RESEARCH ARTICLE

Evaluation of potato cultivars and fungicides for the management of late blight (*Phytophthora infestans* (mont) de bary) in Holleta, West Showa, Ethiopia.

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ABSTRACT

Late blight caused by *Phytophthora infestans* (Mont) de Bary is one of the most significant constraints to potato production in Ethiopia. Fungicides and host plant resistance are among the most efficient control options available to growers. Field trials were conducted during the year 2015-2016 in Holleta Agricultural Research Center, Holleta, Ethiopia, to evaluate the effectiveness of four fungicides viz. Ridomil MZ 68 WG, Victory 72 WP (Mancozeb with Metalaxyl), Horizon 680 WG and Mancozeb application in weekly intervals on three potato cultivars Gudene (CIP-386423.13; Relatively Resistant), Gera (KP-90134.2; Moderate Relatively Resistant) and Jalene (CIP-384321.19, Susceptible cultivar). Late blight infection was prevalent in the experimental year and significant amount of disease incidence and severity were detected. Application of fungicide treatments considerably reduced late blight disease progress, with a corresponding decrease in disease index and increase in their tuber yields. The disease incidence reached the maximum of 91.5 % on the unsprayed control susceptible variety, Jalene and 55 and 38.5 % was recorded on moderate resistant varieties, Gudene and Gera, respectively. The percent final disease severity was recorded significant difference in sprayed and unsprayed plots. The highest severity (78%) reduction was recorded in all fungicide treated Gera variety. The highest severity was recorded in varieties of Jalene (83.5%) and Gudene (30%) with untreated control. In this study, Victory 72 WP retarded late blight development consistently when combined with all varieties and the highest yields were obtained from plots treated with Victory 72 WP. Higher tuber yield was recorded on the variety Gera (48.47 tons/ha) followed by Gudene and Jalene and the lowest tuber yield was recorded in the control treatments (no sprays). Based on late blight disease occurrence, application of Victory 72 WP and Ridomil MZ 68 WG fungicides reduced disease development and increased tuber yield significantly in all the cultivars as compared to the other two fungicides. Economic analysis revealed that the highest net benefit was obtained from Gera when sprayed at weekly intervals followed by Gudene and the least was obtained from Jalene unsprayed plot. Overall, the present study demonstrated that the application of fungicides, Victory 72 WP and Ridomil

MZ 68 WG in weekly intervals were more economical and feasible for the management of late blights of potato and increases tuber yields markedly. Further, cost effective and feasible integrated management options need to be developed for potato late blight in the country.

Keywords: Fungicides, Host resistance, Potato cultivars, late blight, *Phytophthora infestans.*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food crops grown in more than hundred countries in the world, in which the tuber provides high energy, carbohydrates and high quality protein as well as substantial amount of vitamins, minerals and trace elements (Horton and Sawyer, 1985). The crop was introduced to Ethiopia in 1858 by a German Botanist; Wilhelm Shimper (Medhin *et al*., 2006). Ethiopia is one of the major potato producers in Africa, with 70 % of its arable land in the high altitude areas between 1,500-3,000 meters being suitable for potato production (FAOSTAT, 2008). At present in Ethiopia, potato area had grown to 160,000-ha, with average yields around 8 tons/ha (Medhin *et al*, 2006). It is one of the most important food and cash crops and also become an important garden crop especially in high and mid altitude areas of Ethiopia (Borgal *et al.,*1980). But cultivation was limited to potato growing voluntarily in fields in the colder highlands until wider adoption of the potato occurred at the end of the 19th century in response to a prolonged famine (Medhin *et al*., 2001).

Yield of vegetable crops are generally lowest in tropical Africa as a result of both biotic and abiotic factors, of which the former include primarily insect pests, diseases and weeds. The most important factors responsible for the low productivity of potato are diseases and insect pests. Farmers get lower yield mainly due to pests and sub-optimal fertilization (Tesfaye, 2008). However, there are many factors which limits potato yield in Ethiopia, which includes: the lack of improved well performing varieties, poor fruit setting due to heavy rains and excessively high temperatures, insect pests and diseases, of which fungal, viral and bacterial wilt diseases appear to be significant constraints (Adane *et al*., 2010; Bekele *et al.,* 2011). Among the diseases, Late blight is one of the most important, notorious and widespread phyto-pathogenic soil borne fungal pathogen caused by *Phytophthora infestans* mainly in main and off-cropping seasons as a destructive disease in vegetable crops including potato in Ethiopia ((Fernández-Northcote *et al.*, 2000; Hijmans *et al*., 2000; Namanda *et al*., 2004; Mesfin *et al.,* 2009). Basically, potato crop is the main cash vegetable crop in and around Ambo, Dendi, Ilfeta, Jibat, Holleta and Toke Kutaye districts of Western Showa, Ethiopia. According to CABI (2004), potato yield losses in East Africa can be as high as 88 % and pests and diseases account for 56 % of that loss. Yield losses caused by *P. infestans* are estimated at 50 - 100 % in traditional potato production areas (Ajanga, 1993). As the crop is vegetative propagated, the diseases can easily be transmitted through tubers and cause very high economic losses across wide geographic areas. Furthermore, the percent incidence of late blight is as high as 45 to 55% on potato (EARO, 2002, HARC, 2005) was recorded in major potato producing areas of Ethiopia, giving good indication of the losses due to the disease can cause in major tomato producing areas of Ethiopia particularly in Ambo, Dendi, Holleta and Toke Kutaye districts of Western Showa.

Management of late blight requires aggressive measures that include combined use of cultural, scouting, sanitation, and most importantly the combi-nation of host plant resistance with application of fungicides (Johnson *et al*., 1998; Namanda *et al*., 2004; Kirk *et al.,* 2005). Yield losses due to the disease are attributed to both premature death of foliage and diseased tubers. In Ethiopia, the disease occurs throughout the major potato production areas and it is difficult to produce the crop during the main rainy season without chemical protection measures (Borgal *et al*., 1980; Bekele and Medhin, 2000; Habtamu *et al.,* 2012). To effectively manage late blight, farmers have increasin-gly adopted fungicide application as a main control strategy. Nonetheless, losses due to the disease were estimated to be 65-70% and complete crop failures are frequently reported (Bekele and Yaynu, 1996).

Phytophthora infestans has a high pathogenic variability and therefore, specific resistance has contributed little in controlling the disease and varietal resistance only helps in reducing the amount of fungicides required and the rate of disease development (Denitsa and Naidenova, 2005). However, a need to explore the other strategies to supplement the existing measures to curb the heavy economic losses inflicted by the disease. Apart from yield losses, the disease reduces the market value of the crop due to brown color that forms in tubers of potato during storage (Hartman and Huang, 1995; Cao and Forrer, 2001; Ghorbani *et al.,* 2007). Due to the devastating nature of the disease, it poses a threat to food security since many resource poor farmers cannot afford the numerous fungicide applications required to control it (Denitsa and Naidenova, 2005). Successful control of late blight disease needs an accurate control by using efficient fungicides.

