JOURNAL OF PLANT PROTECTION RESEARCH
Vol. 43, No. 2 (2003)

EFFECT OF NOZZLE TYPES AND ADJUVANTS ON THE LEAF COVERAGE AND BIOLOGICAL EFFICACY OF FUNGICIDES IN POTATO

Roman Kierzek, Marek Wachowiak

Institute of Plant Protection
Miczurina 20, 60-318 Poznań. Poland
e-mail: r.kierzek@ior.poznan.pl

Accepted: June 6, 2003

Abstract: The influence of different nozzle types and adjuvants on the biological efficacy of fungicides in potato was investigated in four growing seasons in the years 1997–2000. The studied foliar plant disease was late blight (*Phytophthora infestans*). The biological efficacy of fungicides (alone or with adjuvants) applied with coarse air induction nozzles was comparable to fine standard flat fan nozzle. The differences between the nozzle types tested were small in control of late blight in potato with systemic and contact fungicides. Coverage of upper side of leaf blades was from three to four times higher than lower side of leaf blades. In general, the highest coverage of upper and lower side of leaf was achieved when the full dosage rate of fungicide (copper oxychloride) was used with both the flat fan XR 110-03 and air induction DB 120-03 nozzle. Adding Atpolan 80 EC and Zero Piany 62 SL to 50% dosage rate of copper oxychloride decreased the spray coverage on lower side of leaf as well as with both the XR 110-03 and DB 120-03 nozzles. However, addition of adjuvants to spray solution did not decrease the deposition on upper side of leaf blade. In general, adjuvants did not considerably influence the biological efficacy of the fungicide treatments sprayed with both the flat fan and the air induction nozzles but had favourable influence on potato yield.

Key words: adjuvants, fungicides, flat fan nozzle, air induction nozzle, leaf coverage, late blight, *Phytophthora infestans*

INTRODUCTION

Nozzle tips are important part of a field sprayer because they are the last point of contact before the plant protection product is introduced to the environment. Proper selection and use of nozzle types has a direct effect on the amount and uniformity of pesticide application on the intended target. Flat fan nozzles are recommended for all field fungicide applications. All spray tips produce a range of droplet sizes. The size may range from very fine to coarse. Fungicide use usually requires

droplets, which are from fine to middle of this size range. Very fine droplets should be avoided because they will readily drift away from the intended target. However, very coarse droplets may not provide sufficient coverage of the target area particularly if the spray must penetrate a canopy of leaves (e.g. control of late blight).

The difficulty in defining an optimum size of droplets in relation to efficacy arises from different reasons. The biological efficacy obtained by fungicide application requires a number of other factors that interact with droplet size. The spray target and the properties of the spray liquid are important factors. The surface properties of the spray target in combination with the properties of the spray liquid influence retention (Crosba et. al. 1995). If penetration into the crop is required in order to reach the target (e.g. disease appears on lower leaves), another application method might be optimal. An evaluation of different atomiser systems must be solid in order to give a general conclusion on the different application systems required.

The aim of experiments was to investigate the influence of the leaf coverage with air induction and flat fan nozzles on control of late blight (*Phytophthora infestans*) with fungicides and to determine the effect of adjuvants on this foliar disease.

