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Management of Late Blight [*Phytophthora Infestans* (Mont.) De Bary] of Potato in Central Ethiopia

Adina Getinet*, Mashilla Dejene (PhD), Dr. Bekele Kassa (PhD), Dr. Wassu Mohammed (PhD)

Ethiopia

Corresponding Author:** ***Adina Getinet, *Ethiopia*

Abstract: *The experiment was conducted at Holetta Agricultural Research Center and on-farm at Tikur Enchini during the 2017 main season to assess efficacy of alternate fungicides application and potato varieties on late blight epidemics. Treatments were factorial arranged in a randomized complete block design with three replications. Analysis was performed combined for the two locations due to homogeneous error variances. Combined analysis of variance indicated that effect of varieties, fungicide, locations and their interactions significantly reduced Late blight epidemic parameters and enhanced yield. The lowest mean AUDPC values (168, 291.15 and 456.5-%unit-days) were recorded on plots sprayed with Trust-Cymocop 439.5 WP +Ridomil Gold MZ 68 WG + Mancozeb 80 WP (TRM) spray sequence on the varieties Belete, Gudenie and Jalenie, respectively. High disease epidemics (AUDPC values of 1135.35, 963.35 and 1965.85-%unit-days) occurred on unsprayed plots of the varieties Belete, Gudenie and Jalenie, respectively. Alternate fungicide application with TRM spray sequence reduced late blight severity up to 75%, 60.84% and 68.33% on the varieties Belete, Gudenie and Jalenie, respectively, compared to the control. The overall results revealed that alternate fungicide application with TRM spray sequence are found effective to slow down potato late blight epidemics and improve potato productivity; and thus, recommended for the study areas along with other crop management practices.*

Keywords: *Area under disease progress curve (AUDPC), disease progress rate, Phytophthora infestans, potato, severity.*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food crops worldwide. It ranks third after rice and wheat for human consumption [1]. Annual world production of potato is about 330 million tons harvested from 18,651,838 ha and, in Africa, the total production is about 17,625,680 t from a total cultivated area of 1,765,617 ha [2]. In Ethiopia, total cultivated area of potato is 70,131.32 ha from which 943,233.44 tons is harvested [3]. The national average tuber yield is lower than the world average yield. The national average potato tuber yield on farmers' fields in Ethiopia is also only 13.4t ha^{-1}, which is much lower than 38 t ha^{-1} reported from experimental plots [1].

There are many factors contributing to low yield of potato in Ethiopia, of which late blight [*Phytophthora infestans*] is the major disease that cause yield loss up to 100% [4]. In Ethiopia, it has been reported that late blight is a major limitation to potato production in high humid elevations; with estimate average yield losses of about 30–75% on susceptible varieties [5].

Late blight is a polycyclic disease, having several cycles of infection and inoculum production during one growing season [6]. The polycyclic nature of the pathogen forced the potato growers to apply fungicides many times in one growing season. Spray of fungicides up to 15–20 times per growing season was reported depending on the climatic conditions and intensity of the potato cultivation, to protect the crop against late blight [7]. However, repeated application of fungicides slow disease suppression activity due to a gradual loss of sensitivity of the targeted pathogen population to the fungicide in addition to the increase in production costs and environmental risk. For instance, resistance to Ridomil or metalaxyl appeared in 1980, within a few years after its introduction, and led to control failures in Ireland and the Netherlands [8]. Past studies have revealed that the occurrence of Ridomil or metalaxyl resistance in *P. infestans* populations is associated with severe late blight epidemics, genetic diversity and pathogen resurgence [9]. Hence, it is important and imperative to rotate fungicides with various modes of action on weekly or bi-weekly bases to reduce the risk of resistance development and increase the effectiveness of fungicides . Therefore, the objective of this study was to investigate efficacy of alternate fungicides application and potato varieties on late blight epidemic development in potato production areas of centeral Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the Study Areas

The experiment was conducted under rain- fed conditions at Holetta Agricultural Research Center and at Tikur Enchini on farm in Central Ethiopia during the 2017 main cropping season. Holetta Agricultural Research Center is located at 9^{o}00'N, 38^{o}30'E at an altitude of 2400 meters above sea level (m.a.s.l.). Tikure Enchini is located at 8.84^{o}00'N, 39.67^{o}30'E at an altitude of 2477 (m.a.s.l.).

