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Impact of simulated rainfall on persistence of fungicides used against late blight (*Phytophthora infestans*) of tomato (*Solanum lycopersicum*)

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ABSTRACT

Persistence of mancozeb 75%WP and metalaxyl 8%+mancozeb 64 %WP fungicides was studied on tomato (*Solanum lycopersicum* L.) leaves with respect to different simulated rain amounts (0, 5, 10 and 15mm) after different number of days (0, 2, 4, 6, 8 and 10) after fungicidal spray. Rainfall applied immediately after fungicidal spray removed fungicides from the leaf surface resulting in higher disease severity. As rain amount increased from 5 to 15 mm, disease was also increased in both the test fungicides. In case of metalaxyl 8%+mancozeb 64 %WP @ 0.25 per cent, disease severity was less as compared to the mancozeb 75%WP @ 0.25 per cent. The delaying of rainfall by 2 days after fungicidal spray resulted in significant reduction in disease severity in case of metalaxyl 8%+mancozeb 64 %WP sprayed tomato plants. Metalaxyl 8%+mancozeb 64%WP being a systemic fungicide was absorbed into the system of the plant. However, this was not true in case of mancozeb 75%WP sprayed tomato plants. Since, mancozeb 75 %WP a non systemic fungicide was washed with the application of rain.

Key words: Fungicide, Persistence, Simulated rainfall, Tomato

Tomato crop and yield is suffered every year due to number of pathogenic diseases caused by fungi, bacteria, viruses and nematodes (Wani 2011). Among the fungal diseases, late blight caused by *Phytophthora infestans* (Mont.) de Bary is the most destructive disease. It assumes epiphytotic proportion in moist, cool, rainy, and humid environments. The Punjab state experiences late blight epidemics after every 4 to 5 years resulting in significant crop losses ranging from 15-100 percent (Thind and Mohan 1998, Thind *et al.* 2004). Without the use of fungicide, a profitable crop of tomatoes (*Solanum lycopersicum* L.) is impossible. Tomato is generally sprayed with fungicides (mancozeb and metalaxyl) to get rid of late blight disease. High humidity and rains favour the spread of the disease and in the months of November and December rains are encountered in Punjab. Rain is known as one of the main weather factors that affects the persistence of fungicides on fruit and leaf surface (Lukens 1971). Rainfall can significantly affect the environmental fate of foliar-applied pesticides and the elapsed time between pesticide application and the first rainfall event can affect pesticide persistence and wash-off losses (Phong *et al.* 2008). High intensity rains are known to wash-off fungicides from the foliage. Keeping in view the above mentioned facts, a study was undertaken to know the impact of simulated rainfall on persistence of fungicides on tomato foliage.

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MATERIALS AND METHODS

Field, pot and laboratory experiments were conducted in the Department of Plant Pathology, Punjab Agricultural University Ludhiana during during 2010 and 2011 to study the impact of differential amounts of rainfall on the persistence of applied fungicides. Differential amounts of rain were simulated using an indigenously fabricated rain simulator. It was made from a petrol engine-driven Knapsack sprayer with the adjustable nozzle. The water supply was regulated through a pressure gauge at 0.45 kg/cm^2 into the nozzle pipe devised by Kukal and Sur (2004). This pressure was created by an engine speed of 4500 rpm. The water jet was broken into rain drops with median drop diameter (D_{50}) of 1.85 mm with the air-pressure produced by an air pump. The height of fall of the raindrops was maintained at 2 m so as to achieve 95 per cent of the terminal velocity. In this method simulated rain amount with 5, 10 and 15 mm rain was standardized with the help of rain gauge at specific time and engine speed. This was further monitored and rechecked with the help of rain gauge at the time of application of rain. The pots were protected from any natural rainfall during the growth period. The soil was packed in the earthen pots (with top and bottom diameters of 45 cm and 22.5 cm) at a known bulk density of 1.5 g/cm^3. The fungicides, viz. mancozeb 75%WP and metalaxyl 8%+mancozeb 64 %WP each @ 0.25% were sprayed on 4