MATERIALS AND METHODS

During four growing seasons (1997–2000) field trials were carried out to determine the efficacy of potato protection against late blight with application of recommended program and with different nozzle design and adjuvants used. The experiments were established at the Institute of Plant Protection in Poznań. The protection program included: suitable time of application, different type of fungicides, dosage rate of fungicides with or without adjuvant and succession of treatments. During the vegetation season 3 or 4 treatments were conducted. Experiments were set up in potato cultivar susceptible to late blight: in the year 1997 – cv. Mila, 1998 – cv. Bekas and in 1999, 2000 – cv. Bryza. The potato plots measured 6 by 20 m in ridges 67.5 cm apart. The applications were carried out with a TeeJet® extended range flat fan nozzle (XR 110-03) and the air induction nozzles ID 120-03 or DB 120-03 produced by Lechler® and Lurmark®, respectively. The nozzle used and their approximate classification according to the BCPC classification are given in table 1. In general, the flat fan XR 110-03 nozzle was used as the reference nozzle. All experimental treatments were applied using plot sprayer equipped with tested nozzle tips at the forward speed of 4.0 km/h and a spray volume rate of 400 l/ha. In trials recommended fungicides at full and lower dosage rate (limited to 50%) also with adjuvant were used. The adjuvants added to 50% dosage rate of fungicides were: Olbras 88 EC

Table 1. Description of nozzle types used in experiments in the years 1997–2000

Nozzle design	Code of nozzle	Nozzle flow rate [l/min]	Spray pressure (kPa)	Spray quality(*) at 400 kPa pressure
Flat fan	XR 110-03(1)	1.36	400	fine
Air induction	ID 120-03(2)	1.36	400	coarse
Air induction	DB 120-03(3)	1.36	400	coarse

(1)spraying Systems (Extended Range XR TeeJet®); (2)Lechler®; (3)Lurmark®
(*) spray quality according to BCPC classification

(modified rape oil plus free fatty acids) in the years 1997and 1998; Atpolan 80 EC (mineral paraffin oil) and Zero Piany 62 SL (polyalkylene glycol) in 1999 and 2000. An accurate description of fungicide treatments in all years is presented in the tables 2–5. The treatment efficacy was determined by fungicide coverage of potato leaves with chemical method application (Bojarski 1972) which was based on removal of copper trace from leaves to blotting paper and classification of results on the 0–400 scale (index 400 – full coverage of leaves by copper oxychloride fungicide). Leaves from each row both with upper and lower part of the plant were examined. Also both sides of leaf discs were evaluated. During the treatments values of surface tension were assessed with the aid of stalagmometric method. Spraying was carried out under controlled conditions of temperature, humidity and wind speed. Furthermore, the spray drift during application through respective type of spray equipment was observed. The development progress of late blight was estimated by periodic control of separate object and classification of leaves stroke with the 1–9 Moore scale. The final effect of treatments was assessed according to yield of tubers.

Data were subjected to analysis of variance and means were compared using t-Student test at the 5% significance level.

RESULTS

Spray coverage

All adjuvants applied at 1.5 l/ha and added to the spray solution containing half of dosage rate of fungicide decreased surface tension of spray liquid (Tabs. 2–5). Spray coverage was measured on different heights in the potato crop. Spray coverage of upper or lower side of leaves is presented as average from two heights in potato.

Coverage of upper side of leaf blades was from three to four times higher than lower side of leaf blades. In general, deposition of copper oxychloride on leaf was higher when higher (full recommended) dosage rate of fungicide was applied. Adding Olbras to 50% dosage rate of fungicide did not influence the spray coverage on potato leaves sprayed with flat fan (XR 110-03) and air induction (ID 120-03) nozzles (Tabs. 2, 3). In general, applying of copper oxychloride at 50% dosage rate with or without Olbras 88 EC and with XR 110-03 nozzle gave better spray coverage of upper and lower side of leaf as compared with ID 120-03.

Similar as earlier, in the years 1999 and 2000 coverage of upper side of leaf blades was higher from three to four times as compared with lower side of leaf blades (Tabs. 4, 5). The highest coverage of upper and lower side of leaf was achieved when the full dosage rate of fungicide was used with both the flat fan XR 110-03 and air induction DB 120-03 nozzle. Adding Atpolan 80 EC and Zero Piany 62 SL to 50% dosage rate of copper oxychloride decreased the spray coverage on lower side of leaf as well as with both the XR 110-03 and DB 120-03 nozzles. However, addition of adjuvants to spray solution did not decrease the deposition on upper side of leaf blade.