2.2. Experimental Materials and Procedures

Three potato varieties (Belete, Gudanie and Jalenie) recommended by Holetta Agricultural Research Center for cultivation in the central highlands and similar agro-ecologies in other parts of Ethiopia were used for the experiment. The varieties Belete, Gudanie and Jalenie (Table 1) are selected as resistant, moderately resistant and susceptible to late blight [10]. Three fungicides including the systemic Ridomil Gold MZ 68 WG, (Metalaxyl – 4% + Mancozeb – 64%), Trust-Cymocop 439.5 WP (Cymoxanil 42 g kg^{-1} + Copper oxychloride 397 g kg^{-1}) and contact fungicide Mancozeb 80 WP, which were recommended for late blight control, were used as treatments. Fungicides application was started as soon as the disease symptom was observed on the field.

Table1. *Description of potato varieties used for the field experiment*

Name of Variety	Accession Code	Year of release	Altitude (m.a.s.l.)	Tuber yield (t ha^{-1})	
				Research Field	Farmer's Field
Belete	CIP-393371.58	2009	1600-2800	47.2	28.0-33.8
Gudanie	CIP-386423.13	2006	1600-2800	29.0	21.0
Jalenie	CIP-37792-5	2002	1600-2800	40.3	29.1

Source: *[11]*

2.3. Treatments and Experimental Design

A total of 21 treatments arranged in a factorial experiment using three potato varieties in combination with three fungicide sprays alternating with one another at each spray sequence and three sole fungicide application sequences (six fungicides alternate and sole fungicide application sequence and control). Therefore, there were two factors, viz. potato varieties and fungicide sprays alternating with one another at each spray sequence and also spraying individually each fungicide at all intervals for each variety. The treatments were arranged in a randomized complete block design (RCBD) with three replications.

The treatment combinations include the following:

1. Belete+Control (no fungicide application)
2. Belete+Ridomil + Mancozeb + Trust-Cymocop
3. Belete +Trust cymocop + Ridomil + Mancozeb
4. Belete +Mancozeb + Trust Cymocop + Ridomi
5. Belete +Mancozeb + Mancozeb + Mancozeb
6. Belete +Trust Cymocop + Trust Cymocop + Trust Cymocop
7. Belete +Ridomil + Ridomil + Ridomil
8. Gudenie+Control (no fungicide application)
9. Gudenie +Ridomil + Mancozeb + Trust-Cymocop
10. Gudenie +Trust cymocop + Ridomil + Mancozeb
11. Gudenie +Mancozeb + Trust Cymocop + Ridomi
12. Gudenie +Mancozeb + Mancozeb + Mancozeb
13. Gudenie +Trust Cymocop + Trust Cymocop + Trust Cymocop
14. Gudenie +Ridomil + Ridomil + Ridomil
15. Jalenie+Control (no fungicide application)

16. Jalenie +Ridomil + Mancozeb + Trust-Cymocop
17. Jalenie +Trust cymocop + Ridomil + Mancozeb
18. Jalenie +Mancozeb + Trust Cymocop + Ridomi
19. Jalenie +Mancozeb + Mancozeb + Mancozeb
20. Jalenie +Trust Cymocop + Trust Cymocop + Trust Cymocop
21. Jalenie +Ridomil + Ridomil + Ridomil

2.4. Experimental Field Management

The gross plot size was 3 x 3 m = 9 m^2, which accommodated 10 plants per row and thus 40 plants per plot. Medium-sized and well-sprouted potato tubers of three selected potato varieties were planted on prepared ridges of four rows per plot at spacing of 75 cm between rows and 30 cm between plants. The spacing between plots and adjacent replications was 1 m and 2 m, respectively. Fungicide application was started when disease symptoms appeared in the field. Subsequent spray was made at 7 and 14 days' interval for the contact (Mancozeb) and systemic (Ridomil Gold MZ 68 WG, and Trust-Cymocop 439.5 WP) fungicides, respectively. The plots were managed properly as per the package recommendation for potato production.