month old plants with a Knapsack sprayer as per the treatments. These plants in the pots were then subjected to differential amount of simulated rainfall (0, 5, 10 and 15 mm) after 0, 2, 4, 6, 8 and 10 days interval. The leaves were placed in plastic trays lined with moist blotting sheets and were inoculated following detached leaf technique with *Phytophthora infestans* isolated from diseased leaves (4×10^4 sporangia/ml) using an atomizer (Thind *et al.* 1989) after 0, 24 and 48 hr to record weathering of fungicides due to rain. After inoculations trays were covered with polythene sheet to ensure high relative humidity and kept in growth room maintained at a temperature of 18±2°C with 12 hr period of fluorescent light. Leaves were monitored for initial disease appearance and development of disease was recorded.

RESULTS AND DISCUSSION

Inoculation immediately after rain application

The results pertaining to the persistence of mancozeb 75%WP and metalaxyl 8%+mancozeb 64 %WP against late blight development with respect to simulated rainfall applied 0, 2, 4, 6, 8 and 10 days after fungicide spray on detached leaves of tomato and inoculated immediately after rain application are presented in Table 1. The highest disease severity of 61.3, 59.7, 55.0 and 52.0 per cent was observed with rain amount of 15, 10, 5 and 0 mm, respectively in case of control (no fungicide) when rain was delayed by 10 days. In case of mancozeb 75%WP @ 0.25 per cent, the disease was not observed up to 6 days after fungicidal spray in absence of rain. However, disease appeared with severity of 32.0 per cent when 5 mm rain was applied immediately after spray. This increased significantly to 36.0 per cent when rain was increased to 10 mm and to 40.0 per cent with 15 mm of rain. When rain was delayed by 10 days, the disease severity of 51.0, 48.0, 43.7 and 30.0 per cent was observed with rain amount of 15, 10, 5 and 0 mm, respectively.

In case of metalaxyl 8%+mancozeb 64 %WP @ 0.25 per cent, no disease was observed up to 8 days after fungicidal spray in the absence of rain. The disease severity with 5 mm rain immediately after spray was 30.0 per cent, which increased significantly to 35.0 and 42.0 per cent when rain was increased to 10 and 15 mm, respectively. The disease severity decreased significantly when rain was delayed by 2 days. The disease severity remained very low when rain was delayed by 4, 6 and 8 days. The disease severity of 35.0, 30.0, 25.0 and 10.0 per cent was observed with rain amount of 15, 10, 5 and 0 mm, respectively when rain was delayed by 10 days.

The reduction in disease severity with delaying of rain can be explained by the fact that systemic fungicide was absorbed into the system of the plant. Similar observations were observed by Mohan and Thind (1999) after evaluating efficacy of various fungicides against *Phytophthora infestans* under laboratory conditions. The efficacy of metalaxyl 8%+mancozeb 64 %WP was found better in comparison to mancozeb 75 %WP, further it was reported that systemic fungicides exhibited longer persistence than the protectant fungicides both under field and laboratory conditions.

Table 1 Effect of simulated rain applications after fungicidal spray on late blight of tomato inoculated immediately after rain

