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THE EFFECT OF SPRAY QUALITY PRODUCED BY DIFFERENT NOZZLES ON EFFICACY OF WEED CONTROL IN SPRING BARLEY

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Abstract: In four-year experiments the influence of droplet size and nozzle designs on the activity of a commercial herbicides triberenuron-methyl (Granstar 75 WG) and mixture of 2,4 D, dicamba, and mecoprop (Aminopielik Tercet 500 SL) applied to broadleaf weeds in spring barley was examined. The recommended and half doses were applied at 200 and 280 l ha^{-1} and at 250–570 μm (VMD) diameter droplet sizes, using air inclusion (ID 12003), low drift (TT 11003) and conventional flat fan (11003 XR) nozzles.
The results showed that smaller droplet size increased herbicide performance at constant spray volume, regardless of the droplet size range investigated. A significant interaction between the droplet size and herbicide type was observed. Generally, for triberenuron-methyl a performance was increased at smaller droplet size (250–270 μm), but significant increase of herbicide activity only at half dose was obtained. There were no significant interactions between droplet size and performance of mixture 2,4 D, dicamba, and mecoprop.

Key words: droplet size, nozzle design, triberenuron-methyl, mixture of 2,4 D, dicamba, and mecoprop, herbicide dose, spring barley

INTRODUCTION

The number of postemergence herbicide treatments has increased in recent years. Although current chemical application methods and spray techniques have improved application accuracy considerably, herbicide spray application remains still an inefficient operation. In some cases only a small portion of the intended herbicide rate reaches the target and ensures to the desired biological effect. On the other hand, it has become impractical in both economy and environment to continue to use great amounts of herbicides to obtain the desired high level of weed control. Application of herbicides requires management decisions that involve compromises among efficacy, safety, and economics. The application of greater volumes of spray solution may improve herbicide efficacy but also increases treatment costs. Smaller droplet sizes increase drift potential, but may improve herbicide efficacy. Despite a general appreciation for these variables, the relationships between efficacy, droplet size, and spray volume or working pressure have not been demonstrated enough.

Some interactions among spray application and solution characteristic were reported. Interactions between droplet size and spray volume were observed. Many of reports examining the influence of droplet size and spray volume on herbicide activity have shown conflicting results (Knoche 1994). Fisher and Young (1950) found that 2,4 D was more effective in larger droplets, whereas McKinlay et al. (1972), and Prasad and Cadogan (1992) reported that 2,4 D, triclopyr, and glyphosate were more effective in smaller droplets. Other reports (Liu and Campell 1996; Merritt 1982) indicated that efficacy of glyphosate, paraquat, and MCPA was not affected by droplet size. Generally, droplet size effects were pronounced at low carrier volume and decreased as spray volume increased (Lake and Taylor 1974; McKinlay et al. 1974; Philips et al. 1980).

The best droplet size for a foliar application is a compromise between drift reduction and adequate coverage. Particularly, droplet size should not be smaller than that adequate to obtain good coverage, because droplets that are too fine typically never reach the target. The distribution of spray deposits within canopies depends on impaction efficiency, leaf surface retention and the amount of foliage in the path of droplets. Impaction efficiency will be high with large droplets (Spillman 1984), but overall retention may decrease. However, this also depends on other factors such as foliage angle, surface characteristics of the foliage, physical properties of the liquid, total spray volume and droplet velocity (Lake 1977).

Information on the relationship between the amount of herbicide taken up into the leaf and the biological performance are not available enough. Generally, herbicide performance is usually increased when leaves absorb more herbicide. Herbicide absorption is increased with greater herbicide concentrations (active ingredient) in the spray solution and more contact area between the leaf surface and the herbicide solution (McKinlay et al. 1972; 1974; Cranmer and Linscott 1991). Increasing concentration (a.i.) by reducing spray volume increasing efficacy of glyphosate (Buhler and Burnside 1987; Liu and Campbell 1996), but concentration did not affect the efficacy of paraquat and MCPA (Merritt 1982).

The contact area between the spray solution and leaf surface is increased by increasing the amount of spray volume, decreasing droplet size, which increases droplet density and using adjuvants to reduce droplet surface tension. Although greater spray volumes should improve herbicide distribution on the leaf surface, several scientists have reported reduced phytotoxicity with increasing spray volumes (McKinlay et al. 1972;1974; Buhler and Burnside 1984; 1987; Cranmer and Linscott 1991). A recent paper by Huang et al. (2000) confirms and improves understanding of how spray deposition (droplet number, droplet circumference – size, herbicide concentration) affects triclopyr ester efficacy. The experiments have shown that triclopyr efficacy is lost when spray droplet size is increased and spray volume does not change. The same experiences have shown that increasing herbicide concentration in the spray solution does not fully maintain efficacy when increasing droplet size, if spray volume is not increased.

