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Effect of adjuvant and spray volume on mancozeb residue on potato and onion leaves and on *Phytophthora infestans* in potato and *Peronospora destructor* in onion

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vegIMPACT
Improved Vegetable Production and Marketing for small farmers to Increase the Food Security status and to promote Private Sector Development in Indonesia

vegIMPACT is a program financed by The Netherlands' Government promoting improved vegetable production and marketing for small farmers in Indonesia, contributing to the food security status and private sector development in Indonesia. The program builds on the results of previous joint Indonesian-Dutch horticultural development cooperation projects and aligns with recent developments in the horticultural private sector and retail in Indonesia. The program activities (2012 – 2016) include the Development of Product Market Combinations, Strengthening the Potato Sector, Development of permanent Vegetable Production Systems, Knowledge Transfer and Occupational Health.

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Summary

As part of the vegIMPACT project a laboratory test in the Netherlands was done with potato (*Solanum tuberosum*) var. Bintje and onion (*Allium cepa*) var. Sturon. In both crops mancozeb was sprayed with and without the adjuvants Bond and Indostick. In both crops these three treatments were applied with high and low spray volumes. After spraying, rain was simulated (0.5, 3 or 6 hours after spraying and a control without rain) to test the sticker properties. After five days, plant leaves were analysed on mancozeb residue. Five days after spraying the potato plants were inoculated with *Phytophthora infestans* and onions with *Peronospora destructor*. Subsequently, disease symptoms were observed and visually rated as percentage of infected leaves.
In potato lower mancozeb residue levels were measured at high spray volumes.
Under dry conditions the effect of adjuvant on mancozeb residue in potato was limited. In onion the spreader characteristics of the adjuvants resulted in higher mancozeb residue concentrations than without adjuvant.
The impact of rain simulation was much bigger than the impact of adjuvant on mancozeb residue and late blight incidence. Therefore, it is not recommended to spray when rain is expected within the same day as spraying.
With rain simulation in both onion and potato more mancozeb residue was present when using the adjuvant Bond than when spraying mancozeb without an adjuvant. However, also with Bond after rain simulation high amounts of mancozeb were washed off. Mancozeb with Bond in potato resulted in less late blight incidence than with spraying mancozeb without adjuvants.
Overall the adjuvant Bond performed better than Indostick in terms of mancozeb retention on both potato and onion leaves . Indostick had good spreading properties that under dry conditions resulted in higher mancozeb residue levels in onion. Under rainy conditions the effect of Indostick on mancozeb residues was not or only slightly better than mancozeb without adjuvant.

1. Introduction

In Indonesia late blight (*Phythophtora infestans*) is a destructive disease in potato (*Solanum tuberosum*) that can destroy a complete crop. Similar in shallots (*Allium cepa var. aggregatum*) anthracnose and downy mildew are important diseases that can cause high yield losses. Therefore, Indonesian farmers spray frequently mancozeb-based fungicides in potato and shallot to prevent infection. To improve the efficacy of the fungicides farmers can add adjuvants to the spray solution. Adjuvants are chemical products supposedly improving the rainfastness of fungicides and the spreading of spray droplets on the crops. In a selected group of potato farmers in Garut and Pangalengan more than 50% of the farmers used adjuvants in two subsequent growing seasons (De Putter et al., 2014; Van de Brink et al., 2015). Furthermore, farmers in Indonesia use relatively high volumes of water for spraying fungicides. In potato volumes exceeding 1000-1400 l/ha are quite common (De Putter et al., 2014; Van de Brink et al., 2015). In shallot spray volumes ranging from 600 to 1400 l/ha have been observed.
A range of adjuvants is for sale in Indonesia but depending on their chemical properties their activity is different and when used inappropriately they could negatively affect the control of pests and diseases. The quality of the adjuvants in Indonesia is not known. Many adjuvants sold in agrochemical stores contain the suffix 'stick' in the brand name but in reality are 'spreaders' with some sticking properties. Stickers usually contain a latex component to stick the spray droplets to the leaves which will improve rainfastness but it does not enhance the spreading of droplets that improves coverage of the leaves with pesticides. In contrast, spreaders contain components to reduce the water tension improving the distribution of spray droplets over the leaf surface, but they do not increase the rainfastness. Especially in onion and shallot surface spreaders can improve the coverage of the leaves with the fungicide. However, the use of spreaders increases the risk of run off especially if used in combination with large spray volumes. Generally, adjuvants with excellent sticker properties comprise components that improve also the spreading of droplets and as a result also the use of stickers may increase the risk of run off and loss of active ingredient of the agrochemical.
This report describes the results of greenhouse experiments to assess the effect of stickers in combination with different spray volumes and interval between spraying and intervals between spraying and rainfall on mancozeb residue on leaves and on disease control in potato and onion. The study was performed in the Netherlands and in Chapter 2 the potato experiment is described, followed by the onion experiment in Chapter 3. In the concluding Chapter 4 the results of the sticker experiments in potato and onion are discussed in a broader context, followed by a number of practical recommendations on the use of stickers and spreaders.

2. Potato experiment

2.1 Materials and methods

Potato plants cv. Bintje were planted in pots with a top diameter of 20 cm and a volume of 5 liter on 28 May 2015. The plants were raised in a greenhouse at ambient temperature, rooftop windows were opened when inside temperature exceeded 5^{o}C. When the greenhouse temperature became too high and outdoor conditions were dry, plants were placed outdoors.
The potato plants were sprayed on 2 July with the treatments shown in Table 2.1. Per treatment 4 pots were used. The fungicide used in the test was Tridex 75 DG containing 75% mancozeb. In Indonesia other mancozeb products are used comparable to the Tridex 75 DG. None of these products are available in the Netherlands. The adjuvant Indostick was bought in an Indonesian agro shop, the adjuvant Bond was kindly provided by Nufarm in the Netherlands. Bond is not used in Indonesia but was used as a reference since this product has proven sticker characteristics; Bond contains 10% spreader and 45% latex (sticker) (Bus et al., 2005). Characteristics and applied rates of Tridex 75 DG in the experiment and the two used adjuvants are presented in Table 2.2.