Treatment	Rain amount (mm)	Disease severity (%) after rain application (no. of days after fungicidal spray)						Mean
		0	2	4	6	8	10	
Mancozeb 65	0	0.0 (0.0)*	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	20.7 (27.0)	30.0 (33.1)	30.9(31.2)
%WP (0.25 %)	5	32.0 (34.4)	32.3 (34.6)	34.3 (35.8)	34.7 (36.0)	35.3 (36.4)	43.7 (41.3)	
	10	36.0 (36.8)	34.0 (35.6)	37.7 (37.8)	38.3 (38.2)	40.3 (39.4)	48.0 (43.8)	
	15	40.0 (39.2)	41.7 (40.1)	37.0 (37.4)	36.0 (36.5)	40.7 (39.5)	51.0 (45.5)	
Metalaxyl 8%+	0	0.0 (0.0)*	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.0 (18.3)	17.8(22.1)
mancozeb 64 %	5	30.0 (33.1)	17.0 (24.3)	20.0 (26.5)	19.0 (25.8)	20.0 (26.5)	25.0 (29.9)	
WP (0.25 %)	10	35.0 (36.2)	15.0 (22.7)	18.0 (25.0)	20.0 (26.4)	20.0 (26.4)	30.0 (33.1)	
	15	42.0 (40.3)	17.7 (24.8)	19.3 (25.9)	20.3 (26.7)	16.0 (23.4)	35.0 (36.2)	
No fungicides	0	48.7 (44.2)*	49.7 (44.7)	50.7 (45.3)	50.0 (44.9)	50.7 (45.3)	52.0 (46.1)	55.36(46.7)
	5	52.0 (46.1)	49.3 (44.5)	52.0 (46.1)	50.0 (44.9)	54.0 (47.2)	55.0 (47.8)	
	10	54.0 (47.2)	51.3 (45.7)	54.0 (47.2)	50.7 (45.3)	55.7 (48.2)	59.7 (50.5)	
	15	57.0 (49.0)	54.0 (47.2)	55.0 (47.8)	52.0 (46.1)	56.0 (48.4)	61.3 (51.5)	
Mean		35.5 (33.9)	30.1 (30.3)	31.5 (31.2)	30.9 (30.9)	34.11 (34.0)	41.7 (39.8)	
CD (P≥0.05)	Fungicides (F) = 0.72							
	Rain amount (RA) = 0.83							
	Rain interval (RI) = 1.0							
	Fungicides × Rain amount (F × RA) = 1.4							
	Fungicides × Rain amount × Rain interval (F × RA × RI) = 3.5							

*Mean of three replications. Figures in parentheses are arc sine transformed values

Table 2 Effect of simulated rain applications after fungicidal spray on late blight of tomato inoculated 24 hr after rain

Treatment	Rain amount (mm)	Disease severity (%) after rain application (no. of days after fungicidal spray)						Mean
		0	2	4	6	8	10	
Mancozeb 75	0	0.0 (0.0)*	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	22.7 (28.4)	36.0 (36.8)	29.4
%WP (0.25 %)	5	32.0 (34.4)	31.7 (34.2)	35.0 (36.2)	32.3 (34.6)	35.0 (36.2)	38.7 (38.4)	(30.2)
	10	40.0 (39.1)	33.0 (35.0)	38.0 (38.0)	32.0 (34.4)	35.0 (36.2)	37.7 (37.8)	
	15	45.0 (42.1)	37.0 (37.4)	37.3 (37.6)	35.0 (36.2)	30.0 (33.1)	42.0 (40.3)	
Metalaxyl 8%+	0	0.0 (0.0)*	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (22.0)	16.9
mancozeb 64 %WP	5	31.0 (33.7)	14.0 (21.9)	15.0 (22.7)	14.0 (21.8)	17.0 (24.3)	26.7 (31.0)	(21.4)
(0.25 %)	10	33.7 (35.4)	15.0 (22.7)	18.0 (250)	12.0 (20.2)	21.7 (27.6)	27.7 (31.7)	
	15	42.7 (40.7)	18.0 (25.0)	19.0 (25.8)	14.0 (21.9)	22.3 (28.1)	29.3 (32.7)	
No fungicides	0	48.0 (43.8)*	47.0 (43.2)	50.0 (44.9)	52.0 (46.1)	50.0 (44.9)	52.3 (46.3)	50.5
	5	42.0 (40.3)	43.0 (40.9)	40.0 (39.1)	48.0 (43.8)	45.0 (42.1)	50.0 (44.9)	(45.2)
	10	50.0 (44.9)	51.0 (45.5)	52.0 (46.1)	52.0 (46.1)	51.0 (45.5)	57.0 (49.0)	
	15	51.0 (45.5)	55.0 (47.8)	56.0 (48.4)	55.0 (47.8)	52.0 (46.1)	62.0 (51.9)	
Mean		34.6 (33.3)	28.7 (29.5)	30.0 (30.3)	28.8 (29.4)	31.8 (32.7)	39.4 (38.6)	

