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Efficacy of Reduced Dose of Fungicide Sprays in the Management of Late Blight (*Phytophthora infestans*) Disease on Selected Potato (*Solanum tuberosum* L.) Varieties Haramaya, Eastern Ethiopia

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Abstract
Potato is the most worldwide important tuber crop. Potato late blight disease is the major bottleneck in potato production in Ethiopia. The Field experiments were carried at Haramaya University during 2010 to determine the efficacy of reduced dose of fungicide sprays in the management of late blight disease on selected potato varieties. Combinations of five potato varieties with different levels of resistance and five rates of Ridomil applications were used. The experiment was laid out in a factorial arrangement in randomized complete block design with three replications. The combination of moderately resistant, moderately susceptible and susceptible varieties with different rates of Ridomil applications varied significantly ($P < 0.001$) in disease severity, disease progress rate and area under disease progress curve. Onset of the disease was delayed by almost 20 days on the moderately resistant varieties as compared to the moderately susceptible and susceptible varieties. Up to 80, 76, 75.5, 69 and 68% severity reduction was obtained from the varieties Bedassa, Gabissa, Chiro, Harchassa and Zemen plots treated with Ridomil at 3 kg ha^{-1} rate of application, respectively. The highest disease severity and lowest yield were recorded from the control plots, especially on moderately susceptible and susceptible varieties. The best management of late blight and high marginal rate of return was obtained on plots treated with combinations of all tested potato varieties and 0.75 kg ha^{-1} Ridomil applications followed by 1.5 kg ha^{-1} Ridomil. The lowest rate of marginal return was obtained at combinations of these varieties with the 3 kg ha^{-1} Ridomil. This study revealed that reduced rates of Ridomil resulted in better management of potato late blight. However, further studies at different agro-ecological zones of the country are important for preference of potato varieties and specific rates of Ridomil as opposed to approval of the blanket recommendation of the manufacturer.
Keywords: Late blight, Potato, Area under disease progress curve, Ridomil, Disease severity.

1. Introduction

Potato (Solanum tuberosum L.) is one of mankind's most valuable food crops (FAO 2004). Ethiopia has possibly the highest potential for potato production of any country in Africa. Potato is a highly recommended food security crop that can help shield low-income countries from the risks posed by rising international food prices (FAO 2008). It is prone to more than a hundred diseases caused either by bacteria, fungi, viruses or mycoplasms (Paul 1992). However, potato late blight caused by Phytophthora infestans (Mont) de Bary is the major bottleneck in potato production in Ethiopia (Bekele & Yaynu 1996) and other parts of the world (Fry & Goodwin, 1997). Late blight is the most devastating and destructive disease of potatoes in areas with frequent cool and moist weather (Agrios 2005). No potato varieties are fully resistant to late blight in the world (ATTRA, 2004). There are some released improved varieties that have lost their resistance to late blight, but still some are best in tolerating late blight when supported by reduced dose and rates of fungicide application (GILB & CIP 2004).

Cultural control measures such as eliminating cull piles and volunteer potatoes, using proper harvesting and storage practices, can be used to reduce the pathogen populations by reducing its survival, dispersal and reproduction (Garrett & Dendy 2001). Use of fungicides like metalaxyl in controlling the disease was found to boost potato yield in various East African countries (Nsemwa *et al*. 1992; Rees *et al*. 1992). Potato late blight management strategies have changed considerably following the migration of metalaxyl resistant isolates of P. infestans from Mexico to North America (Fry & Goodwin 1997) and necessitated utilization of cultural control measures and modification of the previous chemical control practices. The failure of Ridomil in giving perfect control of the disease in some countries of the Sub-Saharan Region (Mesfin & Gebremedhin 2007) and in some cases the intensive frequency of usage (Williams & Gisi 1992; Schiessendoppler *et al*. 2003), leads to the development of an integrated disease management strategy involving resistant and susceptible varieties and fungicide sprays. Despite the prevalence and seriousness of late blight causing losses to the potato crop in the field as well as storage in Ethiopia, adequate studies have not been made. In addition, only the maximum rate of application of fungicides, such as Ridomil, has been used in the management of late blight. Information on integration of potato varieties with different level of resistance (tolerance) and reduced rates of fungicide application for the management of this disease is not available. Integrated management alternatives, such as using tolerant varieties together with reduced rates of fungicide sprays, have not been tried at all. Hence much remains to be done on the management of potato late blight. In this regard, it is imperative to develop suitable integrated management alternatives for the management of the disease for sustainable production of potato and increasing the income of farmers by reducing the expenses of fungicide sprays in this country. Therefore, the present study was initiated with the objective to determine efficacy of reduced dose of fungicide sprays in the management of late blight disease on the selected potato varieties.