Potato plants were sprayed in a spraying cabin developed by Applied Plant Research (Figure 2.1). The fungicides were sprayed using a spray boom with three spray nozzles, placed 50 cm apart. The boom at a height of approximately 40 cm between nozzle and plant moved at a steady speed over the top of the potato plants. Spray volume was 750 l/ha or 250 l/ha.
Rain simulation took place 0.5, 3 or 6 hours after the spray treatments were carried out. Heavy rainfall that can occur in Indonesia was simulated with 36 mm applied in 15 minutes using a spray boom (Figure 2.2).

On 7 July, i.e. 5 days after the spray treatment, per pot four compound leaves were picked for residue analyse. Per two pots one sample was made to create duplicate samples per treatment except for the 3 hour rain simulation treatment with only one sample per treatment. Mancozeb residues on the leaves are expressed in mg residue per kg fresh weight of leaves.
Inoculation was carried out with *Phytophthora infestans* on air dry plants on 7 July 2015. After inoculation, plants were incubated at a high relatively humidity for 18 hours.

Table 2.1. Treatments in the potato test and applied doses.

Code	Agrochemical	Adjuvant	spray volume (l/ha)	Period between spraying and rain simulation (hr)	Residue analyse (number of samples)	P. infestans observation (nr of pots)
A 0 0	none	no	none	no rain	1	4
A 0 6	none	no	none	6	1	4
B 250 0	Tridex 75 DG	no	250	no rain	2	4
C 250 0	Tridex 75 DG	Bond	250	no rain	2	4
D 250 0	Tridex 75 DG	Indostick	250	no rain	2	4
E 250 0	Tridex 75 DG	no	250	no rain	2	4
F 250 0	Tridex 75 DG	Bond	250	no rain	2	4
G 250 0	Tridex 75 DG	Indostick	250	no rain	2	4
B 250 3	Tridex 75 DG	no	250	3	1	4
C 250 3	Tridex 75 DG	Bond	250	3	1	4
D 250 3	Tridex 75 DG	Indostick	250	3	1	4
E 250 3	Tridex 75 DG	no	250	3	1	4
F 250 3	Tridex 75 DG	Bond	250	3	1	4
G 250 3	Tridex 75 DG	Indostick	250	3	1	4
B 250 6	Tridex 75 DG	no	250	6	2	4
C 250 6	Tridex 75 DG	Bond	250	6	2	4
D 250 6	Tridex 75 DG	Indostick	250	6	2	4
E 250 6	Tridex 75 DG	no	250	6	2	4
F 250 6	Tridex 75 DG	Bond	250	6	2	4
G 250 6	Tridex 75 DG	Indostick	250	6	2	4
B 750 0	Tridex 75 DG	no	750	no rain	2	4
C 750 0	Tridex 75 DG	Bond	750	no rain	2	4
D 750 0	Tridex 75 DG	Indostick	750	no rain	2	4
E 750 0	Tridex 75 DG	no	750	no rain	2	4
F 750 0	Tridex 75 DG	Bond	750	no rain	2	4
G 750 0	Tridex 75 DG	Indostick	750	no rain	2	4
E 750 0.5	Tridex 75 DG	no	750	0.5	2	4
F 750 0.5	Tridex 75 DG	Bond	750	0.5	2	4
G 750 0.5	Tridex 75 DG	Indostick	750	0.5	2	4
B 750 3	Tridex 75 DG	no	750	3	1	4
C 750 3	Tridex 75 DG	Bond	750	3	1	4
D 750 3	Tridex 75 DG	Indostick	750	3	1	4
E 750 3	Tridex 75 DG	no	750	3	1	4
F 750 3	Tridex 75 DG	Bond	750	3	1	4
G 750 3	Tridex 75 DG	Indostick	750	3	1	4
B 750 6	Tridex 75 DG	no	750	6	2	4
C 750 6	Tridex 75 DG	Bond	750	6	2	4
D 750 6	Tridex 75 DG	Indostick	750	6	2	4
E 750 6	Tridex 75 DG	no	750	6	2	4
F 750 6	Tridex 75 DG	Bond	750	6	2	4
G 750 6	Tridex 75 DG	Indostick	750	6	2	4

Table 2.2. The fungicide and adjuvants used in the pot experiment.

Product name	Active ingredients	Dose rate
Tridex 75 DG	mancozeb 750 g/kg	2 kg/ha
Bond	styrene butadiene co-polymer 45% w/w + alcohol alkoxylate 10% w/w	0.14%
Indostick 100/20 SL	nonylphenol ethylene oxide condensate 95 g/l + polyvinyl alcohol 19 g/l	0.15%

Figure 2.1. Spray cabine at PPO Lelystad used to spray the plants.

Figure 2.2. Rain simulation with 36 mm of tap water in a period of 15 minutes.

Five, seven and nine days after infection *Phythopthora infestans* symptoms were observed in potato plants and visually rated as percentage of infected leaf area surface (Table 2.3).

Table 2.3. Timing of activities in the potato experiment.

Date	Activity
28 May	Planting of potato tubers
2 July	Spraying with the different treatments Rain simulation 0.5, 3 or 6 hours after spraying
7 July	Sampling of leaves for analyse on mancozeb residue Plants were infected with 11 ml containing 12,000 spores/ml of *Phytophthora infestans* Blue 13 strain.
11 July	First *Phytophthora infestans* observation
13 July	Second *Phytophthora infestans* observation
16 July	Third *Phytophthora infestans* observation
7-12 July	Analyse of leaf samples with Headspace GCMS method by TLR International laboratories.

