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Evaluation of Fungicide Frequency and Rotation for Tomato Late Blight Management in Rain-Fed and Irrigated Conditions

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Abstract

Tomato late blight is among the major constraints that limit production in most tomato-growing areas. The field experiment was conducted in the Ambo Agricultural Research Center on-station and Toke Kutaye district in 2020/22 to evaluate fungicide application frequency and rotation and determine the economic cost of fungicide application for the management of late blight under rain-fed and irrigated conditions of tomato production. Cochoro, the tomato variety that is well adapted to the area, was used in the experiment. Five frequencies and rotations of fungicide application were arranged in an RCBD design with three replications. The result showed that the rotations of fungicide Victory 72 WP, Mancozeb 80% WP, and Ridomil Gold MZ 68 WP spray were found to have the lowest disease incidence (39.57%), percent severity index (25.02%), AUDPC (66.82% days), and highest marketable yield (29.75ton ha^{-1}) in all locations as compared to the untreated plots that exhibited the highest percent disease incidence (100%), percent severity index (56.2%), and AUDPC (147.47%). Therefore, from the present study, the application of fungicides in the alternating order of Victory 72 WP to Mancozeb 80% WP to Ridomil Gold MZ 68 WP at a 7-day interval is recommended to reduce the late blight damage on tomato crops. In addition, the present finding has suggested that the planting of tomatoes should start during the mid-summer (late July or early August) to avoid the high-risk conditions for the late blight epidemic and reduce the frequency of fungicide sprays in the main rainy season.

Keywords: Rotation; Incidence; Late Blight; Severity index; Tomato

Introduction

Tomato *(Lycopersicon esculentum Mill.)* is one of the most important and well-liked vegetables in Ethiopia. According to the CSA (2013), Ethiopia has 6894.60 hectares of land planted with tomatoes, with a total output estimate of 277,745.38 quintals. The majority of fresh market tomatoes are grown by small farmers (MoA, 2018). Given their high value as a commodity and top priority in Ethiopian vegetable research, tomatoes are becoming more and more significant (Tsedeke, 2007) [1].

Tomato production faces several constraints among which biotic and abiotic factors are the most yield limiting. The biotic and abiotic factors contributing to the lower yield of tomatoes in Ethiopia include diseases (mainly fungal diseases such as late blight, early blight, Septoria spot, fusarium wilt, and powdery mildew (Negesa, 2022)), insect pests (Gashawbeza et al.,2009), plant parasitic weeds (Etagegnehu et al.,2009), drought, heat, and poor cultural practices (Dessalegn et al., 2008), shortage of varieties that are adaptable to different agro-ecologies, poor quality seeds, high post-harvest loss, lack of awareness of existing improved technology and poor marketing systems (Dessalegn et al., 2002). Among the major disease of tomatoes in Ethiopia, late blight (Phytophthora infestans (Mont) de Bary) has been a serious problem in tomato production worldwide (Tumwine et al., 2002). Farming communities in Ethiopia, attempt to produce tomatoes both under rain feed and small-scale traditional irrigation systems (Lemma, 2002). Complete management of late blight is difficult to achieve, especially during heavy rainy seasons (Getachew, 2018) [2].

Late blight caused by P. infestans is one of the most significant constraints to tomato production with up to 90% of crop losses in cool and wet weather conditions in the country (Denitsa, 2005). Tomato losses due to the disease is estimated to be € 5.2 billion per annum (Haverkort et al., 2009). Because it causes complete crop failure, it is difficult to produce tomato during the main rainy season (Amin et al., 2013, Mesfin et al., 2009) [3].