The size of the spray droplet can have a direct influence on herbicide performance, so selecting the proper nozzle type to control spray droplet is an important management decision. The optimum droplet size for specific applications is still unknown. Various nozzles are available providing many choices of droplet size and spectrum. Ideally, nozzles should produce only a narrow range of droplet sizes. The optimum droplet size may change as conditions change with the many variables affecting the performance of herbicides.

Nozzle selection for herbicide treatments must maintain the balance between biological efficacy, human and environmental safety with particular respect to drift (Powell et al. 1999). Conventional nozzles generally produce a few larger droplets and many smaller droplets that are prone to drift. New nozzle designs, such as low drift and air inclusion nozzles (or venturi and air induction nozzle) have been introduced. Spray drift control with these nozzles is superior compared to standard flat fan nozzles due to their coarser atomization. Both agronomic and environmental point of view, it is important that the biological efficacy of herbicides applied with alternative nozzle designs is maintained. Therefore it is necessary to document the biological performance of herbicides applied with this technique. If the drift reducing nozzles achieved the same efficacy and usefulness as the standard nozzle can be possible to replace the standard flat fan nozzles more generally.

The purpose of this study was to determine the influence of droplet size and spray volume on biological efficacy of weed control in spring barley with different herbicides.

MATERIALS AND METHODS

Laboratory tests

Studies under laboratory condition were conducted to determine spectrums of droplet sizes from different nozzles. The droplet size distribution was measured with a Drop and Particle Size Analyser (AWK). The liquid was sprayed vertical into analyser which was placed 45 cm from the nozzle. Droplet size was expressed in *volume median diameter* (VMD, sometimes labelled $Dv_{50\%}$) and measured in microns (μm).

The nozzles included in the study were: 1) Lechler ID 12003 (Lechler®), 2) Turbo TeeJet TT 11003 (Spraying Systems®), and 3) Teejet XR 11003 (Spraying Systems®). The Lechler ID nozzle is air inclusion type, Turbo Teejet – low drift, whereas TeeJet XR is a conventional flat fan nozzle. All measurements were made at pressures of 150 and 300 kPa. Two nozzles (TT 11003 and XR 11003) had a 110-degree spray angle and ID 12003 had 120-degree spray angle. All nozzles produced the same output (flow rate = 0.3 gallon per minute).

Field experiments

Field experiments in spring barley were carried out during 1996–1999 at the Experimental Station of Institute of Plant Protection in Winna Góra. The soil type was a sandy loam. The commercial formulations of triberenuron-methyl (Granstar 75

WG containing 75% a.i. l^{-1} triberenuron-methyl) and tank-mix 2,4 D, dicamba, and mecoprop (Aminopielik Tercet 500 SL containing 300 g a.i. l^{-1} 2,4 D; 160 g a.i. l^{-1} dicamba and 40 g a.i. l^{-1} mecoprop) were applied at an early growth stage of spring barley (4–6 leaf stage) and weeds at 2–4 leaf stage. Recommended and half dose of herbicides were applied at two spray volumes 200 and 280 liters ha^{-1}. The Granstar 75 WG was applied at 15 g a.i. ha^{-1} and 7.5 g a.i. ha^{-1} and Aminopielik Tercet 500 SL was applied at 1.0 kg a.i. ha^{-1} and 0.5 kg a.i. ha^{-1}, respectively. A randomised complete block design with a four replications and a plot size of 16.5 m^2 was used. Applications were made with a one-wheel experimental sprayer and travelling speed was 5.0 km h^{-1}. The spray boom was operated about 50 cm above the plant canopy. Solution was delivered to the nozzles by compressed air.

The biological effect was conducted 4 weeks after spraying by measurement a fresh weigh of weeds. In each plot, weeds were cut out within four randomly chosen 0.25 m^2 rectangular areas of 0.25 m (perpendicular to crop rows) by 1.0 m (along crop rows). In trials also effect of spray application factors and nozzles designs on grain yield of spring barley was examined.

Researches focused on the effect of droplet size at constant spray volume on herbicides activity. In experiments was compared the performance of ID 12003 and TT 11003 nozzles and XR 11003 nozzle for controlling broadleaf weeds. Spray volumes were applied at 150 and 300 kPa pressure using all nozzles and herbicide combinations.