In the remainder of this report, "Tridex" refers to the treatment of Tridex applied without any adjuvant, "Bond" refers to the treatment of Tridex applied with the adjuvant Bond and "Indostick" refers to the treatment of Tridex applied with the adjuvant Indostick.

Data on residue and *P. infestans* rating were analysed as a randomized block design using the statistical program Genstat. All data was analysed as a oneway analysis while interactions were analysed with a three way analysis (sticker x rain simulation x spray volume) only of the no rain, 3 and 6 hours rain simulation treatments excluding the untreated controls.

2.2 Results

Without rain simulation and 250 l/ha spray volume the mancozeb residue with both Bond and Indostick was not different from Tridex without adjuvant (Table 2.4 and Fig. 2.3). Most mancozeb residue was found at the plants treated with Bond and was significant higher than the residue present with Indostick. With 750 l/ha spray volume, Bond showed significantly more residue than Indostick and Tridex without adjuvant, while the latter two were not different.
Simulation of rain six hours after spraying significantly lowered residue levels compared to the treatments without rain simulation. At both 250 and 750 l/ha spray volume Bond showed higher mancozeb residue levels than Tridex without adjuvant. Indostick showed also higher residue levels but these were not significantly different from Tridex without adjuvant.
Rain simulation three hours after spraying showed almost similar residue levels as levels found with rain simulation six hours after spraying. At both spray volumes Bond showed a significant higher mancozeb residue level than Tridex without adjuvant but only at 250 l/ha the difference was significant.
Rain simulation 0.5 hour after spraying in combination with 750 l/ha spray volume showed for Bond a higher residue level than Tridex without adjuvant, a difference that was almost significant.
All three treatments showed lower mancozeb residue levels at a spray volume of 750 l/ha compared to 250 l/ha. The average residue level of 250 and 750 l/ha of the no rain, six and three hour rain simulation treatments of Bond showed a significantly higher mancozeb residue level than the other two treatments ($p<0.001$; lsd=12.6). The residue level with Indostick was not significantly different from Tridex without adjuvant. With rain simulation after three and six hours the mancozeb residue was significantly lower than with no rain simulation ($p<0.001$; lsd=21.8). The difference in residue levels between three and six hours was not significant.

Table 2.4. Effect of adjuvant, spray volume and rain simulation on mancozeb residue on potato leaves (mg/kg). All data: p< 0.001; LSD = 30.4.

		Period between spraying and rain simulation (hour)				
	spray volume (l/ha)	**0.5**	**3[1)]**	**6**	**no rain**	**Mean[2)]**
Tridex	250	-[3)]	46	53	100	70
Tridex + Bond	250	-	79	89	126	102
Tridex + Indostick	250	-	66	71	94	79
Tridex	750	44	62	36	75	53
Tridex + Bond	750	73	71	86	113	88
Tridex + Indostick	750	54	61	54	82	63
untreated control	0	-	-	0	0	
Mean [4)]			64	65	98	

[1)] one replication only
[2)] excluding 0.5 hour rain simulation
[3)] not tested
[4)] excluding untreated control

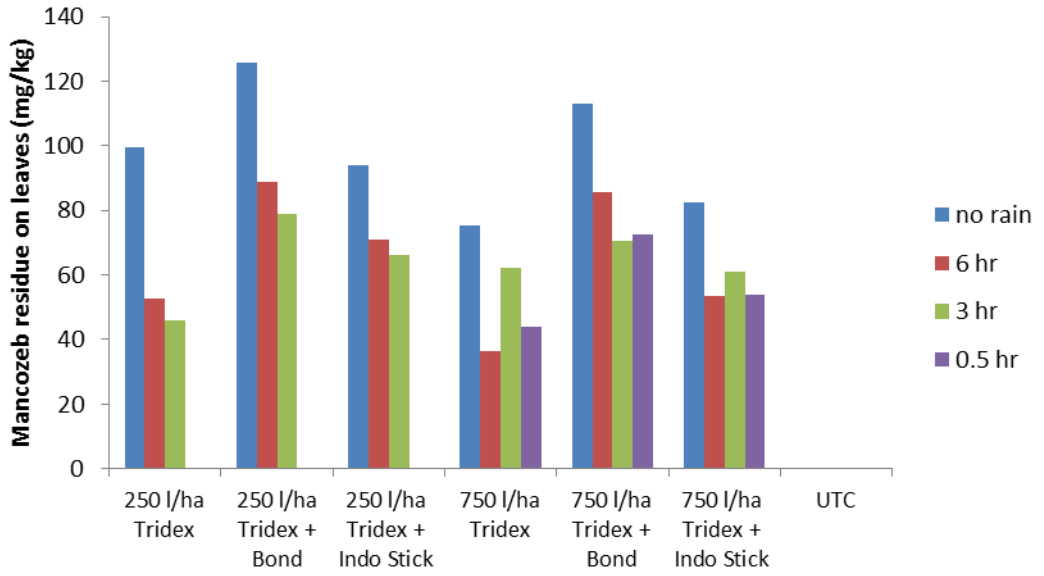

Figure 2.3. Effect of adjuvant, spray volume and rain simulation on mancozeb residues on potato leaves (mg/kg).

Figure 2.4 shows the effect of the rain simulation three hours after spraying on remaining mancozeb residue on potato leaves as percentage of the residue level measured in the treatment without rain after fungicide treatment. With 250 l/ha and Tridex the residue was 46% of the level without rain. When using Bond 63% of the residues were retained, while with Indostick this was 73%. With a spray volume of 750 l/ha the Tridex residue was about 80% of the residue level without rain. This relatively high percentage is related to the already low (absolute residue) levels measured at high spray volumes without rain simulation, i.e. rainfall three hours after spraying does result in much higher losses. With Bond and Indostick the residue percentages were comparable to the percentages with 250 l/ha.