The use of protectant and systemic fungicides for managing late blight has perhaps been the most studied aspect of this disease management in temperate countries (Olanya *et al.,* 2001). Preventive fungicides principally inhibit spore germination and penetration, but once the pathogen enters the leaves, these fungicides become ineffective. Under such conditions a product having some curative and systemic activity, such as metalaxyl is desirable (Schwinn and Margot, 1991). The National Potato Program within the Ethiopian Institute of Agricultural Research (EIAR), together within the International Potato Center (CIP) and several Ethiopian Universities have worked over the last two decades to introduce potato cultivars with resistance to *P. infestans.* But, some of them have lost their resistance soon after dissemination. The profound ability of the disease to reach an epidemic level within short periods, the inadequate efficiency of cultural practices to reduce high level of disease severity, and rapid development of resistance to fungicides and breakage of plant resistance in potato cultivars within short period of time have made integrated use of different disease management strategies very essential in late blight management. Thus, the combined uses of fungicide and resistance varieties have evolved as one of the most important options in the management of the disease (Namanda *et al*., 2001). Potato cultivars grown in Ethiopia have low levels of general resistance to late blight. Mostly the commercial potato farmers rely on fungicide applications for control of *P. infestans* (Habtamu *et al.,* 2012).

Integrating fungicide applications with varieties by choosing the best fungicide-cultivar combinations improves the durability/sustainability of the released potato varieties in the potato production system. This is particularly important in developing countries such as Ethiopia, where the setup of efficient and sustainable breeding programs for potatoes are inadequate. Integration of fungicides with cultivars has been commonly practiced for sustainable production of potatoes in most developed world (Namanda *et al*., 2001). In addition to the benefits of reducing yield losses due to epidemics of late blight, the combined uses of fungicide with resistance varieties can also contribute to reduce the health risks associated with high fungicide applications. Integration of fungicide with potato cultivars could reduce the need of application of high fungicide and able to decrease the risk to human health, environmental contamination, and increase the economic benefit of farmers. Production of potato in the rainy season (main cropping) in Ethiopia could not be envisaged without fungicide application to control late blight. Due to the risk of late blight, the farmers are not able to cultivate potato during the main rainy season in Holleta of West Showa, Ethiopia. The efficacy of some chemicals against late blight has been reported in Ethiopia (Habtamu *et al.,* 2012) and other countries (Matheron and Matejka, 1991; Ghani *et al.,* 1995; Shuja, 1995; Namanda *et al.,* 2004; Rahman et al., 2008; Usman Ghazanfar *et al.,* 2010), but large scale testing of newly registered fungicides against late blight has not been explored so far. However, there is inadequate information with regard to the plant growth promotion; use of potato cultivars combination with fungicides against late blight of potato in Ethiopia. Management of this disease through chemicals and the use of cultivars are possible. Therefore, this study was undertaken to evaluate the potato cultivars and fungicides for the management of late blight and to identify the most effective fungicide combined with cultivar against potato late blight and also to assess the economics of fungicides and cultivars.

MATERIALS AND METHODS

Description of the study site

The field experimental study was conducted in Holleta Agricultural Research Center, Holleta, West Showa, Oromiya Region, Ethiopia from July to October 2015. Holleta district has total geographical area of 78887 sq.km and is located at 8^{o} 57 'North latitude and 38^{o} 0

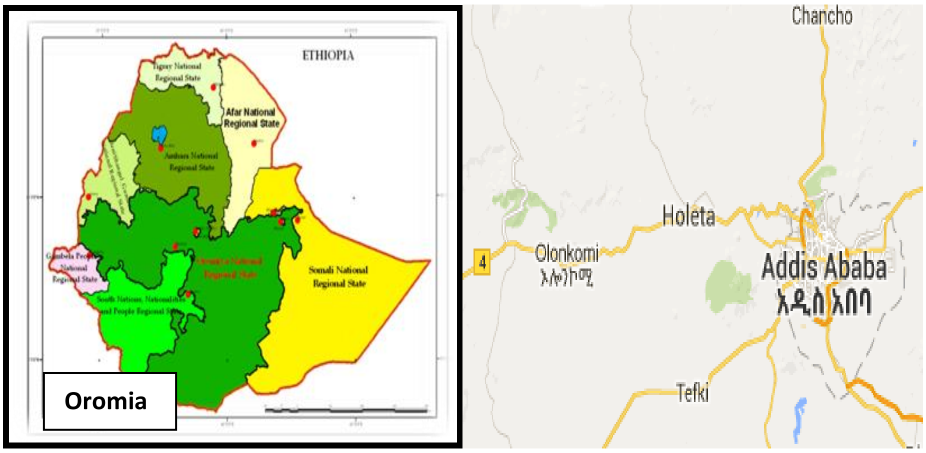


Fig.1 Map showing the study area- Holleta with Oromia Region

Figures 2 and 3 Experimental field with different fungicide treatments on potato cultivars

Table 1.Treatment combination of field experiment

1	Gudene (CIP-386423.13) + Mancozeb
2	Gudene (CIP-386423.13)+ Victory 72 WP
3	Gudene (CIP-386423.13) + Ridomil MZ 68 WG -Standard check
4	Gudene (CIP-386423.13)+ Horizon 680 WG
5	Gudene + un sprayed, check
6	Jalene + Mancozeb
7	Jalene + Victory 72 WP
8	Jalene + Ridomil MZ 68 WG - Standard check
9	Jalene + Horizon 680 WG
10	Jalene + un sprayed, check
11	Gera(CIP-384321.19) + Mancozeb
12	Gera (CIP-384321.19) + Victory 72 WP
13	Gera (CIP-384321.19) + Ridomil MZ 68 WG -Standard check
14	Gera (CIP-384321.19) + Horizon 680 WG
15	Gera + un sprayed, check

Table 2. Rates and frequencies of application of fungicides in the treatments.

Common name	Rate (kg/ha)	Interval of spray (days)	Frequency
Mancozeb	1.5	7	7 times
Victory72 WP	2.5	7-21	4 times
Horizon 680 WG	2.5	14	4 times
Ridomil MZ 68 WG	2.5	14	4 times

East longitude with elevation range of 1800-2800 m. a. s. l. and it is 45 km far from Addis Ababa of 45 km (Fig. 1). In addition, the district has bi-modal rainfall distribution with small amount of rainfall during Belg (autumn) season and much rainfall during Kremt (summer) season. Heavy rain was observed from onset of July to the end of August. The average annual rainfall of the area is 1040 mm. It has an annual minimum and maximum temperature in the range of 6°C and 21°C, respectively. The soil of the experimental study site is vertisol with light black in color and clay loam in texture with a pH value of 6.8.

