contributes to environmental contamination (Hanks, 1995). It is influenced by many factors such as spray droplet spectra, wind speed, physical properties of liquid, air stability, temperature and humidity. It was found out that especially droplets less than 80 µm are prone to be drifted even at common meteorological conditions (Miller, 1993). The optimal spray spectrum of spray droplets ranges from 80–150 µm. Generally is valid that larger droplet spectra decrease the risk of drift. On the other hand larger droplets mean greater volume of water when we want to maintain an appropriate coverage and efficacy, which means greater cost. In the interest of reaching the best possible coverage at an economy volume of water it is very often necessary, especially in case of contact herbicides, to choose variant with fine droplet spectra.

That is why is important to know when a plant protection product is still efficient enough and when not. Many authors have studied relationship between droplet size, droplet density and coverage and their influence on efficacy of herbicides. The outputs from these studies are different. Some of them found out that better coverage positively influences herbicides efficacy (Merrit, 1977; Ambach and Ashford, 1982; Merrit, 1982; Prasad, 1985; Rogers and Kirkland, 1985; Prasad and Cadogan, 1992; Wolf et al., 1992). Others found out no relationship between coverage and herbicidal efficacy (Gebhardt et al., 1986; Liu et al., 1996). And finally there are studies when large droplets are more effective than small droplets (Bode, 1984; Cadogan et al., 1986).

These studies were focused on examination of droplet density and coverage with homologous droplet size or narrow droplet spectrum influence on efficacy of foliage applied systemic and contact herbicides. Most of them were focused on aerially applied herbicides with low volumes of water or on greenhouse experiments, where the different droplet density and coverage was created by using disc atomizers or laboratory devices for creating monodisperse droplets.

For the herbicidal treatment in field conditions is typical wide droplet spectrum which creates the final coverage. The objective of this study was to examine the influence of different coverage on efficacy of systemic and contact herbicides, to confirm the general knowledge that for efficacy of contact herbicides is the coverage crucial factor and identify the borderline when a contact herbicide is still efficient enough and when not, to investigate the possible influence of coverage on systemic herbicides using different droplet spectra for creating different coverage.

MATERIAL AND METHODS

Leaves coverage

Different level of coverage was reached by the use of different size and type of spray nozzles and calculated from values of droplet size for each type of nozzles and droplet density per cm^2. Droplet size was estimated by the silicon capture method. Droplet were captured, photographed and then measured and counted on the computer screen (Prokop and Kejklíček, 2002). The total area for determination of droplet number per cm^2 differed for each nozzle according the magnification which was used for their counting (Tab. I). The degree of coverage (*P*) was then calculated according following formula:

$$P = N/4 \cdot D^2 \cdot 100\ (\%),$$

where *N* is the number of droplets per cm^2, D^2 is Volume Median Diameter (mm^{-1}).

I: *Magnification and the area for determination of droplet number*

Nozzle	Magnification	Area (cm²)
015F110	88×	2.6
03F110	88×	2.6
LD03F110	88×	2.6
LD05F110	44×	5.2
DB05F120	44×	5.2

Herbicides experiments

Contact and systemic herbicides were used in field trials to estimate their efficacy at different surface coverage. The overview of variants is shown in Tab. II and Tab. III. As a systemic herbicide was used mixture of clethodim 240 g/l + surfactant (90% raps fluid, 10% polyetoxyl esters), formulated as Select 2 EC-H + Ekol, against *Elytrigia repens* (L.) Desv. The active substance dose per hectare was 96 g and the dose of surfactant was 1.2 l per hectare, spray volume 200 l/ha. Plots were fully randomized and sprayed with five different percentages of coverage.

As contact herbicides were used two formulation types: bentazone 600 g/l formulated as Basagran 600 and bentazone 480 g/l + activator 150 g/l (Wettol LF) formulated as Basagran Super. The dose in case of formulation bentazone 600 g/l was in both experimental years 960 g per hactar. In case of mixture of bentazone 480 g/l and activator 150 g/l two doses were used: 720 g/ha active substance plus 225 g/ha activator; and 960 g/ha active substance plus 300 g/ha activator. Five fully randomised, complete blocs included variants with different degrees of coverage. For variants 1 and 2 was reached the coverage more that 100% (Tab. III). It was caused by the fact that the spray droplet density was so high that on the spray target area droplets partly overlapped each other.