2.5. Disease Assessment

Disease assessment began on 31 and 35 days after planting at Holetta and Tikur Enchini, respectively, when the disease symptom was observed on the field and continued every seven days until senescence. Disease incidence was recorded by counting plants with disease symptom to the total plant population in the central two rows. Disease severity was assessed based on percent leaf area infected by using Key for assessing severity of late blight under field conditions [12]. Area under disease progress curve (AUDPC) was calculated for each plot using the formula developed by [13].

$$AUDPC = \sum_{ni=1}^{n-1}([0.5(x_{i+1} + x_i)(t_{i+1} - t_i)]$$

Where Xi is the cumulative disease severity expressed as a proportion at the i^{th} observation, t_i is the time (days after planting) at the i^{th} observation and n is the total number of observations.

2.6. Data Analysis

Analysis of variance (ANOVA) was performed for disease incidence, disease severity and AUDPC to determine the effect of treatments and their interactions. [14]. Analysis was performed combined for the two locations due to homogeneous error variances. The data analyses were done using the Statistical Analysis System (SAS) Version 9. Least significant difference (LSD at 5% probability level) was used for mean separation. Relationship of final SI and AUDPC with yield and yield components were examined using correlation analysis. Logistic, ln [(Y/1 – Y)], [15] and Gompertz, -ln[-ln(Y)] [16] models were compared for estimation of disease progression from each treatment. The goodness of fit of the models was tested based on the magnitude of the coefficient of determination (R2) and residuals (SE) obtained using each model [17]. As a result, there was higher coefficient of determination (R2) and lower standard error (SE) from logistic than from Gompertz model. Data had better fit to logistic than Gompertz model. Therefore, rate of increase in bacterial wilt was estimated and compared using the logistic model.

3. RESULTS AND DISCUSSION

3.1. Disease Incidence

The combined analysis of disease incidence had highly significant differences (P ≤0.001) among potato varieties, fungicide, locations and their interactions (data not shown). The highest disease incidence (98.33 and 78.33%) were showed on the variety Belete sprayed with TTT and MMM, spray sequence respectively, while the lowest disease incidence (14.14 and 18.34%**)** showed on Belete variety sprayed with RRR and TRM spray sequence, respectively. TRM and RRR spray sequence did not significantly differ from each other with respect to mean disease incidence reduction; however, both spray sequences significantly (p≤0.05) reduced mean disease incidence as compared to the unsprayed plot. On Gudenie variety the lowest (14.17%) mean disease incidence was showed on when the variety sprayed with TRM spray sequence, while the highest mean disease incidence (80%) was recorded on variety Gudenie sprayed with TTT spray sequence. On variety Jalenie the lowest

(17.5%) mean disease incidence was obtained on when the variety sprayed with RRR spray sequence. The second lowest (41.67%) mean disease incidence also showed on the variety sprayed with TRM spray sequence and significantly reduced mean disease incidence as compared to the unsprayed plots. While the highest mean disease incidence (100%) was recorded on plots sprayed with TTT spray sequence which was not differ from the unsprayed plot (Table 2). Thus alternate fungicide application with TRM spray sequence effectively reduced mean disease incidence in all tested varieties.