Biological efficacy

In 1997, the late blight infection pressure was high (Tab. 2). Generally, the efficacy of four fungicide treatments (I and II – cymoxanil + mancozeb, II and III – cop-

Table 2. Spray coverage, late blight (*Phytophthora infestans*) control and yield of potato with fungicide treatments as affected by adjuvant and nozzle designs (1997)

Treatment[a]	Spray volume [l/ha]	Surface tension [mN/m]	Index of leaf coverage by fungicide in 0–400 scale[b]		Disease index at various dates at Moore 1–9 scale[c]						Yield [t/ha]
			upper side of leaf	lower side of leaf	10.07	24.07	07.08	19.08	27.08	03.09	
Flat fan (XR 110-03)											
100%	400	71.4	361 ab	156 a	2.0	2.0	4.0	5.5	6.0	6.5	32.5 a
50%	400	67.0	334 bc	101 bc	2.0	3.5	5.0	6.0	7.5	7.5	13.7 c
50% + Olbras 88 EC	400	32.8	331 cd	98 c	2.0	3.0	4.5	5.5	7.0	7.0	21.9 b
Air induction (ID 120-03)											
100%	400	71.4	365 a	138 ab	2.0	2.0	3.5	5.0	6.0	7.5	26.9 ab
50%	400	67.0	306 d	105 bc	2.0	3.0	5.0	6.0	7.0	7.5	21.3 b
50% + Olbras 88 EC	400	32.8	306 d	95 c	2.0	2.0	4.0	5.5	7.0	7.5	26.8 ab
Untreated	–	–	–	–	2.0	4.0	5.5	8.0	9.0	9.0	20.5 bc
										LSD (0.05)	7.35

[a] treatment – nozzle; fungicide dosage and adjuvant (Olbras 88 EC – 1.5 l/ha)
[b] fungicide – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha
Fungicides (four treatments): I and II – cymoxanil + mancozeb (Curzate M 72,5 WP) – 100% = 2 kg/ha; II and III – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha
[c] scale Moore: 1 = no disease; 9 = crop completely dead
Values in columns followed by the same letter are not significantly different at p=0.05

per oxychloride) was not influenced by nozzle type and dose rate. However, the efficacy of the lower dosage rate (50%) was lower when sprayed with both the flat fan (XR 110-03) and the air induction (ID 120-03) nozzles. Although adding Olbras 88 EC did not significantly improve the efficacy of fungicide treatments, a tendency for an increased efficacy was observed. In experimental plots with 50% dosage rate of fungicides sprayed with both the flat fan and the air induction nozzles significant decrease yield of potato tubers as compared to other treated plots and untreated was obtained.

In 1998 late blight on potato was observed relatively late (Tab. 3). The first infection symptom was observed at the end of July. Adding Olbras 88 EC did not result in a better efficacy of three fungicide treatments (I – oxadixyl + mancozeb, II – dimethomoph + mancozeb; III – copper oxychloride). The efficacy of fungicide treatments was not influenced by nozzle type and dosage rate. Yield of potato tuber in all experimental plots was not significantly different as compared with untreated plot.

In the 1999 the late blight infection entered very late and all time the disease index was low (Tab. 4). Addition of adjuvants Atpolan 80 EC or Zero Piany 62 SL to the 50% dosage rate of fungicides applied with the flat fan and air induction nozzles had no effect on late blight control. There was obtained the same disease index with

Table 3. Spray coverage, late blight (*Phytophthora infestans*) control and yield of potato with fungicide treatments as affected by adjuvant and nozzle designs (1998)

