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Tuber yield loss assessment of potato (*Solanum tuberosum* L.) varieties due to late blight (*Phytophthora infestans*) and its management Haramaya, Eastern Ethiopia.

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Abstract
Potato is the most important food security crop with a fast-growing pattern. However, its production is highly affected by potato late blight disease. Field experiments were carried out at Haramaya University in 2010 main cropping season to assess yield losses of selected potato varieties with different levels of resistance to late blight disease. 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 and different rates of Ridomil applications varied significantly in yield and yield components of potato. Up to 57, 42, 39, 38 and 29% tuber yield losses were recorded from the varieties Harchassa, Chiro, Bedassa, Zemen and Gabissa on untreated plots, respectively, as compared to losses from plots protected with 3 kg ha^{-1} Ridomil. The highest (23 t ha^{-1}) marketable tuber yield was obtained from the variety Gebissa plots treated with 0.75 and 1.5 kg ha^{-1} Ridomil applications. The combinations of the varieties Gabissa, Chiro, Harchassa, Bedassa and Zemen with 0.75 kg ha^{-1} Ridomil application were resulted in up to 28, 21, 18, 16 and 13% marginal rate of returns, respectively. 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 with high tuber yield. However, further researches at different agro-ecological zones of the country are important for preference of potato varieties and specific rates of Ridomil application.
Keywords: Late blight, *Phythophtora infestans*, Potato, Tuber yield loss, Marginal rate of return

1. Introduction
Potato (*Solanum tuberosum* L.) is the most important vegetable crop in terms of quantities produced and consumed worldwide (FAO 2005). Ethiopia has possibly the highest potential for potato production of any country in Africa (FAO 2008). Potato is prone to more than a hundred diseases caused either by bacteria, fungi, viruses or mycoplasms (Paul 1992). However, late blight is one of the few plant diseases that can absolutely destroy a crop, producing a 100% crop loss (Mercure 1998). The potential economic and social impact of this disease is best illustrated by the well-publicized role it played in the Irish Famine in the middle of the 19th century when it destroyed a large portion of the potato crop, either by eliminating foliage prior to the harvest or by causing massive tuber rot in storage (Bourke 1993). Late blight is the most devastating and destructive disease of potatoes in areas with frequent cool and moist weather (Agrios 2005). It caused yield losses ranging from 31-100% in Ethiopia depending on the variety used (HARC 2007). Farmers had stopped using their old local potato varieties due to the devastation of their plots by late blight. Most resistant varieties are not immune to late blight but possess varying degrees of resistance to various races of the pathogen (Popokova 1972).
The modern approaches in chemical control emphasizes on reducing fungicide inputs, combined with using potato cultivars possessing acceptable levels of non-race specific resistance to late blight (Secor &Gudmestad 1999; Kirk *et al.* 2001). 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. According to Fontem & Aighew (1993) report, application of fungicides for late blight management increases potato tuber yield by as much as 60%. 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 and reduced rates of fungicide application for the management of this disease is not available. Hence much remains to be done on the management of potato late blight and assessment of its yield loss. 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 specific objectives to assess yield losses of selected potato varieties with different levels of resistance to late blight and its management.

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 Design and Materials

This experiment was designed to evaluate tuber yield loss of 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. 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. Yield Assessment

Yield per hectare (t ha^{-1}): was calculated by converting the yield obtained from harvested two middle rows in each plot into hectare.
Average tuber weight (g): was calculated as weight of tubers from two middle rows divided by the total number of tubers of each plot.
Marketable yield (t ha^{-1}): was calculated as all the weight of harvested tubers which were disease free and with weight of greater than 50 g.
Unmarketable yield (t ha^{-1}): was calculated as the weight of tubers which were diseased, insect attacked, deformed tuber or and those having weighs less than or equal 50 g.
The percent yield increase (PYI) was calculated using the following formula suggested by (Lung'aho *et al*. 2003):

$$PYI = \frac{\text{tuber yield of a fungicide treated plot} - \text{yield of control plot}}{\text{yield of control plot}} \times 100$$

The relative loss in tuber yield was calculated separately for each treatment combination with different levels of disease, using the following formula of Robert and James (1991):

$$\text{RPYL} = \frac{YP - YT}{YP} \text{ x } 100$$

Where RPYL = relative percent yield loss, YP = yield from the maximum protected plot (3 kg ha^{-1}) Ridomil application and YT =Yield from plots of other treatments (i.e. with differing level of disease).