3.2. Disease Severity

The combined analysis of disease severity showed highly significant differences ($P \leq 0.001$) among interactions effects of the three potato varieties, fungicide application sequence and locations (data not shown). On Belete variety the lowest (8.34 and 14.17%) mean disease severity exhibited on plots sprayed with RRR and TRM spray sequence respectively, while the highest disease severity (81.67%**)** was exhibited on plots sprayed with TTT spray sequence. TRM and RRR spray sequence on this variety did not significantly differ from each other with respect to mean disease severity reduction; however, both fungicide spray sequence significantly reduced mean disease severity as compared to the unsprayed plot. All fungicide spray sequence on Gudenie potato variety significantly ($p \leq 0.05$) reduced mean disease severity as compared to unsprayed plots. On variety Jalenie the lowest (10% and 15%) disease severity showed on plots sprayed with RRR and TRM spray sequence, respectively, while the highest disease severity (75%**)** showed on the plots sprayed with TTT spray sequence. TRM and RRR spray sequence did not significantly differ from each other with respect to mean disease severity reduction, however, both fungicide spray sequence reduced mean disease severity as compared with the unsprayed plot. Thus, alternate fungicide application with TRM spray sequence effectively reduced mean disease severity on all tested varieties. The current finding is consistent with the observation of [18] who reported that using the systemic fungicide Ridomil alone and Ridomil and Mancozeb applied sequentially was more effective in lowering severity of late blight than the sole use of the protectant fungicide Mancozeb.

3.3. Area under Disease Progress Curve (AUDPC)

The combined analysis of area under disease progress curve (AUDPC) value showed highly significant differences ($P \leq 0.001$) among interactions effects of the three potato varieties, fungicide application sequence and locations (data not shown). On variety Belete the lowest AUDPC values (150.4, 151.3 and 168 -% unit-days) showed on plots sprayed with RRR, RMT and TRM spray sequence, respectively, while the highest AUDPC value (820-%unit-days) showed from plots sprayed with TTT spray sequence. TRM, RMT and RRR spray sequence did not significantly differ from each other with respect to mean AUDPC value reduction however, all the three fungicide spray sequences significantly reduced mean AUDPC value as compared to unsprayed plots. Thus alternate fungicide application with TRM spray sequence on Belete potato variety effectively reduced mean AUDPC values.

On variety Gudenie all spray sequences did not significantly differ from each other with respect to mean AUDPC value reduction however, all fungicide spray sequences significantly reduced mean AUDPC value as compared to unsprayed plots. Thus alternate fungicide application with TRM spray sequence on the variety Gudenie effectively reduced mean AUDPC values.

On variety Jalenie the highest mean AUDPC value reduction showed on plots sprayed with RRR and TRM, spray sequence which did not significantly differ from each other with respect to mean AUDPC value reduction, however, both fungicide spray sequence significantly reduced mean AUDPC value as compared to the variety sprayed with other spray sequence and unsprayed plots. Thus alternate fungicide application with TRM spray sequence effectively reduced mean AUDPC value.

Table2. *Interaction effect of alternate fungicide application and potato varieties on late blight incidence severity and area under disease progress curve*

Varieties	Fungicide	Incidence (%)	Severity (%)	AUDPC (-% unit-days)
Belete	Unsprayed	100^{a}	89.17^{a}	1135.5^{bc}
	RMT	33.33^{ef}	17.50^{gh}	151.25^{i}
	TRM	18.33^{gh}	14.17^{ghi}	168^{i}
	MTR	48.33^{d}	20.00^{fg}	306.58^{ghi}
	MMM	78.33^{b}	40.83^{d}	455^{fg}
	TTT	98.33^{a}	81.67^{ab}	820.67^{de}
	RRR	14.17^{h}	8.33^{i}	150.42^{i}

Gudenie	Unsprayed	93.33^{a}	71.67^{c}	963.33^{cd}
	RMT	18.33^{gh}	12.50^{ghi}	273.58^{hi}
	TRM	14.17^{h}	10.83^{hi}	291.17^{ghi}
	MTR	25.00^{fg}	15.83^{ghi}	316.42^{ghi}
	MMM	48.33^{d}	10.00^{hi}	291.75^{ghi}
	TTT	80.00^{b}	29.17^{e}	503.08^{f}
	RRR	20.83^{gh}	11.67^{hi}	263.17^{hi}
Jalenie	Unsprayed	100.00^{a}	83.33^{a}	1965.83^{a}
	RMT	66.67c	26.67^{ef}	685.33^{e}
	TRM	41.67^{de}	15.00^{ghi}	456.67^{fg}
	MTR	71.67^{bc}	34.17^{de}	734.5^{e}
	MMM	75.00^{bc}	34.17^{de}	699.58^{e}
	TTT	100.00^{a}	75.00^{bc}	1277.92^{b}
	RRR	17.50^{gh}	10.00^{hi}	361.25^{fgh}
LSD (0.05)		10.61	7.76	174.4