2. Materials and methods

2.1. Description of the Study Area

The study was conducted at the Haramaya University research field traditionally known as Rarer during the 2010 main cropping season. The experimental site is located at 517 kilometers from Addis Ababa, at 42º 30′ E longitude, 9º 26′ N latitude and at an altitude of 1,980 meters above sea level. It is situated in the mid-altitude tropical belt of eastern Ethiopia and characterized by a sub-humid type of climate with an average annual rainfall of about 790 mm, annual mean temperature of 17 ºC with mean minimum and mean maximum temperature is 11 ºC and 25 ºC, respectively. The soil is alluvial soil and the previous crop was wheat.

2.2. Experimental materials, treatments and design

This experiment was designed to determine effects of reduced dose of fungicide in the management of the disease using potato varieties with different levels of resistance to late blight. The varieties were two moderately resistant (Gabissa and Harchassa), two moderately susceptible (Bedassa and Zemen), and susceptible variety (Chiro) were used (Table 1). The recommended rate of Ridomil was 3 kg ha^{-1} (Syngenta Group Company 2010). In this study, one fourth, half, three fourth and full dose of the recommended rate were used, i.e. five rates (0.00, 0.75, 1.50, 2.25 and 3.00 kg ha^{-1}). The experiment was laid out in a factorial arrangement in randomized complete block design with three replications. There were a total of 25 treatment combinations, i.e. five varieties and Ridomil at five rates of applications. Each plot consisted of 3 m x 3 m (9 m^2) with four rows and 75 x 30 cm spacing between rows and plants, respectively. In each plot 40 plants were grown and each row had 10 plants. The first fungicide application was done right after the appearance of the disease symptom on Chiro and Zemen at 38 days after planting (DAP). Three consecutive sprays were done at 10 days interval and the last spray was done 58 days after planting.

2.3. Disease Assessment

Assessment of potato late blight in the experimental plots was done using disease incidence, percent severity index (PSI), area under the disease progress curve (AUDPC) and the disease progress rate(r). Disease incidence was assessed on 10 randomly selected and tagged plants in the middle two rows and plants showing symptoms of the disease were counted and expressed in percent (%) infection. Disease severity was assessed as the proportion of leaf area affected by the disease from the 10 randomly selected plants in the middle two rows. Disease severity were assessed at every seven days after the first appearances of the disease symptom, beginning at 37 DAP and finally 6 recording were done. Disease severity was assessed by using 1- 9 point scale suggested by Henfling (1987), where 1= none or very few lesions on the leaf lets, 2 = less than 10% of the leaf area covered, 3= more than 10% but less than 25% of the leaf area covered, 4 = more than 25% but less than 50% of the leaf area covered, 5 = half of the foliage destroyed, 6 = more than 50% but less than 75% of the leaf area covered, 7 = more than 75 % but less than 90% of the leaf area covered , 8 = only very few green areas leaf (much less than 10%) and 9 = 100% of the forage destroyed based on percent foliage damage.

Severity grades were converted into percentage severity index (PSI) for analysis using the formula suggested by Wheeler (1969):

$$PSI = \frac{Snr}{Npr \times Mss} \times 100$$

Where Snr = the sum of numerical ratings, Npr = number of plant rated, Mss = the maximum scale of the disease.

Area under the disease progress curve (AUDPC) was calculated for each plot using PSI value and the values were calculated for each plot using the following formula. The values were expressed in %- days (Shaner & Finney 1977):

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

Where x_i is the disease severity expressed in percentage at i^{th} observation, $t_{i,}$ $_{is}$ time (days after planting) at the i^{th} observation, $t^{'}$ is the epidemic duration for each treatment and n is total number of disease assessment was made. The disease infection rates (r) were calculated basing on the linearized logistic model (Van der Plank 1963; Campbell & Madden 1990) and the calculated value were analysed by using SAS software:

$$r = \frac{\left(\text{Ln}\frac{X}{1\text{-}X}\right)\text{-}\left(\text{Ln}\frac{X_o}{1\text{-}X_o}\right)}{t}$$

Where r is infection rate, X_o is initial disease severity, X is final disease severity and **t** is the duration of the epidemic Ln = Natural logarithm.

Days to first disease symptom appearance: was recorded by counting the number of days from planting to first disease symptoms observed on the leaves of the plant.