Experimental materials used

Three cultivars of potato viz. Gudene (CIP-386423.13; Relatively Resistant), Gera (KP-90134.2; Moderate Relatively Resistant) and Jalene (CIP-384321.19; Susceptible cultivar) were used in this experimental study. All the three cultivars were obtained from Holleta Agricultural Research Center, Ethiopian Agricultural Research Institute, Hollet and also all the cultivars have wide-range of environmental adaptations in Ethiopia. Gera (KP-90134.2) was released in 2003, Gudene (CIP-386423.13) was released in the year 2006 while Jalene (CIP-384321.19) was released in 2002 (Woldegiorgis *et al.,* 2008; MoARD, 2013). Four fungicides were used in this study viz. Ridomil MZ 68 WG, Victory 72 WP (Mancozeb with Metalaxyl), Horizon 680 WG and Mancozeb against potato late blight disease. All the fungicides, except victory 72 which was obtained from Ambo University, were obtained from Holleta Agricultural Research Center, Ethiopia. In this experiment, Ridomil MZ 68 WG was used as a standard control (check). Likewise, Horizon 680 WG was the new fungicide which has not been widely used before the control of potato late blight disease in Ethiopia.

Experimental design, treatments and applications

A randomized complete block design with three replications was employed in a factorial arrangement at Holleta Agricultural Research Center. Each potato variety was randomly combined with one of the four fungicide (Ridomil MZ 68 WG, Victory 72 WP, Horizon 680 WG and Mancozeb) and a non-spray treatment was used as a control (Table 1; Figures 2 and 3).Plots consisted of 5 rows with spacing of 0.3 m between plants and 0.75 m between rows, giving an overall dimension of 2.4m X 3.75m. The fungicides were applied as per the recommendation of the manufacturers using a manually-pumped knapsack sprayer of 15 liter capacity (Table 2). Spraying was started soon after the first late blight lesions were observed on the foliage and continued depending on the recommendation of the fungicide. Di-ammonium phosphate (DAP) and urea were applied at planting and during weeding at the rate of 195 kg/ha and 165 kg/ha, respectively (Rotem and Sari, 1983). In all field plots, normal agronomic practices were carried out as necessary. Unsprayed control and Ridomil gold sprayed plots were used as a check.

Disease assessment

Disease incidence and severity

Starting with the appearance of the first late blight symptoms, each plant within each plot was visually evaluated for percent foliar infection (severity). Late blight incidence (number of plants infected) and severity were assessed as of the disease onset at 7 days' intervals from the pre-tagged 10 plants/plot in the three central rows of each plot. Number of plants that showed symptoms of late blight was counted and the percentage of disease incidence (PDI) were calculated according to the formula by Wheeler (1969)

$$PDI((\%) \quad \frac{\text{Number of diseased plants}}{\text{Total number of plants inspected}} \; X\,100$$

The data on disease severity was recorded using percent rating scale of Shutong *et al.* (2007) (Table 3). The severity grades were converted into Percentage Severity Index (PSI) according to the formula by Wheeler (1969).

$$PSI\ (\%) = \frac{\sum \text{Individual numerical ratting}}{\text{Total no. of. Plants assessed X Max. Score in the scale}} \; X\,100$$

Area under disease progressive curve and disease progress rates

The effect of variety and fungicide combinations on disease severity data was integrated into area under disease progress curve (AUDPC), as described by Campbell and Madden (1990).

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

Where n is the total number of assessments, t_i is the time of the i^{th} assessment in days from the first assessment date, x_i is percentage of disease severity at

i^{th} assessment. AUDPC was expressed in percent-days because the severity (x) was expressed in percent and time (t) in days. The rates of disease progress in time was determined by recording the severity of late blight at 7 days interval right from the appearance of the first disease symptoms (37 DAS) till the maturity of the crop in the different treatments.

Assessment of yield

At maturity, potato tubers were harvested from the central three rows on each plot of each treatment. Additionally, the weights of marketable yield of potato tuber per plot were recorded. Tuber yield per plot was converted into yield of tons per hectare.

Yield loss estimation

The relative loss in yield of each treatment was determined as percentage of that of protected plots of the experiment. Losses were calculated separately for each of the treatment and yield component of the potato was determined as a percentage of that of the protected plots and the yield loss was calculated based on the formula of Robert and Janes, (1991):

$$RL\ (\%)\ \frac{(Y_1\ - Y_2)}{Y_1}\ X\ 100$$

Where, RL – relative loss (reduction of the parameters yield and yield component), Y_1 mean of the respective parameter on protected plots (plots with maximum protection) and Y_2 - mean of the respective parameter in unprotected plots (i.e. untreated plots or treated plots). Percent yield recovery was calculated to compare the yield differences among fungicides and cultivars and other treatments using the formula:

$$YR\ (\%)\ \frac{PY\ - YUP}{YSP\ - YUP}\ X\ 100$$

Where, YR is yield recovery in percent, PY is plot yield, YUP is yield of unsprayed plot and YSP is maximum yield of sprayed plots.

Cost and benefit analysis

The price of all the three potato tubers was assessed from the local market and the total price of the yield obtained from each treatment was computed on hectare basis. Input costs like fungicide, cultivars and labor were converted into hectare basis according to their frequencies used. The prices for each cultivar per kg were assessed. Fungicides cost was estimated based on the price of company. Cost of the labor was in Birr per man-days; cost of spray and spray equipment to spray one week, two weeks and three weeks up to nine weeks per hectare were also calculated. Cost of spray equipment (knapsack sprayer) was in Birr per day assessed. Based on the obtained data from the above mentioned parameters, cost benefit analysis was performed using partial budget analysis. 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 (practice) 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:

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

Table 3. Rating scale for the assessment of late blight severity on potato leaves (Shutong *et al.,* 2007)

Disease severity rating grade	Disease incidence %	Level of resistance /Susceptibility
0	0.0	No disease
1	10	Small lesion on the inoculated point with the lesion area less than 10% of the whole leaflet.
3	10 and 20	Lesion area between 10% and 20% of the whole leaflet
5	20 and 30	Lesion area between 20% and 30% of the whole leaflet, the waterish area less than 505 of the whole leaflet
7	30 and 60	Lesion area between 30% and 60% of the whole leaflet.
9	Over 60	Lesion area over 60% of the whole leaflet.