2.4. Cost/Benefit Analysis

The cost and benefit of each treatment was analysed partially and marginal rate of return (MRR) was computed by considering the variable cost available in the respective treatment. Yield and economic data were computed to compare the advantage of different potato varieties and different rates of fungicide applications in different treatment combinations. Economic data included input cost that varies; cost for chemical and labour during production time. The price of Ridomil MZ-68 WG was $US 26.13 kg^{-1}; of labour cost of $US 1.01 man-days for applications was taken. As an output, total growth benefit was calculated from tuber yield of the crop. Local market price of potato tuber was $US 0.20 kg^{-1} during the 2010 at harvest and was changed into hectare basis. Partial budget analysis is a method of organizing data and information about the cost and benefit of various agricultural alternatives (CIMMYT 1988). Partial budgeting is employed to assess profitability of any new technologies (practices) on to be imposed to the agricultural business. Marginal analysis is concerned with the process of making choice, between alternative factor-product combinations considering small changes. Marginal rate of return is a criterion which measures the effect of additional capital invested on net returns using new managements compared with the previous one (CIMMYT 1988). It provides the value of benefit obtained per the amount of additional cost incurred percentage. The formula is as follows:

$$MRR = \frac{DIC}{DNI}$$

Where, MRR is marginal rate of returns, DNI, difference in net income compared with control, DIC, difference in input cost compared with control.

2.5. Data Analysis

Data on potato tuber yield and yield components 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 GenStat version 12.1 Software (GenStat 2009). Least significant difference (LSD) was used to separate treatment means. Correlation analysis was performed to determine the association of different yield and yield components obtained from the interactions of different varieties and rates of fungicide applications. Simple cost-benefit analysis of each combination was reformed to evaluate the economic benefits expected using the farm gate price of potato at the time of harvest.

3. Results and Discussion

3.1. Tuber Yield

Analysis of tuber yield data showed highly significant ($P < 0.001$) differences among the five potato varieties with different levels of resistance treated with five rates of Ridomil applications (Table 1). The highest (30.06 and 29.02 t ha^{-1}) tuber yields were obtained from the variety Gabissa plots treated with 0.75 and 1.5 kg ha^{-1} Ridomil applications, respectively. The next highest (28.36 t ha^{-1}) tuber yield was obtained from the variety Zemen plots treated with recommended rate of Ridomil application, which were significantly higher than plots treated with other combinations. On the other hand, the lowest (9.66 t ha^{-1}) tuber yield was recorded from Harchassa plots treated with Ridomil at zero (on control plots), followed by (14.73 and 15.09 t ha^{-1}) from the varieties Bedassa and Chiro plots treated with zero rate of Ridomil, respectively, which were significantly lower than that of other treatment combinations (Table 1). Combinations of the moderately susceptible and susceptible varieties with higher rates of Ridomil applications resulted in high tuber yield. Even-though the yield was high on these varieties when combined with higher rates of Ridomil applications, they became less profitable due to the high cost of the fungicide. Therefore, it seems advisable to use moderately resistant potato varieties in combination with lower rates of Ridomil application rather than applying the recommended rate by the manufacturer. Based on their marginal rate of return (MRR), it is also effective to use both moderately susceptible and susceptible varieties in combinations with reduced rates of Ridomil applications (Table 6). The result of the present study is consistent with the report of Namanda *et al*. (2004); the benefits of appropriate fungicide use strategy were high yield and improved marginal rate of return (MRR) from the reduced cost of fungicide applications as well as increased quality of potato tubers. Although fungicides have been used to manage late blight, the appearance of fungicide resistant strains, high costs and environmental concerns pose a major challenge to their continued use (Kirk *et al*. 2001).

3.2. Relative Tuber Yield Losses

Tuber yield losses differed significantly among plots treated with different combinations of potato varieties and different rates of Ridomil applications (Table 2). Highest (56.95%,) relative tuber yield loss was recorded on untreated Harchassa plots, followed by plots treated with combinations of 0.75 kg ha^{-1} Ridomil application on all varieties except on Gabissa. In this study, up to 42.01, 39.09, 37.59 and 29.00% relative tuber yield losses were recorded from the untreated plots of the varieties Harchassa, Chiro, Bedassa, Zemen and Gabissa, respectively, as compared to plots protected with combinations of these varieties and the recommended rate (3 kg ha^{-1}) of Ridomil. The second highest (42.01%) tuber yield loss was obtained from the variety Chiro plots treated with Ridomil at zero rates (on control plots) as compared to treatment with 3 kg ha^{-1} Ridomil application. Generally, the combinations of potato varieties and Ridomil at both reduced and full rates of applications resulted in reduced tuber yield losses. The highest tuber yield losses were recorded on potato plots that were not supplemented with recommended rate of the fungicide (Ridomil) applications. The present study indicated that the main cropping season in Haramaya was highly conducive for late blight epidemics to cause high tuber yield loss on potato production. The results indicated the integrating Ridomil with potato varieties with different levels of resistance to delay the onset of the disease and to minimize its effect on potato production. The results of this study are consistent with reported range of yield loss estimates due to late blight on susceptible varieties (Bekele