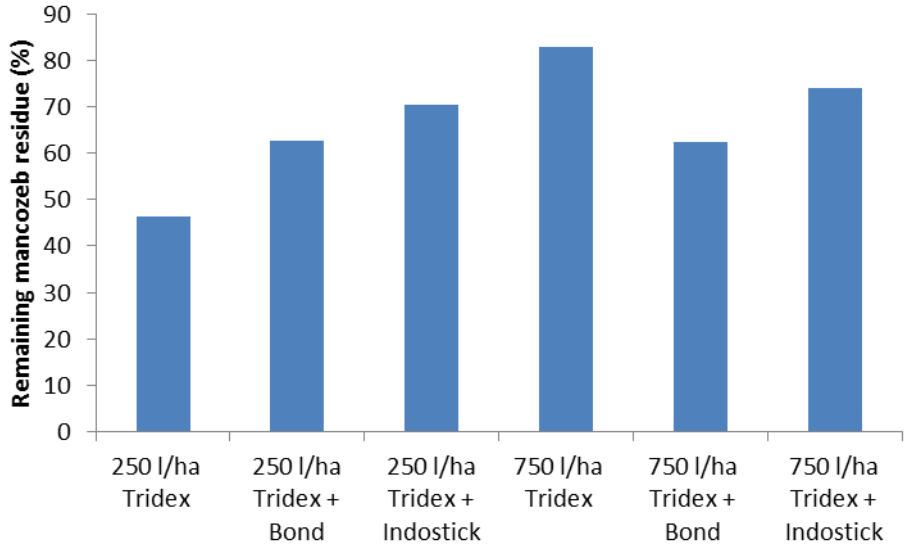

Figure 2.4. *Effect of rain simulation three hours after spraying on remaining mancozeb residue on potato leaves as percentage of the residue level measured in the treatment without rain after fungicide treatment.*

In 2014 the effect of a flowable mancozeb formulation (Brabant Mancozeb Fl) in combination with different adjuvants was tested on mancozeb residue and *Phythophthora infestans* (Schepers, et al., 2014). In this test, spraying took place with 750 l/ha only and rain simulation 0.5 hour after spraying. Although not tested in the same experiment with the flowable mancozeb formulation lower mancozeb residue percentages were observed than with the Tridex DG formulation (Fig. 2.5). At Brabant Fl without adjuvant mancozeb residue after rain simulation was only 8% of the level present without rain. With Tridex DG 59% of the fungicide was retained. In combination with Bond the percentage mancozeb with Brabant Fl was 12% while with Tridex DG it was 63%.

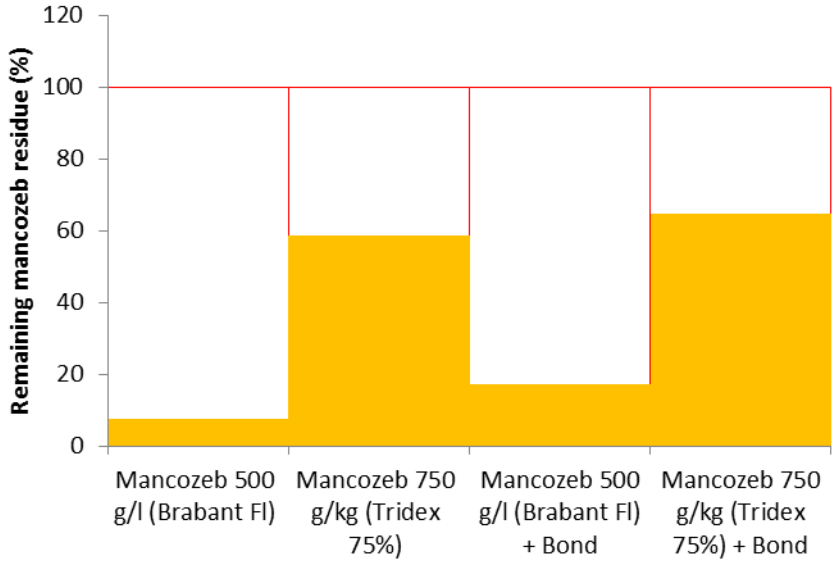

Figure 2.5. *Effect of mancozeb formulation and adjuvant on remaining mancozeb residue with rain simulation 0.5 hour after spraying as percentage of the residue level measured in the treatment without rain after fungicide treatment. (Based on Schepers, et al., 2014)*

Phytophthora infestans infection increased in five days from 48 to 93% in the untreated control (Fig. 2.6) When spraying mancozeb the infection increased from about 10 to 40%.