Spray volume was 300 l/ha. Two weeds were observed and evaluated (*Chenopodium album* L., *Galium aparine* L.) to determine the influence of different leaves coverage on herbicide efficacy.

The experiments were conducted in two years and the crop was potato. The width of the plots was 3 m (4 rows of potato) and the length was 8 m. The plots estimation was done on the two rows in the middle of the plots. The absolute values of weed plants on the plots were recorded and compared with the untreated variant in case of *Chenopodium album* L. and *Galium aparine* L.

In case of *E. repens* (L.) Desv. was recorded the weight of weed on 0.5 m^2 and then compared with untreated plot. Finally the ratio of treated and 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 was 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.

II: *Variants of systemic herbicide Select 2 EC-H + Ekol*

Variant	Nozzle	Number droplets per cm²	Coverage (%)
1.	LURMARK 015F110	31.90	93.89
2.	LURMARK 03F110	10.14	63.37
3.	LURMARK LD03F110	4.08	48.03
4.	LURMARK LD05F110	1.44	32.54
5.	LURMARK DB05F120	0.28	18.96
6.	Untreated control		

III: *Variants of contact herbicides:Basagran 600 and Basagran Super*

Variant	Nozzle	Number droplets per cm²	Coverage (%)
1.	LURMARK 015F110	55.42	144.89
2.	LURMARK 03F110	19.86	111.30
3.	LURMARK LD03F110	8.63	80.90
4.	LURMARK LD05F110	3.60	66.29
5.	LURMARK DB05F120	0.48	31.27
6.		Untreated control	

RESULTS

Systemic herbicide

Tab. IV shows differences between variants treated with systemic herbicide (clethodim 240 g/l + surfactant) at different coverage of spray liquid. The coverage ranged from 18.96% (0.28 droplets per cm^2) to 93.89% (31.9 droplets per cm^2). No significant difference was found between compared variants in both years (2001–2002).

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 on the variants (five weeks after treatment) and their comparison with the untreated plots, the percentage of decrease follows and the last column shows differences between variants on the statistical level of 95%.

Contact herbicides

The efficacy differences between tested variants after herbicidal treatment against two model weeds (*G. aparine* L., *Ch. album* L.), are shown in Tab. V–VIII. There are sequences of variants, initial state (number of weed plants before treatment) final state (number of weed plants four weeks after treatment) and percentage of decrease in the tables. The last column shows differences between variants on statistical level of 95%.

For both bentazone 600 g/l and the mixture of bentazone 480 g/l + activator 150 g/l was crucial the treatment with coverage of 31.27% (0.48 droplet per cm^2) – variant 5.

This treatment was on statistical level of 95% less effective than the treatment which was used in others variants (1–4). The percentage of decrease of weed number on experimental plot for variant 5 ranged for *G. aparine* L. from 64.36% to 74.64% and for *Ch. album* L. from 41.67% to 80.28% for all model herbicide treatments. On the contrary the percentage of decrease of weed was above 87.60% in variants 1–4 for both model weed plants and for all herbicide treatments.

The experiments proved that on statistical level of 95% were no difference between treatments of variant with coverage ranged from 66.29% (3.6 droplets per cm^2) to 144.89% (55.42 droplets per cm^2). Vice versa the coverage of 31.27% (0.48 droplets per cm^2) in variant 5 was not sufficient and the efficacy of both herbicides significantly decreased.

IV: *Comparison of efficacy on E. repens (L.) Desv. (Select 2 EC-H + Ekol)*

Var.	Initial state (% of weed per 0.5 m²)	Final state (% of weed per 0.5 m²)	Decrease %	95%
2001				
3.	100.54	16.84	83.30	A
1.	111.20	18.69	83.18	A
2.	107.41	18.57	82.68	A
4.	90.51	16.37	81.63	A
5.	97.11	17.80	81.61	A
6.	100.00	100.00	0.00	. B
2002				
5.	95.59	12.85	86.57	A
3.	101.48	14.16	86.02	A
4.	95.26	13.94	85.43	A
1.	99.94	14.60	85.38	A
2.	103.21	15.57	84.95	A
6.	100.00	100.00	0.00	. B