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

Statistical analysis

Analysis of variance (ANOVA) was performed for the disease parameters (Incidence, severity, AUDPC) and yields parameters (tuber yield per plant and yield loss) using Statistical Analysis System (SAS) version 9.1.3 software (SAS Institute, 2003). Least significance difference (LSD) was used to separate treatment means (P<0.05). Correlation analysis was performed to examine the relationship between severity of the disease (AUDPC, the independent variables) and tuber yield in the field plots.

RESULTS AND DISCUSSION

Effect of fungicide application and late blight occurrence in relation to potato cultivars

Disease incidence, severity and AUDPC

During the study period in Holleta, late blight disease is favored by cool and humid conditions and it spread very fast under favorable conditions. Late blight incidence was high in Holleta during the main cropping season. The disease incidence was reached at the maximum of 91.5 % on the unsprayed control susceptible variety, Jalene and 55 and 38.5 % was recorded on moderate resistant varieties, Gudene and Gera, respectively (Table 4; Figures 4 and 5). The percent final disease severity was recorded significant difference in sprayed and unsprayed plots. The highest severity reduction (78%) was recorded in all fungicide treated Gera variety. The highest severity was recorded in varieties of Jalene (83.5 %) and Gudene (30%) with untreated control (Table 4; Figures 6, 7, 8 and 9). On the whole, the application of fungicides, Victory 72 WP, Ridomil MZ 68 WG, Mancozeb and Horizon 680WG have arrested disease development more effectively compared to unsprayed control application. In all varieties, the application of fungicides reduced the progress of the disease as compared to unsprayed control, but Victory 72 WP highly reduced the progress of the disease compared to other three fungicides in all varieties (Table 4). In general, the results of the combined analysis showed that the interaction of varieties (host resistance) and fungicides was significant. The results showed that, no significant variations in late blight incidence and severity among the varieties and fungicides combinations. Nonetheless, significant variations in late blight incidence and severity were obtained when the fungicides were applied on susceptible variety, Jalene. The late blight symptoms appeared to start in treated and untreated plots at about the same time (about 37DAP) with uneven distribution of the pathogen. But gradually the disease severities become varied within treatments.

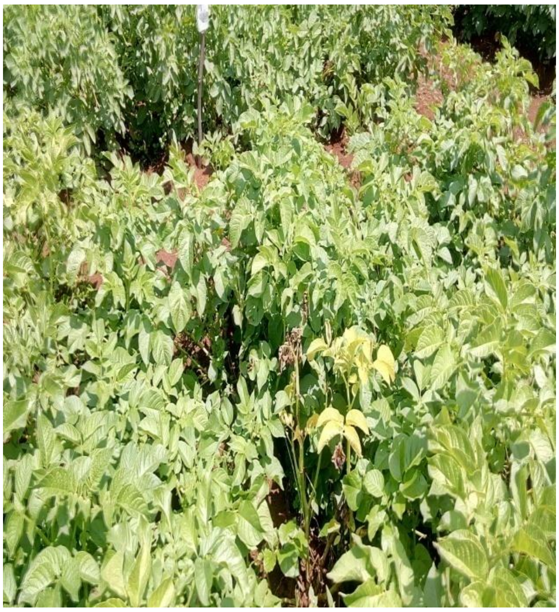



Figure 4 Experimental field study with Victory 72 fungicide treated of potato cultivar, Gera.
Figure 5 Experimental field study site with unsprayed control plot of potato cultivar, Jalene.

Table 4 Effect of fungicides and cultivar combinations on percentage disease incidence, percentage disease severity and area under disease progress curve (AUDPC) against late blight

Cultivar	Fungicide	Incidence (%)	Severity (%)	AUDPC
Gudene	Mancozeb	6.5	5	302.5
	Victory 72 WP	5	5	268.5
	Ridomil MZ 68 WG	5	6.5	278.5
	Horizon 680 WG	5	6.5	296
	Usprayed control	55	30	480
Jalene	Mancozeb	11.5	8.5	579
	Victory 72 WP	8.5	5	510
	Ridomil MZ 68 WG	6.5	5	442.5
	Horizon 680 WG	6.5	5	556.5
	Usprayed control	91.5	83.5	2457.5
Gera	Mancozeb	5	5	285
	Victory 72 WP	5	5	279
	Ridomil MZ 68 WG	5	5	244
	Horizon 680 WG	5	5	267.5
	Usprayed control	38.5	25	561
Mean	Mean	17.3	13.65	520.5
CV	CV	30.88	69.64	26.86
LSD (5%)	Fungicides	8.78	9.19	135.01
LSD (5%)	varieties	3.88	7.12	104.58

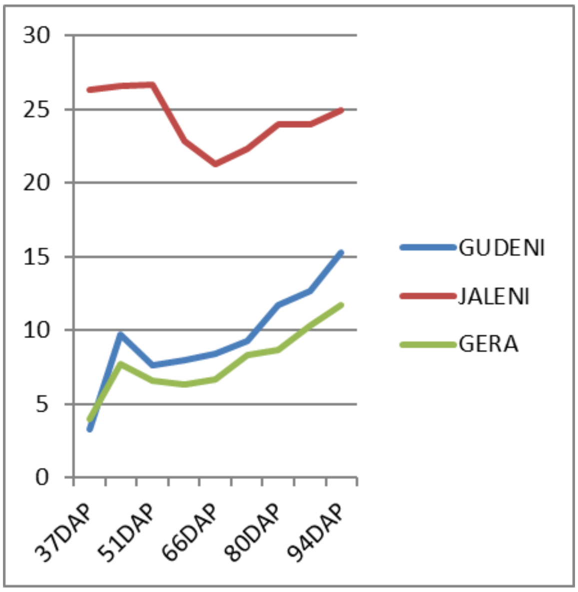


Figure 6.

