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Fungicidal Management of Garlic Rust (*Puccinia allii*) and Assessment of Yield Losses Due to the Disease

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Abstract

Garlic rust which is caused by *Puccinia allii* is the most common and economically important foliar disease. Assessing the relationship between rust and yield loss of a given disease on a specific crop serves to know the effect of a given disease on specific crop directly on it yield. The objective of this study was to manage garlic rust through fungicide, and determine the extent of yield losses. Field experiments were conducted to evaluate the effects of systemic fungicide (Natura) spray at rates (0.25, 0.5, and 0.75 L/ha) and frequencies of application (7, 14, 21, 28 days) with unsprayed control. The treatments were tested for their effects on severity and yield and yield components of garlic. The field experiment fungicide treatments were depicted different severity levels that resulted in different garlic yield losses. The final levels of severity were about 89.9% at MWRRS and 87.2% at SARC. The different disease severity levels created by different fungicide spray frequencies and rates caused different amount of losses in total yield. The highest relative total garlic bulb yield loss of 54.26% and 48.30% was occurred at MWURRS and SARC, respectively when plots were left unsprayed. Linear regression of the AUDPC was used for predicting the yield loss in garlic due to rust. The estimates indicated that -0.15, -0.098, and -0.091t/ha yield losses were predicted on 0.25 L/ha, 0.5 L/ha, and 0.75 L/ha, respectively for every % of days increase of AUDPC at MWURS. Similarly at SARC, the estimated slopes were b1=-0.104, -0.090 and -0.086 on 0.25 L/ha, 0.5 L/ha, and 0.75 L/ha, respectively. However, from this finding, use of Natura fungicide at rate of 0.75 L/ha within 14 days spray interval was found to be effective management option. Since the study was first hand exercise similar study need to be conducted using more number of location and seasons.

Keywords: *Allium sativum*; *Puccinia allii*; fungicide; percent severity index; AUDPC.

Introduction

Garlic is among the most important bulb vegetable crops used as a seasoning or condiment of foods because of its pungent flavor. It possesses high nutritive value. The nutritional composition of garlic bulb contains approximately 65% water, 28% carbohydrates 2.3% organosulfur compounds, 2% protein, 1.2% free amino acids and 1.5% fiber. Briefly, raw garlic contains water, carbohydrate, and proteins in the amounts of 58.58, 33.06, and 6.36 g/100 g, respectively [1]. Furthermore, Garlic is one of the earliest documented examples of plants employed for treatment of disease and maintenance of health [2]. It is the second most widely cultivated Allium species next to onion in Ethiopia [3]. However, its Production is constrained by several biotic and abiotic factors. Lack of proper disease management and absence of high yielding varieties are major limitations in Ethiopia [4]. Garlic rust caused by *Puccinia allii* is the most important disease problem in almost all garlic producing regions of Ethiopia [5-7]. Heavily infected plants may be more susceptible to secondary infections and there can be direct bulb yield losses. Worldwide, garlic rust has caused significant losses to garlic, leek, and onion production. Yield losses as high as 83% have also been reported by Ahmad and Iqbal [8] on garlic due to rust disease in Nepal. Bulbs infected with garlic rust remain small and are of low storage quality [9]. Garlic rust is the most significant disease of the crop. Worldwide, garlic rust has caused significant losses to garlic, leek, and onion production. The outbreak resulted in yield losses of 51% and an economic loss of 27% to the industry in USA [10]. In the late 1990s, outbreaks in the United States of America reduced crop yields by up to 75% in some fields [11]. Yield losses as high as 83% have also been reported by Ahmad and Iqbal [8] on garlic due to the same disease in Nepal. Bulbs infected with garlic rust remain small and are of low storage quality [9]. It is also an important disease in Ethiopia too as it resulted in yield losses of 48% [12] and almost 50% [6]. Garlic rust is the most important disease of the crop in the highlands of Bale and causing a total bulb yield loss as high as 58.75% [7]. To control this disease, limited options are available due to wind dispersal nature of these pathogens. There are several fungicides recommended for the control of rust on different *Allium* crops in different countries. In USA tebuconazole consistently provide best control of rust and gives the highest yields [13]. Hence, tebuconazole is active ingredients of natura, those fungicides that contain tebuconazole as active ingredient were effective in controlling garlic rust and were recommended for the management of garlic rust and other disease of garlic [3,7,14]. In addition, one of the active ingredients of this fungicide, tebuconazole, is found effective in controlling garlic rust in Ethiopia [13]. Spraying a fungicide for the control of a given disease at different rate and frequency has different effect on the development of the disease. Foliar fungicidal sprays are frequently used in Ethiopia particularly in Bale highlands, but recommendations on the rates and frequency schedules are made based on commercial rather than technical criteria. Assessing the relationship between rust and yield loss of a given disease on a specific crop serves to know the effect of a given disease on specific crop directly on it yield. Therefore, this work was aimed to quantify the amount of loss in yield incurred due to rust on garlic and (ii) assess the relationship between rust and yield loss of garlic in the Bale Highlands under field conditions.

