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EFFECT OF AIR INDUCTION NOZZLE AND OIL ADJUVANT ON SPRAY RETENTION AND WEED CONTROL

ROMAN KIERZEK

INSTITUTE OF PLANT PROTECTION, MICZURUNA 20, 60-318 POZNAŃ

Abstract. In greenhouse trials in 1998-1999, the effects of using new spray techniques on the activity of two herbicides for broad-leaved weeds control were examined. Also retention of spray solution containing herbicides with and without addition of oil adjuvant on *Chenopodium album* and *Sinapsis alba* leaves was measured. Results showed that air induction and conventional flat fan nozzle gave similar control of tested plants, except *Chenopodium album* control where fine sprays applied with conventional flat fan nozzle improved efficacy compared with very course spray obtained with air induction nozzle. Also results showed that oil adjuvant addition enhanced biological efficacy for all nozzles, regardless of using herbicide and controlled plant species.
Droplet size was the most important factor determining spray retention and activity of herbicides. Efficacy of spray retention depends on the wetting characteristics of the plant, spray application and solution factors.

Key words: nozzle, air induction nozzle, weed control, retention, biological efficacy, herbicide, oil adjuvant

I. INTRODUCTION

The proper choice and use of spray application equipment have direct influence on application efficacy. Conventional hydraulic nozzles are used commercially to apply herbicides. It is well known that changes in application technique affect the herbicide performance and deposition of spray on plants, but the reasons for this are not always clear.

Nozzles produce a wide range of droplet sizes. A flat fan nozzle forces the liquid under pressure through orifice and the liquid spreads out into a thin sheet that breaks up into different-sized droplets. A nozzle that can produce only one size droplet is not presently available. In the conventional hydraulic nozzle we find mix of big and small fast and slow droplets. Therefore, the goal in the proper application of pesticides is to achieve a uniform spray distribution while retaining the spray droplets within the intended target area.

Several recent developments have been aimed at modifying existing equipment to increase biological performance of pesticides, deposition efficiency of droplets while reducing the potential for drift. In general, this has been obtained by using new nozzles, air-assist system, or some kind of shield to overcome the drift-producing air currents and turbulence that occur around the nozzle during spraying. In this study attention to new nozzles designed (ventiri nozzles) has been paid.

Venturi nozzles are also known as "air induction" or "air inclusion" nozzles. Essential drift reductions have been observed with these tips while good spray coverage has generally been maintained. The reason is that the droplets are filled with air bubbles, and after spray droplet impaction on the leaf, providing similar coverage to finer, conventional sprays.

The air induction nozzles are designed to produce larger droplets while reducing the percentage of fine droplets. These nozzles (e.g. Lechler ID, TeeJet AI, Turbo Drop) have a pre-orifice ahead of the exit orifice to reduce the pressure exerted on the liquid at the point of discharge. As the liquid passes through the orifice plate air is sucked into the nozzle body. As the liquid is discharged from the nozzle tip, droplets filled with air are produced. Upon leaving the nozzle orifice, the air included in the nozzle expands, which makes the size of droplets somewhat larger and causes an increase in velocity of droplets. In addition to the large droplets, having a higher velocity on the nozzles further improves the chances the droplet will reach the target before becoming subject to drift. Another benefit mentioned by the manufacturers of this nozzle is that the large droplets shatter and splatter on contact, causing the small air-filled drops to spread out on the target for better coverage. Cecil (1997) described the advantages of such air induction nozzles.

Efficacy of spray retention depends on the wetting characteristics of plant and spray application and solution parameters. For foliage-applied herbicides the efficiency of spray retention determines the quantity of active ingredient potentially available for uptake into the leaf (Stock 1991). For many herbicide application of large droplet gives good biological results, but for good plant coverage, large droplets may not give enough adequate effect. However this varies widely with target surface. If we look at the targets they differ very much: some plants have waxy leaves others not, some have vertical leaves others horizontal and even on the same plant there is many different leaf surfaces. Usually, on difficult -to-wet surfaces, where contact angle of pure water droplets <110 degrees (Holloway 1970), retention is related to droplet size and their speed. Small droplets tend to stick but big droplets will also stick if their speed is low. Big, fast droplets after impact may shatter forming smaller droplets that stick.

The objective of this research was to determine the efficacy of herbicides applied to two plants species by using standard flat fan and air induction nozzles. In experiment the influence of oil adjuvant on biological efficacy and the spray retention on leaves of *Chenopodium album* and *Sinapis alba* was also evaluated.