Droplet size and spray volume or spray pressure effects on herbicide performance were investigated separately. For instance, variation of droplet size was not confounded with a simultaneous change of spray volume. The different droplet sizes were obtained without change of nozzle orifice size, but with various nozzle designs (conventional hydraulic nozzle, low drift and air inclusion nozzles). In this way, in constant spray pressure different droplet size was obtained. These assumptions were necessary because interpretation of studies may be limited, owing to differences in droplet speed, overlapping and droplet distributions.

In many studies spray application factors were confounded. For example, spray volume was varied by changing of nozzle orifice size or droplet sizes were compared at different spray volumes (Bowmer et al. 1993). Confounding of application factors can not be completely avoided. Effect of droplet size at constant spray volume and herbicide dose on herbicide performance is always confounding with droplet frequency (number) and density.

Differences between droplet size and dose of herbicides (at constant spray volume) were determined with a factorial analysis of variance to test for significance of interactions between spray application parameters. Tukey's protected least significant difference (LSD) was used to identify treatment means differing at the 5% level.

RESULTS

The nozzle design, nozzle orifice size, operating pressure, and the properties of the spray solution determine the droplet sizes and distribution of droplet sizes formed by an individual nozzle. The droplet spectra measurements with different nozzle designs and spray pressures are summarized in table 1.

Generally, the larger the VMD the less risk of drift. Droplets less than 150 microns are considered to be susceptible to off-target movement. The air inclusion nozzle ID 12003 increased the VMD and decreased the volume in droplets less than 150 microns compared to the extended range XR 11003 flat fan tip. For example, the VMD for the XR flat fan was 270 and 250 μm compared to 570 and 485 μm for the Lechler ID nozzle (at spray pressure of 150 and 300 kPa, respectively). As would be expected, increasing spray pressure reduced the VMD while increasing the percentage of spray in small droplets.

The laboratory experiments also evaluated the uniformity of the pattern across the width of the boom with the different nozzle types. Both the ID 12003 and the TT 11003 produced fewer drift-prone droplets than the extended range flat fan tip XR 11003. The percentage of spray volume in droplets smaller than approximately 150 μm is considered to be an important factor in determining the degree of drift hazard. The percentage of spray volume in droplets less than 150 μm was much less with the ID 12003 and the TT 11003 than the conventional XR tip (5.7 or 8.0% and 3.2 or 4.2% compared to 1.1 or 1.3%). However, the amount of spray droplet in range above 500 μm significant increased with air inclusion tip (59.3 and 24.6% of spay volume). These measurements indicate that when used correctly, these nozzles can assist in reducing the amount of drift from herbicide application.

In summary, both the ID 12003 and the TT 11003 nozzles reduced the percentage of spray volume in droplets prone to movement off the target site. However, the air inclusion ID and low drift TT nozzles generally produced a more variable pattern across the boom width than the XR flat fan tip.

In field trial weed infestation of spring barley is summarized in table 2. Common lambsquarters (*Chenopodium album*) at all experimental years dominated in field. Also, field violet (*Viola arvensis*), white mustard (*Sinapis alba*) and cleavers (*Galium aparine*) were important weed infestation of spring barley. Average number of weeds per unit area varying from 68 to 189 plants per m^{-2}.

Table 1. Characteristics of spray droplets using different nozzle designs, and spray pressures

Type	Nozzle	Spray pressure (kPa)	Nozzle flow rate (l/min)	VMD* (μm)	Percent spray volume in droplets diameter (mm) ranges				Spray quality
					<150 μm	150–250 μm	250–500 μm	>500 μm	
Conventional	XR 11003[1]	150	0.84	270	5.7	37.2	56.0	1.1	medium
		300	1.17	250	8.0	50.6	40.4	1.0	fine
Low drift	TT 11003[1]	150	0.84	325	3.2	17.8	67.5	11.5	coarse
		300	1.17	300	4.2	25.4	63.0	7.4	medium
Air inclusion	ID 12003[2]	150	0.84	570	1.1	4.5	35.1	59.3	very coarse
		300	1.17	485	1.3	4.7	48.4	45.6	very coarse

* – Volume Median Diameter

(1) – Spraying Systems (Extended Range XR TeeJet®, Turbo Teejet), (2) – Lechler®

Table 2. Weed infestation in spring barley during four-year experiments (1996–1999). Results are expressed as average number of weeds per unit area (no. $m.^{-2}$)

Weed species	Year			
	1996	1997	1998	1999
Anthemis arvensis L.	–	–	–	32
Chenopodium album. L	21	73	32	81
Sinapis alba L.	–	2	19	13
Viola arvensis L.	12	11	6	46
Galium aparine L.	3	1	7	2
Stellaria media L.	–	–	–	1
Thlaspi arvense L.	–	2	4	1
Capsella bursa-pastoris L.	–	1	–	–
Brassica napus L.	–	–	–	13
Fumaria officinale L.	52	–	–	–
Total (no. $m.^{-2}$)	87	90	68	189