Material and Methods

Experimental design and treatments

Field experiments were conducted during 2017/2018 main cropping

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season over two locations at Madda Walabu University Research Site (MWURS) and Sinana Agricultural Research Center (SARC). Three different rates of natura (0.25 L/ha, 0.5 L/ha and 0.75 L/ha) and four spraying intervals (7, 14, 21, and 28 days) were used. During fungicide application, plastic sheet was used to separate the plot being sprayed from the neighboring plots to prevent inter-plot interference due to spray drift. Uniform size of local garlic variety from local market was used; planting was done during main cropping season on August 22, 2017. The experiment were laid out in a factorial treatment combinations of three fungicide rates and four spray frequencies using a randomized complete block design (RCBD) with three replications. Thus, with the addition of one control (unsprayed plot); there were 13 total treatments. Spacing of 30 cm between rows and 10 cm between plants were uniformly adopted along other recommended cultural practices. Spacing of 0.5 m between plots and 1m between blocks were used. The middle three rows were used as net plot for data while the exterior single rows in both sides were left to control the border effect. All other agronomic practices, such as weeding and cultivation were implemented during the course of the study as per specific recommendation for garlic.

Disease assessment

Disease severity were recorded on 12 pre-tagged plants from the middle three rows of each plot at an interval of seven days starting from one week after the appearance of the disease symptom. Seven assessments were done at both locations. Severity was rated by estimating the percentage of leaf area diseased using standard disease scales of 1-5 rust severity, where, 1 = 1 - 10%, 2 = 11 - 25%, 3 = 26 - 50%, 4 = 51 - 75%, and 5 = 76 - 100% of the leaf surface covered with lesion (Koike et al., 2001). The scores were changed into percentage severity index (PSI) for analysis using the following formula:

$$\text{Disease severity } (\%) = \frac{\text{Total points score} \times 100}{\text{Total number of plants} \times \text{highest score}}$$

Area under disease progress curve will be calculated for each plot by using the following formula:

$$\text{AUDPC} = \sum_{i=1}^{n-1} [0.5(y_{i+1} + y_i)(t_{i+1} + t_i)]$$

Where, y_i= The cumulative disease severity expressed as a proportion at the i^{th} observation,

t_i =The time of i^{th} assessment in days, n=The total number of observation.

2.3. Assessment of crop growth, yield and yield components

Observations on the following yield attributes will be made from each plot in each replication.

- **Plant height (cm):** The mean heights of 12 plants were measured using a ruler from the soil surface to the tip of the mature leaves.
- **Days to maturity**: The total number of days from emergence until 85% of the plants has attained full physiological maturity.
- **Bulb weight (g):** Average weight of 12 bulbs from each plot after curing.
- **Bulb diameter (mm):** The average size of 12 bulbs measured from each plot after curing; were measured using caliper.
- **Number of cloves per bulb:** Average number of cloves of 12 bulbs was taken from each plot.
- **Clove weight (g):** Determined by average weight of 12bulbs, dividing the bulb weight by the number of cloves per bulb.
- **Total bulb yield (Kg/ha):** Total bulb yield were estimated from the middle row after curing and transformed to Kg per hectare.
- **Marketable yield:** Bulbs which were free of mechanical, disease and insect pest damages, uniform in color and medium to large in size were considered as marketable. The weight of such bulbs obtained from each plots was measured in kilogram using sensitive balance and expressed as Kg per hectare.
- **Unmarketable yield:** Harvested bulbs which are damaged, undersized, misshaped, and decayed were sorted and considered as unmarketable, determined by visual observation and by feeling with hand.

Analysis of data

Percentage severity, yield and yield component data were subjected to ANOVA to determine treatment effect. Least significance differences (LSD) value was used to separate the means. All data analysis was conducted using the SAS statistical version 9.2 software (SAS, 2008). For each response, assumption of ANOVA (normal distribution and constant variance of the error terms or homogeneity) was tested by examining the residuals. After all assumption of the model met, analysis of variance was performed using the general linear model (PROC GLM) procedure. Linear regression analysis was conducted by plotting yield data for individual varieties against AUDPC. Regression analysis was performed to determine intercept (b0), regression slope (b1) and coefficient of determination (R^2). Coefficient of determination (R^2) estimated the proportion of the variation explained by the regression.

Yield loss estimation

Yield data were directly analyzed and relative percent yield loss from each plot was calculated using the following formula.

$$\text{Relative yield loss } (\%) = \frac{Y_p - Y_t}{Y_p}$$

Where, Yp is the yield of maximum protected plot and Yt is yield from plots of other treatments.