Treatment[a]	Spray volume [l/ha]	Surface tension [mN/m]	Index of leaf coverage by fungicide in 0–400 scale[b]		Disease index at various dates at Moore 1–9 scale[c]				Yield [t/ha]
			upper side of leaf	lower side of leaf	24.06	9.07	23.08	4.08	
Flat fan (XR 110-03)									
100%	400	61.5	308	133	1.0	1.0	2.0	2.5	39.2 a
50% + Olbras 88 EC	400	30.5	358	125	1.0	1.0	2.0	2.5	41.2 a
Air induction (ID 120-03)									
100%	400	61.5	319	113	1.0	1.0	2.0	2.5	41.2 a
50% + Olbras 88 EC	400	30.5	271	96	1.0	1.0	2.0	2.5	39.6 a
Untreated	–	–	n.s.	n.s.	1.0	1.0	3.0	4.0	37.4 a
								LSD (0.05)	10.05

[a] treatment – nozzle; fungicide dosage and adjuvant (Olbras 88 EC – 1.5 l/ha)
[b] fungicide – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha
Fungicides (three treatments): I – oxadixyl + mancozeb (Sandofan Manco 64 WP) – 100% = 2 kg/ha; II – dimethomoph + mancozeb (Acrobat MZ 69 WP) – 100% = 2 kg/ha; III – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha
[c] scale Moore: 1 = no disease; 9 = crop completely dead
Values in columns followed by the same letter are not significantly different at p=0.05 probability level
n.s. – not significant differences

the 100 and 50% dosage rate of fungicides. The efficacy of the spray programme including three treatments (I- benalaxyl + mancozeb, II – copper oxychloride, III – oxadixyl + mancozeb) was not influenced by nozzle types or dosage rate. Adding Zero Piany 62 SL to the 50% dosage rate of fungicides applied with the flat fan XR 110-03 resulted in a significantly higher yield of tuber as compared with 100 and 50% dosage rate.

In 2000 the potato crop was considerable infected with late blight (Tab. 5). All treatments significantly reduced the disease progress as compared to untreated.

The highest efficacy of the spray programme with four treatments (I – metalaxyl-M + mancozeb, II – propineb, III – copper oxychloride, IV – fluazinam) was achieved when the fungicides were sprayed with the air induction nozzles DB 120-03 and Zero Piany 62 SL to the 50% dosage rate was added.

In general, adding Atpolan 80 EC or Zero Piany 62 SL to the 50% dosage rate of fungicides applied with both the flat fan and the air induction nozzles did not influence their efficacy but had favourable influence on potato yield.

DISCUSSION

The control of potato disease requires the highest precision of fungicide application on the leaves. Under Polish climatic conditions intensive crop protection dur-

Table 4. Spray coverage, late blight (*Phytophthora infestans*) control and yield of potato with fungicide treatments as affected by adjuvants and nozzle designs (1999)

Treatment[a]	Spray volume [l/ha]	Surface tension [mN/m]	Index of leaf coverage by fungicide in 0–400 scale[b]		Disease index at various dates at Moore 1–9 scale[c]				Yield [t/ha]
			upper side of leaf	lower side of leaf	02.07	12.07	23.07	05.08	
Flat fan (XR 110-03)									
100%	400	66.2	378	175	1.0	1.0	2.0	2.0	24.6 bc
50%	400	71.8	347	127	1.0	1.0	2.0	2.0	24.6 bc
50% + Atpolan 80 EC	400	49.4	311	108	1.0	1.0	2.0	2.0	28.0 abc
50% + Zero Piany 62 SL	400	35.3	355	92	1.0	1.0	2.0	2.0	35.2 a
Air induction (DB 120-03)									
100%	400	66.2	364	120	1.0	1.0	2.0	2.0	25.1 bc
50%	400	71.8	361	120	1.0	1.0	2.0	2.0	32.0 ab
50% + Atpolan 80 EC	400	49.4	347	103	1.0	1.0	2.0	2.0	29.4 abc
50% + Zero Piany 62 SL	400	35.3	355	117	1.0	1.0	2.0	2.0	28.8 abc
Untreated	–	–	n.s.	n.s.	1.0	1.0	2.5	3.0	23.0 c
								LSD (0.05)	7.62