& Yaynu 1996; Olanya *et al*. 2001). In Ethiopia, tuber yield losses due to late blight ranged from 31-100%, depending on the variety used (HARC 2007). 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 rates of fungicide applications (GILB & CIP 2004).

3.3. Percent Yield Increase

The calculated values of percent yield increase (PYI) showed high difference among potato varieties treated with different rates of Ridomil applications. The highest (132.30%) yield increase was obtained from Harchassa plots treated with recommended rate of Ridomil application, whereas the lowest (25.76%) yield increase was obtained from the variety Zemen plots treated with 0.75 kg ha^{-1} Ridopmil application. All five potato varieties had significant differences in yield increase when integrated with different rates of Ridomil applications. On Gabissa, which was moderately resistant variety, the highest (68.88%) tuber yield increase was obtained from plots treated with 0.75 kg ha^{-1} Ridomil and the lowest (40.84%) was at recommended (3 kg ha^{-1}) rate of Ridomil application. From this, we can conclude that the rate 0.75 kg ha^{-1} Ridomil was satisfactory on the variety Gabissa. On Harchassa, highly significant difference in yield increase with 132.30% and 68.12% yield increase was recorded between 0.75 and 3 kg ha^{-1} rates of Ridomil applications, respectively (Table 2). In this study, up to 132.30, 64.02, 60.23 and 72.43% yield increases were recorded on the varieties Harchassa, Bedassa, Zemen and Chiro plots treated with 3 kg ha^{-1} Ridomil application, respectively (Table 2). In general, percent yield increase (PYI) and rate of Ridomil application in the treatment combinations had positive relationship *i.e.* as the rate of Ridomil application in the combinations was increased, percent tuber yield increase also increased on all the tested potato varieties except on Gabissa. On the variety Gabissa, as rate of Ridomil application was increased in its combination PYI was decreased (Table 2). Eventhough the tuber yield with increase in fungicide rate, it becomes less cost effective due to increased cost of input as compared with the lower rate (0.75 kg ha^{-1}) of Ridomil application. This resulted in the lowest marginal rate of return (MRR) of all the combinations with reduced rates of Ridomil applications in relation to managing late blight (Table 6).

3.4. Average Tuber Weight

Combination of five potato varieties and five rates of Ridomil applications showed highly significant ($P < 0.001$) difference among their average tuber weights (Table 3). From all combinations of these potato varieties and rates of Ridomil applications, the highest tuber weight was recorded on the potato varieties Gabissa and Chiro plots treated with Ridomil at both reduced as well as recommended rates of applications. On the other hand, the lowest tuber weight was obtained from the variety Bedassa plots treated with Ridomil at all rates of applications. Generally, the results of this study indicated that integration of potato varieties and Ridomil at different rates had considerable effect on tuber weight. From this, it can be generalized that integrating potato varieties with different rates of fungicide application plays an important role in improving tuber weight. As the average tuber weight increased, the marketable tuber as well as total tuber yield increased.

3.5. Marketable Tuber Yield

The data on marketable tuber yield from five potato varieties treated with five rates of Ridomil applications revealed highly significant ($P < 0.001$) differences among their combinations (Table 4). The highest (23.02 and 22.66 t ha^{-1}) marketable tuber yield was obtained from the variety Gebissa plots treated with 0.75 and 1.5 kg ha^{-1} Ridomil applications, respectively, which was significantly higher than from plots that received other treatment combinations. The second highest (20.42 t ha^{-1}) marketable tuber yield was recorded on the variety Zemen plots treated with 3 kg ha^{-1} Ridomil application, followed by 20.27 t ha^{-1} on the varieties Gabissa and Chiro plots treated with 2.25 and 3 kg ha^{-1} Ridomil applications, respectively. On the other hand, the lowest (4.06 and 2.55 t ha^{-1}) marketable tuber yield was obtained from the varieties Gabissa and Bedassa plots treated with zero rates of Ridomil applications. In general, the highest marketable tuber yield was obtained from the moderately resistant variety (Gabissa) treated with reduced rates of Ridomil application. However, the lowest marketable tuber yield was obtained from the variety Bedassa plots treated with all rates of Ridomil applications.