Tables 3 and 4 show the effect of droplet size on triberenuron-methyl performance and spring barley yields at constant spray volumes. The control of weeds at half dose of triberenuron-methyl showed significant difference between spray parameters. At both constant spray volumes herbicide performance increased as droplet size decreased. The highest level of weed control with conventional XR nozzles and droplet size 270 and 250 μm measured by VMD was observed (75.8 and 82.1%, respectively). Treatments with low drift nozzle TT and the intermediate droplets (325 and 300 μm) were not significantly different from either the 270 or 250 μm (conventional XR) treatments. Weed control with triberenuron-methyl was significant reduced with increasing droplet size to 570 and 485 μm (58.0 and 72.5%, respectively). Application of air induction nozzle (ID) which produced very coarse spray quality decreased herbicide performance about 18% and 10% compared to treatments with conventional nozzle XR tip.

Table 3. Four-year averages of weed control and spring barley yields after application of tribenuron-methyl (Granstar 75 WG) at half and normal doses as affected by droplet size (at constant spray volume 200 l ha^{-1} and spray pressure 150 kPa)

Herbicide dose*	Droplet size (nozzle design)	Weed control (%)	Yield (t ha^{-1})
Half dose	270 μm (XR 11003)	75.8 a	5.36a
	325 μm (TT 11003)	70.2ab	5.31a
	570 μm (ID 12003)	58.0b	5.34a
Normal dose	270 μm (XR 11003)	80.6a	5.22a
	325 μm (TT 11003)	81.5a	5.56a
	570 μm (ID 12003)	67.6ab	5.49a
LSD (0.05)		14.05	0.346

* Tribenuron-methyl (Granstar 75 WG) applied at half dose (7.5 g a.i. ha^{-1}) and normal dose (15 g a.i. ha^{-1}).

Means followed by the same letter within a column do not differ significantly at the 0.05 probability level according to Tukey's multiple range test

Table 4. Four – year averages of weed control and spring barley yields after application of tribenuron-methyl (Granstar 75 WG) at half and normal doses as affected by droplet size (at constant spray volume 280 l ha^{-1} and spray pressure 300 kPa)

Herbicide dose*	Droplet size (nozzle design)	Weed control (%)	Yield (t ha^{-1})
Half dose	250 μm (XR 11003)	82.1a	5.27b
	300 μm (TT 11003)	76.9a	5.72a
	485 μm (ID 12003)	72.5b	5.48ab
Normal dose	250 μm (XR 11003)	87.0a	5.33b
	300 μm (TT 11003)	85.4a	5.37b
	485 μm (ID 12003)	81.2a	5.42ab
LSD (0.05)		14.05	0.346

*Tribenuron-methyl (Granstar 75 WG) applied at half dose (7.5 g a.i. ha^{-1}) and normal dose (15 g a.i. ha^{-1})

Means followed by the same letter within a column do not differ significantly at the 0.05 probability level according to Tukey's multiple range test

Droplet size of the triberenuron-methyl spray solutions had no significant effect on weed control at normal herbicide dose at both 200 and 280 l ha^{-1} constant spray volumes. However, the level of weed reduction increased as droplet size decreased. As previously, the similar trends in droplet size effects on herbicide activity were obtained. Generally, treatments with spray volume of 280 l ha^{-1} and spray pressure of 300 kPa, had greater efficacy than the treatments at 200 l ha^{-1} and 150 kPa spray pressure, regardless of herbicide dose and droplet size. Spring barley yields were not significantly different in all treatments with triberenuron-methyl at constant spray volume 200 l ha^{-1}. Also, a small difference between yields at higher spray volume 280 l ha^{-1} was observed. However, barley yields were the highest when half dose was applied at 300 μm (5.72 t ha^{-1}) and both doses at droplet size of 485 μm were applied (5.48 and 5.42 t ha^{-1}).

In summary, application of triberenuron-methyl at lower dose appeared significant diversity in weed control with different droplet size and nozzle designs. Performance of triberenuron-methyl was increased when droplet size was decreased at constant spray volume.

Effect of droplet size on weed control with 2.4 D, dicamba, and mecoprop mixture is presented in tables 5 and 6. Mean efficacy of weed control at constant spray volume of 200 l ha^{-1} ranged from 70.6 to 93.9% among sprayed treatments (Tab. 5). At the reduced dose there were significant differences between droplet sizes performance. The highest level of weed control (82.7%) with intermediate droplet size of 325 μm was obtained. Similar effect with droplet size of 270 μm was assessed (81.2%). There was no significant difference in control of weeds between droplet size with mixture of 2,4 D, dicamba, and mecoprop applied at normal dose and at spray volume of 200 l ha^{-1}. However, decreasing droplet size enhanced performance of herbicide mixture.