2.4. Data Analysis

Data on potato late blight incidence and percentage severity index (PSI) were examined separately. Analysis of variance (ANOVA) was performed using general linear model (GLM) procedure of SAS software version 9.2 software (SAS 2009) except mean separation for significant interaction effects, which was carried out using Gen Stat version 12.1 Software (GenStat 2009). Least significant difference (LSD) was used to separate treatment means. Correlation analysis was performed to determine the association between different disease parameters such as disease severity index (PSI) calculated from the 10-tagged plants at weekly interval, AUDPC and apparent disease progress rate(r) were correlated to each other on each treatment combinations.

3. Results and discussion

3.1. Days to first disease symptom appearance

Analysis of the data of days to first disease symptom appearance revealed highly significant differences (P<0.001) among varieties, significant differences (P<0.05) among rates and, and non-significant differences (P>0.05) among their combinations (Table 2). In the fungicide untreated plots, late blight appeared within 50 days after planting (DAP) and it was delayed by 2 days from plots treated with 3 kg ha^{-1} Ridomil application. On the other hand, the disease appeared within 40 days on Zemen and 41 days and on Chiro, which were moderately susceptible and susceptible varieties, respectively. In the moderately resistant varieties Gabissa and Bedassa, the first disease symptom appearance was delayed by almost 20 days due to their different degrees of resistance compared to Zemen and Chiro. In general, the disease was appeared early on moderately susceptible and susceptible varieties than moderately resistant ones.

3.2. Disease Incidence

Analysis of the 59 DAP disease incidence showed highly significantly differences (P < 0.001) among interactions effects of the five potato varieties and five rates of Ridomil applications. Potato late blight symptoms were evaluated at 59 DAP. On the lower leaves small, light-to-dark green, and circular-to irregularly-shaped, water-soaked lesions were observed. High (100%) incidence was recorded on the treatment combinations of the varieties (Harchassa, Zemen and Chiro) and without application of Ridomil. And low incidence was recorded on plots treated with combinations of moderately resistant varieties (Gabissa and Bedassa) and reduced (1.5 and 2.25 kg ha^{-1}) as well as full rates (3 kg ha^{-1}) of Ridomil applications. The combination of moderately resistant varieties and reduced rate of Ridomil application resulted in lowering incidence of the disease at 59 DAP. As Berger (1988) stated disease incidences among varieties are variable and increase in time at epidemic rates much faster than disease severities for the same pathosystem under the same conditions. The maximum incidence for many pathosystem is near 100% and this maximum commonly is reached early in the season, when disease severity may be low.

3.2. Disease Severity

Analysis of PSI data at 66 DAP revealed highly significant (P < 0.001) difference among interactions of the five potato varieties and five rates of Ridomil applications (Table 3). The highest (90.74%) PSI was recorded on unsprayed plots of Chiro, which was highly significantly different from other treatment combinations. The second highest (71.48%) PSI was recorded on unsprayed plots of Zemen. The lowest (11.11%) PSI was recorded on plots treated with combinations of the variety Gabissa and 1.5, 2.25 and 3 kg ha^{-1} Ridomil applications and on Bedassa at 3 kg ha^{-1} Ridomil application. At all treatment combinations, highly significant differences in PSI were obtained among plots treated with combinations of the moderately resistant varieties (Gabissa and Bedassa) and Ridomil at both reduced rates as well as full rate of applications. At 66 days after planting, a significant reduction in late blight severity was obtained from combinations of potato varieties and Ridomil at different rates of applications. On the varieties Bedassa, Chiro, Harchassa and Zemen plots treated with 3 kg ha^{-1} Ridomil, up to 80.00%, 75.51%, 68.95% and 67.98%, respectively, severity reduction were obtained. On the other hand, 76.19% severity reduction was obtained from the variety Gabissa plots treated with 1.5, 2.25 and 3 kg ha^{-1} Ridomil as compared with control plots (Table 3).

Generally, combinations of the five potato varieties and Ridomil at full rate of application reduced PSI. The results of the present study verified the idea of Agrios (2005) that suggested that it is always advisable to use resistant varieties, even when sprays with fungicides are considered the main control strategy. Resistant varieties delay the onset of the disease or reduce its rate of development so that fewer sprays on it may be needed to obtain a satisfactory level of control of the disease. In considering the environment, public health, and fungicide resistance have stimulated efforts to reduce the amount of fungicide used in late blight management (Shtienberg *et al*. 1994).