[a] treatment – nozzle; fungicides dosage and adjuvant (Atpolan 80 EC – 1.5 l/ha; Zero Piany 62 SL – 1.5 l/ha)

[b] fungicide – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha

Fungicides (three treatments): I – benalaxyl + mancozeb (Galben M 73 WP) – 100% = 2 kg/ha; II – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha; III – oxadixyl + mancozeb (Sandofan Manco 64 WP) – 100% = 2 kg/ha

[c] scale Moore: 1 = no disease; 9 = crop completely dead

Values in columns followed by the same letter are not significantly different at p=0.05

n.s. – not significant differences

ing vegetation period should be conducted for at least 2–3 months (Kapsa and Osowski 1997). Control of late blight requires several treatments during vegetation season, especially (the most frequently) when potato plants have the most number of leaves and the leaves are the most exuberant. Disease control treatments, especially after contact fungicide application require the most accurate coverage of the both sides of leaf surfaces (upper and lower side of leaf blade). For those treatments in agriculture practice standard tractor sprayers with flat fan nozzles, which give fine-medium spray quality are used. During spraying with conventional flat fan nozzles sometimes appears a spray drift. Under field conditions small droplets are exposed to drift and evaporation even under good weather conditions, and this may lead to reduce deposition of the small droplet on leaves. An air induction nozzle with air bubble jet system deserves special notice. These nozzles work with higher

Table 5. Spray coverage, late blight (*Phytophthora infestans*) control and yield of potato with fungicide treatments as affected by adjuvants and nozzle designs (2000)

Treatment [a]	Spray volume [l/ha]	Surface tension [mN/m]	Index of leaf coverage by fungicide in 0–400 scale [b]		Disease index at various dates at Moore 1–9 scale [c]					Yield [t/ha]
			upper side of leaf	lower side of leaf	01.08	04.08	08.08	12.08	19.08	
Flat fan (XR 110-03)										
100%	400	63.3	329	113 ab	1.0	1.5	4.0	6.0	7.0	35.6 a
50%	400	64.8	312	84 bc	2.0	1.0	4.5	7.0	8.0	33.8 a
50% + Atpolan 80 EC	400	42.2	308	67 c	2.0	3.0	5.0	7.0	8.0	38.4 a
50% + Zero Piany 62 SL	400	43.0	321	79 c	2.0	3.5	5.0	7.0	8.0	35.6 a
Air induction (DB 120-03)										
100%	400	63.3	350	134 a	1.0	2.0	4.0	6.0	7.5	37.6 a
50%	400	64.8	304	96 bc	2.0	2.0	5.0	6.5	8.0	33.8 a
50% + Atpolan 80 EC	400	42.2	354	80 c	2.0	3.0	4.5	6.0	7.5	35.2 a
50% + Zero Piany 62 SL	400	43.0	317	75 c	2.0	2.0	4.0	5.5	7.0	35.1 a
Untreated	–	–	n.s.	4.0		6.0	8.0	8.0	9.0	20.8 b
									LSD (0.05)	7.74

[a] treatment – nozzle; fungicides dosage and adjuvant (Atpolan 80 EC – 1.5 l/ha; Zero Piany 62 SL – 1.5 l/ha)

[b] fungicide – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha

Fungicides (four treatments): I – metalaxyl-M + mancozeb (Ridomil Gold MZ 68 WP) – 100% = 2 kg/ha; II – propineb (Antracol 70 WP) – 100% = 1.8 kg/ha; III – copper oxychloride (Miedzian 50 WP) – 100% = 5 kg/ha; IV – fluazinam (Altima 500 SC) – 100% = 0.4 l/ha

[b] scale Moore: 1 = no disease; 9 = crop completely dead

Values in columns followed by the same letter are not significantly different at p=0.05

n.s. – not significant differences

working pressures, which give greater drop energy. Air bubbles contained in droplets cause their crash on the leaves. This process gives better fungicide coverage of protected surface, especially when liquids with lower surface tension are used e.g. spray solution with adjuvant (Cecil 1997).