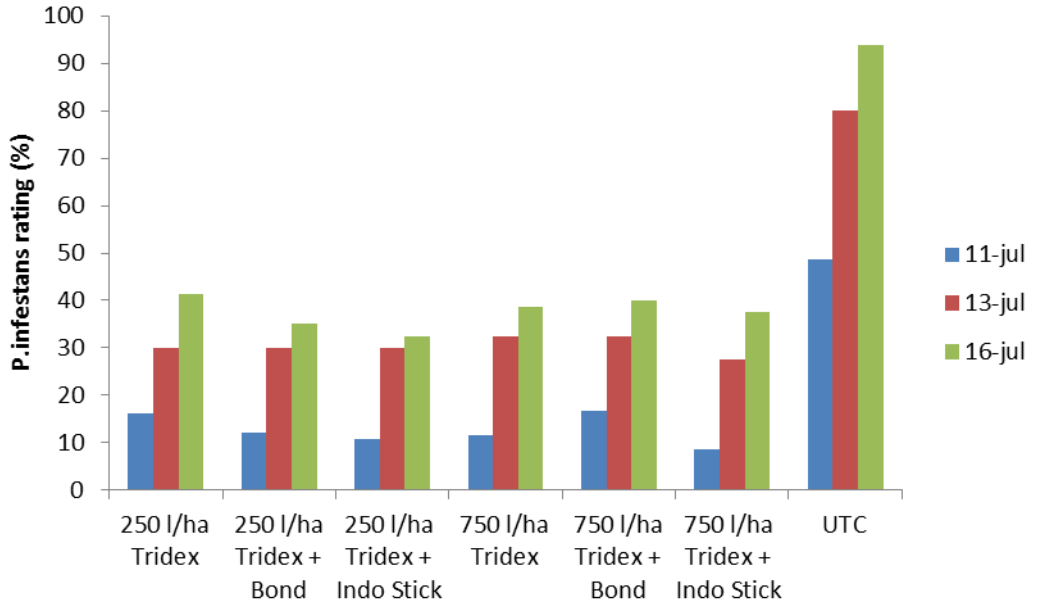

Figure 2.6. *Effect of adjuvant and spray volume on development of Phytophthora infestans in potato without rain simulation on 11, 13 and 16 July, which corresponds with four, six and nine days after the fungicide spraying. UTC=untreated control.*

Without rain after the fungicide treatments the differences in *P. infestans* infection between treatments were not significant (Table 2.5). With rain simulation six hours after spraying and 250 l/ha spray volume Bond showed a significantly lower *P. infestans* incidence than Tridex and Indostick, while latter two did not differ in infection level. With 750 l/ha no differences in *P. infestans* were present between treatments.
With rain simulation three hours after spraying at both 250 and 750 l/ha Bond showed a significantly lower *P. infestans* incidence than Tridex. At 0.5 hour rain both Bond and Indostick showed significantly lower *P. infestans* incidences compared to Tridex. Compared to Indostick Bond showed a significantly lower *P. infestans* incidence when rain was simulated 0.5 h after spray treatment.

Table 2.5. *Effect of adjuvant, spray volume and rain simulation on Phytophtora infestans incidence in potato on 16 July 2015 (% infection). All data: p< 0.001; LSD = 12.3.*

		Period between spraying and rain simulation (hour)				
	spray volume (l/ha)	**0.5**	**3**	**6**	**no rain**	**Mean [1)]**
Tridex	250	- [2)]	66	64	41	57
Tridex + Bond	250	-	53	49	35	45
Tridex + Indostick	250	-	65	65	33	54
Tridex	750	73	65	51	39	52
Tridex + Bond	750	40	46	44	40	43
Tridex + Indostick	750	58	50	48	38	45
untreated control	0	-	-	97	94	
Mean [3)]			58	53	38	

[1)] excluding 0.5 hour rain simulation
[2)] not tested
[3)] excluding untreated control

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Figure 2.7 shows the negative relationship between mancozeb residue on potato leaves and *P. infestans* infection: Increasing mancozeb residue levels on the leaves associated with lower *P. infestans* infection.

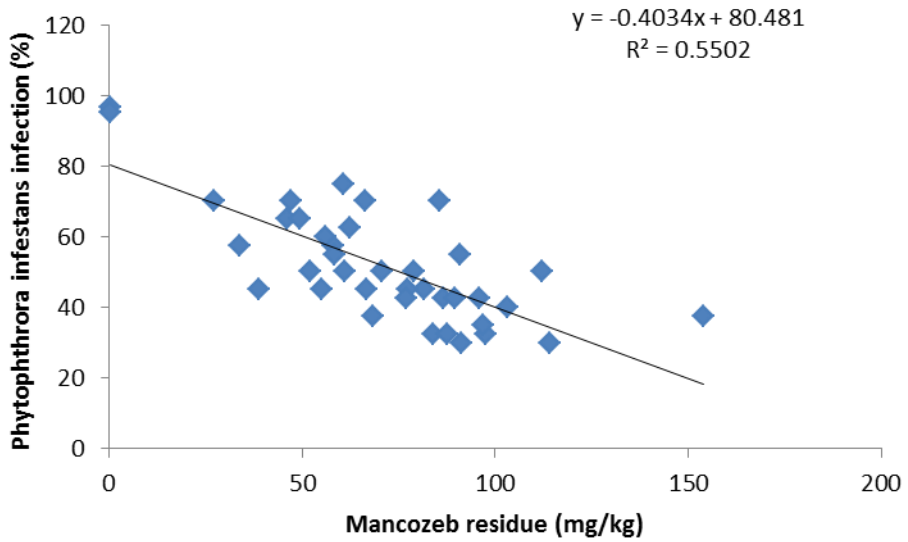

Figure 2.7. *Relationship between mancozeb residue on potato leaves at the time of infection and Phytophthora infestans incidence on 16 July 2015.*

3. Onion experiment

3.1 Materials and methods

The common onion (*Alium cepa*) was selected since this crop is easier to grow in the Netherlands than shallots but still has a similar leaf structure as shallots. In onions the test was done with *Peronospora destructor* since it was not possible to infect with *anthracnose*. In onion the same treatments as in potato were used except for the spray volumes which were 150 and 300 l/ha (Table 3.1).

Table 3.1. Treatments in the onion test and applied doses.

