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Effect of Integrated Climate Change Resilient Cultural Practices on Faba Bean Rust (*Uromyces viciae-fabae*) Epidemics in Hararghe Highlands, Ethiopia

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Abstract

Climate variability due to increasing temperature and erratic precipitation could affect faba bean rust disease epidemics and the crop productivity. Rust caused by *Uromyces viciae-fabae* is one of the serious foliar diseases of faba bean in Ethiopia. Field studies were conducted at Haramaya and Arbarakate during 2012 and 2013 to assess effects of integrated climate change resilient cultural practices on rust epidemics in the Hararghe highlands of Ethiopia. Three climate change resilient cultural practices: intercropping, compost application and furrow planting alone and in integration were evaluated using Degaga and Bulga-70 faba bean varieties and Melkassa-IV maize variety. Treatments were factorial arranged in a randomized complete block design with three replications. Faba bean-maize row intercropping and intercropping integrated treatments significantly reduced disease severity, AUDPC and disease progress rate. These treatments reduced rust mean severity by up to 36.5% (2012) and 27.4% (2013) at Haramaya, and up to 27% in 2013 at Arbarakate on both varieties as compared to sole planting. Compost fertilization also led to slow epidemic progression of rust and significantly reduced disease parameters when integrated with maize row intercropping. Compost fertilization in row intercropping recorded the lowest (23.1%) final mean disease severity and the highest (36.5%) percentage reduction in mean disease severity compared to sole cropping at Haramaya in 2012. The trend was similar in 2013 at both locations. Degaga had the lowest rust disease parameters studied compared to Bulga-70 at both locations over years. The overall results indicated that integrated climate change resilient cultural practices were effective to slow the epidemics of rust and to increase faba bean productivity. Hence, integrated climate change resilient cultural practices along with other crop management systems are recommended in the study areas.

Keywords: Cultural practices; Epidemics; Rust; *Uromyces viciae-fabae*; *Vicia faba*

Introduction

Faba bean (*Vicia faba* L.) is an important pulse crop produced in the world for both human diet and animal feed as source of protein and carbohydrate. It is also an excellent complement of crop rotations for fixing atmospheric N and as green manure [1]. China is the largest producer of faba beans in the world and in Africa, Egypt, Sudan, Ethiopia and Morocco are the dominant producers of faba bean [2]. In Ethiopia, faba bean production is estimated to account for 3.94% of the total grain production [3]. However, yields of faba beans have seen more fluctuations than area harvested and the world cultivated area has decreased in the last 50 years [4]. Climate variability, diseases, weeds and other pests are the major constraints of faba bean production. Diseases have always been the major limiting factors [5] and faba bean is susceptible to several pathogenic fungi, the major ones include rust (*Uromyces viciae-fabae* (Pers.) J. SchrÖt.), chocolate spot (*Botrytis fabae* Sard.) [6] and recently faba bean gall (*Olpidium viciae*) in Ethiopia [7].

Faba bean rust is a major disease of faba bean in almost every area in the world where faba bean is grown [8,9] that can cause up to 70% of yield loss in early infection [8]. The disease is severe and influences yield in areas like the Middle East, North Africa and parts of Australia [9]. It is also widely distributed in Ethiopia [10]. In Ethiopia, rust is devastating next to chocolate spot, and depending on severity of infection, it can cause a seed yield loss ranging from 2 to 15% in lower altitudes and 14-21% for intermediate altitudes [6], the loss may exceed the stated ranges in the present day conditions. Yield loss could be even higher when in mixed infection with chocolate spot disease [11].

Climate variability due to increased temperature and erratic precipitation over time increase susceptibility of faba bean and could also favour disease development. Faba bean production, which is seriously affected by diseases and parasitic weeds, are also worsened by climate change [12]. In faba bean, climate variability in the form of water stress, for example, decreases the final leaf area [13], net photosynthesis [14], light use efficiency [13], pod retention and filling and distorting hormonal balance [15]. Food legume growers are experiencing frequent droughts due to climate change and variability. Drought predisposes resistant varieties to be easily attacked by pathogens, which are not problems during normal growing seasons and new diseases may happen [16] and could decrease grain yield. Thus, climate change and associated changes in disease scenarios will demand changes in crop and disease management strategies. But such studies could be more difficult to undertake in conditions where historical weather and crop disease data are not available and where available facilities are not enabling to generate sound data.