Results

Percent Severity Index (PSI)

Significant variation was observed in final PSI among different rates and frequencies fungicide including the interaction of rate and frequency. During each disease assessment, the lowest percentage severity index of garlic rust was recorded on seven days interval fungicide sprayed plots with rate of 0.5 L/ha (1.1%) and 0.75 L/ha(0%) at MWURS (Table 1). Similarly, at SARC the lowest average severity level of garlic rust was recorded on weekly fungicide sprayed plots with rate of 0.5 L/ha (0.5%) and 0.75 L/ha (0%). But the highest percentage severity index was recorded from unsprayed control at SARC (87.2%) and at MWURS (89.9%). At MWURS there was no significant variation ($p < 0.05$) among plots treated with 0.25 L/ha sprayed at 21- days (82.2%) and 28-days (84.9%) (Table 2). At MWURS those plots treated at rate of 0.5 L/ha had showed significant difference ($p < 0.05$) among different fungicidal spray frequencies 7-days (1.1%), 14-days (28.86%), 21-days (37.2%) and 28 -days (67.2%) interval.

Effect of fungicidal spray rates and frequencies on yield and yield components

The interaction of main effects was showed significant variation on yields, bulb diameter, and marketable yield at MWURRS. Similarly at SARC interaction of main effects was showed significant variation on total yields, marketable yield and bulb weight. Because the interaction of main effects, i.e., fungicide rates and frequencies did not reveal significant difference on the remains components of yields and yield attributes, only their independent effects are presented separately at SARC and MWURRS. At MWURRS and SARC significant difference was recorded on garlic plant height among fungicide spray rates. The unsprayed control plots had the shortest plant height. However, there was no significant difference in plant height among the sprayed with 0.25 L/ha rates plots and unsprayed control. Significant difference was recorded on garlic plant height among fungicide spray rates. However, there was no significant difference in plant height among the sprayed at 0.75 L/ha and 0.5 L/ha rates plots at both sites (Tables 3 and 4). At MWURRS and SARC significant difference was recorded on garlic plant height among fungicide spray frequencies. The maximum plant height was recorded the from 7 and 14-days fungicidal spray frequency. Even if there was some variation significant difference was not exhibited in plant height among the sprayed with 7 and 14- days fungicidal spraying schedule plots at both locations. At SARC and MWURRS Significant variations were obtained in days to maturity among the different foliar fungicide spray. The longest days to maturity were observed from plots treated at rates of 0.5 L/ha and 0.75 L/ha than 0.25 L/ha and unsprayed control plots. The main effects of both fungicide rates and frequencies were significantly affected the mean clove weight at both locations. At MWURRS, clove weights were affected by different rates of fungicides significantly ($p < 0.05$) 0.75 L/ha (1.54g), 0.5 L/ha (1.48g) and 0.25 L/ha (1.17g) were obtained from plots. Similarly at SARC clove weights 1.57g and 0.94g were recorded from plots treated at rates of 0.75 L/ha and unsprayed control respectively (Table 3). At SARC clove weights 1.61g and 1.19g obtained from plots treated with Natura fungicide from 7-days fungicidal spraying interval and 28-days fungicidal spraying interval respectively. The clove weight obtained from plots treated with 0.25 L/ha was the least among sprayed plots at different rates, it was not statistically ($p > 0.05$) different from unsprayed control (0.94). Likewise at MWURRS fungicidal spray frequencies had affected clove weight significantly ($p < 0.05$) the clove weights were 1.54g and 0.88g were recorded from plots treated at rates of 0.75 L/ha and unsprayed control respectively. Highly significant variations were obtained among mean bulb weights recorded from plots that were treated with different fungicide rates at both locations. At SARC the highest bulb weight (35.7g) was obtained from plots treated with Natura at a rate of 0.75 L/ha treated in weekly basis, while the lowest (19.67g) was recorded from unsprayed control (Table 3). At MWURRS highest mean bulb weight (31.3 g) was obtained from plots treated at 7- days spraying interval. However, it was not significantly($P < 0.05$) different from the bulb weight (29.28 g) of plots sprayed at the rate of 14- days spraying interval, on the other hand the bulb weight of the unsprayed plots, which averaged to 19.3g (Table 2). Clove weight also affected by different spray rates of fungicide significantly. The highest mean bulb weight (30.61g) was obtained from plots treated at rate of 0.75 L/ha. However, it was not significantly($p < 0.05$) different from the bulb weight (29.81 g) of plots sprayed at the rate of 14- days spraying interval, on other hand 0.25 L/ha was the lowest among sprayed at different rates of fungicide. Concerning the bulb diameter, Natura fungicide spray rates and frequencies revealed significant difference among the treatments at both experimental sites. Unsprayed plots had lower bulb diameter (24 mm) than the other sprayed plots MWURRS. Plots sprayed with Natura at a rate of 0.25/ha with 21-days interval (25.7mm) and 28-days interval (24.8mm) had relatively better bulb diameter than unsprayed control but not significantly ($p < 0.05$) different (Table 2). At SARC higher mean bulb diameter were recorded from plots that received relatively higher dosages (0.75 L/ha^{-1} and 0.5 L/ha^{-1}) and plots sprayed with 7 and 14 days intervals of Natura fungicide than that of plots sprayed with lower dosage (0.25 L/ha), when compared with reference to the disease parameters, higher dosages of Natura gave higher bulb diameter (Table 4). At SARC the highest yield (8.98 t/ha) was obtained from plots treated with Natura at rate of 0.75 L/ha treated in weekly basis. Although it was not significantly different in yield (8.75 t/ha) from plots treated with at a rate of 0.75 L/ha with 14-days (8.71/ha) and 21- days intervals was (8.04 t/ha). Similarly at SARC there was no significant difference in among the sprayed with (0.5 L/ha) rates fungicide with 7-days 14-days and 21–days interval. Likewise at MWURRS the highest yield (8.92 t/ha) was harvested from plots treated with Natura at a rate of 0.75 L/ha at weekly basis (Table 2). However, it was not significantly different in yield from plots treated with 14-days and 21-days intervals at a rate of 0.75 L/ha. Similarly at SARC there was no significant difference in among the sprayed at (0.5 L/ha) rates fungicide with 7-days 14-days and 21–days interval (Table 2). Like total yield, the interaction of the main effects showed significant difference on marketable yields at both experimental sites. At MWURRS lower (3.26 t/ha) marketable and higher (0.81 t/ha) unmarketable bulb yields were obtained from unsprayed control plots than the unmarketable and marketable yields from sprayed plots with of 0.75 L/ha treated in weekly basis, where the highest (8.48 t/ha) marketable yield. However, it was not significantly different in marketable yield (8.30 t/ha) from plots treated with at a rate of 0.75