II. METHODS

Laboratory tests

Droplet sizes from nozzles were measured using a Drop and Particle Size Analyser (AWK) and the distance between nozzle and analyser was 45 cm. The data obtained from this system included average arithmetical diameter (D_A), average volume diameter (D_V), Number Median Diameter (NMD), Volume Median Diameter (VMD), and the percent spray volume contained in droplets smaller than 150 μm, 100-300, 200-500 and above 500 microns. VMD is the most widely used parameter of droplet size. It is defined as the size of droplet that divides the spray volume into two equal parts by volume. In other words a representative sample of droplets of a spray is divided into two equal parts by volume so that one half of the volume contains droplets smaller than VMD, and the other half of the volume contains droplets larger than VMD.

Greenhouse studies

Greenhouse experiments investigated the effect of different nozzles (conventional and air induction) and addition of oil adjuvant on spray retention and herbicide efficacy against *Chenopodium album* and *Sinapis alba.* These plants represented dicotyledon model of weed with difficult to wet and easy to wet foliage respectively. Conventional flat fan nozzle XR 11003 (Extended Range XR TeeJet®) and air inclusion nozzle ID 12003 (nozzle with air bubble jet system -Lechler®) were used. Application was carried out using a moving sprayer delivering 350 l/ha of spray solution from all two tested nozzles at 300 kPa pressure. In all experiments the distance between the nozzle and the treated surface of plant was 50 cm. The sprayer speed was of 4,0 km/h. Air temperature during the day was 25 ± 5^0C and at the night was 18 ± 5^0C.

Herbicides included in the study were tribenuron-methyl (Granstar 75 WG) at 10 g/ha and the mixture of 2,4 D, dicamba and mecoprop (Aminopielik Tercet 500 SL) at 1,0 l/ha. The herbicides were applied alone and mixed with oil adjuvant (Olbras 88 EC – modified vegetable oil; free fatty acids) at 1,5 l/ha. Distilled water was used as spray carrier.

Lambsquarters *(Chenopodium album)* and white mustard (*Sinapis alba)* were grown from seeds in the greenhouse under natural condition in plastic pots containing a 1:1 (v/v) mixture of sandy soil and peat-based substrate. Seven or fife plants were grown per pot and each plant was at 4-6 or 4 leaf stage for *Chenopodium album* and *Sinapis alba* respectively during treatment. Pots were arranged in a randomized complete block with four replications per treatment. The experiment was conducted in 1998 and repeated in 1999. Data were subjected to analysis of variance and means were compared using the protected LSD (Student's test) at the 5% level.

Retention measurments

Lambsquarters *(Chenopodium album)* and white mustard (*Sinapis alba)* leaves were used to examine the retention of spray solution on a leaves surface. The same application parameters (i.e. nozzles, carrier volume, working speed, and pressure) and herbicides (with and without oil adjuvant) as in biological studies were used. Under greenhouse condition, the plants have grown in plastic pots containing mixture sandy soil and peat-based substrate. Leaves that were about 15 or 25 days old were detached from plant, placed to a card at the angle 30^0 and immediately sprayed using a greenhouse sprayer. Each individual treatment consisted of three replications. Amounts of deposit on tested plant (*Chenopodium album* and *Sinapis alba)* were determined using the phenylosaphranine (20 mg per 100 ml of carrier volume), which was incorporated into spray solution. The spray solution also contained full application rate of herbicides (Aminopielik Tercet 500 SL, Granstar 75 WG) and addition of oil adjuvant respectively. After spraying, single sample (contained 5 leaves of each species) was washed for 10 seconds in 10 ml mixture of distilled water and methanol 2:1(v/v). Concentration of phenylosaphranine in each harvested samples was measured by spectrophotometer Beckman DU 8 at l= 519 nm. The values were expressed as the quantity of sprayed solution recovered from the leaves (μl). The area of treated leaves was measured using a computer system composed with pro-

Table 1

Droplet spectra measurements with different nozzles application

Type	Nozzle	Operating pressure (kPa)	Nozzle flow rate (l/min)	Carrier	D_v* (μm)	D_v** (μm)	NMD*** (μm)	VMD**** (μm)	Percent spray volume contained in droplets				Spray quality
									< 150 μm	100-300 μm	200-500 μm	> 500 μm	
Conventional	XR 11003 (1)	300	1,17	Water	83	147	190	**248**	5.2	76.0	78.2	0.0	fine
				water + oil adjuvant	118	179	196	**272**	4.0	62.4	78.5	0.9	medium
Air induction	ID 12003 (2)	300	1.17	Water	106	233	282	**483**	1.3	13.9	51.8	45.6	very coarse
				water + oil adjuvant	134	262	328	**473**	0.9	11.2	56.9	39.1	very coarse

* – Average arithmetical diameter, ** – average volume diameter, *** – Number median diameter, **** – Volume median diameter

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

gram Multiscan Base v. 8.08, video camera Panasonic WV- CL702 and PC computer. The retention was expressed as amount of spray solution retained per 1 cm^2 leaf area (μl/ cm^2) and percent of spay volume.