In the present study, the higher marketable tuber yield was obtained by integrating the moderately resistant variety Gabissa with the lower rates of Ridomil application than from other treatment combinations. On the other hand, marketable yield from the varieties (Harchassa, Zemen and Chiro) increased with increase in rates of Ridomil applications. Even-though, the marketable tuber yield of these combinations increased, it was not cost effective as the partial cost benefit analysis indicated. This was happened because Ridomil was costly and low outcome sale of the product that could not compensate its input cost. The results of the present study are in agreement with the report of Mantecon (2009), in which yield differences obtained from treated and untreated controls were higher in marketable tubers than in total yield.

3.6. Unmarketable Tuber Yield

Analysis of the data of unmarketable tuber yield revealed highly significant ($P < 0.001$) differences among combinations of the five potato varieties and five rates of Ridomil applications (Table 5). The highest unmarketable tuber yield of all combinations was obtained from the variety Bedassa plots treated with different rates of Ridomil applications. Thus highest (16.18 and 16.14 t ha^{-1}) unmarketable tuber yields were recorded on the variety Bedassa plots treated with 3 and 1.5 kg ha^{-1} Ridomil applications, respectively. The lowest (4.00 and 4.93 t ha^{-1}) unmarketable tuber yield was recorded from variety the Chiro and Gabissa plots treated with combinations of 1.5 and 2.25 kg ha^{-1} Ridomil applications, respectively. The marketable and unmarketable tuber yield revealed negative relationship when the varieties Gabissa, Zemen and Chiro were integrated with different rates of Ridomil applications, *i.e.* as marketable tuber yield increased, unmarketable tuber yield decreased. On other combinations of the varieties (Bedassa and Harchassa) and different rates of Ridomil applications had positive relation among marketable and unmarketable tuber yields. That is, as rates of Ridomil application increased, both marketable and unmarketable tuber yield also increased (Table 4 & 5).

The results showed that the highest unmarketable tuber yield was on plots treated with combinations of the variety Bedassa and all rates of Ridomil applications and these combinations had the lowest marketable yield of all the other treatment combinations. These combinations had also the lowest tuber weight but with the highest number of tubers per hill. From this it can be concluded that production of the variety Bedassa in the combination with both reduced and full rates of Ridomil applications was not profitable in the main cropping season, but as it had the highest number of tuber per hill production of this variety might be effective under irrigation conditions. Irrigation may render the host crop more resistant to diseases through its effect on plant vigour, growth rate, and overall crop development (Olanya *et al*. 2006). In some situations, diseases such as late blight and rust have been avoided through the use of irrigation during off-seasons (Stakman & Harrar 1957).

3.7. Cost Benefit Analysis

Cost/benefit analysis was performed using partial budget analysis for integrated potato late blight management by using five potato varieties having different level of resistance integrated with five rates of Ridomil applications. This analysis is a very useful technology to determine the costs and benefits of a new technology compared to the traditional one (assumes higher yield with higher rate (recommended) of application). The maximum total gross yield benefit (4627.72 \$US ha^{-1}) followed by (4549.31 \$US ha^{-1}) was recorded from the variety Gabissa plots treated with 0.75 and 1.5 kg ha^{-1} Ridomil applications, respectively (Table 6). However, lower gross yield benefit (3811.53 \$US ha^{-1}) was obtained from the combination of this variety with Ridomil at 3 kg ha^{-1}, which is a recommended rate by the manufacturer. On combinations of the variety Harchassa and different rates of Ridomil applications, the highest (3057.67 \$US ha^{-1}) gross benefit was obtained from plots treated with 0.75 kg ha^{-1} Ridomil application. The same is true for the variety Bedassa treated with different rates of Ridomil applications, with the highest (1646.44 \$US ha^{-1}) gross benefit, which was obtained from plots treated with 2.25 kg ha^{-1} Ridomil application. On the other combinations of the varieties (Zemen and Chiro) and different rates of Ridomil applications, the highest gross benefit was recorded from these varieties treated with the recommended rate (3 kg ha^{-1}) of Ridomil application (Table 6).