Late blight can be managed through the use of different management methods such as cultural, chemical, host resistance, biological, and integrated disease management (IDM). In Ethiopia, farmers use intensive fungicide application with unlimited spray frequency to protect the crop from the heavy infestation of the disease. Report indicated that frequent applications of fungicides result in the development of a new virulent strain of the pathogen (Ermias, 2016). Tomato growers in the country mostly depend on the application of fungicides for the management of late blight. Thus, it is important to support farmers on effective fungicide integration (sequencing different modes of action) and cost-effective application frequencies to enhance tomato production under rainfed in Ethiopia. Therefore, the objective of the present study was to evaluate fungicide application frequency, rotation of application of different mod-action fungicides, and determine the economic cost of fungicide application for the management of late blight under rain-fed and irrigated tomato production [4,5].

Materials and Methods

Description of the study area

The experiment was conducted in the districts of West Shewa zone; Ambo (Ambo Agricultural research center on-station, under irrigated condition) and Toke Kutaye (Dadagelan and Birbirsa kebele,

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under rainfed condition) for two successive years (2021 and 2021). The altitude at Dadagelan is 2345 m.a.s.l and its geographical locations at North 8053.02" and East 37046.82", whereas Birbirsa is located at North 8055.04' and East 37044.12" with an altitude of 2112 m.a.s.l. The areas receive heavy rain from July to August. The annual rainfall ranges from 800-1100 mm and the temperature of the district ranges from 9.44°C to 21.86°C with an average of 15.65°C. The soil of the experimental site is light-red clay loam with a pH value of 6.8 (Source: Toke Kutaye Agricultural Office) [6].

Experimental design and treatments

The experiment was laid out in RCBD arrangement with three replications. Plot size of 2 m * 2 m was spaced 40 cm and 70 cm between plants and rows, respectively. Each plot and block was separated by a buffer zone of 1.5 m and 2.0 m, respectively, to minimize the effect of fungicide drift. The first spray of fungicides was started soon after the initial appearance of disease symptoms using a knapsack sprayer. Victory 72 WP, Mancozeb 80% WP, and Ridomil gold fungicides were used for an alternative application of fungicides. The sole application frequency of each fungicide was included in the treatment. The unsprayed plot was used as a control check in the experiment. The alternating and frequency of fungicides were applied 6-times by 7-days interval. One commercial tomato variety (Cochoro) was used for the experiment (Table 1) [7,8].

Preparation of tomato seedlings

Tomato seedlings were raised on a 4 m x 2 m raised bed shaded with grasses, which protected the seedlings from heavy rainfall and sunlight. Twenty-five-day-old seedlings were transplanted to the pre-prepared main field. One seedling was maintained per hole, giving rise to a plant population of 59523 plants/ha. NPK (20:10:10) was used as top dress at a rate of 200 kg/ha and applied in two splits: 5 g/plant four weeks after planting and 5 g/plant two weeks after the first application [9].

Data collection

Late blight disease severity and incidence were assessed at seven-day interval and repeated until the tomato crop matured. Disease incidence refers to the proportion of sick plants, while disease severity is the relative or absolute area of plant tissue affected by the disease. The disease scoring was made by visual assessment of symptomatic leaves, petioles, fruits, and stems on a scale rating. To determine disease severity, individual plant root tissues were assessed according to a 1–9 scale proposed by Abawi and Pastor-Corrales (Abawi *et al*., 1990). Where 1 = no visible symptoms, 3 = light discoloration either without necrotic lesions or with approximately 10% of the hypocotyl and root tissues covered with lesions, 5 = approximately 25% of the hypocotyls and root tissues are covered with lesions, but the tissues remain firm, with some deterioration of the root system. 7 = Approximately 50% of the hypocotyls and root tissues covered with lesions combined with considerable softening, rotting, and reduction of the root system, 9 = approximately 75% or more of the hypocotyl and root tissues affected by advanced stages of rotting combined with a severe reduction in the leaf system. Disease incidence values were calculated using the following formula [10]:

$$\text{Disease Incidence } (\%) = \frac{\textit{Number of diseased plants}}{\textit{Total plants per plot}} x100$$

The severity scales were converted into percentage severity index (PSI) accordingly Wheeler, 1969.

$$PSI = \frac{\textit{Sum of Numerical rating}}{\textit{Total number of Plant observed x Maximum rating}} * 100$$

The area under the disease progress curve (AUDPC) and infection rate Standard formula (Campbell and Madden, 1990).