No significant differences in weed reduction were detected between the half and normal dose of mixture of 2,4 D, dicamba, and mecoprop at constant 280 l ha^{-1} spray volume (Tab. 6). In all treatments, very high reduction fresh weight of weeds

Table 5. Four-year averages of weed control and spring barley yields after application of tank-mix 2,4 D. dicamba. and mecoprop (Aminopielik Tercet 500 SL) at half and normal doses as affected by droplet size (at constant spray volume 200 l ha^{-1} and spray pressure 150 kPa)

Herbicide dose*	Droplet size (nozzle design)	Weed control (%)	Yield (t ha^{-1})
Half dose	270 µm (XR 11003)	81.2bc	5.19a
	325 µm (TT 11003)	82.7b	5.32a
	570 µm (ID 12003)	70.6c	5.16a
Normal dose	270 µm (XR 11003)	93.9a	5.12a
	325 µm (TT 11003)	91.6ab	5.24a
	570 µm (ID 12003)	88.0ab	5.16a
LSD (0.05)		10.82	0.374

*Tank-mix 2,4 D. dicamba. and mecoprop (Aminopielik Tercet 500 SL) applied at half dose (0.5 kg a.i. ha^{-1}) and normal dose (1.0 kg a.i. ha^{-1})
Means followed by the same letter within a column do not differ significantly at the 0.05 probability level according to Tukey's multiple range test

Table 6. Four-year averages of weed control and spring barley yields after application of tank-mix 2,4 D. dicamba. and mecoprop (Aminopielik Tercet 500 SL) at half and normal doses as affected by droplet size (at constant spray volume 280 l ha^{-1} and spray pressure 300 kPa)

Herbicide dose*	Droplet size (nozzle design)	Weed control (%)	Yield (t ha^{-1})
Half dose	250 µm (XR 11003)	88.5a	5.03a
	300 µm (TT 11003)	89.8a	5.23a
	485 µm (ID 12003)	89.1a	5.38a
Normal dose	250 µm (XR 11003)	97.8a	5.28a
	300 µm (TT 11003)	96.8a	5.12a
	485 µm (ID 12003)	96.3a	5.26a
LSD (0.05)	10.82	0.374	

*Tank-mix 2,4 D. dicamba. and mecoprop (Aminopielik Tercet 500 SL) applied at half dose (0.5 kg a.i. ha^{-1}) and normal dose (1.0 kg a.i. ha^{-1})
Means followed by the same letter within a column do not differ significantly at the 0.05 probability level according to Tukey's multiple range test

was obtained (from 88.5 to 97.8%). The treatments applied at different droplet size did not significantly affect on weed control.

There was no significant difference in yield of spring barley with mixture of 2,4 D, dicamba, and mecoprop at two constant spray volumes. Both the half and normal doses did not influence on spring barley yields.

Generally, differences in droplet size and nozzle designs with mixture of 2,4 D, dicamba, and mecoprop did not significantly affect the level of weed control and spring barley yield.

DISCUSSION

Atomisation and pesticide application methods have been studied for many years with the aim of improving the delivery of pesticide to the target and minimising the impact on the environment. During the dynamic processes of spraying, the factors which determine whether droplets impacting leaves are retained or bounced off are complex and not fully understood. In addition to the droplet size, impact velocity, the dynamic surface tension properties of the spray solution, and the leaf surface morphology plays an important role (Anderson and van Haaren 1989).

For a foliage-applied herbicide to be effective it must successfully do the following: reach the plant, be retained on the leaf, penetrate the leaf, move to the site of action, and remain toxic long enough to exert its action. The absorption and uptake of foliar herbicides is affected by the shape and orientation of the leaf and by the nature of the leaf surface: wax, hairs, and cuticle thickness. Weed species differ in their interception and retention of the herbicide droplets. Broadleaf weeds with predominantly horizontal structure of leaves intercept and retain more spray droplets than grass weeds, most of which have narrow upright leaves more prone to droplet runoff.

Several new nozzle types have been introduced in recent years that are designed to minimize the formation of small droplets prone to move from the target site. One of the more popular designs is the air inclusion nozzle. Air induction nozzle is a newer nozzle type that produces a larger spray droplet. Droplet size measured by VMD from air inclusion ID 12003 nozzle was nearly twice as high as these were from conventional flat-fan XR 11003 nozzle. The big increase droplet size provided by air inclusion nozzle may raise questions as to whether these nozzles will provide sufficient coverage of weeds to achieve effective control. In addition, there was also question whether larger spray droplets may provide the same level of weed control with all herbicides.