V: *Comparison of efficacy bentazone 600 g/l (Basagran 600) – G. aparine L.*

Var.	Initial state (Nr. of weed plants)	Final state (Nr. of weed plants)	Decrease %	95 %
2001				
3.	49.25	4.00	93.05	A
2.	40.25	4.75	90.53	A
4.	33.25	4.75	89.43	A
1.	42.00	6.75	85.84	A
5.	38.75	15.25	64.36	. B
6.	45.50	51.75	0.00	. . C
2002				
2.	30.75	3.50	95.54	A
1.	23.75	3.25	93.42	A
3.	25.00	4.50	89.51	A
4.	19.75	4.50	87.86	A
5.	19.00	10.75	67.64	. B
6.	22.00	45.00	0.00	. . C

VI: *Comparison of efficacy bentazone + activator (Basagran Super) – G. aparine L.*

Var.	Initial state (Nr. of weed plants)	Final state (Nr. of weed plants)	Decrease %	95 %
2001 (720 g/ha active substance plus 225 g/ha activator)				
3.	42.25	4.00	92.10	A
1.	40.25	4.5	91.17	A
2.	42.00	5.00	90.10	A
4.	43.25	5.75	84.93	A
5.	37.25	12.75	67.35	. B
6.	38.50	43.75	0.00	. . C
2001 (960 g/ha active substance and 300 g/ha activator)				
1.	40.25	3.50	93.92	A
2.	42.00	4.00	92.10	A
3.	31.75	3.50	90.85	A
4.	49.25	6.25	87.93	AB
5.	37.25	9.75	72.35	. B
6.	45.50	51.75	0.00	. . C
2002 (720 g/ha active substance plus 225 g/ha activator)				
1.	23.75	3.25	93.42	A
3.	25.00	4.00	92.06	A
2.	19.75	4.00	90.75	A
4.	25.00	7.00	86.97	AB
5.	19.00	10.00	73.79	. B
6.	24.25	37.75	0.00	. . C
2002 (960 g/ha active substance and 300 g/ha activator)				
1.	23.00	3.25	95.28	A
3.	25.75	3.75	93.69	A
2.	25.25	3.75	93.65	A
4.	22.75	4.50	90.06	A
5.	23.50	12.75	74.64	. B
6.	22.00	45.00	0.00	. . C

VII: *Comparison of efficacy bentazone 600 g/l (Basagran 600) – Ch. album L.*

Var.	Initial state (Nr. of weed plants)	Final state (Nr. of weed plants)	Decrease %	95 %
2001				
3.	74.25	8.50	90.43	A
1.	82.25	11.00	88.91	A
2.	65.00	9.75	87.69	A
4.	80.50	10.00	87.60	A
5.	73.50	48.25	41.67	. B
6.	92.25	102.75	0.00	. . C
2002				
2	210.25	8.75	96.23	A
1.	220.75	13.50	94.33	A
3.	220.50	15.25	93.41	A
4.	208.00	26.75	87.89	A
5.	193.00	81.75	60.70	. B
6.	211.00	236.25	0.00	. . C

VIII: *Comparison of efficacy bentazone 480 g/l + activator 150 g/l (Basagran Super) – Ch. album L.*

Var.	Initial state (Nr. of weed plants)	Final state (Nr. of weed plants)	Decrease %	95 %
2001(720 g/ha active substance plus 225 g/ha activator)				
1.	56.75	5.25	92.72	A
2.	77.50	8.75	91.55	A
4.	81.50	12.50	89.20	A
3.	78.75	11.50	87.70	A
5.	100.50	53.00	50.06	. B
6.	92.25	102.75	0.00	. . C
2001(960 g/ha active substance and 300 g/ha activator)				
1.	217.00	6.75	97.27	A
2.	110.75	7.00	97.06	A
3.	213.75	9.50	96.07	A
4.	215.50	12.50	94.86	A
5.	216.75	88.25	63.46	. B
6.	211.00	236.25	0.00	. . C
2002 (720 g/ha active substance plus 225 g/ha activator)				
2.	201.25	9.50	96.09	A
1.	212.50	12.75	94.81	A
3.	208.00	13.50	94.31	A
4.	215.75	25.75	89.49	A
5.	193.00	47.00	76.97	. B
6.	198.00	221.25	0.00	. . C
2002 (960 g/ha active substance and 300 g/ha activator)				
1.	217.00	3.88	98.41	A
3.	210.75	3.88	98.34	A
2.	220.75	4.38	98.22	A
4.	210.25	4.75	97.91	A
5.	216.50	46.75	80.28	. B
6.	214.00	236.75	0.00	. . C