3.3. Disease progress rate

Disease progress rate was calculated by using linear logistic model and the values were analysed. Analysis of data of disease progress rate revealed highly significant($P < 0.001$) differences among the treatment combinations of the five potato varieties and five rates of Ridomil applications (Table 4). The highest disease progress rates, 0.172, 0.165, 0.178 and 0.188 were recorded on untreated plots of the varieties Harchassa, Bedassa, Zemen and Chiro, respectively. On the other hand, the lowest infection rates were recorded on the moderately resistant variety (Gabissa) and moderately susceptible variety (Bedassa) plots treated with Ridomil at both reduced as well as full rates. The disease was developed faster on susceptible potato varieties treated with different rates of Ridomil than on moderately resistant varieties treated with different rates of Ridomil. Generally, it was found that the development of late blight or disease progress rate and tuber yield losses of potato varieties could be minimized by integrating moderately resistant potato varieties with reduced rate of Ridomil applications.

3.4. Area under disease progress curve (AUDPC)

The area under disease progress curve (AUDPC) data revealed highly significant ($P < 0.001$) differences among the treatment combinations of the five potato varieties and five rates of Ridomil applications (Table 5). The AUDPC showed highly significant($P < 0.001$) differences at all treatment combinations with the highest AUDPC value of 181.30%-days on Chiro plots treated with zero rate of Ridomil and the lowest AUDPC (44.44%-days) was obtained from the varieties (Gabissa and Bedassa) treated with 1.5, 2.25 and 3 kg ha^{-1} Ridomil. The next higher AUDPC (127.97%-days) AUDPC was obtained from the variety Zemen plots treated with Ridomil at zero rates. Combinations of moderately resistant varieties and Ridomil at different rates of applications showed significant differences as compared to the combinations of susceptible varieties and Ridomil at different rates of applications. The highest value of AUDPC indicated the highest disease development on plots that were not treated with any combinations of these varieties and rates of fungicide applications.

From the results of the present study, it is important to combine reduced rates of Ridomil with moderately resistant varieties in managing late blight by considering the AUDPC values of the disease. From this, it seems important to use reduced rates of Ridomil because of multidimensional advantages in our real environment. The results of the present study were consistent with the report of Mesfin & Gebremedhin (2007) in which moderately resistant varieties had lowest AUDPC when supplemented with fungicide treatment. According to Jones (1998) polygenic resistance has proved to be helpful in reducing the amount of fungicides to be used. Varieties with polygenic resistance have reduced AUDPC values compared with susceptible ones (Fry 1977).

3.5. Correlation among disease parameters

The epidemiological parameters PSI at 66 DAP and AUDPC were highly correlated. A positive correlation ($r = 0.94^{***}$) between PSI at 66 days after planting assessment and AUDPC were observed. Disease progress rate was also highly correlated ($r = 0.85^{***}$ and $r = 0.68^{***}$) with PSI and AUDPC at 66 DAP, respectively (Table 6). This result indicated that these disease parameters were interrelated to each other and the disease developed at faster rate on control plots than other treatment combinations of the five potato varieties with different level of resistance and different rates of Ridomil applications.

4. Conclusions

The integration of different potato varieties and different rates of Ridomil applications varied significantly in different disease parameters of late blight. On the fungicide untreated plots, the disease appeared early on the moderately susceptible and susceptible varieties. On the other hand, onset of the disease was delayed almost by 20 days on the moderately resistant varieties as compared to the moderately susceptible and susceptible varieties. The interaction of moderately resistant varieties with both reduced as well as full rates of Ridomil applications reduced incidence of the disease at 59 DAP. Potato varieties plots treated with reduced rates of Ridomil application reduced disease severity. The highest disease severity was recorded on untreated plots of the varieties Chiro. This result indicates that this variety is tolerant to late blight. In general, the best management of late blight was obtained from potato varieties plots were treated with 0.75 kg ha^{-1} Ridomil application, followed by 1.5 kg ha^{-1} Ridomil applications. According to the result of this study, cost effective management of late blight was obtained by integrating potato varieties with the lowest rate of Ridomil application. Integration of reduced rate of Ridomil in the management of potato late blight is important in reducing environmental pollution and input cost of the fungicide and increase in production and profitability of high quality potato tuber yield. Since this study revealed that reduced rates of Ridomil application resulted in better management of potato late blight with the highest marginal rate of return. However, further studies at different agro-ecological zones of the country are required for specific rates of Ridomil application for recommendation of this fungicide as opposed to approval of the blanket recommendation by the manufacturer.