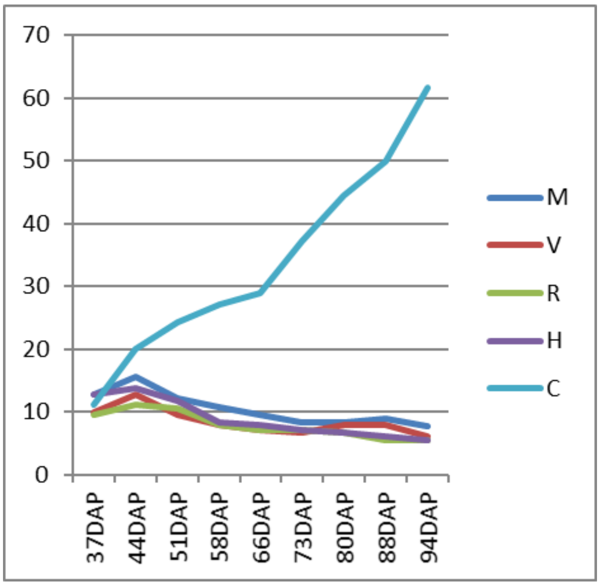
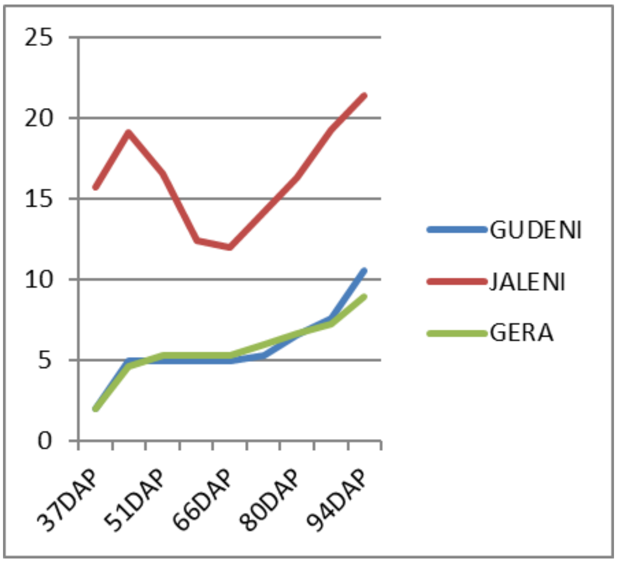


Figure 7

Figure 6. Disease progressive curves of potato late blight incidence on potato varieties
DAP= Days after planting

Figure 7. Effect of fungicides on disease progressive curves of potato late blight percentage incidence
DAP= Days after planting; M= Mancozeb; V= Victory 72 WP; R= Ridomil MZ 68 WG; H= Horizon 680 WG; C=unsprayed control



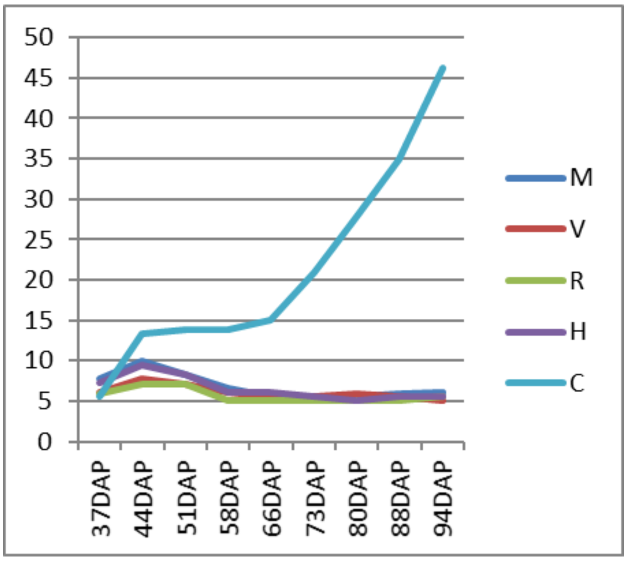


Figure 8 **Figure 9**

Figure 8. Disease progressive curves of potato late blight severity on potato varieties
DAP= Days after planting.
Figure 9 Effect of fungicides on disease progressive curves of potato late blight severity percentage
DAP= Days after planting; M= Mancozeb; V= Victory 72 WP; R= Ridomil MZ 68 WG; H= Horizon 680 WG; C=unsprayed control

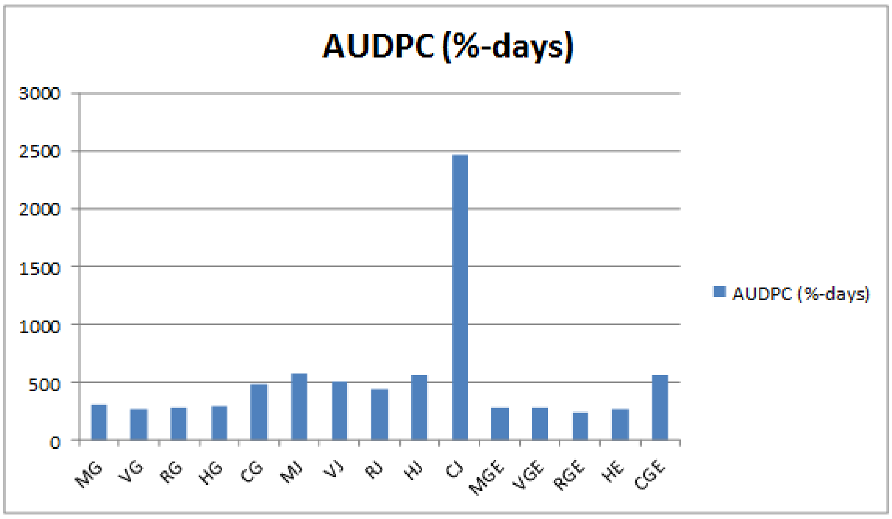


Figure 10 Area under disease progress curve (AUDPC) of late blight in relation to cultivars of potato treated with fungicides under field conditions. MG=Mancozeb with Gudene, VG=Victory 72 with Gudene, RG= Ridomil MZ 68 WG with Gudene, HG= Horizon 680 WG with Gudene, CG= unsprayed control with Gudene MJ=Mancozeb with Jallene, VJ=Victory 72 with Jallene, RJ= Ridomil MZ 68 with Jalene, HJ= horizon 680 with Jalene, CJ=unsprayed control with Jalene MGE=Mancozeb with Gera, VGE=Victory 72 with Gera, RGE= Ridomil MZ 68 with Gera, HGE= Horizon 680 with Gera, CGE=unsprayed control with Gera

Based on this, minimum AUDPC 244% days and 267.5-days was observed on Gera treated with Ridomil MZ 68 WG and Horizon 680 WG followed by Gudene treated with Victory 72 WG (267.5% days). Throughout the cropping season, the combined effect of varieties and fungicides on disease development was significant based on AUDPC values (Table 4; Figure 10). This indicates that different fungicides – variety combinations reduced the late blight development. On the susceptible variety, Jalene, the AUDPC without fungicide spray was over the moderate relatively varieties, Gudene and Gera (Table 4; Figure 10). The data analysis for AUDPC (area under disease progress curve) for severity showed a Co efficient variation (CV) value of 26.86 with least significant difference (LSD) of 104.58 for potato varieties and 135.01 for fungicides, there was significant differences between fungicides and varieties. The maximum AUDPC (2457.5% days) was recorded in absolute control (untreated Jalene). The highest AUDPC values were resulted in reduction of green leaf area on potato which was the principal effects of late blight epidemics contributed to the observed declines in yield and yield components (Figure 10).