The results from field experiments showed that droplet size and nozzle designs influenced on performance of applied herbicides. Generally, broadleaf weeds control was increased as droplet size decreased at constant spray volume. However, only significant effects of droplet sizes with triberenuron-methyl at the reduced dose (half dose) were obtained. Droplet size of 270 or 250 μm obtained with conventional XR nozzle enhanced weed control about 18% and 10% compared to droplet size of 570 or 485 μm with air inclusion ID nozzle. In this study, no differences in weed control with 2,4 D, dicamba, and mecoprop mixture (applied both at half and normal dose) were found between droplet size spectrums of 250, 300 or 485 μm VMD at constant spray volume of 280 l ha^{-1}. The same trend at normal herbicide dose and constant spray volume of 200 l ha^{-1} between 270, 325 and 570 μm was obtained.

Earlier research indicated that weed control was improved for a species as *Brassica napus* that has leaves with waxy surface which are difficult to wet, by choosing a nozzle with smaller droplet size (Jensen and Kirknel 1994; Knoche 1994). In this research common lambsquarters (*Chenopodium album*) at all experimental years dominated in field. Common lambsquarters also have difficult to wet leaf surfaces. Generally, present results confirmed previous reports that decreasing droplet size more frequently enhanced herbicide performance on difficult to wet plants.

Weather factors at the time of and following application can influence herbicide effectiveness. According to Beyer et al. (1988), little is known about how environmental factors influence the phytotoxicity of herbicides. These environmental conditions include soil nitrogen level, temperature, rain, and relative humidity. The biochemical and physiological mechanisms underlying these environmental effects still are not known. The absorption depends upon species involved and the environmental conditions (light, humidity, whether the stomates are open or closed).

Application methods and equipment can vary greatly depending upon the type of herbicide formulation selected for a weed control practice. Herbicides are not sold as pure chemicals but as mixtures or formulations of one or more herbicides with various additives. The type of formulation determines toxicity to plants, uniformity of plant coverage, stability in storage, and effectiveness. Herbicides included in this study had following formulations: solution (2,4 D, dicamba, and mecoprop mixture), which is completely soluble in water, and water-dispersible granule (triberenuron-methyl), which consist of solid particles that can be dispersed in a liquid. Each formulation has advantages related to its way of application and the targeted plant susceptibility to the formulation used. In this research, some interaction between environmental and spray application factors, and formulations of herbicides could occur. However, these interactions were not investigated.

Generally, treatments with spray volume of 280 l ha^{-1} and spray pressure of 300 kPa, gave greater efficacy than the treatments at 200 l ha^{-1} and 150 kPa spray pressure, regardless of herbicide type and dose or droplet size. Increasing the spray liquid pressure increases the velocity of droplets leaving the region of spray formation but also results in a finer spray. The balance between these two factors varies depending upon nozzle design, pressure level and other factors that may influence spray formation. Air inclusion nozzles require to good performance at least spray pressure of 250–300 kPa. However, in these trials biological efficacy of both herbicides applied at normal doses and at lower pressure (150 kPa) with air inclusion ID nozzle was not significantly different from that with low drift TT and conventional XR tips.

The present results illustrate that the application factors and spray techniques affected on biological efficacy of herbicides. Two trends appeared consistently in these experiments, but were not always statistically significant. Efficacy of weed control was inverse proportion to droplet size of the spray mixture, i.e., weed control increased as droplet size decreased. Also, an important interaction between the effect of droplet size and herbicide type and dose or eventually deposition on the target was observed.

When herbicide dose is adjusted according actual condition in the field (e.g growth stage of weeds) it is important to know how the choice of application technique influences on biological efficacy. Many investigations have shown little or small effect of application technique on herbicide performance (Nordbo et al. 1995). There is not necessarily truth because the herbicide dose was chosen so high that full biological control was achieved (Cawood et al. 1995). This situation prevents differentiation between application techniques.

Results of this research have confirmed earlier observations, because at normal (recommended) doses of herbicides did not observe significant difference in weed control with different droplet sizes. For the operator who wants to ensure the success of an application, particularly when herbicide doses are reduced or when time of application is not optimal, such information as reported here may help in adequate nozzle or droplet size choice.