Variation in net benefit was observed among combinations of the five potato varieties and five rates of Ridonil applications. Among all combinations, Gabissa and Ridomil at 0.75 kg ha^{-1} had the highest (3768.87\$US ha^{-1}) net benefit of all other treatment combinations. On the other hand, the lowest (-233.75\$US ha^{-1}) net benefit was recorded on untreated plots of the variety Bedassa. In general, the highest net benefit was recorded on Gabissa plots that received 0.75 kg ha^{-1} Ridomil application,. In this study, the highest marginal rate of return (MRR) was obtained from all tested potato varieties plots treated with 0.75 kg ha^{-1} Ridomil application and the lowest MRR was recorded from the above varieties treated with the recommended rate (3 kg ha^{-1}) of Ridomil application. Generally, by integrating the lower rate (0.75 kg ha^{-1}) of Ridomil application with the varieties (Gabissa, Chiro, Harchassa, Bedassa and Zemen) up to 28.15, 20.97, 17.6, 15.69 and 13.47% MRR were obtained, respectively (Table 6).

The highest (3637.19 \$US ha^{-1}) calculated value of marginal net benefit (MNB) was obtained from the variety Chiro plots treated with recommended rate (3 kg ha^{-1}) of Ridomil application (Fig 1. E). The second highest (3289.41\$US ha^{-1}) MNB was also obtained from the variety Chiro plots treated with 2.25 kg ha^{-1} Ridomil application (Fig 1. E), followed by 3223.07 \$US ha^{-1} from Gabissa treated with 0.75 kg ha^{-1} Ridomil application (Fig 1. A). However, the lowest MNB was obtained from the variety Bedassa plots treated with different rate of Ridomil applications (Fig 1. C). Generally, the highest MNB was recorded on the variety Chiro plots treated with recommended rate of Ridomil application followed by combinations of the moderately resistant variety (Gabissa) and reduced rates of Ridomil application. It is possible to conclude from the following results that the highest net profit and MRR were obtained from the combinations of the moderately resistant variety Gabissa and 0.75 kg ha^{-1} Ridomil application as compared with combinations of the moderately susceptible Bedassa and 3 kg ha^{-1} Ridomil application, with additional saving of \$ US 176.46 of total input cost. The highest net profit and

MRR were obtained on combinations of these varieties and 0.75 kg ha^{-1} Ridomil application as compared to combinations of all tested varieties and the recommended rate of Ridomil application, in addition reducing of $US 176.46 of total input cost. The highest (1:4.4 and 1:4.0) cost: benefit ratio (CBR) were obtained from combinations of the variety Gabissa and Ridomil at (0.75 and 1.5 kg ha^{-1}), respectively (Table 6). In other words, for every $US invested, there was a gain of $US 4.4 and 4.0 from the combination of the variety Gabissa and Ridomil at (0.75 and 1.5 kg ha^{-1}) rates of applications, respectively. In this study, the combination of the moderately resistant variety Gabissa and reduced (0.75 kg ha^{-1}) rate of Ridomil application gave high monetary advantage over the other combinations of different varieties and different rates of Ridomil applications (Table 6). Based on the results of partial budget analysis, the five potato varieties gave the best outcome when they were integrated with the minimum rate (0.75 kg ha^{-1}) of Ridomil application. This result was supported with the report of Macleod & Sweetingham (1999) that indicated when assessing a crop for risk, it is necessary to assess it for the potential to cover the cost of the application which depends on the potential yield. Modern approaches in chemical disease control emphasize on reducing fungicide inputs, combined with using potato cultivars possessing acceptable levels of non-race specific resistance to late blight (Secord & Gudmestad 1999; Kirk *et al.* 2001).

4. Conclusions

In this study on untreated plots high tuber yield losses were recorded on the tested varieties as compared to plots of the same varieties protected with 3 kg ha^{-1} Ridomil application. The yield increments due to interactions of the varieties and Ridomil applications were significant. In the present study high yield increases were recorded, from the verities Harchassa, Bedassa, Zemen and Chiro plots respectively, treated with 3 kg ha^{-1} Ridomil application. But from the variety Gabissa the highest yield increase was obtained on plots that received 0.75 kg ha^{-1} Ridomil application. The highest marketable tuber yield was obtained from Gebissa plots treated with Ridomil at reduced rate of applications. The combinations of potato varieties and reduced rate of Ridomil application resulted in high marginal rate of return. In general, the best management of late blight, and high marginal rate of return 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. The lowest marginal rate of return was obtained from potato varieties that were treated with the recommended rate of 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. 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 research works at different agro-ecological zones of the country are required for specific rates of Ridomil application for its effective manage of potato late blight.