In Ethiopia, potato late blight has been a serious problem since the introduction of the crop in to the country. Between 1987 and 2006, eighteen potato cultivars were released in Ethiopia (Woldegiorgis *et al*., 2008). All of these cultivars came from potato germplasm introduced by the CIP as varieties resistance to *P. infestans.* Since then attempts have been made to identify resistant varieties. Occurrence of *P. infestans* in sub-Saharan Africa has been closely linked to the introduction of susceptible potato varieties (Hakiza *et al*., 2001; Olanya *et al*., 2001). In Ethiopia, Mesfin *et al.,* (2009) reported that Ridomil and Mancozb were used to control potato late blight disease. Habtamu *et al.,* (2012) reported that the fungicides and host plant resistance are among the most efficient control options available to growers. Field trials were conducted at Hawassa and Shashemene, Southern Ethiopia to evaluate the effectiveness of fungicide application regimes on four potato cultivars. Application of fungicides considerably reduced late blight progress, with a corresponding increase in tuber yields. Application of Ridomil WP reduced the disease development and increased tuber yield in all cultivars compared to the other two fungicides, Chlorothanoil and Pencozeb. The field experiment was carried out to evaluate the management of potato (Gudene) late blight using a new fungicide, Victory 72 WP and Ridomil Gold to select the more effective dosage of the new fungicide option against potato late blight under field conditions at Toke Kutaye district of West Showa, Ethiopia (Amin *et al*., (2013). In this study, Victory 72 WP was retarded late blight development consistently when combined with all varieties (Gera, Gudene and Jalene) and the highest yields were obtained from plots treated with Victory 72 WP. The present study was determined that application of Victory 72 WP and Ridomil MZ 68 WG controls late blight and increases yields markedly.

In other country reports also supported by this present study, Speiser *et al.,* (2006) reported that the effect of copper fungicides against late blight for some of the potato cultivars in England. The copper fungicide treatment reduced the foliar blight severity in all the cultivars by 27% on average, and increased yield by 20% on average. Usman *et al.,* (2010) reported that the fungicides and host plant resistance are among the most efficient control options available to growers. Field trials were conducted in 2008 at the vegetable Research area of the Institute of Horticultural Sciences, Faisalabad, Pakistan to evaluate the effectiveness of three fungicides viz. Tazoline, Flint max and Kocide application on eight potato cultivars. Application of fungicides considerably reduced late blight progress, with a corresponding increase in tuber yields. The highest reduction in disease was achieved by applying Tazoline in the cultivar SH-103, followed by Kocide and least by Flint Max at an intervals of 07, 14, 21 and 28 days. In this study, the highest reduction in disease was achieved by applying Victory 72 WP in the cultivars of Jallene, Gudene and Gera, followed by Ridomil MZ 68 WG, and least by Manozeb and Horizon 680 WG. Dowley and Sullivan (1994) conducted field experiments in the Irish Republic to determine the effectiveness of spray programs using mixtures of Phenylamide and Mancozeb in controlling late blight of potatoes and the results revealed that mixtures significantly delayed disease onset in 6 of the 7 years of the experiments, while the level of leaf blight at the end of the season was significantly lower in 5 years.

Effect of fungicide application and variety resistance in potato tuber yield and Yield loss

Tuber yield

Weekly application of fungicide resulted in higher tuber yields in the susceptible variety when compared to the untreated control treatments. Higher tuber yield was 48.47 (tons/ha) was recorded on the variety Gera followed by Gudene and Jalene. The control treatments (no sprays) had the lowest tuber yield. Potato tuber yield was higher in the resistant than the susceptible variety, Jalene (Table 5). Fungicide application considerably increased the yield of susceptible varieties and also resistant varieties. The total tuber yield varied depending on the combination of varieties and fungicide application (Table 5). The moderately resistant varieties, Gudene and Gera gave highest total yield as compared to the susceptible variety, Jalene (Table 5). Application of Victory 72 WP fungicide increased the total yield of potato and gave highest yield as compared to other treatments (Table 5). The results were suggested that superiority of Victory 72 in controlling late blight and ensuring higher yield compared to the other fungicides tested in this experiment. The improved variety Gudene and Gera combined with fungicide application had significantly higher marketable yields as compared to the susceptible variety, Jalene. But there is also significant difference between the yields of the susceptible variety when combined with fungicide application. However, resistance to late blight in these cultivars has since been overcome and significant yield losses experienced (Woldegiorgis *et al*., 2008). Significant variations also existed between the resistant and susceptible varieties in terms of marketable and unmarketable yield (Table 5). This was in agreement with Asamenew and Bahru (2000) have also reported increased marketable and total tuber yield in resistant varieties under Ethiopian conditions. Habtamu *et al*., (2012) also reported that the evaluation of different potato variety and fungicide combinations for the management of potato late blight in Southern Ethiopia, the White flower and Agazar potato varieties were highly susceptible to late blight and early season infection, contributing significantly to the lower yields observed. Fry and Shtienberg (1990) reported that complete suppression of yield in susceptible varieties was possible if the disease occurs early in the season. Mukalazi *et al*. (2001) also reported that the susceptible varieties could be preferred by farmers due to their good agronomic characteristics, and hence fungicides must be used to ensure disease control. It was, therefore, necessary to establish the type of fungicide needed and it was important to establish the response of different cultivars to fungicidal application and variety combined.

For commercial production of potato, Kankwatsa *et al.* (2002) suggested that integration of host resistance and fungicide application reduced late blight severity by more than 50% and resulted in yield gains of more than 30%, which clearly supports the present investigation. Fontem and Aighew (1993) also reported that fungicides applied for late blight management increased tuber yield by as much as 60%. In both resistant and susceptible varieties, in this study showed that highest yield occurred when Victory 72 WP fungicide was used in combinations with both resistant and susceptible varieties.