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

Where n is the total number of disease assessments, it is the time of the i[th] assessment in days from the first assessment date and x_i is the PSI of the disease at the i[th] assessment. AUDPC was expressed in %-days because severity (x) is expressed in percent and time (t) in days.

Tomato fruits were harvested weekly for five consecutive weeks when they reached physiological maturity. Harvested tomato fruits were graded into marketable and unmarketable quality based on the quality accepted by the local market and the weight per plot was recorded. In addition, data on labor cost for fungicide application, price of produce at farm level, days to disease onset, and disease incidence (%) [11].

Data analysis

Data on tomato late blight incidence and severity were transformed before analysis using arc sine and square root transformation, respectively (Gomez and Gomez, 1984, Arunakumara, 2006). All the data were subjected to analysis of variance using the general linear model procedure of the SAS Statistical Package (SAS Institute Inc 1998; Cary, NC, USA.), and treatment means were separated by the least significant difference at P≤0.05 [12].

Economic analysis

A simple cost-benefit analysis was computed for each treatment using the formula of partial budget analysis (CIMMYT, 1988) to determine the profitability of tomato late blight management through alternation and fungicide sprays at different frequencies. The price of fruits per kilogram was obtained from the local market (20 birr per kg). A cost-benefit analysis of each fungicide schedule was done to evaluate the economic benefits expected using the farm gate price of tomatoes at the time of harvest. Marketable fruit yield was measured for sale, and the cost of manpower and water was assumed to be zero. Partial budget analysis showed that Victory 72 WP, Mancozeb 80% WP, and Ridomil Gold MZ 68 WP foliar spray frequencies used gave a high gross field benefit and marginal rate of return. The maximum total gross marketable yield benefit of ETB (895,609.8 and 825,698.6 ha1) was obtained six times, respectively, compared to the other treatment combinations. The highest MRR in comparison with other treatments was obtained (7453.57%) [13].

The results of the alternating use of fungicides on tomato crops have been proven to be positive. To improve tomato productivity in the main harvest season, it is recommended to use an alternative fungicide [14].

Table 1: Selected fungicide for the alternative and frequency efficacy evaluation against tomato late blight.

S/N	Common name	Trade name	Mode of action	Rate (Kg/ha)
1	Metalaxyl 80 gm/kg + Mancozeb 640 gm/kg	Victory 72 WP	Systemic and Contact	2.5-3
2	metalaxyl – M 4% + mancozeb 64%	Ridomil Gold MZ 68 WP	Systemic and Contact	2.5-3
3	Sabozeb 80% + mancozeb 800	Mancozeb	Contact	2

Pearson correlation coefficient was analyzed using SAS software while the costs and benefits were analyzed using the standard procedure developed by CIMMYT (1988).

$$\text{Marginal Rate Return}(\%) = \frac{DNI}{DIC} x100$$

Where MRR% is the percentage marginal rate of return, DNI is the difference in net income compared with the control [change in net benefits (Net benefits from new technology minus net benefits from control)] and DIC is the difference between input cost compared to control [Change in total variable costs (Total variable cost of new technology minus control)]. To compare alternation fungicide application treatment techniques and frequency fungicide application costs and benefits, the ratio of net benefits (Gross margin) to total variable costs was calculated using the formula below. Treatment that showed the highest ratio was reported as the best [15].