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Table 1. The effect of potato varieties and different rates of Ridomil application on tuber yield of potato varieties evaluated at Haramaya, 2010 main cropping season.

Rate of Ridomil (kg ha^{-1})	Tuber yield (t ha^{-1})					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	17.80h	9.66j	14.73i	17.70h	15.09i	15.00
0.75	30.06a	16.24hi	21.70fg	22.26efg	21.35g	22.32
1.50	29.02a	20.84g	23.71cdef	25.81bc	21.45g	24.17
2.25	25.19bc	21.10g	22.61defg	24.96	24.50bc	23.67
3.00	25.07bc	22.44defg	24.16bcde	28.36a	26.02b	25.2
Mean	25.43	18.06	21.38	23.82	21.68	
LSD (0.05)	2.14					
CV (%)	5.91					

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 2. Yield and yield increase of five potato varieties resulting from five rates of Ridomil application and corresponding yield losses due to late blight at Haramaya, 2010 cropping season.

	Fungicide rate	Yield (t ha^{-1})	Relative yield loss (%)	Percent yield increase (%)
Gabissa	R_0	17.80	29.00	0.00
	R_1	30.06	-19.90	68.88
	R_2	29.02	-15.76	63.03
	R_3	25.19	-0.48	41.52
	R_4	25.07	0.00	40.84
Harchassa	R_0	9.66	56.95	0.00
	R_1	16.24	27.63	68.12
	R_2	20.84	7.13	115.73
	R_3	21.10	5.97	118.43
	R_4	22.44	0.00	132.30
Bedassa	R_0	14.73	39.03	0.00
	R_1	21.70	10.18	47.32
	R_2	23.71	1.86	60.96
	R_3	22.61	6.42	53.50
	R_4	24.16	0.00	64.02
Zemen	R_0	17.70	37.59	0.00
	R_1	22.26	21.51	25.76
	R_2	25.81	8.99	45.82
	R_3	24.95	12.02	40.96
	R_4	28.36	0.00	60.23
Chiro	R_0	15.09	42.01	0.00
	R_1	21.35	17.95	41.48
	R_2	21.45	17.56	42.15
	R_3	24.49	5.88	62.29
	R_4	26.02	0.00	72.43

R_0 = 0.0 kg ha^{-1}; R1 = 0.75 kg ha^{-1}; R_2 = 1.5 kg ha^{-1}; R_3 = 2.25 kg ha^{-1}; R_4 = 3 kg ha^{-1} rate of Ridomil application.

Table 3. The effect of potato varieties and different rates of Ridomil application on average tuber weight evaluated at Haramaya in 2010 main cropping season.

Rate of Ridomil (kg ha^{-1})	Average tuber weight (g)					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	37.35fg	26.28hi	15.86j	39.46efg	31.58gh	30.11
0.75	57.48ab	43.85def	25.93hi	39.29efg	54.04abc	44.12
1.50	60.59a	50.02bcd	21.68ij	47.75cde	54.50abc	46.91
2.25	58.61ab	50.45bcd	24.78hij	46.08cdef	54.72abc	46.93
3.00	58.19ab	46.02cdef	25.86hi	58.72ab	59.25ab	49.61
Mean	54.44	43.32	22.82	46.26	50.82	
LSD (0.05)	9.60					
CV (%)	13.43					

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 application on marketable tuber yield evaluated at Haramaya, 2010 main cropping season.

Rate of Ridomil (kg ha^{-1})	Marketable tuber yield (t ha^{-1})					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	10.69g	4.06j	2.55j	8.55h	5.87i	6.34
0.75	23.02a	10.38g	7.77h	12.51f	14.12e	13.56
1.50	22.66a	13.97ef	7.57h	17.31d	17.44cd	15.79
2.25	20.27b	15.21e	8.19h	17.99cd	18.54cd	16.04
3.00	18.96bc	14.89e	7.98h	20.42b	20.27b	16.50
Mean	19.12	11.70	6.81	15.36	15.25	
LSD (0.05)	1.66					
CV (%)	6.99					

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 unmarketable tuber yield evaluated at Haramaya, 2010 main cropping season.