PSI			
Rates	**Frequencies**	**MWURRS**	**SARC**
0.25 L/ha	7	60	58
	14	69.9	67.2
	21	82.2	77.2
	28	84.9	83.3
Control		89.9	87.2
Mean		77.38	74.58
CV (%)		2.9	3.9
LSD (0.05)		4.2	5.4
0.5 L/ha	7	1.1	0.5
	14	28.9	24.9
	21	37.2	30.5
	28	67.2	59.4
Control		89.9	87.2
Mean		44.86	40.5
CV (%)		6.8	5
LSD (0.05)		5.8	3.8
0.75 L/ha	7	0	0
	14	23.7	21.6
	21	34.4	26.6
	28	63.3	54.5
Control		89.9	87.2
Mean		42.26	37.98
CV (%)		2.2	6.8
LSD (0.05)		1.8	5
PSI: Percentage Severity Index; MWURRS: Madda Walabu University, Robe Research Site; SARC: Sinana Agricultural Research Center			

Table 1: Effect different rates and frequencies of Natura foliar fungicide on garlic rust severity at SARC and MWURS.

Variables		Yield and yield components					
		SARC			MWURRS		
Rate	**Frequency**	**TY (t/ha)**	**BW (g)**	**MY (t/ha)**	**TY (t/ha)**	**BD (mm)**	**MY (t/ha)**
0.25	7	6.4	27.4	5.97	6.07	36.3	5.54
	14	5.15	24.27	4.65	4.94	31.13	4.3
	21	5.05	21.8	4.5	4.32	25.7	3.58
	28	4.83	21.38	4.26	4.21	24.8	3.47
Control		4.64	19.67	4.02	4.08	24	3.26
Mean		5.22	22.9	4.68	4.72	28.39	4.03
CV (%)		12.54	2.9	14.25	3.84	4.23	12.32
LSD (0.05)		12.3	1.25	1260	7.77	2.26	7.78
0.5	7	8.94	34.5	8.62	8.84	39.13	8.4
	14	8.71	32	8.38	8.62	37.79	8.15
	21	8.04	29.8	7.7	8.06	37.3	7.57
	28	5.87	25.3	5.44	5.59	33.7	4.96
Control		4.64	19.67	4.03	4.08	24	3.26
Mean		7.24	28.25	6.83	7.04	34.38	6.47
CV (%)		8.17	2.43	8.52	10.82	1.8	10.23
LSD (0.05)		1.11	1.29	1.1	1.41	1.16	1.46
0.75	7	8.98	35.7	8.67	8.92	40.1	8.48
	14	8.75	32.1	8.44	8.76	38.54	8.3
	21	8.28	31.2	7.92	8.35	37.46	7.84
	28	6.25	25.36	5.8	5.82	35.1	5.26
Control		4.64	19.67	4.02	4.08	24	3.26
Mean		7.38	28.81	6.97	7.19	35.04	6.63
CV (%)		7.26	2.07	8.1	4.13	3.23	4.66
LSD (0.05)		10.89	1.13	1.07	5.53	2.13	5.82
TY: Total Yield, BW: Bulb Weight, BD: Bulb Diameter, MY: Marketable Yield, CV: Coefficient Of Variation, LSD: Least Significant Difference							

Table 2: Effect of garlic rust on total yield and bulb diameter of garlic under combination of different fungicide spray rates and frequencies at MWURRS and SARC during 2017 cropping season.