Code	Agrochemical	Adjuvant	spray volume (l/ha)	Period between spraying and rain simulation (hr)	Residue analyse (number of samples)	P. destructor observation (nr. of pots)
A 0 0	none	no	none	no rain	1	4
A 0 3	none	no	none	3	1	4
A 0 6	none	no	none	6	1	4
B 250 0	Tridex 75 DG	no	150	no rain	2	4
C 250 0	Tridex 75 DG	Bond	150	no rain	2	4
D 250 0	Tridex 75 DG	Indostick	150	no rain	2	4
E 250 0	Tridex 75 DG	no	150	no rain	2	4
F 250 0	Tridex 75 DG	Bond	150	no rain	2	4
G 250 0	Tridex 75 DG	Indostick	150	no rain	2	4
B 250 3	Tridex 75 DG	no	150	3	1	4
C 250 3	Tridex 75 DG	Bond	150	3	1	4
D 250 3	Tridex 75 DG	Indostick	150	3	1	4
E 250 3	Tridex 75 DG	no	150	3	1	4
F 250 3	Tridex 75 DG	Bond	150	3	1	4
G 250 3	Tridex 75 DG	Indostick	150	3	1	4
B 250 6	Tridex 75 DG	no	150	6	2	4
C 250 6	Tridex 75 DG	Bond	150	6	2	4
D 250 6	Tridex 75 DG	Indostick	150	6	2	4
E 250 6	Tridex 75 DG	no	150	6	2	4
F 250 6	Tridex 75 DG	Bond	150	6	2	4
G 250 6	Tridex 75 DG	Indostick	150	6	2	4
B 750 0	Tridex 75 DG	no	300	no rain	2	4
C 750 0	Tridex 75 DG	Bond	300	no rain	2	4
D 750 0	Tridex 75 DG	Indostick	300	no rain	2	4
E 750 0	Tridex 75 DG	no	300	no rain	2	4
F 750 0	Tridex 75 DG	Bond	300	no rain	2	4
G 750 0	Tridex 75 DG	Indostick	300	no rain	2	4
E 750 0.5	Tridex 75 DG	no	300	0.5	2	4
F 750 0.5	Tridex 75 DG	Bond	300	0.5	2	4
G 750 0.5	Tridex 75 DG	Indostick	300	0.5	2	4
B 750 3	Tridex 75 DG	no	300	3	1	4
C 750 3	Tridex 75 DG	Bond	300	3	1	4
D 750 3	Tridex 75 DG	Indostick	300	3	1	4
E 750 3	Tridex 75 DG	no	300	3	1	4
F 750 3	Tridex 75 DG	Bond	300	3	1	4
G 750 3	Tridex 75 DG	Indostick	300	3	1	4
B 750 6	Tridex 75 DG	no	300	6	2	4
C 750 6	Tridex 75 DG	Bond	300	6	2	4
D 750 6	Tridex 75 DG	Indostick	300	6	2	4
E 750 6	Tridex 75 DG	no	300	6	2	4
F 750 6	Tridex 75 DG	Bond	300	6	2	4
G 750 6	Tridex 75 DG	Indostick	300	6	2	4

In 5 l pots with a top diameter of 25 cm 15 onion bulbs cv. Sturon were planted on 17 June 2015. Plants were raised in a greenhouse at ambient temperature. Rooftop windows were opened when indoor temperature exceeded 5^{o}C. When the temperature was still too high plants were placed outdoors but only under dry conditions.
Onions were sprayed on 16 July with the same method described for potato in section 2.1. Rain was simulated 0.5, 3 or 6 hours after spraying by placing the pots under a spray boom for 15 minutes with 36 mm water. On 21 July leaf samples were collected for mancozeb residue analyse by TLR laboratories by taking six leaves per pot. Per treatment two duplicates were made by adding leaves from two replicates together. From the three hour rain simulation treatment was only one sample per treatment. On 21 July after the leaf sample collection onions were infected by spraying the plants with a pathogen solution of 22,000 spores/ml. Plants were placed at high relative humidity (>98%) for one night and subsequently placed outdoor for 14 and 15 days when the infected plants were moved to a room with high relative humidity to enhance symptom development by downy mildew. Observations on downy mildew symptoms took place on 6, 8, 11 and 14 August. See Table 3.2 for the activity sequence.

Table 3.2. Timing of the activities in the onion experiment.

Date	Activity
17 June	Planting of onion bulbs
16 July	Spraying with the different treatments
	Rain simulation 0.5, 3 or 6 hours after spraying
21 July	Sampling of leaves for analyse on mancozeb residue
	Plants were infected with *Peronospora destructor* (downy mildew)
4-5 August	Plants kept at high Relative Humidity
6 August	First downy mildew observation
8 August	Second downy mildew observation
11 August	Third downy mildew observation
13 August	Fourth downy mildew observation

Data on mancozeb residue and downy mildew rating was analysed as a randomized block design using Anova with the statistical programme Genstat.

3.2 Results

Tridex applied with 150 l/ha and 300 l/ha showed mancozeb residue levels of respectively 3.7 mg/kg and 3.2 mg/kg (Table 3.3 and Fig. 3.1). With both 150 l/ha and 300 l/ha Bond resulted in significant higher mancozeb residue levels, while Indostick only showed a clear significant higher level at a spray volume of 300 l/ha. Rain simulation six hours after spraying mancozeb reduced the residue levels significantly compared to no rain, but Bond treatments at both 150 and 300 l/ha still had higher residue levels than Tridex, which were not significant from Indostick. The rain simulation three hours after spraying showed the same differences in residue levels among treatments.

Table 3.3. Effect of adjuvant, spray volume and rain simulation on mancozeb residue on onion leaves (mg/kg). All data: p< 0.001; LSD = 1.2.