CD ($P \geq 0.05$) Fungicides (F) = 0.58
Rain amount (RA) = 0.67
Rain interval (RI) = 0.82
Fungicides × Rain amount (F × RA) = 1.1
Fungicides × Rain amount × Rain interval (F × RA × RI) = 2.8

*Mean of three replications. Figures in parentheses are arc sine transformed values

Inoculation 24 hr after rain application

The data presented in Table 2 indicate that the highest disease severity of 62.0, 57.0, 50.0, and 52.3% was observed with rain amount of 15, 10, 5 and 0 mm, respectively in case of control (no fungicide) when rain was delayed by 10 days. In case of mancozeb 75 %WP @ 0.25 per cent, the disease was not observed up to 6 days after fungicidal spray in absence of rain. However, disease appeared with severity of 32.0% when 5 mm rain was applied immediately after spray. This increased significantly to 40.0% when rain was increased to 10 mm and to 45.0% with 15 mm of rain. The disease severity of 42.0, 37.7, 38.7 and 36.0% was observed with rain amount of 15, 10, 5 and 0 mm, respectively when rain was delayed by 10 days.

In case of metalaxyl 8%+mancozeb 64 %WP @ 0.25 per cent no disease was observed up to 8 days after fungicidal spray in the absence of rain. The disease severity with 5 mm rain immediately after spray was 31.0%, which increased significantly to 33.7 and 42.7% when rains were increased to 10 and 15 mm, respectively. The disease severity decreased significantly when rain was delayed by 2 days. The disease severity remained very low when rain was delayed by 4 and 6 days. The disease severity of 29.3, 27.7, 26.7 and 14.3% was observed with rain amount of 15, 10, 5 and 0 mm, respectively when rain was delayed by 10 days.

Inoculation 48 hr after rain application

Effect of different levels of simulated rain applications after fungicide spray on late blight of tomato inoculated 48 hr after rain is presented in Table 3. The highest disease severity of 63.3, 56.3, 61.3 and 51.0% was observed with rain amount of 15, 10, 5 and 0 mm, respectively in case of control (no fungicide) when rain was delayed by 10 days. In case of mancozeb 75%WP @ 0.25%, the disease was not observed up to 4 days after fungicidal spray in absence of rain. However, disease appeared with severity of 31.7% when 5 mm rain was applied immediately after spray. This increased significantly to 38.7% when rain was increased to 10 mm and to 45.0% with 15 mm of rain. The disease severity of 48.0, 46.0, 41.7 and 27.7% with rain amount of 15, 10, 5 and 0 mm, respectively when rain was delayed by 10 days.

In case of metalaxyl 8%+mancozeb 64 %WP @ 0.25% no disease was observed up to 6 days after fungicidal spray in the absence of rain. The disease severity with 5 mm rain immediately after spray was 31.0%, which increased significantly to 35.0 and 40.0% when rains were increased to 10 and 15 mm, respectively. The disease severity was decreased significantly when rain was delayed by 2 days. The disease severity was observed very low when rain was delayed by 4 days. The disease severity of 28.0, 25.7, 25.0 and 16.0% was observed with rain amount of 15, 10, 5 and 0 mm, respectively when rain was delayed by 10 days.

Perusal of data revealed that rainfall immediately after the fungicidal spray removes protectant fungicides from the leaf surface hence under such situations disease severity is high. A low amount of 5 mm of rain 2 or 4 days after fungicidal spray is not able to remove fungicide from the leaf surface. However, 10 mm or 15 mm rain can remove

Table 3 Effect of simulated rain applications after fungicidal spray on late blight of tomato inoculated 48 hr after rain