Table 5 Effect of fungicides and cultivar combinations on marketable tuber yield, yield advantage over control and percent yield loss against late blight

Cultivar	Fungicide	Marketable yield (tons/ha)	Yield advantage over control (%)	Yield loss (%)
Gudene	Mancozeb	46.92	137.81	3.2
	Victory 72 WP	43.84	122.2	9.55
	Ridomil MZ 68 WG	46.61	136.24	3.84
	Horizon 680 WG	44.45	125.29	8.29
	Usprayed control	35.81	81.5	26.12
Jalene	Mancozeb	39.21	98.73	19.1
	Victory 72 WP	43.21	119.01	10.85
	Ridomil MZ 68 WG	40.13	103.4	17.21
	Horizon 680 WG	30.03	52.2	38.04
	Usprayed control	19.73	0	59.29
Gera	Mancozeb	40.77	106.64	15.89
	Victory 72 WP	48.47	145.67	0
	Ridomil MZ 68 WG	45.07	128.43	7.01
	Horizon 680 WG	41.36	109.63	14.67
	Usprayed control	31.49	59.55	35.04
Mean	Mean	40	--	--
CV	CV	9.65	--	--
LSD (5%)	fungicides	3.73	--	--
LSD (5%)	varieties	2.89	--	--

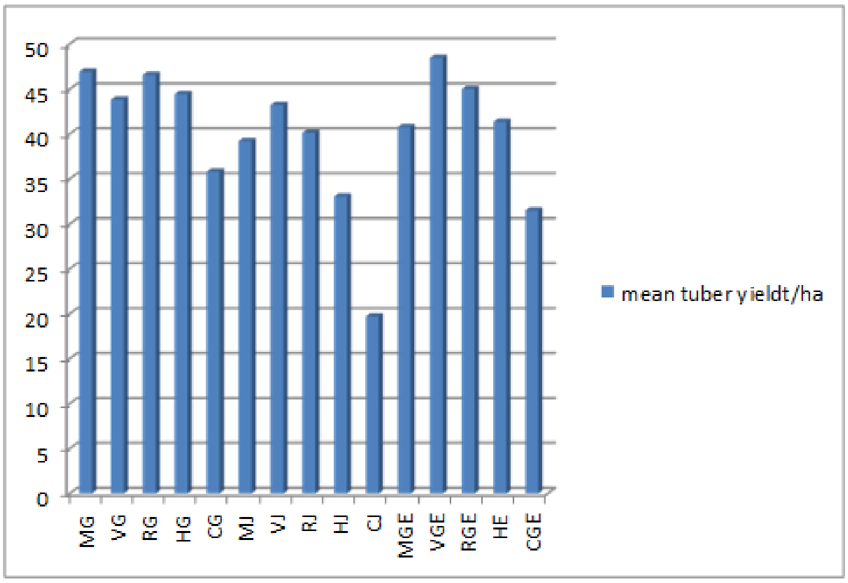


Figure 11 Mean potato tuber yield tons/ha in different treatments against late blight of potato
MG=Mancozeb with Gudene, VG=Victory 72 with Gudene,RG= Ridomil MZ 68 WG with Gudene, HG= Horizon 680 WG with Gudene, CG= unsprayed control with Gudene MJ=Mancozeb with Jallene, VJ=Victory 72 with Jallene, RJ= Ridomil MZ 68 with Jalene, HJ= horizon 680 with Jalene, CJ=unsprayed control with Jalene MGE=Mancozeb with Gera, VGE=Victory 72 with Gera, RGE= Ridomil MZ 68 with Gera, HGE= Horizon 680 with Gera, CGE=unsprayed control with Gera

Nyankanga *et al*. (2003) suggested that if susceptible potato varieties are used with rigorous spray regimes of Ridomil fungicide, then effective late blight control and high yield can be attained. Hakiza *et al.* (2001) and Olanya *et al*. (2001) reported that even if occurrence of *P. infestans* in sub-Saharan Africa has been closely linked to the introduction of susceptible potato varieties, successful management of late blight through the foliar fungicides application is dependent on several factors such as proper timing of initial fungicide application, use of effective dosage, timely scheduling of fungicide intervals and adequate coverage of foliage. In this study, Victory 72 WP consistently retarded late blight development when combined with all varieties and the highest yield was obtained from plots treated with Victory 72 WP. The present study has determined that an application of Victory 72 WP and Ridomil MZ 68 WG controls late blight and increases yields markedly (Table 5). Results of this study were consistent with previous studies and indicate that a combination of resistance varieties and scheduled application of protective and contact fungicides can reduce foliar late blight to acceptable levels in most situations (Clayton and Shattock, 1995; Kirk *et al*., 2001). The use of protectant and systemic fungicides for managing late blight has perhaps been the most studied aspect of late blights management in temperate countries (Olanya *et al.,* 2001). Olanya *et al.* (2001) also reported that, with the exception of optimum or scheduled fungicide applications based on favorable weather conditions, the most economical option for disease management is the use of host-plant resistance. The use of cultivars with durable resistance combined with scheduled applications of protective fungicides has been reported as useful for managing late blight (Simons, 1972), as well as other diseases (Van der Plank, 1963). The performance of Victory 72 and Ridomil MZ in controlling late blight under present investigation has been supported by many researchers throughout the world (Singh and Shekhawat, 1999; Singh *et al.,* 2001; Islam *et al.,* 2002; Tsakiris *et al.,* 2002; Amin *et al*., 2013). In tropical Africa, the contact fungicide Dithane M 45 (Mancozeb 80% WP) and the systemic fungicide Ridomil MZ are widely used to control late blight (Olanya *et al*., 2001; Fontem, 2001).

Yield loss estimation

The variations in tuber yield losses were observed among different treatments. In comparison, tuber yield losses in untreated plots were notably higher than sprayed plots. The highest tuber yield losses next to the absolute control (59.29%) was recorded from Jalene treated with Horizon 680 WG (38.04%)

followed by untreated Gera (35.04%). According to Bradshaw (1992) and Thind *et al.* (1989), potato yield loss attributed primarily to late blight is dependent on variety susceptibility or tolerance / resistant and disease management practices.

Correlation among yield and disease parameters

Potato tuber yield was correlated with different disease parameters, varieties and fungicides using SAS software. The correlations among the disease parameters with the tuber yield showed a significant negative correlation. There was significant difference between varieties with all parameters and there were significant variations with fungicides and yield. On the other hand, there was high relationship between all the parameters viz. severity, incidence and yield while severity and incidence showed negative correlation with yield (Table 6). Habtamu *et al.,* (2012) also reported that the highly significant correlation between disease severity and percentage reductions in tuber yield due to late blight in Hawassa.

Cost and benefit analysis

Total costs of production of any crop include both variable (operating) and fixed costs. Variable operating costs vary across the treatments because of local material needs and costs. Major variable costs for producing potatoes for hectare include investment purchases for treatments, tubers, fertilizers and management (labor) costs. Similarly, cost and benefit ratio was computed for all treatments using the partial budget analysis method. The price of potato tubers at Holleta from July to October was assessed and an average price 5 birr/kg was taken and used to compute the total sale (Gross field benefits) and Net benefit of the total produce obtained. The cost of chemicals for hectare was calculated to be 5000 birr for hectare on average. The data analysis indicated that the highest Gross field benefits was maintained from Gera treated with Victory 72 WP (211,850 birr /ha) followed by Gudene treated with Mancozeb and Ridomil MZ 68 WG with mean values of 204,100 birrs /ha and 202,550 birr /ha respectively. Moreover, Gera treated with Ridomil MZ 68 WG and Gudene treated with Horizon 680 WG also recorded promising net benefit with mean value of 194,850 birr /ha and 191,750 birrs /ha respectively. The least Net benefit next to the absolute control (75,150 birr /ha) was untreated with Gera and Jalene treated with Horizon 680 with mean value of 133,950 birr /ha and 134,650 birr /ha, respectively (Table 6).