		Period between spraying and rain simulation (hour)				
	spray volume (l/ha)	**0.5**	**3[1)]**	**6**	**no rain**	**Mean[2)]**
Tridex	150	-[3)]	0.2	0.4	3.7	1.7
Tridex + Bond	150	-	3.1	2.8	6.0	4.1
Tridex + Indostick	150	-	0.6	0.9	4.6	2.3
Tridex	300	0.4	0.4	0.8	3.2	1.4
Tridex + Bond	300	3.8	3.8	5.6	6.1	5.1
Tridex + Indostick	300	0.9	1.6	1.5	4.7	2.6
untreated control	0	-	-	0.1	0.0	
Mean [4)]			1.6	2.0	4.7	

[1)] one replication only
[2)] excluding 0.5 hour rain simulation
[3)] not tested
[4)] excluding untreated control

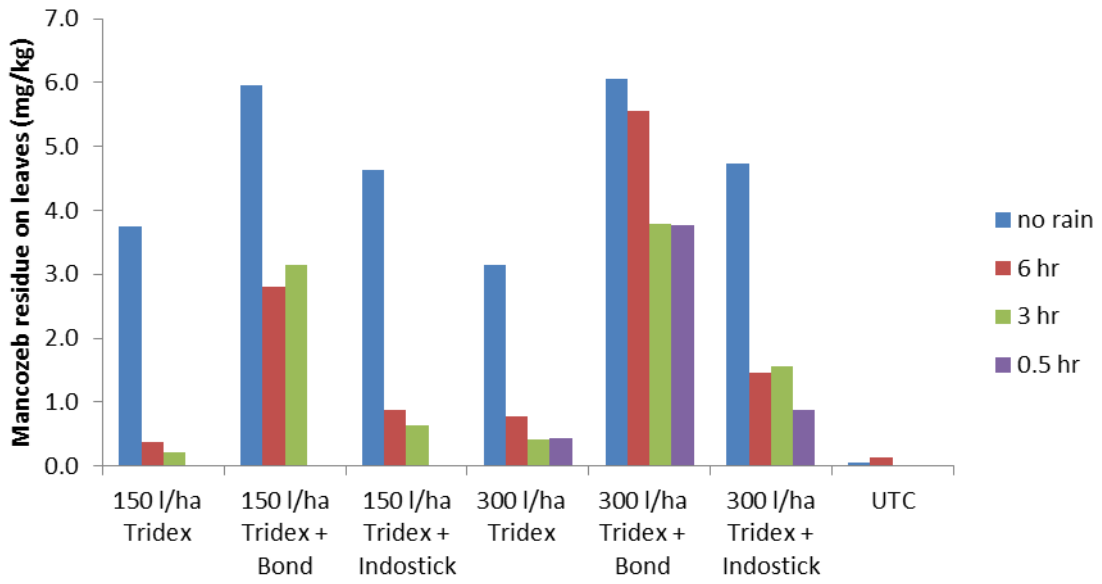

Figure 3.1 Effect of adjuvant, spray volume and rain simulation on mancozeb residue on onion leaves (mg/kg).

With rain simulation three hours after spraying the mancozeb residue level of the Tridex treatments (both 150 and 300 l/ha) were reduced with approximately 90% (Fig. 3.2). With Bond 54% was retained when spraying at 150 l/ha and 63% when spraying at 300 l/ha. With Indostick these percentages were much lower compared to Bond, i.e. about 15 and 35%, respectively.

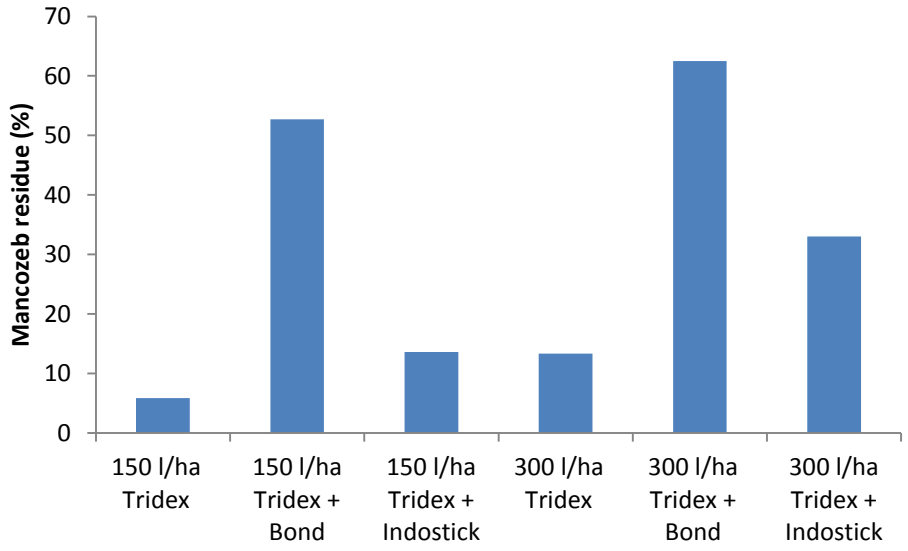

Figure 3.2. *Effect of adjuvant and spray volume with rain simulation three hours after spraying on mancozeb residues on onion leaves as percentage of the residue level measured in the treatment without rain after fungicide spraying.*

Downy mildew was present only at low levels in the untreated control: 6% incidence was observed on 11 August (Table 3.4). At the other observation dates incidence of downy mildew was even less than 6%. When spraying Tridex in almost all cases no downy mildew was observed. Remarkable is the fact that (slightly) higher incidences of downy mildew were observed in the treatments with 150 l/ha where rain simulation was performed six hours after spraying.

Table 3.4. *Effect of adjuvant, spray volume and rain simulation on downy mildew incidence on onion leaves (%).All data: p < 0.001; lsd=1.7.*

		Period between spraying and rain simulation (hour)				
	spray volume (l/ha)	**0.5**	**3**	**6**	**no rain**	**Mean[1)]**
Tridex	150	- [2)]	0.0	1.8	0.0	0.6
Tridex + Bond	150	-	0.0	1.8	0.0	0.6
Tridex + Indostick	150	-	0.0	0.0	0.0	0.0
Tridex	300	1.3	0.8	0.3	0.0	0.3
Tridex + Bond	300	0.0	0.0	0.0	0.0	0.0
Tridex + Indostick	300	0.0	0.0	0.0	0.0	0.0
untreated control	0	-	6.0	0.0	6.0	4.0
Mean [3)]			0.1	0.6	0.0	