Hence, climate change effects studies could be approached through climate change resilient crop management practices. These are practices that enhance the capacity of an ecological system to absorb

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stresses and maintain its organizational structure and productivity, the capacity for self-organization, and the ability to adapt to stress and change following a perturbation [17]. They are generally designed to reduce climate change and its impacts in order to sustain agricultural crop production. Thus, a "resilient" agroecosystem would be capable of providing food production, when challenged by severe drought or by erratic rainfall [18] and better prepared for future climate change effects (used in the sense of mitigating/adaptive strategy in this paper).

The most important climate change resilient crop management practices include enhancing functional crop diversification to adjust to changing temperature and precipitation patterns [19] in the form of intercropping [20,21], effective soil nutrient management [22], and efficient soil moisture conservation via furrow planting and mulching [23,24] to reduce risk from crop failure due to climate change. Integrating these climate change resilient cultural practices for the management of crop diseases and sustainable crop production has a dual role for understanding the effects of climate change and the role of these cropping strategies for mitigation or adaptation. However, despite the significance of crop diseases in limiting crop productions and food supply, there has been limited field-based empirical research to assess the potential effects of climate change on plant diseases [25,26]. The integral role of climate change resilient cultural practices for the management of plant diseases and sustaining crop production in the face of climate change is not well addressed. Therefore, the objective of this study was to assess the effects of integrated climate change resilient cultural practices on the epidemics of faba bean rust in Hararghe highlands, Ethiopia.

Materials and Methods

Experimental sites

Field experiments were conducted at two locations in the 2012 and 2013 main cropping seasons. The 2012 field experiment was conducted at Haramaya University main campus experimental field on a sandy clay loam soil [27]. The station is located at 9°26'N and 42°3'E with an altitude of 2006 m.a.s.l. The highest mean annual rainfall for the location is 790 mm with mean minimum and maximum temperatures of 14.0°C and 23.4°C, respectively. The 2013 field experiment was conducted both at Haramaya University and Arbarakate Farmers' Training Center (FTC) on clay vertisol soil during the main cropping season. Arbarakate FTC is located at 9°2.86'N and 40°54.79'E with an altitude of 2274 m.a.s.l. in West Hararghe zone. Arbarakate was characterized by extended higher precipitation (estimated to exceed 1300 mm per annum) and many rainy days than Haramaya during the cropping periods with mean daily temperatures ranging between 13.1 and 17.5°C.

Experimental sites' weather data

Daily maximum and minimum temperatures (°C), relative humidity (%), and total rainfall (mm) were obtained for Haramaya University experimental site for both seasons from its weather station. The weather data obtained for Arbarakate from the nearby stations were found unrepresentative. However, the weather trend at Arbarakate was characterized by extended period of rainfall and many rainy days and relatively mild temperature levels. The daily mean minimum and maximum temperatures of Arbarakate were derived using the Adiabatic Lapse Rate Model [28] from nearby meteorological stations; and the daily minimum temperatures range from 5.31 to 12.43°C and the daily mean maximum temperatures range from 20.17 to 22.61°C (June to November) in 2013. The monthly total rainfall and the monthly average temperature in the cropping seasons are presented in Table 1.

Experimental materials

Planting material: The two faba bean varieties used in this study were Degaga (moderately resistant to major faba bean diseases) and Bulga-70 (moderately susceptible) and their characteristic features are presented in Table 2. Both faba bean varieties were obtained from Holleta Agricultural Research Center, Ethiopia. The maize variety used as a component crop was Melkassa-IV (*ECA-EE-36*), which was obtained from Melkassa Agricultural Research Center, Ethiopia. Melkassa-IV was released in 2006 with an agronomic attribute: area of adaptation (altitude of 1000-1600 meters above sea level, rainfall of 500-700 mm annual rainfall), early maturing (105 days) and a production potential of 2-4 t ha^{-1}.