$$\text{Cost Benefit ratio} = \frac{Net\ Benefit}{Total\ Variable\ Cost}$$

Results and Discussion

Disease intensity and yield components under irrigated conditions

The data revealed that late blight exhibited significant differences ($P<0.05$) within treatments. The maximum disease incidence was recorded on unsprayed plots (95.00%) and Victory 72 WP 2 times spray (77.67%). The minimum disease incidence recorded on the plots sprayed with Victory 72 WP + Mancozeb 80% WP + Ridomil Gold, Mancozeb 80% WP + Ridomil Gold + Victory 72 WP (39.67, 40.67%), and Mancozeb 80% WP + Ridomil Gold + Victory 72 WP (41.0%) [16]. The maximum percentage severity index recorded on unsprayed plots (56.22%) followed by two-time Victory application (39.05%) while the minimum percent severity index was recorded on the plots treated with Victory 72 WP + Mancozeb 80% WP + Ridomil Gold, Ridomil Gold + Victory 72 WP + Mancozeb 80% WP(25.02, 22.39%), and Mancozeb 80% WP + Ridomil Gold + Victory 72 WP(29.35%). The maximum AUDPC under irrigation was recorded on check (147.47%) followed by plots treated with Victory 72 WP 2 times spray (116.64%). The minimum AUDPC under irrigation was achieved using alternate application of Victory 72 WP + Mancozeb 80% WP + Ridomil Gold, Mancozeb 80% WP + Ridomil Gold + Victory 72 WP, (73.83, 66.82) control, and Ridomil Gold + Victory 72 WP + Mancozeb 80% WP (62.21). Maximum marketable yield was obtained through rotation application of Victory 72 WP + Mancozeb 80% WP + Ridomil Gold (29.75 tons ha-1) while the least marketable yield was recorded on check (5.33 tons/ha) (Table 2) [17].

Disease intensity and yield components under rainy seasons

The minimum disease incidence was recorded on plots treated with rotation application of Victory 72 WP + Mancozeb 80% WP + Ridomil Gold, Ridomil Gold + Victory 72 WP + Mancozeb 80% WP (70.00, 70.33%), and Mancozeb 80% WP + Ridomil Gold + Victory 72 WP (70.50%). Maximum disease incidence was recorded on control (100.00%) followed by Victory 72 WP 2 times spray (95.50%). The minimum disease severity index was recorded on plots treated with rotation application of Ridomil Gold + Victory 72 WP + Mancozeb 80% WP, Mancozeb 80% WP + Ridomil Gold + Victory 72 WP (27.07, 27.61%), and Victory 72 WP + Mancozeb 80% WP + Ridomil Gold (27.80%) [18].

Under rainy condition, the minimum AUDPC was recorded in treatments of Ridomil Gold + Victory 72 WP + Mancozeb 80% WP, Mancozeb 80% WP + Ridomil Gold + Victory 72 WP (67.92, 69.96), and Victory 72 WP + Mancozeb 80% WP + Ridomil Gold(73.13), while the maximum AUDPC values were recorded on the control plot (150.35) and Victory 72 WP 2 times spray (129.34). Maximum marketable yield was recorded on the plots treated with alternating application of Victory 72 WP + Mancozeb 80% WP + Ridomil Gold and Ridomil Gold + Victory 72 WP + Mancozeb 80% WP (28.62 a ton ha-1). In contrast, the least marketable yield was recorded in untreated plots (4.42 tons/ha) and sole application of Victory 72 WP 2. Maximum unmarketable yield was recorded in treatments obtained from Control (2.50-ton ha-1) and Victory 72 WP 2 times (2.44-ton ha-1) (untreated or controls), and two times the same fungicide was used in both varieties (Table 3) [19].

The highest percent severity index obtained on the tomato which was produced under rainfed condition than the one produced using irrigation (Figure 1). In both seasons of tomato production, the lowest late blight PSI were recorded in alternations of fungicide treatment (VMR (Victory, Mancozeb, and Redomil), MRV (Mancozeb, Redomil, and Victory), and RVM (Redomil, Victory, and Mancozeb) compared to the sole application of Victory fungicide and the unsprayed plots. The percent severity index of tomato late blight decreased as the number of

Table 2: Effect of fungicide rotation and frequency of application on late blight disease Intensity and yield components of Tomato crop during the 2020 growing irrigation Season at Ambo district (Ambo Agricultural Research Center on-station).