Five rates of Ridomil (kg ha^{-1})	Unmarketable tuber yield (t ha^{-1})					Mean
	Gabissa	Harchassa	Bedassa	Zemen	Chiro	
0.00	7.11ghij	5.60lm	12.19c	9.15de	9.22d	8.65
0.75	7.05 ghij	5.85jklm	13.93b	9.75d	7.24fghi	8.76
1.50	6.39hijkl	6.87 ghijl	16.14a	8.50def	4.00n	8.38
2.25	4.93mn	5.90jklm	14.42b	6.95 ghijk	5.95jklm	7.63
3.00	6.11ijklm	7.55fgh	16.18a	7.95efg	5.75klm	8.71
Mean	6.32	6.35	14.57	8.46	6.43	
LSD (0.05)	1.27					
CV (%)	9.16					

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. Partial budget analysis of Ridomil application treatments at different rates on five potato varieties at Haramaya, 2010 main copping season.

Variety	Fungicide rate	1.MTY(t ha^{-1})	2.P ($US t^{-1})	3.SR(1x2) ($US ha^{-1})	4.TIC ($US ha^{-1})	5.MC ($US ha^{-1})	6.NP (3-4) ($US ha^{-1})	7.MNB ($US ha^{-1})	8.MRR(7/5)(%)	CBR(6/4)
Gabissa	R_0	10.69	201.03	2149.01	744.37	0.00	1404.64	0.00	0.00	1.9
	R_1	23.02	201.03	4627.72	858.85	114.48	3768.87	3223.07	28.15	4.4
	R_2	22.63	201.03	4549.31	918.04	173.67	3631.27	3144.67	18.11	4.0
	R_3	20.27	201.03	4074.88	976.67	232.30	3098.21	2670.24	11.49	3.2
	R_4	18.96	201.03	3811.53	1035.31	290.94	2776.23	2406.89	8.27	2.7
Harchassa	R_0	4.06	201.03	816.18	744.37	0.00	71.81	0.00	0.00	0.1
	R_1	10.38	201.03	2086.69	858.85	114.48	1227.85	2014.88	17.60	1.4
	R_2	13.97	201.03	2808.39	918.04	173.67	1890.35	2736.58	15.76	2.1
	R_3	15.21	201.03	3057.67	976.67	232.30	2081.00	2736.58	12.85	2.1
	R_4	14.89	201.03	2993.34	1035.31	290.94	1958.03	2921.53	10.04	1.9
Bedassa	R_0	2.55	201.03	510.62	744.37	0.00	-233.75	0.00	0.00	-0.3
	R_1	7.77	201.03	1562.0	858.85	114.48	703.16	1795.76	15.69	0.8
	R_2	7.57	201.03	1521.8	918.04	173.67	603.76	1755.55	10.11	0. 7
	R_3	8.19	201.03	1646.44	976.67	232.30	669.77	1880.19	8.09	0. 7
	R_4	7.98	201.03	1604.22	1035.31	290.94	568.92	1837.97	6.32	0.5
Zemen	R_0	8.55	201.03	1718.81	744.37	0.00	974.44	0.00	0.00	1.3
	R_1	12.51	201.03	2514.89	858.85	114.48	1656.04	1542.46	13.47	1.9
	R_2	17.31	201.03	3479.83	918.04	173.67	2561.79	2507.40	14.44	2.8
	R_3	17.99	201.03	3616.53	976.67	232.30	2639.86	2644.10	11.38	2.7
	R_4	20.42	201.03	4105.04	1035.31	290.94	3069.73	3130.60	10.76	3.0
Chiro	R_0	5.87	201.03	1182.06	14811.1	0.00	435.68	0.0	0.00	0.6
	R_1	14.12	201.03	2838.55	744.37	114.48	1979.70	2400.86	20.97	2.3
	R_2	17.45	201.03	3507.98	918.04	173.67	2589.94	3070.29	17.70	2.8
	R_3	18.54	201.03	3727.1	976.67	232.30	2750.43	3289.41	14.16	2.8
	R_4	20.27	201.03	4074.88	1035.31	290.94	3039.58	3637.19	12.50	2.9

MTY = marketable tuber yield; P = price; SR = Sale revenue; TIC = total input cost; MC = marginal cost; NP = net profit; MNB = marginal net benefit; MRR = marginal rate of return: CBR = cost benefit ratio; R_0 = 0.0 kg ha^{-1}; R_1 = 0.75 kg ha-1; R_2 = 1.5 kg ha-1; R_3 = 2.25 kg ha-1 and R_4 = 3 kg ha-1of Ridomil spray application.
Input cost of fungicide (Ridomil) at different rates: For 0.75 Kg ha^{-1} = 6.66$US, 1.5 Kg ha^{-1} = 13.32 $US, 2.25 Kg ha^{-1} = 19.98 $US and 3 Kg ha^{-1} = 26.64 $US.