	Yield and yield components					
Frequency	**BW (g)**	**CN/B**	**CW (g)**	**UMY (t/ha)**	**PH (cm)**	**DM (days)**
7	31.3	23.59	1.57	0.45	43.63	146
14	29.28	22.06	1.44	0.51	42.44	144.3
21	27.31	21.42	1.4	0.58	42.08	143.53
28	23.73	19.41	1.17	0.64	40.11	141.97
Control	19.3	15.67	0.88	0.81	38.5	139
Mean	26.18	20.43	1.29	0.6	41.35	142.96
CV	5.27	6.07	9.64	7.21	3.47	1.55
LSD (0.05)	2.42	2.16	0.22	0.69	2.44	3.76
			Rate			
0.75 L/ha	30.61	23.4	1.54	0.49	43.12	145.55
0.5 L/ha	29.81	22.5	1.48	0.49	43.01	145.14
0.25 L/ha	23.3	18.96	1.17	0.65	40.06	141.15
Control	19.3	15.67	0.88	0.81	38.5	139
Mean	25.76	20.13	1.27	0.61	41.17	142.71
CV	5.27	6.07	9.64	7.21	3.47	1.55
LSD (0.05)	2.42	2.16	0.22	0.69	2.44	3.76
BW: Bulb Weight, BD: Bulb Diameter, CN/B: Clove Number Per Bulb, CW: Clove Weight, UMY: Unmarketable Yield, PH: Plant Height, DM: Days To Maturity, CV: Coefficient Of Variation, LSD: Least Significant Difference And Ns: Non-Significant						

Table 3: Effect of different rate and frequency nature foliar disease fungicide evaluated for control of rust on yield and yield components of garlic at MWURRS 2017 main cropping season.

L/ha with 14-days interval. At both locations the two upper doses had lower unmarketable yields unsprayed than unsprayed control statically (Tables 3 and 4). The marketable yield obtained from plots treated with 0.25 L/ha at frequencies of 21 (3.58 t/ha) and 28 (3.47 t/ha) – days of interval were the least among sprayed plots, it was not statistically ($p > 0.05$) different from unsprayed control at both locations. In general, higher mean yield, components of yields and yield attributes, were recorded from plots that received relatively higher dosages (0.5 L/ha and 0.75 L/ha) of fungicide than that of plots sprayed with lower dosage (0.25 L/ha).

Association of disease parameters with total yield and clove weight

The association of yield and clove weight with disease parameters which includes severity at different assessment dates and AUDPC were evaluated using correlation analysis. At MWURRS correlation analysis revealed significant ($p \leq 0.001$) negative relationships between garlic rust severity and total yield, and Clove weight (Table 5). Similarly at SARC, correlation analysis revealed significant ($p \leq 0.001$) negative relationships between garlic rust severity and total yield, and Clove weight (Table 6). At MWURRS the association of yield and clove weight with, AUDPC and disease progress rate also revealed very highly significant difference ($p \leq 0.001$) and negatively associated with yield and clove weight (Table 5). Similarly at SARC, the association of yield and clove weight with, AUDPC and disease progress rate also revealed very highly significant difference ($p \leq 0.001$) and negatively associated with yield and clove weight (Table 6). Linear regression of the AUDPC was used for predicting the yield loss in garlic due to rust (Figure 1); because the linear regression of AUDPC better described the relationships between yield and disease severity compared to percent severity index. The estimate showed that for each unit increase in percent of rust AUDPC, there were yield losses. The estimated slope of the regression line obtained indicated that the increment of the diseases progress. Based on coefficient of determination (R^2) value, the equations explained the variation in yield due to rust severity. At MWU the relationship described by the model accounted for 58.3% to 70.8% of the variance (Figure 1). The estimated slope of the regression line for rust obtained at MWURS on 0.25 L/ha, 0.5 L/ha, and 0.75 L/ha were b1=-0.15, -0.098, and -0.091t/ha, respectively. The estimates indicated that -0.15, -0.098, and -0.091t/ha yield losses were predicted on 0.25 L/ha, 0.5 L/ha, and 0.75 L/ha, respectively for every %-days increase of AUDPC. At SARC the estimated slopes were b1= -0.104, -0.090 and -0.086 on 0.25 L/ha, 0.5 L/ha, and 0.75 L/ha, respectively. The estimates indicated that -0.104 t/ha on 0.25 L/ha, -0.090 t/ha on 0.5 L/ha and -0.086 t/ha on 0.75 L/ha yield loss were predicted for every %-days increase of AUDPC at MWURS (Figure 1).

Relative yield loss due to garlic rust

Yield losses differed among plots treated with the different rates and frequencies of fungicide. Losses were notably higher in unsprayed plots than in treated plots with Natura (Table 7) at both locations. Relatively the lower losses were obtained from plots sprayed with 0.75 L/ha and 0.5 L/ha with 7-days spray interval and 14- days spray interval at both locations. However, total bulb yield losses were reduced