III. RESULTS

The results of laboratory trials indicate that air induction nozzles have very coarse spray characteristics (Tab. 1). The results showed that the presence of air bubbles system in air induction nozzle significantly increases VMD and decreases the percentage of spray particles with a volume of less than 150 μm. Droplet size measurements showed that conventional XR nozzles produced droplet sizes much more uniform in size across the spray pattern than air induction ID nozzles (76% and 14% of spray volume contained in range 100 – 300 μm respectively). Droplet size measured by VMD from air induction ID nozzle was nearly twice as high as these from conventional flat-fan XR nozzle (483 μm and 248 μm respectively). Droplet spectra, described by VMD were affected by the adjuvant. Addition of oil adjuvant to spray increased droplet size produced by conventional flat-fan XR nozzles (about 10%), but decreased droplet size with air induction ID nozzle (2%). Vegetable oil as an additive to spray showed positive effects in the form of reduced droplet size spectrum, and thereby air induction nozzle produced droplet sizes much more uniform in size across the spray pattern. Control of *Chenopodium album* and *Sinapis alba* at the 4-6 and 4 leaf stage respectively in two separate trials using herbicide Granstar 75 WG with conventional and air induction nozzles was investigated (Tab. 2). The air induction ID nozzle gave significantly reduced efficacy of *Chenopodium album* control when with conventional

Table 2

Control of *Chenopodium album* and *Sinapis alba* with Granstar 75 WG (with and without oil adjuvant) using conventional and air- induction nozzles

Treatment	Efficacy of two plant control with conventional and air induction nozzles (%)			
	Chenopodium album		*Sinapis alba*	
	XR 11003	ID 12003	XR 11003	ID 12003
Without oil adjuvant	48.8	38.0	80.4	83.2
With oil adjuvant	91.7	89.6	83.5	81.4
LSD $_{0.05}$ (Student's test)	7.90		6.18	

XR was compared. Applied without adjuvant, efficacy was significantly lower with the very coarse sprays than with the fine spray. This effect may indicate that larger droplet sizes require increased application rates of herbicide for greater efficacy. The addition of oil adjuvant to spray solution gave essential increased efficacy both with conventional and air induction nozzles. In this case significant differences between nozzles were not observed. Control of *Sinapis alba* with Granstar 75 WG and different nozzles gave not significant difference. Also addition of oil adjuvant had no effect on herbicide efficacy as well as with conventional and air induction.

Control of *Chenopodium album* with Aminopielik Tercet 500 SL using conventional and air induction nozzles gave similar effect (Tab. 3). In this trial addition of adjuvant to spray solution using both conventional and air induction gave not significantly increased efficacy. However, in all cases adjuvant addition enhanced biological efficacy for all nozzles. Similar results with *Sinapis alba* control were obtained. This effect can explain that this herbicide formulation contain, the active ingredient and other chemical, including adjuvants, which serve several purposes such as wetting and emulsification. Data on the relative mortality of *Sinapis alba* indicated that larger droplet sizes (air induction) require increased application rates of herbicide for greater efficacy.

Many species of broad-leaved weeds have different surface structure on their leaves that influence wettability, and this probably explains variable results in Table 2 and 3. The results of foliar retention the evaluation of herbicide indicate that broad-leaved targets have very different retention of spray droplets, especially larger air containing droplet produced by the air induction ID nozzles (Tab. 4 and 5). The use of large droplets, particularly when they are fast moving can lead to reduce levels of retention on the leaves. However, the presence of air inclusions may modify the behaviour of large droplets on contact with the surface of the target and maintain retention levels (Rutherford et al. 1989).

There were pronounced differences in spray retention on *Chenopodium album* and *Sinapis alba* leaves when fine sprays with conventional XR nozzle were compared with very coarse spray obtained with air induction ID nozzle.