The work described here mainly focused on fungicide application with respect to the application technique and usefulness of certain adjuvants added to fungicides. The results showed that adjuvants did not significantly influence the biological efficacy of the fungicide treatments against late blight. At lower dosage rates the essential redistribution of fungicides sprayed with flat fan and air induction nozzles is probably high enough to reach a good coverage of the leaf surface. Application of fungicides to potato (easy-to-wet) revealed no difference in the biological effects of spray characteristics, and no significantly difference in efficacy was obtained with

fungicides applied with or without adjuvant. On smooth, easy-to-wet leaf surface droplet retention is high and only little affected by application and solution characteristics (Grayson et al. 1991). In trials average index of leaf coverage by fungicide (copper oxychloride) was similar when the upper and lower sides of leaf blade were compared between treatments with or without adjuvants, respectively. Results showed that yield of potato tubers from separate experimental objects was not really different, except for the year 1997 where appearance of late blight was very significant. In years with a low infestation of late blight large reductions in the use of chemicals for crop protection can be obtained (Van de Zande et al. 1999).

In these investigations late blight control with contact and systemic fungicides also was used as the primary tool to estimate the efficacy of different nozzles tips. It is concluded that applying fungicides in potato even in lower dosage rates with air induction nozzles does not decrease the efficacy of late blight control as compared with spraying with flat fan nozzles. In general, control of late blight in potato with fungicides was not dependent on nozzle types and addition of adjuvants to spray solution. In field trials only small differences in efficacy between the included nozzles were found, despite the fact that several significant differences in spray coverage were obtained. Jensen et al. (2001) demonstrated the same missing correlation between deposition and fungicidal efficacy. A similar limited influence of application technique on biological efficacy of systemic fungicides in cereals was presented by Permin et al. (1992).

Spraying with air induction nozzles reduces spray drift by 90% but the percentage leaf area coverage is lower as compared with the fine – medium sized droplets produced by flat fan nozzles (Schepers and Meier 2001). However, normal field spraying is often carried out under less favourable weather conditions and such conditions should be relatively more favourable for coarse atomising nozzles. The results reported here indicate that the use of coarse air induction nozzles on late blight control gives similar effect as fine flat fan nozzles. This conclusion is interesting because time of application is often a very important factor for farmer and probably it could be in some situations an advantage to use a coarse spray instead of waiting for weather conditions that allow a finer application.

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POLISH SUMMARY

WPŁYW TYPU ROZPYLACZA I ADJUWANTÓW NA POKRYCIE LIŚCI I SKUTECZNOŚĆ DZIAŁANIA FUNGICYDÓW W ZIEMNIAKU

W badaniach polowych w latach 1997–2000 określano wpływ różnych typów rozpylaczy i adiuwantów na jakość pokrycia liści i skuteczność działania fungicydów podczas zwalczania zarazy ziemniaka (*Phytophthora infestans*).

Dodanie adiuwantów Olbras 88 EC, Atpolan 80 EC lub Zero Piany 62 SL do fungicydów spowodowało obniżenie napięcia powierzchniowego stosowanych cieczy użytkowych, lecz nie wpływało na poprawę jakości pokrycia liści. Nie stwierdzono wyraźnych różnic w porażeniu naci zarazą i plonie bulw ziemniaka na obiektach chronionych za pomocą standardowych rozpylaczy TeeJet XR 110-03 oraz ežektorowych typu Lechler ID 120-03 lub Lurmark DB 120-03, a także fungicydów stosowanych w dawkach zalecanych i obniżonych o 50% lecz z dodatkiem adiuwantów Olbras 88 EC, Atpolan 80 EC lub Zero Piany 62 SL.