The use of very coarse sprays (e.g with air induction nozzle) may reduce biological efficacy of herbicides (Enfalt et al. 1997; Jensen 1999). When a coarser spray is used, droplet numbers hitting the weed target are reduced. This has often been used as an argument against the use of low drift or air inclusion nozzles for weed control with foliar applied herbicides. Droplet density has been suggested as being one of major importance in the effectiveness of foliar-applied herbicides. However is available very little evidence about the influence of droplet density (number per unit area) on biological efficacy. In this study, reducing droplet size or increasing spray volume increased droplet density, and generally increased phytotoxicity. Campbell and Huang (2000) assessed, separately, the effect of spray solution concentration, droplet size and droplet number on triclopyr efficacy using a constant dose of herbicide per target plant. Maintaining droplet number (density) at constant while varying concentration and droplet size gave more consistent efficacy, than either holding concentration at constant (while varying droplet number and size) or holding droplet size at constant (while varying droplet number and concentration).

The results of this investigations did not support the theory that very large droplets and lower droplet numbers always reduce herbicide activity since effect of droplet size on herbicides performance was more depended on herbicide type and application doses than droplet density. For instance, the low drift (TT 11003) and air inclusion nozzles (ID 12003) which produce larger droplets and do not maintain a uniform spray pattern, give similar efficacy of weed control as conventional flat fan nozzle (XR 11003) with 2,4 D, dicamba, and mecoprop mixture. However, evident reduction in weed control (often difference were significant) with these two nozzle designs and with triberenuron-methyl was obtained. Further information is also necessary, particularly on the biological efficacy of air inclusion nozzles. Resent data (Cooper and Taylor 1999) suggest that air induction nozzles can be as effective as conventional flat fan designed for some targets (but not all). It should be noted, though, that these tips are not recommended for all herbicide applications. Larger droplets reduce coverage and the herbicide label should be consulted for any specific recommendations on nozzle type, operating pressure, application rate, and eventually adjuvant use. Investigations are also required to examine other herbicides and the study the performance of this technique and application parameters under a range of environmental conditions.

The general conclusions are following:

- Spray droplet size is one of many important factors that influence on herbicide performance.
- The effect of droplet size on herbicide efficacy depends on a number of other factors, particularly on mode of action of herbicide and leaf surface morphology.
- Decreasing droplet size or increasing spray volume increased droplet density, and generally increased phytotoxicity of herbicides.

- The effect of droplet size on weed control is more visible when herbicides are applied at lower doses.
- The type and formulation of herbicide in combination with droplet size may affect on herbicide activity.
- Atomizing the spray solution into small droplets increases the coverage, but also increases the potential for drift or spray evaporation.
- The use of very coarse sprays (e.g. with air induction nozzle) may reduce biological efficacy of weed control with some foliar applied herbicides but is an important factor in reducing herbicide drift.

REFERENCES

Anderson T.M., Van Haaren P.E. 1989. Rainproofing glyphosate with 'Bondcrete' cement additive for improved bitou bush control. Plant Protection Quarterly, 4: 45–46.

Beyer E.M., Duffy M.J., Hay J.V., Schlueter D.D. 1988. Herbicides: Chemistry, Degradation, and Mode of Action. Sulfonylureas 3: 117–189.

Bowmer K.H., Eberbach P.L., McCorkelle G. 1993. Uptake and translocation of ^{14}C-glyphosate in *Althernatera philoxeroides*. I. Rhizome concentrations required for inhibition. Weed Research 33: 53–57.

Buhler D.D., Burniside O.C. 1984. Effect of application factors on postemergence phytotoxicity of fluazifop-butyl, haloxifop-methyl, and sethoxydium. Weed Science 32: 547–583.

Buhler D.D., Burniside O.C. 1987. Effects of application variables on glyphosate phytotoxicity. Weed Technology 1: 14–17.

Cawood P.N., Robinson T.H., Whittaker S. 1995. AN investigation of alternative application techniques for the control of black-grass. Proc. Br. Crop Prot. Conf. – Weeds: 521–527.

Cranmer J.R., Linscott D.L. 1991. Effects of droplet composition on glyphosate absorption and translocation in velvetleaf (*Abutilon theophrasti*). Weed Science 39: 251–254.

Cooper S.E., Taylor B.P. 1999. The distribution and retention of sprays on contrasting targets using air-inducing and conventional nozzles at two wind speeds. Proc. Br. Crop Prot. Conf. – Weeds: 461–466.

Enfalt P., Enquist A., Bengtsson P., Alness K. 1997. The influence of spray distribution and drop size, on the dose response of herbicides. Proc. Br. Crop Prot. Conf. – Weeds: 381–389.

Fisher C.E., Young D.W. 1950. The effect of herbicide droplet size on the control of mesquite when applied by airplane equipment. Proc. North Cent. Weed Conference 7: 84–86.