Means within the same column followed by the same letter(s) are not significantly different, LSD (0.05) = Least significant difference at P≤0.05, M = Mancozeb 80 WP, R = Ridomil Gold MZ 68 WG, T = Trust-Cymocop 439.5 WP applied with the indicated sequence in the three successive sprays

3.4. Disease Progress Rate

On variety Belete, the lowest (0.03, 0.06, and 0.07 units per day) progress rate showed on plots sprayed with RRR, RMT and TRM spray sequence; while the highest (0.2 units per day) progress rate showed on plots sprayed with TTT spray sequence and unsprayed plots at Holetta (Table 3). At Tikur Enchini the lowest (0.0455 units per day) progress rate was recorded on plots sprayed with TRM spray sequence; while the highest (0.142units per day) progress rate was recorded on the variety unsprayed plots (Table 4). Thus at both locations alternate fungicide application with TRM spray sequence showed the lowest disease progress rate on the variety Belete.

On the variety Gudenie The lowest (0.0271 and 0.0434units per days) progress rate showed on plots sprayed with MMM and TRM spray sequence, respectively, while the highest (0.181units per day) progress rate was showed on unsprayed plots of the variety at Holetta (Table 3). At Tikur Enchini the lowest (0.00424 units per day) progress rate was showed on plots sprayed with TRM spray sequence; while the highest (0.0613units per day) progress rate was showed on the variety unsprayed plots. Thus at both locations alternate fungicide application with TRM spray sequence showed the lowest disease progress rate on the variety Gudenie.

On the variety Jalenie the lowest (0.0083 and 0.0201units per day) progress rate showed on plots sprayed with RRR and TRM spray sequences, respectively; while the highest (0.179 and 0.157units per day) progress rate showed on the variety sprayed with TTT spray sequence and unsprayed plots at Holetta (Table 3). At Tikur Enchini the lowest (0.00863 and 0.0107 units per day) progress rate showed on the variety sprayed with RRR and TRM spray sequence, respectively, while the highest (0.067units per day) progress rate showed on the variety unsprayed plots (Table 4). Thus at both locations alternate fungicide application with TRM spray sequence showed the lowest disease progress rate on the variety Jalenie.

Table3. *The effect of alternate fungicide application and potato varieties on late blight progres rate at Holetta in 2017 season*

Varieties	Fungicide spray Sequence	DSi	DSf	Rate units/day	SE of intercept	SE of constant	R2
Belete	Unsprayed	9.00	99	0.224	-14.8	1.982	81.3
	RMT	2.00	10	0.0589	-7.23	0.5766	78
	TRM	3.00	20	0.0708	-7.61	1.052	60.6
	MTR	2.00	20	0.0942	-8.53	0.8107	80.7
	MMM	2.00	35	0.114	-9.66	0.8077	87
	TTT	2.00	92.66	0.227	-15.8	1.985	81.6
	RRR	3.00	6.66	0.0326	-5.27	1.073	23.9
	Unsprayed	11.67	96	0.181	-12	1.933	74.8

Gudenie	RMT	3.00	16.67	0.0608	-6.85	0.9433	58.5
	TRM	4.33	15	0.0434	-5.43	0.5636	66.8
	MTR	3.67	23.33	0.0801	-7.68	0.6674	83
	MMM	5.00	10	0.0271	-4.47	0.3817	63.1
	TTT	5.00	35	0.0919	-7.94	0.8193	81
	RRR	5.00	16.67	0.0563	-6.27	1.269	40
Jalenie	Unsprayed	45.00	99	0.157	-8.69	1.04	88.6
	RMT	11.66	26.67	0.0278	-3.66	0.6375	39.2
	TRM	13.33	21.67	0.0201	-3.07	0.7168	21.1
	MTR	13.33	35	0.0399	-4	0.6183	58.6
	MMM	13.33	43.33	0.0542	-4.74	0.5078	79.4
	TTT	23.33	99	0.179	-11.2	1.844	74.4
	RRR	8.33	11.66	0.0083	-2.93	0.74	4.1