Yield and yield components						
Frequency	BW (g)	CN/B	CW (g)	UMY (t/ha)	PH (cm)	DM (days)
7	31.3	23.59	1.57	0.45	43.63	146
14	29.28	22.06	1.44	0.51	42.44	144.3
21	27.31	21.42	1.4	0.58	42.08	143.53
28	23.73	19.41	1.17	0.64	40.11	141.97
Control	19.3	15.67	0.88	0.81	38.5	139
Mean	26.18	20.43	1.29	0.6	41.35	142.96
CV	5.27	6.07	9.64	7.21	3.47	1.55
LSD (0.05)	2.42	2.16	0.22	0.069	2.44	3.76
Rate						
0.75 L/ha	30.61	23.4	1.54	0.49	43.12	145.55
0.5 L/ha	29.81	22.5	1.48	0.49	43.01	145.14
0.25 L/ha	23.3	18.96	1.17	0.65	40.06	141.15
Control	19.3	15.67	0.88	0.81	38.5	139
Mean	25.76	20.13	1.27	6.15	41.17	142.71
CV	5.27	6.07	9.64	7.21	3.47	1.55
LSD (0.05)	2.42	2.16	0.22	0.069	2.44	3.76
BW: Bulb Weight, BD: Bulb Diameter, CN/B: Clove Number Per Bulb, CW: Clove Weight, TY: Total Yield, UMY: Unmarketable Yield, PH: Plant Height, DM: Days to Maturity, CV: Coefficient of Variation LSD: Least Significant Difference and Ns: Non-Significant						

Table 4: Effect of different rate and frequency natura foliar disease fungicide evaluated for control of rust on yield and yield components of garlic at SARC 2017 main cropping season.

Parameters	71DAP	78DAP	85DAP	92DAP	99DAP	106DAP	113DAP	AUDPC	DPR
TY	-0.34ns	-0.74**	-0.87**	-0.96***	-0.93***	-0.97***	-0.95***	-96***	-94***
CW	-0.37ns	-0.81**	-0.9***	-0.97***	-0.9***	-0.97***	-0.96***	-0.98***	-0.97***
Ns: No Significant, **: Correlation Is Significant At The 0.01 Level, *** : Correlation Is Significant at the 0.001 Level, TY: Total Yield; CW: Clove Weight, AUDPC: Area Under Disease Progress Curve, DPR: Disease Progress Rate									

Table 5: Correlation coefficients (r) between garlic rust severities on different dates of assessment and AUDPC with total yield and bulb weight at MWURRS, 2017 main cropping season

Parameters	75DAP	82DAP	89DAP	96DAP	103DAP	110DAP	117DAP	AUDPC	DPR
TY	-0.5 ns	-0.82**	-0.89***	-0.95***	-0.97***	-0.98***	-0.99***	-0.97***	-0.95***
CW	-0.49 ns	-0.85**	-0.93***	-0.95***	-0.99***	-0.99***	-0.99***	-0.99***	-0.98***
Ns: No Significant, **: Correlation Is Significant At The 0.01 Level, *** : Correlation Is Significant At The 0.001 Level, TY: Total Yield; CW: Clove Weight, AUDPC: Area Under Disease Progress Curve, DPR: Disease Progress Rateable.									

Table 6: Correlation coefficients (r) between garlic rust severities on different dates of assessment and AUDPC with total yield and clove weight at SARC 2017 main cropping season.

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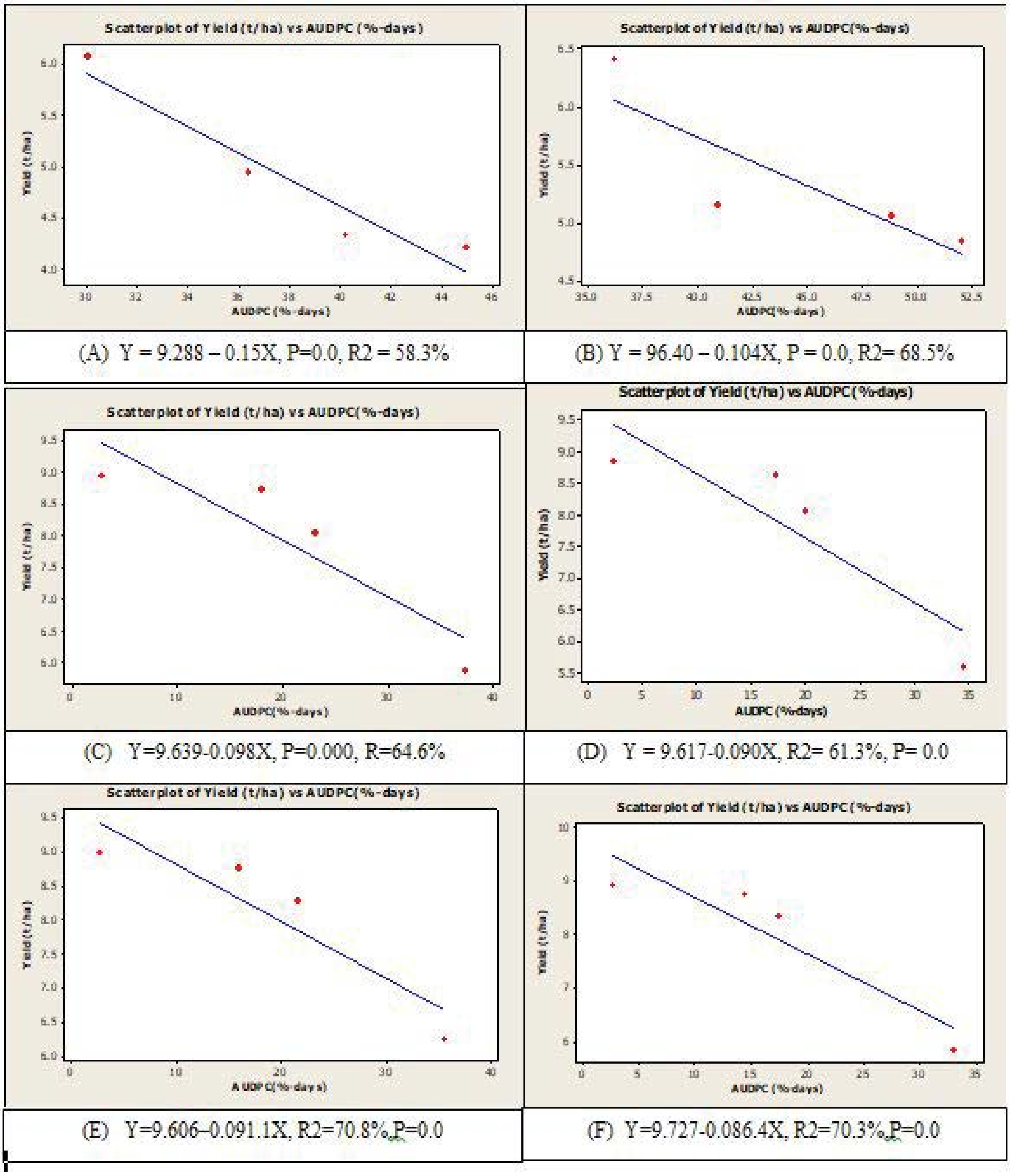