Huang J.Z., Campbell R.A., Studens J. A., Fleming R. A. 2000. Absorption and translocation of triclopyr ester in *Populus tremuloides* as affected by concentration, and droplet size and number. Weed Science 48: 680–687.

Jensen P.K. Kirknel E. 1994. Influence of spray quality on crop tolerance and weed control with foliage-applied herbicides in combining peas. Crop Protection 3: 189–194.

Jensen P.K. 1999. Herbicide performance with low volume low drift and air inclusion nozzles. Proc. Br. Crop Prot. Conf. – Weeds: 453–460.

Knoche M., 1994. Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Protection 13: 163–178.

Lake J.R., 1977. The effect of drop size and velocity on the performance of agricultural sprays. Pesticide Science 8: 515–520.

Liu H., Campell R. A. 1996. Efficacy of glyphosate on *Populus tremuloides* as affected by droplet size and spray volume. New Zealand Journal of Forestry Science 26: 276–287.

Merritt C.R. 1982. The influence of form of deposit on the phytotoxicity pf MCPA, paraquat and glyphosate applied as individual drops. Annals of Applied Biology 101: 527–532.

Lake J.R., Taylor W.A. 1974. Effect of the form of a deposit on the activity of barban applied to *Avena fatua* L. Weed Research 14: 13–18.

McKinlay K.S., Ashford R., Ford R.J. 1974. Effects of drop size, spray volume and dosage on paraquat toxicity. Weed Science 22: 31–34.

McKinlay K.S., Brandt S.A., Morse P., Ashford R. 1972. Droplet size at phytotoxicity of herbicides. Weed Science 20: 450–452.

Nordbo E., Steensen J.K., Kirknel E. 1995. Deposition and efficiency of herbicide sprays in sugar beet with twin-fluid, low drift and conventional hydraulic nozzles. Crop Protection 14: 237–240.

Phillips M.C., Bradford A., Harris P. 1980. The effect on weed control of drop size, water volume and rate of herbicide applied by spinning disc. Proc. Br. Crop Prot. Conf. - Weeds: 747–752.

Powell E.S., Orson J.H., Miller P.CH. 1999. Guidelines on nozzle selection for conventional sprayers. Proc. Br. Crop Prot. Conf. - Weeds: 467–472.

Prasad R., Cadogan B.L. 1992. Influence of droplet size and density on phytotoxicity of three herbicides. Weed Technology 6: 415–423.

Spillman J.J. 1984. Spray impaction, retention and adhesion: an introduction to basic characteristics. Pesticide Science 15: 97–106.

POLISH SUMMARY

WPŁYW WIELKOŚCI KROPEL WYTWARZANYCH PRZEZ RÓŻNE ROZPYLACZE NA SKUTECZNOŚĆ ZWALCZANIA CHWASTÓW W JĘCZMIENIU JARYM

W badaniach polowych w latach 1996–1999 określano wpływ wielkości kropel na chwastobójcze działanie triberenuron-methyl (Granstar 75 WG) i mieszaniny 2,4 D, dikamba i mekoprop (Aminopielik Tercet 500 SL) w jęczmieniu jarym. W doświadczeniach stosowano zalecane i obniżone o 50% dawki herbicydów w stałych ilościach cieczy użytkowej na hektar tj. 200 i 280 l ha^{-1}. Zróżnicowanie wielkości kropel uzyskano poprzez dobór różnych typów rozpylaczy (standard XR 11003, antyznoszeniowy TT 11003, eżektorowy ID 12003) charakteryzujących się tym samym wydatkiem jednostkowym cieczy przy tym samym ciśnieniu roboczym. Dobór rozpylaczy pozwalał na uzyskanie zróżnicowanej wielkości kropel od 250 do 570 μm (wielkość kropel mierzona wartością VMD).

Wyniki badań wskazują, że chwastobójcze działanie herbicydów ulegało zwiększeniu, gdy ciecz użytkowa rozpylana była na mniejsze wielkości kropel z jednoczesnym zachowaniem stałej ilości cieczy użytkowej na hektar. Odnotowano wyraźne różnice w skuteczności chwastobójczej w zależności od wielkości kropel oraz dawki i typu stosowanego herbicydu. Chwastobójcze działanie triberenuron-methyl wzrosło odpowiednio o 18 i 10%, gdy zastosowano krople o wielkości 270 lub 250 μm (XR 11003), w porównaniu do kropel o wielkości 570 i 485 μm (ID 12003). Statystycznie istotny wzrost skuteczności działania tego herbicydu uzyskano w dawce obniżonej o 50% w stosunku do zalecanej. Nie odnotowano istotnego wpływu wielkości kropel, typu rozpylacza na skuteczność działania mieszaniny 2,4 D, dikamba i mekoprop.