S/N	Treatment description	Incidence (%)	PSI (%)	AUDPC	MYD ton/ha	UNMYD ton/ha
1	Victory 72 WP + Mancozeb 80% WP + Ridomil Gold	39.67^{e}	25.02^{d}	66.82^{ef}	29.75^{a}	0.40^{d}
2	Mancozeb 80% WP + Ridomil Gold + Victory 72 WP	40.67^{e}	29.35^{cd}	73.83^{def}	28.60^{b}	0.94^{c}
3	Ridomil Gold + Victory 72 WP + Mancozeb 80% WP	41.00^{e}	22.39^{d}	62.21^{f}	27.37^{c}	1.04^{c}
4	Ridomil Gold + Ridomil Gold + Ridomil Gold	61.33^{c}	34.60^{bc}	96.09^{bcd}	26.25^{d}	1.75^{b}
5	Mancozeb 80% WP + Mancozeb 80% WP + Mancozeb 80% WP	64.00^{c}	28.35^{cd}	106.50^{bc}	25.89^{d}	1.60^{b}
6	Victory 72 WP (2 times)	77.67^{b}	39.05^{b}	116.64^{b}	12.54^{h}	2.93^{a}
7	Victory 72 WP (3 times)	65.67^{c}	32.95^{bc}	100.9^{bc}	15.85^{g}	1.91^{b}
8	Victory 72 WP (4 times)	65.00^{c}	32.45^{bc}	99.23^{bc}	18.95^{f}	1.80^{b}
9	Victory 72 WP (5 times)	52.00^{d}	29.29^{cd}	87.55^{cde}	22.57^{e}	1.93^{b}
10	Victory 72 WP (6 times)	43.67^{e}	22.44^{d}	73.26^{ef}	26.11^{d}	0.93^{c}
11	Control check	95.00^{a}	56.22^{a}	147.47^{a}	5.33^{i}	3.19^{a}
CV (%)		6.38	12.89	14.26	2.05	15.66
LSD (0.5)		6.37	7.03	22.75	689.76	0.45

PI=Percent incidence, PSI=Percent Severity Index, AUDPC=Area Under Disease Progress Curve, MYD=Marketable Yield, UNMYD=Unmarketable Yield
*Means followed by the same letter (s) within the column (lowercase letter) are not significantly different from each other at P<0.05.

Table 3: Effect of fungicide alternations and frequency of application on late blight disease Intensity and yield components of Tomato crop during the 2021/22 growing main Season at Toke Kutaye district.

S/N	Treatment description	Incidence (%)	PSI (%)	AUDPC	MYD ton/ha	UNMYD ton/ha
1	Victory 72 WP + Mancozeb 80% WP + Ridomil Gold MZ 68 WP	70.00^{f}	27.80^{fg}	73.13^{ef}	28.62^{a}	1.56^{d}
2	Mancozeb 80% WP + Ridomil Gold MZ 68 WP + Victory 72 WP	70.50^{f}	27.61^{fg}	69.96^{f}	25.88^{b}	1.70^{cd}
3	Ridomil Gold + Victory 72 WP + Mancozeb 80% WP	70.33^{f}	27.07^{g}	67.92^{f}	23.97^{c}	1.65^{cd}
4	Ridomil Gold MZ68WP + Ridomil Gold MZ68WP Ridomil Gold MZ68WP	78.17^{d}	36.97^{d}	93.47^{d}	23.85^{c}	1.73^{cd}
5	Mancozeb 80% WP + Mancozeb 80% WP + Mancozeb 80% WP	78.67^{d}	44.91^{c}	113.76^{c}	22.91^{cd}	1.83^{bcd}
6	Victory 72 WP (2 times)	95.50^{b}	51.53^{b}	129.34^{b}	21.80^{de}	2.50^{a}
7	Victory 72 WP (3 times)	84.00^{c}	44.50^{c}	112.68^{c}	20.41^{e}	2.04^{b}
8	Victory 72 WP (4 times)	82.33^{c}	44.49^{c}	112.94^{c}	16.92^{f}	1.85^{bcd}
9	Victory 72 WP (5 times)	74.00^{e}	32.26^{e}	81.06^{e}	13.10^{g}	1.93^{bc}
10	Victory 72 WP (6 times)	73.67^{e}	30.97^{ef}	92.89^{d}	10.84^{h}	1.90^{bc}
11	Control check	100.00^{a}	59.72^{a}	150.35^{a}	4.42^{i}	2.44^{a}
CV (%)		1.19	4.35	4.83	4.2	7.16
LSD (0.5)		2.11	3.77	10.73	1.81	0.31