DISCUSSION

Leaves coverage and droplet deposit are generally considered to be important factor of herbicidal treatment and many scientists were engaged in testing how these factors can influence herbicidal efficacy. Especially the experiments with systemic herbicides show different results. One of the most experimental used chemical compounds is glyphosate which was tested for its efficacy by many authors. Prasad et al. (1992) found out that better coverage of leaves with small droplets of glyphosate were more phytotoxic than less coverage with rough droplet spectra. Similar result was reported by Shartl et al. (1988). Small droplets and better coverage increased control with glyphosate, diclofos-methyl, fluziafop-buthyl and sethoxydim especially when reduced carrier rates were used (Rogers, 1989). On the other hand Liu et al. (1996), Kudsk (1988) and Meritt (1982) found no differences in efficacy of glyphosate applied at different coverage of leaves. These differences could be explained by different way of creating of different coverage degree. While Prasad et al. (1992) achieved the different coverage by different droplet size which was generated with special devise and strictly uniform the others authors used devises which generated droplets in certain range.

In our experiments clethodim was used as systemic active substance. Clethodim is rapidly absorbed and readily translocated from treated foliage to the root system and growing parts of platns. The experiments were conducted with herbicide formulated as a mixture of clethodim 240 g/l + surfactant (90% raps fluid, 10% polyetoxyl esters) in treatment against *E. repens* (L.) Desv. and compared the efficacy of five leaves coverage. Different leaves coverage was achieved by different droplet spectra which were generated by different size and kind of flat fan nozzles. Flat fan nozzles generated wide droplets spectra with wide range of droplets size and the experiments showed no difference between variants which ranged in percentage of leaves coverage from 18.96% (0.28 droplet per cm^2) to 93.89% (31.9 droplets per cm^2). The translocation of herbicide into all parts of weed plants compensated enough the smaller coverage of leaves with herbicide and ensure sufficient efficacy also in such a small coverage as it was in case of variant 5 (18.96%). This result is in consistence with previous results which found no differences in efficacy of systemic herbicides and used for creating different coverage wide droplet spectra.

Previous studies with contact herbicides had included both experiments creating different coverage with narrow droplet spectrum and with wide droplet spectrum. The results had been in both ways of investigation identical. The better coverage with smaller droplet spectrum (droplet size) had caused improved efficacy of herbicides (McKinlay et al., 1972, 1974; Merritt, 1982; Reichard and Triplett, 1983). Douglas (1986) found out that better coverage with smaller droplets improve efficacy of herbicide paraquate.

Also the experiments with bentazone 600 g/l and bentazone 480 g/l + activator in 2001 and 2002 demonstrated the dependence of contact herbicides efficacy on leaves coverage. The results were reached by using broad droplet spectra with different kind of flat fan nozzles. In case of bentazone experiments three variants of herbicidal treatment were used. Application of herbicide alone in dose of 960 g/ha, application of herbicide in dose of 720 g/ha plus the activator and application of herbicide in dose of 960 g/ha plus the activator. Bentazone is a contact herbicide, absorbed mainly by the foliage, with very little translocation. The role of activator in formulation mixture is to improve a herbicide infiltration into a plant and faster effect on a weed in initial period of action.

The results in tables V–VIII indicate that for all three herbicide treatments the coverage spectrum ranged from 66.29% (3.6 droplets per cm^2) to 144.89% (55.42 droplets per cm^2) did not significantly influence efficacy of herbicide. But having a look again at the tables we could see also other aspects of the experiment. One of these aspects is the use of activator and efficacy connected with that. The full dose of herbicide (960 g/ha) with the activator reached higher percentage of efficacy than remaining two variants. The variants with lower dose of herbicide (720 g/l) with activator reached similar results in efficacy as variants with full dose of herbicide without activator. This fact proved that the addition of the activator in the formulation positively influenced the action of herbicide. On the other hand the addition itself did not improved the efficacy enough to ensure that also the variant 5 (31.27% of coverage; 0.48 droplets per cm^2) would be properly efficient. The range of efficacy is other specific feature of variants with activator which is narrower than in case of treatments without the activator. This is caused by faster herbicide infiltration into a plant, by faster initial efficacy, and thus the differences between tested variants are smaller.