On *Chenopodium album* leaves was retained nearly three times less than on *Sinapis alba* with Granstar 75 WG (Tab. 4). Also *C. a.* leaves retained about one-third of the spray when this herbicide was applied without the adjuvant, but on *Sinapis alba* leaves almost

Table 3

Control of *Chenopodium album* and *Sinapis alba* with Aminopielik Tercet 500 SL (with and without oil adjuvant) using conventional and air- induction nozzles

Treatment	Efficacy of two plant control with conventional and air induction nozzles (%)			
	Chenopodium album		*Sinapis alba*	
	XR 11003	ID 12003	XR 11003	ID 12003
Without oil adjuvant	42.8	47.8	71.7	65.5
With oil adjuvant	58.4	63.8	80.9	81.5
LSD $_{0.05}$ (Student's test)	15.77		12.04	

Table 4

Spray retention on *Chenopodium album* and *Sinapis alba* leaves of Granstar 75 WG (with and without oil adjuvant) using conventional and air- induction nozzles

Treatment	Retention of spray solution on two plant species with different nozzles application (μl/cm^2 and% applied of carrier volume)							
	Chenopodium album				*Sinapis alba*			
	XR 11003		ID 12003		XR 11003		ID 12003	
	μl/cm^2	%	μl/cm^2	%	μl/cm^2	%	μl/cm^2	%
Without oil adjuvant	0.53	15.1	0.57	16.3	1.32	35.7	1.77	50.6
With oil adjuvant	1.52	43.4	2.05	58.6	1.71	48.9	1.72	49.1

Table 5

Spray retention on *Chenopodium album* and *Sinapis alba* leaves of Aminopielik Tercet 500 SL (with and without oil adjuvant) using conventional and air- induction nozzles

Treatment	Retention of spray solution on two plant species with different nozzles application (μl/cm^2 and% applied of carrier volume)							
	Chenopodium album				*Sinapis alba*			
	XR 11003		ID 12003		XR 11003		ID 12003	
	μl/cm^2	%	μl/cm^2	%	μl/cm^2	%	μl/cm^2	%
Without oil adjuvant	1.20	34.3	1.85	52.6	1.66	47.4	1.93	55.2
With oil adjuvant	1.16	33.1	1.64	46.9	1.75	50.0	2.30	65.7

the same amount of liquid was retained. Experimental date indicate that leaf surface that is difficult to wet (e.g. *C. a.*) as a result of crystalline epicuticular waxes is the main retention-reducing factor (Taylor et. al. 1983). It was confirmed in this experiment. However, smaller differences in spray retention on *Sinapis alba* were obtained.

In case of herbicide Aminopielik Tercet 500 SL (Tab. 5) markedly differences in spray retention on *Chenopodium album* and *Sinapis alba* leaves were obtained when conventional XR nozzle compared with air induction ID nozzle. The oil adjuvant enhanced the retention only on *Sinapis alba* leaves, but addition of the adjuvant to spray solution decreased the retention by *Chenopodium album* leaves. In all cases higher spray retention was measured with air induction nozzles, regardless of spray solution (herbicides with and without adjuvant) and leaf surface.

Generally, efficacy of weed control using Granstar 75 WG with both nozzle types was related to retention of spray solution. Usually, good biological effect reflected higher retention on tested leaf surfaces. In some cases, herbicide performance was not related to spray retention. For instance, addition of adjuvant to herbicide Aminoplielik Tercet 500 SL using both conventional and air induction nozzles enhanced *Chenopodium album* and *Sinapis alba* control but increased deposit of spray solution only on *Sinapis alba* leaves. Also control of *Sinapis alba* with Granstar 75 WG using air induction ID nozzle gave adverse result.

IV. DISCUSSION AND CONCLUSIONS

The effect of nozzle type on biological efficacy is complex, depending on many interrelated variables such as droplet size, droplet speed, application volume, pesticide concentration, sprayer forward speed and others (Powell et al. 1999). When a new application technique (air induction nozzle) is introduced it is very important to note not only the physical behaviour (e.g. droplet size), but also the biological performance of pesticides applied by this technique.

The investigation demonstrated that weed control was improved for a species such as *Chenopodium album* that has true leaves with a waxy surface which are difficult to wet, by using nozzle with a smaller VMD (conventional XR nozzle). Application of herbicides against *Sinapis alba* (easy to wet) revealed no difference in effect of spray quality, and similar efficacy with air induction and conventional nozzles were obtained. Recent data (Cooper and Taylor 1999; Jensen 1999) suggest that air induction nozzles can be as effective as conventional nozzles only for some targets (not for all). There are also differences in the surface morphology. Some weeds are more difficult targets than others, particularly the difficult-to-wet weeds, such as lambsquarters (*Chenopodium album*), cleavers (*Galium aparine*) and green foxtail (*Setaria viridis*). These weeds generally require finer sprays to maintain effective coverage and efficacy (e.g. conventional nozzles). Large droplets may give lower biological efficacy than smaller droplets under perfect conditions (Enfalt et al. 1997). The above observations indicate that leaf surface characteristics and herbicide distribution on leaf surfaces are not consistent.