M = Mancozeb 80 WP, R = Ridomil Gold MZ 68 WG, T = Trust-Cymocop 439.5 WP applied with the indicated sequence in the three successive sprays

Table4. *The effect of alternate fungicide application and potato varieties on late blight proggres rate at Tikur Enchini in the 2017 season*

Varieties	Varieties	Fungicide spray Sequence	DSi	DSf	Rate units/day	SE of intercept	SE of constant	R2
Belete		Unsprayed	2.33	78.33	0.142	-10.8	0.4458	98
		RMT	3.00	18.33	0.16	-15.1	2.039	90.5
		TRM	5.67	8.33	0.0455	-6.14	3.332	20.9
		MTR	6.00	20.00	0.108	-10.7	3.158	64.6
		MMM	6.67	46.67	0.117	-10.2	1.199	88.2
		TTT	3.67	70.00	0.117	-9.57	1.113	83.8
		RRR	4.00	10.00	0.0745	-8.62	2.867	51.1
Gudenie		Unsprayed	5.00	46.67	0.0613	-5.81	0.5928	77
		RMT	5.00	8.33	0.00696	-3.14	0.4108	8.2
		TRM	5.00	6.67	0.00424	-3.01	0.3505	4.4
		MTR	4.00	4.00	0.0164	-3.82	0.3742	37.4
		MMM	4.33	4.33	0.0204	-3.94	0.2717	63.7
		TTT	5.00	5.00	0.0367	-4.55	0.4092	71.6
		RRR	5.00	6.67	0.0119	-3.73	0.646	20.9
Jalenie		Unsprayed	6.67	66.67	0.0674	-5.39	0.7967	69.1
		RMT	5.00	26.67	0.0366	-4.16	0.6932	46.6
		TRM	5.00	8.33	0.0107	-3.46	0.2629	34.2
		MTR	4.67	33.33	0.0516	-5.17	0.401	83.8
		MMM	5.00	25.00	0.0355	-4.33	0.2929	82.1
		TTT	5.00	50.00	0.0606	-5.43	0.3314	91.3
		RRR	5.00	8.33	0.00863	-3.23	0.3503	15.9

M = Mancozeb 80 WP, R = Ridomil Gold MZ 68 WG, T = Trust-Cymocop 439.5 WP applied with the indicated sequence in the three successive sprays

4. CONCLUSIONS

In conclusion, the result of this study showed that, high late blight disease epidemics occurred on unsprayed plots of all the varieties Belete, Gudenie and Jalenie as compared to the best protected plots sprayed with TRM spray sequence. Therefore, production of potatoes in all studied varieties including variety Belete that was previously reported as resistant varieties in other locations should be supplemented with fungicide spray. Alternate fungicide application with TRM spray sequence highly reduced potato late blight epidemics and enhanced the growth and yield parameters of the crop. These are recommended to manage the disease and sustain production.

Moreover, among the three sole fungicide spray sequence three times application of Trust-Cymocop (Cymoxanil 42g/kg + Copperoxychloride397 g/kg at the company recommendation rate (1.5kg/ha) was less effective than Mancozeb (Mancozeb 80 WP) and Ridomil Gold (Metalaxyl – 4%+Mancozeb – 64%), at the company recommendation rates (3kg/ha). This could be due to the reduce amount of rate to suppress high disease pressure than the other two fungicides for this location. Therefore, further evaluations should be undertaken on the rate determination of the fungicide Trust-Cymocop (Cymoxanil 42g/kg + Copperoxychloride397 g/kg) for this specific area.

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