Remarkable is also fact that the variants 4 (66.29% coverage; 3.6 droplets per cm^2), although statistically not less efficient in comparison with other variants, in nine cases of twelve did not reached the level of 90% in efficacy. This fact is important especially from practical point of view because generally the efficacy of 90% is regarded as a borderline for main weeds in a crop and especially *Ch. album* belongs to main weeds in potato.

The experiments with systemic and contact herbicides in 2001 and 2002 shoved different effect of leaves coverage on herbicidal efficacy. While the systemic compound was not influenced by different coverage the contact herbicides responded very sensitively on decrease coverage with decrease of efficacy. The borderline for the contact active compound bentazone was found below the coverage level of 66.29%. While the coverage of 66.29% did not influence significantly the efficacy the treatment of variants with the coverage of 31.27% was not enough efficient.

Proved results mean that an application of a contact herbicide is more sensitive to the treatment conditions and especially to a choice of correct spraying technology. Although the efficacy of bentazone was found sufficient on a relatively low level of leaves coverage, still we have to bear in mind that final level of a coverage is influenced not only by the size of used nozzles but also by many other factors, which is important to know especially in borderline condition of treatment. To factors which influence droplet deposit belong 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 further examination to find which factor is more or less important, especially under different weather condition.

SOUHRN

Pokrytí ošetřované plochy postřikovou kapalinou a vliv na účinnost herbicidu

V maloparcelkových pokusech byl sledován vliv počtu kapek na cm^2 a pokrytí ošetřené plochy aplikační kapalinou na účinnost kontaktních a systémově působících herbicidů. Rozdílného pokrytí ošetřované plochy bylo dosaženo použitím různých velikostí a typů trysek. Jako modelová formulace pro systémově působící herbicidy byla vybrána směs účinné látky clethodim 240 g/l (Select 2 EC-H) s povrchově aktivní látkou (90% řepkový olej, 10% polyetoxylové estery, Ekol). Sledovaným plevelem byl pýr plazivý (*Elytrigia repens* (L.) Desv.). Pokusy prokázaly, že rozdílné pokrytí ošetřené plochy herbicidem v rozsahu od 18,96% (0,28 kapky na cm^2) do 93,89% (31,9 kapek na cm^2) nemělo významný vliv na účinnost provedeného zásahu na hladině statistické významnosti 95%. V případě kontaktních herbicidů byly použity dvě modelové formulace: bentazone 600 g/l (Basagran 600) a bentazone 480 g/l + aktivátor (150 g/l) (Basagran Super), které byly aplikovány ve třech variantách: formulace samotné účinné látky bentazone v plné dávce 960 g/ha; formulace směsi účinné látky bentazone a aktivátoru v redukované dávce (720 g/ha účinné látky a 225 g/ha aktivátoru); formulace směsi účinné látky bentazone a aktivátoru v plné dávce (960 g/ha účinné látky a 300 g/ha aktivátoru). Sledovanými plevely u kontaktních herbicidů byly merlík bílý (*Chemopodium album* L.) a svízel přítula (*Galium aparine* L.). Výsledky ukázaly, že pokryvnost pohybující se v rozmezí od 66,29% (3,6 kapek na cm^2) do 144,89% (55,42 kapek na cm^2) neměla vliv na účinnost ošetření herbicidy na hladině významnosti 95%. Ovšem snížení pokryvnosti na úroveň 31,27% (0,48 kapky na cm^2) se projevilo významným snížením účinnosti aplikovaných herbicidů. Díky rychlejšímu pronikání účinné látky do plevelných rostlin a vyšší počáteční účinnosti znamenal přídavek aktivátoru ve formulaci herbicidu zvýšení účinnosti a snížení rozdílů v účinnosti mezi jednotlivými variantami. Tento pozitivní vliv nebyl však natolik silný, aby kompenzoval v dostatečné míře sníženou pokryvnost použitou ve variantě 5 (31,27%; 0,48 kapek na cm^2) a zajistil rovněž v tomto případě účinnost herbicidu na potřebné úrovni. Vliv pokrytí a počtu kapek na cm^2 na účinnost herbicidů je patrný především při použití kontaktně působících účinných látek a ani přídavek aktivátoru do formulace herbicidu nedokázal tuto skutečnost změnit. Systémově působící účinná látka naopak dokázala nedostatečnou pokryvnost eliminovat svou translokací v rostlinných pletivech.

aplikace pesticidů, pokrytí aplikační kapalinou, herbicidy, clethodim, bentazone

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