PI=Percent Incidence, PSI=Percent Severity Index, AUDPC=Area Under Disease Progress Curve, MYD=Marketable Yield, UNMYD=Unmarketable Yield
*Means followed by the same letter (s) within the column (lowercase letter) are not significantly different from each other at P<0.05.

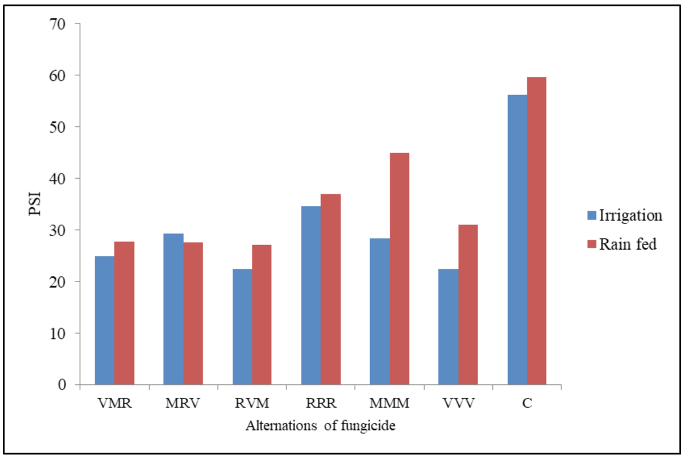

Figure 1: Percent severity index of tomato late blight variations between irrigation and rain-fed due to alternation fungicide treatments

VMR (Victory, Mancozeb and Redomil) MRV (Mancozeb, Redomil and Victory, RVM (Redomil, Victory and Mancozeb), RRR (Redomil, Redomil and Redomil), MMM (Mancozeb, Mancozeb and Mancozeb), VVV (Victory, Victory and Victory) and C (Control)

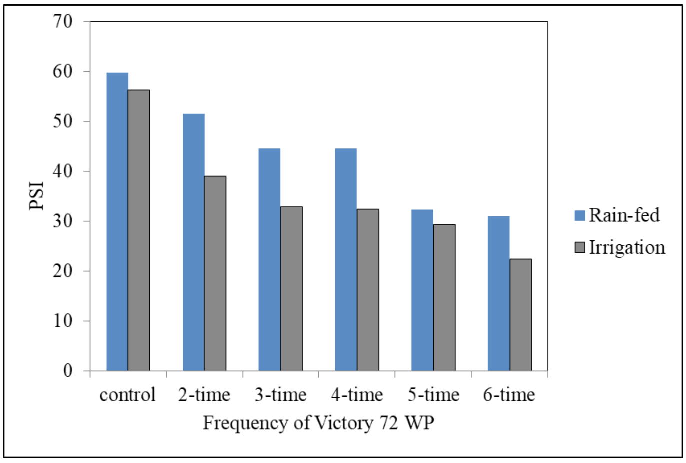

Figure 2: Percent severity index of tomato late blight variations between irrigation and rain-fed due to frequency of Victory 72 WP fungicide

Victory 72 WP application frequency increased (Figure 2) [20].