Compost: The compost used in this study to substitute the application of mineral fertilizer was mainly made of a pile of khat (*Catha edulis* Forsk) residues collected from the nearby market of Awaday, eastern Ethiopia. Well-decomposed and matured compost was air-dried and sieved. Composite random samples were taken for chemical analysis before application. The compost constituted organic carbon (8.01%), organic matter (13.80%), total nitrogen (0.69%), available phosphorus (234.80 mg kg^{-1}) and C:N ratio of 11.61. In the experiment, the compost was row applied to a depth of 10-15 cm at the rate of 8 t ha^{-1} and mixed with the soil a week before maize planting and four weeks in 2012 and three weeks in 2013 before faba bean planting. Furrows were prepared by digging about 20 cm deep rows once the faba bean was planted and established as seedling, and rain water was made to stagnate.

Treatments, experimental design and procedure

Three on-farm based climate resilient cultural practices (crop diversification in the form of intercropping, moisture conservation as planting in furrows and soil nutrient management as compost application), two faba bean varieties and one open pollinated Melkassa-IV maize variety were used in this study. Thus, the treatments included faba bean-maize row intercropping, furrow planting, compost application and sole faba bean row planting. The treatments were applied solely and in integration with each other (Table 3). A total of 16 treatments (for both faba bean varieties) were laid out in a randomized complete block design in a factorial arrangement with three replications. In a gross plot size of 4 m×3.2 m, a 1 maize: 1 faba bean planting pattern of row intercropping was maintained by planting maize rows spaced 0.80 m apart and planting one row of faba bean between the two maize rows. In the row intercropping, 5 rows of maize were intercropped with 4 rows of faba bean variety each at the center of the two maize rows per plot. In addition, sole faba bean row planting was included as experimental treatment, which was planted at 0.40 m×0.10 m inter-row and intra-row spacing, respectively. In case of sole faba bean row planting there were 10 rows per plot. In the intercrops, maize was planted three weeks in 2012 and two weeks in 2013 prior to faba bean planting. The spacing between blocks was 1.5 m and that between plots was 1 m.

Sowing of maize was done manually by planting two seeds per hill, which were later thinned to one plant per hill. The faba bean varieties were also manually planted. Maize was planted at Haramaya on 21 June 2012 and on 27 June 2013; and at Arbarakate on 3 July 2013. Faba bean was planted at Haramaya on 11 July 2012 and on 12 July 2013; and at Arbarakate on 16 July 2013. The crops were grown without application of any chemical fertilizer and no artificial pathogen inoculation was performed. Weeding and other agronomic practices were done properly and uniformly as per the recommendations to grow a successful crop.

Cropping month	Mean of temperature (ºC)			Monthly rainfall (mm)	
	Haramaya		Arbarakate	Haramaya	
	2012	2013	2013	2012	2013
June	19.97	19.30	17.52	0.00	15.80
July	18.56	17.63	15.81	214.00	215.40
August	18.90	18.25	16.48	149.50	185.10
September	18.73	18.43	16.62	105.00	142.10
October	15.50	16.82	15.47	4.60	71.60
November	14.68	15.04	13.14	0.50	81.70
Mean	17.72	17.58	15.84	78.93	118.62

Table 1: Monthly mean temperature (ºC) and monthly total rainfall (mm) during faba bean growing periods at Haramaya and Arbarakate, Ethiopia in 2012 and 2013 main cropping seasons.

Faba bean variety	Year of release	Area of adaptation		Maturity (days)	Seed size (g)	Yield (t/ha)	
		Altitude (m)	Annual rain-fall (mm)			On station	On farm
Degaga	2002	1800-3000	800-1100	116-135	400-450	2.5-5.0	2.0-4.5
Bulga-70	1994	2300-3000	800-1100	143-150	400-450	2.0-4.5	1.5-3.5

Table 2: Characteristic features of faba bean varieties used for the field experiment at Haramaya and Arbarakate during the 2012 and 2013 main cropping seasons.