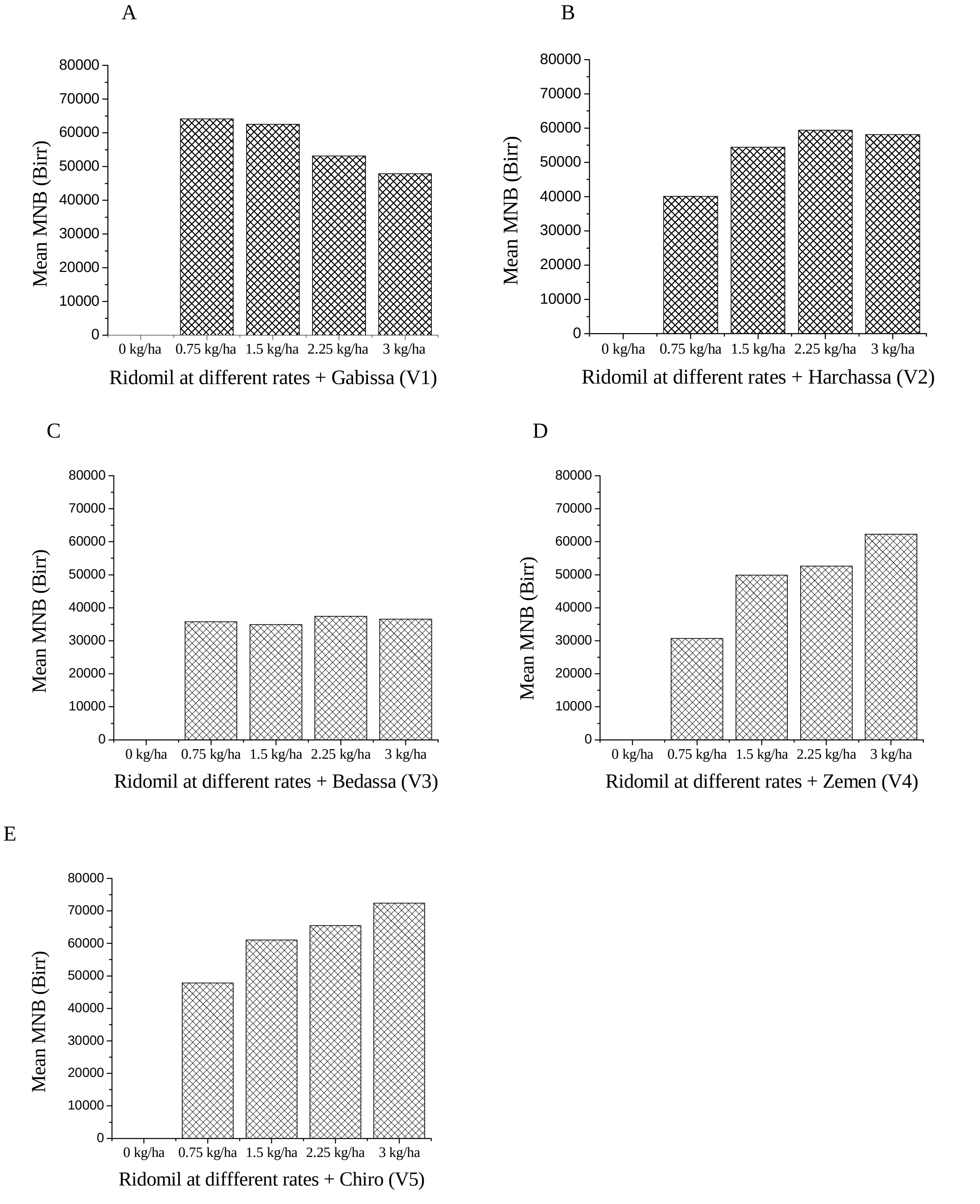

Figure 1. Marginal net benefit (MNB) of different rates of the systemic fungicide (Ridomil) application on potato varieties Gabissa (A), Harchasaa (B), Bedassa (C), Zemen (D) and Chiro (E) at Haramaya, 2010 main cropping season.
NB: 1Birr = 0.050 US Dollar.