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Table 1: Characterstic features of potato varieties used in determining the efficacy of reduced dose of fungicide sprays in the management of late blight disease.

S.N	Variety	Pedigree Name	Year of Release	Disease Reaction	Days to Maturity	Yield (t ha^{-1})	
						Research Center	Farmers Field
1	Gabissa	CIP-3870-96-11	2005	MR	85-110	40.00	31.00
2	Harchassa	CIP-3870-96-09	2005	MR	86-105	39.50	29.00
3	Bedassa	AL-114	2001	MS	96-117	40.59	31.50
4	Zemen	AL-105	2001	MS	76-101	37.18	28.50
5	Chiro	AL-111	1997/98	S	95-120	41.00	32.00

MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible
Source: Potato Improvement Program of Haramaya University.

Table 2. Two-way table showing the effect of potato varieties and different rates of Ridomil applications on days to first disease symptom appearance

Rate of Ridomil (kg ha^{-1})	Disease symptom appearance (days)					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	56.00	49.00	55.67	37.00	40.67	49.67c
0.75	59.00	52.67	62.00	40.33	40.67	50.93ab
1.50	62.33	48.67	59.00	40.33	40.33	50.13b
2.25	62.00	52.33	59.67	41.00	40.00	51.10ab
3.00	63.00	51.33	64.33	42.00	41.00	52.33a
Mean	60.47a	50.80b	60.13a	40.13c	40.53c	
LSD (0.05) for varieties	1.84					
LSD (0.05) for Fungicide	1.84					
LSD (0.05) for Interaction	Ns					
CV (%)	5.00					

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column or row are not significantly different at 0.05 probability level.

Table 3. The effect of potato varieties and different rates of Ridomil application on percent severity index of potato late blight at 66 days after planting

Rate of Ridomil (kg ha^{-1})	Percent severity index (PSI)					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	46.67e	63.71c	55.56d	71.48b	90.74a	65.63
0.75	18.52i	31.85gh	20.37i	37.04fg	37.78f	29.1
1.50	11.11j	30.15h	20.00i	30.37h	32.22gh	24.70
2.25	11.11j	20.00i	11.85j	30.37h	31.85gh	21.11
3.00	11.11j	19.78i	11.11j	22.89i	22.22i	17.42
Mean	19.70	33.10	23.78	38.43	42.96	
LSD (0.05)	5.46					
CV (%)	10.53					

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column or row are not significantly different at 0.05 probability level.

Table 4. The effect of potato varieties and different rates of Ridomil applications on the disease progress rate of potato late blight

Rate of Ridomil (kg ha^{-1})	Disease progress rate					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	0.154bcd	0.172ab	0.165abc	0.178ab	0.188a	0.171
0.75	0.061h	0.126e	0.073gh	0.132de	0.141cde	0.107
1.50	0.000i	0.120ef	0.074gh	0.122e	0.126e	0.088
2.25	0.000i	0.080gh	0.010i	0.122e	0.127 de	0.069
3.00	0.000i	0.079gh	0.000i	0.094fg	0.092g	0.053
Mean	0.043	0.115	0.064	0.130	0.135	
LSD (0.05)	0.027					
CV (%)	17.06					

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column or row are not significantly different at 0.05 probability level.

Table 5. The effect of potato varieties and different rates of Ridomil applications on the area under disease progress curve (AUDPC) of late blight

Rate of Ridomil (kg ha^{-1})	Area under disease progress curve (AUDPC)					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	71.85de	108.89c	77.41d	127.97b	181.30a	113.48
0.75	48.14j	55.92ghi	49.81hij	67.77ef	67.42ef	57.81
1.50	44.44j	56.37gh	48.89j	61.48fg	58.33g	53.90
2.25	44.44j	49.26ij	44.81j	58.52g	57.40g	50.89
3.00	44.44j	49.44ij	44.44j	56.29gh	56.70g	50.26
Mean	50.66	63.97	53.07	74.41	84.23	
LSD (0.05)	6.85					
CV (%)	6.39					

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column or row are not significantly different at 0.05 probability level.

Table 6. Correlation coefficients (r) among different disease parameters of potato late blight

	PSI at 66 DAP	AUDPC	Rate (r)
PSI at 66 DAP	1		
AUDPC	0.94^{***}	1	
Rate (r)	0.85^{***}	0.68^{***}	1

***refers to significant level at $P < 0.001$; PSI at 66 DAP = percent severity index at 66 days after planting; AUDPC = area under disease progress curve; Rate (r) = infection rate.

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