[1)] excluding 0.5 hour rain simulation
[2)] not tested
[3)] excluding untreated control

4. Discussion and conclusions

4.1 Effect of spray volume

Mancozeb residue on potato leaves was lower with high spray volumes of 750 l/ha compared to 250 l/ha (p=0.074) probably because of increased run off at higher spray volumes. In onion mancozeb residue levels with a spray volume of 150 l/ha were lower compared to a spray volume of 300 l/ha (p=0.007). In the case of onion with a spray volume of 150 l/ha a similar result as with 300 l/ha was present when no rain was simulated. In general, a spray volume of 150 l/ha is too low to protect onion properly when rain is expected after spraying.
A spray volume of 250 l/ha had a similar effect on *Phytophthora infestans* incidence in potato as 750 l/ha. Hence, a same amount of mancozeb applied with low spray volumes (250 l/ha) give a similar level of late blight control as 750 l/ha.

4.2 Effect of rain simulation

Rain simulation treatments had a big impact on the measured mancozeb residue on leaves. In both potato and onion considerable lower mancozeb residue levels were found after rain simulation compared to the treatments without the rain simulation. More mancozeb was lost in potato when rain simulation took place sooner after spraying mancozeb. As a result, late blight incidence was higher in treatments that received rain after three hours compared to treatments receiving rain after six hours after spraying.
In potato rain simulation resulted in comparable mancozeb residue levels for both Bond and Indostick. In onion significant more mancozeb was left on leaves with Bond compared to Indostick.
With Bond the absolute level of mancozeb residue on potato leaves was high without and with rain simulation compared to the other treatments. However, after rainfall mancozeb residue losses with Bond were relatively high.
In onion (300 l/ha spray volume) less mancozeb residue was measured with rain simulation three hours after spraying compared to six hours. Even when rain took place six hours after spraying a high amount of mancozeb was lost.

4.3 Effect of adjuvants

In both potato and onion Bond gave higher mancozeb residue levels especially after rain simulation. Without rain simulation no significant effect of adjuvant on mancozeb residue or *Phytophthora infestans* incidence was observed in potato. In onion higher mancozeb residue levels were observed after rain simulation in treatments with adjuvants, especially Bond (Fig. 3.2). In potato a significant lower infection with *Phytophthora infestans* was observed in the Bond treatments compared to Tridex without adjuvant. Indostick too showed lower *Phytophthora* incidence than Tridex but higher than with Bond. In onion no differences in downy mildew between the treatments were observed, which was also related to very low infection of onion with downy mildew in the entire experiment.
In 2007 a field test in onion was carried out in Lelystad to investigate the effect of the adjuvants Zipper and Fullstop (Meier and Schepers, 2007). The results of this test showed that Tridex DG in combination with one of these adjuvants significantly reduced *Botrytis squamosa* symptoms in onion. Downy mildew was not present in the test and effect of the adjuvants on this disease could therefore not be observed.

4.4 Effect of mancozeb formulation

Although not within the scope of this test it seems that the rain fastness of mancozeb Tridex DG is better than the rain fastness of Brabant mancozeb Fl. When comparing the relative mancozeb residue

levels after 0.5 hour rain simulation in two separate experiments a higher percentage was still present with Tridex DG than with Brabant mancozeb Fl (Fig. 2.5).

4.5 Concluding remarks

Adjuvant, rain as well as spray volume have an impact on mancozeb residue in potato and onion and on the infection of *Phytophthora infestans* in potato. When significant amounts of rain occur, even six hours after spraying mancozeb, considerable amounts of mancozeb are lost compared to a no-rain situation. Under dry conditions the use of adjuvant in potato did not result in higher mancozeb residue levels or less *Phytophthora* incidence. In onion, the addition of an adjuvant to Tridex DG resulted in an increase in mancozeb residues but no effect on downy mildew incidence could be observed. However, the incidence of downy mildew in onion was at a very low level, even in the control treatment (Table 3.4).
The adjuvant Bond showed in both potato and onion higher mancozeb residue levels than untreated. In potato also less *Phytophthora infestans* was present in the Bond treatments. Bond seems to be an adjuvant with both good spreading and sticking properties.
Indostick showed in potato and onion higher mancozob residue levels than Tridex without an adjuvant. However, especially in onion no significant effect of indostick on mancozeb residue was present after rain simulation. Indostick improved the adhesion of mancozeb to the crop due to the spreading properties but sticking performances were not improved.
In potato less mancozeb residues were present when applying the same amount of the product with 750 l/ha than with 250 l/ha. In onion, fungicide runoff with 300 l/ha is low while with 150 l/ha the coverage of the leaves with fungicide is not optimal.

4.6 Practical recommendations

Based on the results of these tests and the test carried out in 2014 (Schepers et al., 2014) the following can be recommended:

- Preferably use a wetable powder (WP) or water dispersible granules (DG) mancozeb formulation for spraying since these formulations are more rain fast than a flowable (FL) formulation.
- Do not spray potato and onion when heavy rain is six hours after spraying because high amounts of mancozeb can be washed off resulting in high infection risks.
- For a good control of late blight in potato a spray volume of 250 l/ha is sufficient, but with the same mancozeb dose per hectare as with 750 l/ha. A high spray volume bears the risk of increased run off from the leaves and thus reducing the crop protection.
- When no rain is expected after spray operations in potato adding of an adjuvant to the spray solution is not needed. In onion the addition of an adjuvant improves the adhesion or retention of mancozeb to the leaves both under dry and rainy conditions.
- When rain is expected shortly after a spraying operation and there is no option to postpone the spraying an adjuvant can increase the rain fastness of the fungicide in both onion and potato. However, a proper adjuvant with good sticking properties needs to be selected. Indostick showed good spreading properties but less sticking properties. Bond showed both good spreading and sticking properties in the experiments.

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