Figure 1: Linear regression relating AUDPC of garlic rust with total bulb yield (t/ha), 0.25 L/ha (A) at 17 MWURRS, 0.25 L/ha (B) at SARC, 0.5 L/ha (C) at MWURRS, 0.5 L/ha at SARC (D), on 0.75 L/ha (E) at MWURS and 0.75 L/ha (F) at SARC.

by all fungicide treatments as compared to the unsprayed control plots. The highest relative total garlic bulb yield loss of 54.26% and 48.30% were occurred MWURRS and SARC respectively; when plots were left unsprayed.

Discussion

Different frequencies and rates of fungicide had significant on plant height effect on plant height at both locations. The maximum plant height was recorded at the rate of 0.75 L/ha at both locations. Plots treated with at 14 and 7 days were significant difference on garlic plant height when compared with unsprayed control. Because, garlic leaves that are heavily infected by rust dry prematurely and plants remained green get longer time to grow, so the growth and development directly affect plant height (12). At both locations Significant variations were obtained in days to maturity among the different rates of foliar spray and frequencies. The days to maturity by forcing early maturing of

Variables		MWURRS	SARC
Rate	Frequency	RTYL (%)	RTYL (%)
0.25	7	0	0
	14	18.61	19.53
	21	28.83	21.09
	28	30.64	24.53
Unsprayed		32.78	27.5
0.5	7	0	0
	14	2.57	2.48
	21	10.06	8.82
	28	36.76	34.34
Unsprayed		53.84	48.09
0.75	7	0	0
	14	1.79	2.56
	21	6.39	7.79
	28	34.75	30.4
Unsprayed		54.26	48.32
RTYL: Relative Total Yield Loss			

Table 7: Yield and yield components of garlic and the corresponding relative losses due to garlic rust under different fungicide spray rates and frequencies at MWURRS and SARC in 2017 main cropping season.

the plants, reducing photosynthetic efficiency and as a result of garlic leaves that were heavily infected by rust and that dried prematurely [6,12]. In this case, the plots treated with fungicides extended the days to physiological maturity. The delay in days to physiological maturity means more time for photosynthesis, which might increase yield. According to Hassen [15], harvest dates could be postponed where leaf diseases were controlled, resulting in a higher yield in faba bean. Increasing fungicide application from 0.25 L/ha to 075 and reducing chemical spraying interval from 21 to 7 more significantly affects the days to physiological maturity in garlic crop at both sites. The heavier cloves weight were recorded at the rate of 0.75 L/ha at both locations. The garlic clove weight was affected by garlic rust under Ethiopian condition (6). Koike et al. [12] who reported 25% to 60% clove weight loss due to garlic rust. The outbreak of garlic resulted in clove weight losses of 51% and an economic loss of 27% to the industry [10].