The changes in liquid properties caused by the addition of adjuvants can lead to significant changes in the quality of the spray produced by flat fan nozzles. It is important to measure properties of the liquid in order to establish what determines the break-up mechanism and consequently whether a spray liquid will increase or decrease droplet size. The variation of droplet size with liquid properties is also significant when considering nozzle classification. For example, nozzle that is classified as "fine" may produce a spray that is "medium" when spray liquid contains additions (e.g. vegetable oil). However, addition of adjuvant to spray solution is necessary for properly formation of air inclusions within the larger droplets. In case of aqueous sprays, adjuvants play a major role in enhancing adhesion of droplets into plant leaves. More biological data is needed particularly for field conditions and consideration of the range for using adjuvants that will enhance the retention and activity of large droplets (Taylor et al.1999). It is also known that the properties of spray liquid influence spray characteristics (Butler Ellis et al. 1997). Resent data suggest that the spray characteristics from air induction nozzles are more strongly dependent upon spray liquid properties than other nozzles, and this may further influence future estimation their usefulness for conventional sprayers.

The physical properties of pesticide solution markedly influence on spray retention on the target. This factor is probably as important as droplet coverage when considering biological efficacy. Research also suggested that traditional higher volume coarser spray nozzles do not necessarily give a linear increase in retention as application volume increases. Larger weeds typically make chemical control more difficult, and these conditions may also reveal some performance differences between nozzles.

The general conclusions from this study are following:

1. Droplet size measurements showed that conventional XR nozzles produced droplet sizes much more uniform in size across the spray pattern than air induction ID nozzles.
2. Droplet size measured by VMD (Volume Median Diameter) from air induction ID nozzle was nearly twice as high as these from conventional flat-fan XR nozzles.
3. The changes in liquid properties caused by the addition of adjuvants can lead to significant changes in the quality of the spray produced by flat fan nozzles. Addition of oil adjuvant to spray increased droplet size produced by conventional flat-fan XR nozzles, but decreased droplet size with air induction ID nozzle.
4. Leaf surface morphology and physical characteristics of herbicide deposits on leaf surfaces in connection with nozzle type influenced on herbicide performance.
5. Droplet size produced by tested nozzles was the most important factor determining spray retention and activity of herbicides.
6. Efficacy of spray retention depends on the wetting characteristics of the plant, spray application and solution factors.
7. No consistent trends were found for the effect of droplet size on the retention on tested plant leaves. Also no consistent trends were found between herbicide efficacy and retention of spray solution.

It is important to note that the data presented in this publication applies only to the specific sizes of these nozzles tested and the actual test conditions. Using the same type of nozzle under another condition (e.g. specific field condition) and at different pressure or carrier volume sometimes may provide contradictory results. Further information is needed to evaluate the influence of air induction nozzles on the biological efficacy of herbicide.

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Roman Kierzek

WPŁYW ROZPYLACZY EŻEKTOROWYCH I ADIUWANTA OLEJOWEGO NA RETENCJĘ CIECZY UŻYTKOWEJ I SKUTECZNOŚĆ ZWALCZANIA CHWASTÓW

W latach 1998-1999 prowadzono badania szklarniowe nad przydatnością nowoczesnych rozpylaczy eżektorowych w zwalczaniu dwóch gatunków chwastów dwuliściennych (*Chenopodium album* i *Sinapis alba*). W doświadczeniach określano także wpływ testowanych rozpylaczy na retencję cieczy użytkowej w zależności zastosowanego herbicydu i dodatku adiuwanta olejowego.

Stwierdzono, że użycie w zabiegach chwastobójczych rozpylaczy eżektorowych ID przyczyniło się do uzyskanie równie wysokiej skuteczności biologicznej jak stosowanie tradycyjnych rozpylaczy szczelinowych XR. Jedynie podczas opryskiwania drobnokroplistego (rozpylacz standardowy XR) z użyciem herbicydu Granstar 75 WG uzyskano istotnie wyższą skuteczność zwalczania *Chenopodium album* w porównaniu z opryskiwaniem bardzo grubokroplistym, charakterystycznym dla rozpylacza eżektorowego ID.

Adiuwant olejowy istotnie zwiększył skuteczność działania kombinacji herbicydowych, niezależnie od zwalczanego gatunku roślin.

Zróżnicowana wielkość kropel uzyskiwana z testowanych rozpylaczy wyraźnie wpływała na retencję. Struktura powierzchni liści oraz właściwości fizyko-chemiczne cieczy użytkowej wykazywały ścisły związek z ilością cieczy użytkowej zatrzymanej na opryskiwanych obiektach doświadczalnych.