The data analysis indicated that the highest Marginal rate of return was maintained from Gera treated with Victory 72 WP (1951.4%) followed by Gudene treated with Mancozeb and Ridomil MZ 68 WG with mean values of 1842.1% and 1820%, respectively. Moreover, Gera treated with Ridomil MZ 68 WG and Gudene treated with Horizon 680 WG also recorded promising Marginal rate of return with mean values of 1710 and 1665.7%, respectively (Table 7). Generally, successful potato production and management are always challenging and, as for any agriculture commodity, which is very difficult. However, potato production remains an economically feasible and profitable enterprise for many growers at Holleta district, West Showa, Ethiopia.

Table 6 Correlation coefficient (r) among disease parameters and tuber yield components in different fungicides and cultivars under field conditions.

	Pearson Correlation Coefficients N = 45 Prob > |r| under H0: Rho=0				
	Varieties	Fungicides	AUDPC severity	AUDPC incidence	Yield
Varieties			0.9909	0.7349	0.4897
Fungicdes			0.40896	0.47087	-0.56178
AUDPC severity				0.96264	-0.75804
AUDPC incidence					-0.77607
Yield					

Table 7 Yield and cost inputs for the management of potato late blight using different fungicides and varieties

	UNIT	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Marketable yield tons/ha	Tons	46.92	43.84	46.61	44.45	35.81	39.21	43.21	40.13	33.03	19.73	40.77	48.47	45.07	41.36	31.49
Gross field benefits	Thousands of birr	234.6	219.2	233.05	222.25	179.0	196.05	216.05	200.65	165.15	98.65	203.85	242.35	225.35	206.8	157.45
Cost of treatments	Thousands of birr	17	17	17	17	10	17	17	17	17	10	17	17	17	17	10
Cost of labor and management	Thousands of birr	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Total cost	Thousands of birr	30.5	30.5	30.5	30.5	23.5	30.5	30.5	30.5	30.5	23.5	30.5	30.5	30.5	30.5	23.5
Net benefit	Thousands of birr	204.1	188.7	202.55	191.75	155.5	165.55	185.55	170.15	134.65	75.15	173.35	211.8	194.85	176.3	133.95

Table 8 Partial budget analysis for the management of potato late blight using different fungicides and potato varieties under field conditions.

Parameters	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Potato tuber yield (tons/ha)	46.92	43.84	46.61	44.45	35.81	39.21	43.21	40.13	33.03	19.73	40.77	48.47	45.07	41.36	31.49
Potato sale (thousand birr /ton)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Sale Revenue(1*2)	234.6	219.2	233.05	222.25	179.0	196.05	216.05	200.65	165.15	98.65	203.85	242.35	225.35	206.8	157.45
Input and labor cost (Thousand birr)	30.5	30.5	30.5	30.5	23.5	30.5	30.5	30.5	30.5	23.5	30.5	30.5	30.5	30.5	23.5
Marginal cost (Thousand birr /ha)	7	7	7	7	0	7	7	7	7	0	7	7	7	7	0
Net profit (3-4) (thousand birr/ha)	204.1	188.7	202.55	191.75	155.5	165.55	185.55	170.15	134.65	75.15	173.35	211.85	194.85	176.3	133.95
Marginal benefit (thousand birr/ha)	128.95	113.55	127.4	116.6	80.35	90.4	110.4	95	59.5	0	98.2	136.6	119.7	101.15	58.8
MRR (7/5) (%)	1842.1	1622.1	1820	1665.7	0	1291.4	1577.1	1357.1	850	0	1402.9	1951.4	1710	1445	0
Cost benefit ratio (CBR)	6.69	6.19	6.64	6.29	6.62	5.43	6.08	5.58	4.41	3.2	5.68	6.95	6.38	5.78	5.7

T1=Mancozeb with Gudene cultivar, T2=Victory 72 with Gudene cultivar,T3= Ridomil MZ 68 WG with Gudene cultivar, T4= Horizon 680 WG with Gudene, T5= unsprayed control with Gudene cultivar; T6=Mancozeb with Jalene cultivar, T7=Victory 72 withJalene cultivar, T8= Ridomil MZ 68 withJalene cultivar, T9= horizon 680 withJalene cultivar, T10=unsprayed control with Jalene cultivar; T11=Mancozeb with Gera cultivar, T12=Victory 72 with Gera cultivar, T13= Ridomil MZ 68 with Gera cultivar, T14= Horizon 680 with Gera cultivar, T15=unsprayed control with Gera cultivar.

CONCLUSIONS

Late blight caused by *Phytophthora infestans*(Mont) de Baryis one of the most significant constraints to potato production in Holleta, West Showa, Ethiopia. However, no endeavor has been made in the management of the disease so far in Holleta district of West showa, Ethiopia. Fungicides and host plant resistance are among the most efficient control options available to growers. Application of fungicide treatments considerably reduced late blight disease progress, with a corresponding decrease in disease index and increase in their tuber yields. In this study, Victory 72 WP has retarded late blight development consistently when combined with all varieties and the highest yields were obtained from plots treated with Victory 72 WP. Higher tuber yield was 48.47 (tons/ha) was recorded on the variety Gera followed by Gudene and Jalene and in the control treatments (no sprays) had the lowest tuber yield. Potato tuber yield was higher in the resistant varieties than the susceptible variety, Jalene. Economic analysis revealed that the highest net benefit was obtained from Gera when sprayed fungicides at intervals followed by Gudene and the least were obtained from Jalene unsprayed plot. The present study has determined that an application of Victory 72 WP and Ridomil MZ 68 WG were more economical and feasible for the management of potato late blight and increases tuber yields markedly. Further, cost effective and feasible integrated management options need to be developed for potato late blight in the country. To validate and recommend the management strategy, the study should be repeated in the area using resistant cultivars in integration with other recommended cultural practices in the area should be given attention to provide other alternative for late blight management in potato. Small and large scale farmers of potato growers should be encouraged to use host plant resistance varieties in conjunction with victory 72 WP and Ridomil MZ 68 WG fungicides applications in late blight endemic areas.

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