Treatment	Rain amount (mm)	Disease severity (%) after rain application (no. of days after fungicidal spray)						Mean
		0	2	4	6	8	10	
mancozeb 75%	0	0.0 (0.0)*	0.0 (0.0)	0.0 (0.0)	5.0 (10.4)	9.0 (17.2)	27.7 (31.7)	30.9
WP (0.25 %)	5	31.7 (34.2)	35.7 (36.6)	33.0 (35.0)	33.7 (35.4)	35.7 (36.6)	41.7 (40.1)	(31.4)
	10	38.7 (38.4)	35.7 (36.6)	36.7 (37.2)	39.7 (39.0)	34.0 (35.6)	46.0 (42.6)	
	15	45.0 (42.1)	41.7 (40.1)	40.7 (39.6)	41.7 (40.1)	42.7 (40.7)	48.0 (43.8)	
Metalaxyl 8%+	0	0.0 (0.0)*	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.7 (14.7)	16.0 (23.3)	18.7
mancozeb 64 %WP	5	31.0 (33.7)	20.0 (26.5)	18.0 (25.0)	20.0 (26.4)	18.0 (25.0)	25.0 (29.9)	(23.2)
(0.25 %)	10	35.0 (36.2)	20.0 (26.5)	16.0 (23.5)	22.0 (27.9)	21.0 (27.1)	25.7 (30.4)	
	15	40.0 (39.2)	21.7 (27.6)	20.0 (26.5)	22.0 (27.9)	23.0 (28.6)	28.0 (31.9)	
No fungicides	0	45.0 (42.1)*	48.0 (43.8)	47.0 (43.2)	52.0 (46.1)	50.0 (44.9)	51.0 (45.5)	53.19
	5	48.3 (44.0)	49.0 (44.4)	47.7 (43.6)	53.0 (46.7)	48.7 (44.2)	61.3 (51.5)	(46.5)
	10	50.0 (44.9)	52.0 (46.1)	54.3 (47.4)	52.0 (46.1)	60.3 (50.9)	56.3 (48.6)	
	15	54.0 (47.2)	56.0 (48.4)	55.7 (48.2)	51.7 (45.9)	60.3 (50.9)	63.3 (52.7)	
Mean		34.9 (33.5)	31.6 (31.4)	30.7 (30.8)	30.2 (32.6)	34.1 (34.7)	40.8 (39.3)	
CD (P≥0.05)	Fungicides (F) = 0.69							
	Rain amount (RA) = 0.80							
	Rain interval (RI) = 0.98							
	Fungicides × Rain amount (F × RA) = 1.3							
	Fungicides × Rain amount × Rain interval (F × RA × RI) = 3.4							

*Mean of three replications. Figures in parentheses are arc sine transformed values

fungicide from the foliage to some extent and moderate disease is evident under such situation. Ebeling (1963) has observed that loss of pesticides from leaf surfaces is determined by physical and chemical conditions of those surfaces and of the pesticides and by environmental factors, of which rainfall has been considered most important one. Neely (1970) reported that mancozeb did not persist long on leaves and plants sprayed at a longer interval which were unprotected during the period when the environment was especially conducive to blight. Similar results were obtained by Fry (1977). Ripley (1985) also found that the only effect of rainfall, if any occurred within the first 24 hr after metalaxyl application, rainfall occurring more than 24 hr after application had no influence on metalaxyl residues. Similarly, Mauricio *et al.* (2006) showed that mancozeb was washed-off easily from the leaf surface of apple seedlings due to the impact of a few millimeters rain, and a higher volume of rain caused little additional removal of fungicide.

Likewise, Van Bruggen *et al.* (1987) observed that metalaxyl was washed off rapidly in the first few minutes of rainfall. They reported that when simulated rain was applied to metalaxyl treated leaves within 1 hr of application, there was a steep decline in the proportion of metalaxyl remaining on the foliage. However, an increase in the rain application interval to 48 hr did not affect the effectivity of metalaxyl. Similarly, Bruhn and Fry (1982) also reported that systemic nature of metalaxyl makes it much different than conventional protectant fungicides for which rainfall is an extremely important environmental factor.

Present study has clearly shown that in case of protectant fungicide, low rainfall after 2 days of spray has no effect on persistence and hence there is no need to repeat the spray under such conditions. However, rainfall immediately after spray or rainfall more than 10 mm requires spray to be repeated. In case of systemic fungicide, rainfall at 24 hr after spray has no effect on disease control. Hence, there is no need to repeat spray if rainfall occurs 24 hr after spray irrespective of the amount of rainfall. The reduction in disease severity after 24 and 48 hr of rain can be explained by the fact that systemic fungicide was absorbed into the system of the plant.

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