Clove weight directly affected total yields. Concerning to bulb diameter, Natura fungicide spray rates and frequencies revealed significant difference among the treatments at both experimental sites. The present study revealed that, different disease severity levels created by different fungicide spray intervals caused different amount of losses in bulb diameters. The results are supported by the findings of Mengesha et al., [6] all the fungicide treated plots gave higher bulb diameters than the unsprayed plots. Again Meseret [16], reported bulb diameter, fungicide spray rates revealed significant difference among the treatments; lower data was recorded from unsprayed controls. All the fungicide-treated plots gave higher bulb diameter than the unsprayed plots [13]. Highly significant variation was observed in bulb weight among different rate and frequency fungicide. All plots treated with the fungicide gave bulbs with higher average weight than the unsprayed plots. Ahmed et al., [17], garlic rust had significant effect on bulb weight. The results are supported by the findings of Mengesha et al., [6], all the fungicide-treated plots gave higher bulb weight than the unsprayed plots. Also Meseret [17] reported bulb diameter, fungicide spray rates revealed significant difference among the treatments; lower data was recorded from unsprayed controls. The previous study revealed that, different disease severity levels created by different fungicide spray intervals caused different amount of losses in bulb weight. All plots treated with the fungicide gave bulbs with higher average weight than the unsprayed plots [13], at both locations effect of fungicidal spray rates and frequencies had significant effect on number of cloves number per bulb. On the contrary; Mengesha et al. [6], reported that fungicides sprayed show any significant difference on the number cloves in the bulbs. But the present study revealed that garlic rust had significant effect ($p>0.05$) on number of cloves per bulb, this might be due to vigorous plants that produce larger bulb and more number of cloves per plant when healthy. The effects of Natura fungicide rates and frequencies were showed highly significant difference in total yield, significantly increased total yield over the control. Controlling garlic rust by spraying the fungicide every 14 or 21-day interval gave significantly higher yield than the 28-days interval and the unsprayed plot treatments at both upper rates and locations. These indicated that rates fungicide spraying andfrequencies on garlic fields infected with garlic rust have different effect on garlic total bulb yield. The importance of the rust is increasing, with devastating disease outbreak in USA, where most of the US commercial hectarage is concentrated [11]. Garlic reduced crop yields by up to 75% in some fields [11].

Fungicide spray at different spray intervals on wheat rust significantly varied in grain yield harvested for each cultivar under Ethiopian condition from unsprayed control [18]. Like total bulb yields reducing frequencies of fungicide from weekly basis to 14- day's intervals was not significantly different at both locations the two upper rates of fungicide in terms of marketable yield. Controlling garlic rust by spraying the fungicide every 14- or 21-day interval gave significantly higher marketable yield than the 28-days interval and the unsprayed plot treatments at both upper rates and locations. The difference between the marketable yields on plots treated with fungicide at interval of 14- and 21-days statistically, non-significant at the upper rates of fungicide (Table 7). Previous research studies revealed garlic rust can significantly minimize the garlic bulb quality i.e., bulb weight, bulb size, number of cloves per bulb and yield, [17]. Again bulbs infected with garlic rust remain small and are of low storage quality [9]. The presence of rust pustules on plants reduces the quality of the product and thus the crop's market value [19]. Among sprayed plots, only Natura at rate of 0.75 L/ha with 7-days spray interval at both locations treatment gave nil total yield losses. Relatively the lower losses were also obtained from plots sprayed with 0.5 L/ha with 7-days spray interval and 14-days spray interval at both locations. However, total bulb yield losses were reduced by all fungicide treatments as compared to the unsprayed control plots. The highest relative total garlic bulb yield loss of 54.26% and 48.3% occurred at MWURRS and SARC respectively; when plots were left unsprayed. This amount of yield loss is slightly less than the 58% bulb yield loss on garlic reported from loss assessment study on rust under Ethiopian condition [13]. Similarly, Ahmad and Iqbal [8] estimated about 83% garlic bulb yield loss in Nepal. However, yield loss at SARC is approximately the same yield loss (48.3%) reported in USA [12]. The importance of the rust is increasing, with a recent devastating disease outbreak in California in 1998, where most of the USA commercial hectares are concentrated. This outbreak resulted in yield losses of 51% and an economic loss of 27% to the industry [10].

In the late 1990s, outbreaks in the same United State of America reduced crop yields by up to 75% in some fields [11]. The association of yield and clove weight with disease parameters which includes severity at different assessment dates and AUDPC were evaluated using correlation analysis revealed significant ($p \leq 0.001$) negative relationships. This indicates that the observed levels of the disease had considerable adverse effects on yield and yield components of garlic. The high negative correlations observed between disease parameters and clove weight would indicate the extent to which garlic rust might affect garlic total yield this observation is in agreement with the finding of Worku and Dejene [6] who reported that the negative relationships between garlic rust ratings and yield and yield components pinpoint that rust is a limiting factor in garlic productivity. Linear regression of the AUDPC was used for predicting the yield loss in garlic due to rust; because AUDPC linear regression better indicated the relationship of yield loss and the disease than the other disease parameters linear regression (Figure 1).

On the other hand, disease progress curves are highly sensitive to fluctuations in epidemiological factors during disease development so they are not good predictors of the relationship of yield and disease severity. The area under disease progress curve is a very convenient summary of plant disease epidemics that incorporates initial intensity, the rate parameter, and the duration of the epidemic which determines final disease intensity [20]. These types of relationship was used by Sahile et al. [21] and Hassen [15] to investigate the relationship between yield loss fababean foliar disease under Ethiopian conditions.

Conclusion

Since the study was first hand exercise in determining the effect of different rate of natura fungicide and spray intervals to control Garlic rust (*Puccinia allii*), similar study need to be conducted using more number of districts and more number of seasons.

Competing Interests

The authors declare that they have no competing interests.

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