Correlation among tomato late blight and yield parameters

The simple correlation analysis showed that disease parameters, namely disease incidence, percentage severity index, AUDPC, and marketable tomato yield, were significantly ($P < 0.05$) correlated with each other. The correlation analyses indicate that all disease parameters exhibited a strong negative correlation with marketable yield ($P < 0.05$). This suggests that as disease pressure increases, marketable tomato yield decreases as well, and conversely, as disease pressure decreases, marketable yield increases. This result is consistent with the conclusion reached by Fekede (2011), which stated that yield parameters were negatively correlated with the associated disease parameters (Table 4) [21].

Partial budget analysis and marginal rate of return, irrigation

A partial budget and marginal rate of return analysis were undertaken to evaluate the economic feasibility of tomato late blight management using the alternating fungicide application technique on irrigated tomato production. Result indicates that the alternating fungicide application method especially the systemic (Victory) + contact (Mancozeb) + systemic (Ridomil Gold) technique for tomato late blight management was found to be economically viable and cost-effective. A gross field benefit, net benefit income and marginal rate of return of contact + systemic + contact fungicide application by using alternation was 404773.50, 400143.90, and 7453.571 ETB per hectare, respectively [22,23].

Partial budget analysis and marginal rate of return, rainfed

Like fungicide application rotation and frequency under irrigated tomato production, partial budget and marginal rate of return analysis of rainfed tomato production also indicates that the rotation application fungicide method especially the systemic (Victory) + contact (Mancozeb) + systemic (Ridomil Gold) technique for tomato late blight management was found to be economically viable and cost-effective. A gross field benefit, net benefit income and marginal rate of return of contact + systemic + contact fungicide application by using rotation was 389513.85, 384884.25 and 9810.03 ETB per hectare, respectively [24-26].

Conclusion and Recommendation

Rotation in fungicide application and spray regimes have significant influences on late blight disease incidence, percent severity index, area under disease progress curve, marketable yield, and unmarketable yield of tomato. Results reveal that Victory, Ridomil Gold and Mancozeb fungicides have higher field efficacy against P. infestans. In West Shewa, because it is high late-blight epidemic area, farmers plant tomato at the end of August and supplement with one- to two-time irrigation. This allows them to escape the high disease pressure in the main rainy season. Nevertheless, as tomato late blight disease they are obliged to intensively apply fungicides (by 3 days intervals in some cases) which may result in increased production cost and environmental effect.

In the present study, rotation application of systemic and contact fungicides up to six times effectively controlled tomato late blight both under rainfed and irrigated condition. Victory fungicides (Systemic and Contact), Mancozeb (Contact), and Redomil (Systemic and Contact) applied at a 7-day interval up to six-times effectively reduced the disease severity and increased marketable yield of tomato. Fungicidal spray regimes significantly reduced disease severity when compared to the un-spraying regime (control). The highest values of percent incidence (100 and 95.00%), percent severity index (56.2 and 259.72%), AUDPC (147.47 and 150.35), unmarketable yield (3.19-ton ha-1- and 2.5-ton ha-1) and the lowest marketable yield were observed on unsprayed plots in irrigated and rainfed condition, respectively. On the other hand, the lowest value of percent incidence, percent severity index, AUDPC, unmarketable yield and the highest marketable yield and were observed on the plots applied with fungicides.

The fungicide treatments tested in the current experiment resulted in lower disease levels, higher tomato fruit yield, gross field benefits, net benefit, and marginal rate of return (MRR) as compared to the untreated controls. The exception was the alternation application twice for each fungicide, which resulted in a higher net benefit and marginal rate of return than the control plots.

In general, the best management option for late blight was observed on late planting in August with 1-2 times supplementary irrigation and alternative application of fungicides up to six times. This not only increases tomato productivity but also helps safe and economical use of fungicides.

Conflict of Interest

Regarding the materials, the authors did not declare any conflicts of interest.

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