S.No.	Treatment	Treatment combination description
1	SP	Sole faba bean row planting (control)
2	FP	Furrow faba bean planting
3	CA	Faba bean planting using compost application (compost fertilization)
4	RI	Faba bean-maize row intercropping
5	FP+CA	Faba bean furrow planting with compost application
6	FP+RI	Faba bean furrow planting in faba bean-maize row intercropping
7	CA+RI	Faba bean planting using compost application in faba bean-maize row intercropping
8	FP+CA+RI	Faba bean furrow planting with compost application in faba bean-maize row intercropping

Table 3: Treatment combinations used for faba bean field experiments at Haramaya and Arbarakate during 2012 and 2013 main cropping seasons and their respective descriptions.

Disease severity assessment

Disease severity was assessed six times at Haramaya and four times at Arbarakate on weekly intervals starting from the first visible disease symptoms both in 2012 and 2013. For disease severity assessments, 12 plants were randomly selected from central rows of each plot and tagged prior to disease symptom appearance. Disease severity assessment began at 50 days after planting (DAP) in 2012 and 44 DAP in 2013 at Haramaya. At Arbarakate, disease severity recording began from 65 DAP onwards during 2013. Disease severity was scored using a 1-9 scale of ICARDA [29]; where, 1=no pustules or very small non-sporulating flecks; 3=few scattered pustules on leaves, few or no pustules on stem; 5=pustules common on leaves, some pustules on stem; 7=pustules very common on leaves, many pustules on stem; and 9=extensive pustules on the leaves, petioles and stem, many leaves dead and plant defoliated. Disease severity scores were converted into percentage severity index (PSI) for analysis [30]; where,

$$PSI = \frac{\text{Sum of Numerical Ratings} \times 100}{\text{Number of Plants Scored} \times \text{Maximun Score on Scale}}$$

From disease severity data, the area under disease progress curves (AUDPC) in %-days were calculated as used in Campbell and Madden [31]:

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

where, X_i=percentage of disease severity index (PSI) of disease at i^{th} assessment; t_i=time of the i^{th} assessment in days from the first assessment date; and n=total number of disease assessments.

AUDPC was calculated separately for disease assessments made on different DAP for each climate change resilience cultural practices used and the control treatment. Since the epidemic period of the two locations varied in 2013, AUDPC were standardized by dividing the values by the epidemic duration of the respective locations [31]. The epidemic periods were 35 days at Haramaya and 21 days at Arbarakate; and AUDPC values were standardized accordingly.

Data analysis

Analysis of variance (ANOVA) was run for disease severity data and AUDPC values of both faba bean varieties to determine treatment effects on each disease parameter in each year across locations using SAS GLM Procedure [32]. Mean separations were made using LSD at 0.05 probability level. To determine the disease progress rate from the linear regression, a Logistic model, ln[(y/1-y)] [33], was used to estimate the disease progression from each separate treatment. The transformed data were regressed over time, DAP to determine the disease progress rate. The slope of the regression line estimated the disease progress rate. Regression was computed using Minitab (Release 15.0 for windows®, 2007). The two locations and seasons were considered as different environments because of heterogeneity of variances tested using Bartlett's test [34]. As a result, data were not combined for analysis.

Results

Rust severity

Faba bean rust appeared during the flowering growth stage of both faba bean varieties both in 2012 and 2013 at Haramaya and during pod formation growth stage at Arbarakate in 2013 cropping season. The mean disease severity of faba bean rust in the two cropping seasons was significantly different ($P \leq 0.05$) between some of the climate change resilient cultural practices and the control, among some of the climate change resilient cultural practices used and between varieties both at Haramaya and Arbarakate (Table 4). In both cropping seasons, mean disease severity assessments at different DAP showed significant variation between treatments starting from 57 DAP in 2012 and 51 DAP in 2013 at Haramaya in the disease epidemic periods. Whereas at Arbarakate, it was started from 65 DAP during 2013. Higher rust severity was observed on both faba bean varieties in 2013 than in 2012 and it was severe after pod filling growth stage at Haramaya.

The lowest final mean disease severity in 2012 was recorded on both faba bean varieties at Haramaya from integrated climate change resilient cultural practices treated plots as compared to sole planting. A similar trend was obtained in 2013 on both varieties at both experimental locations. Intercropping and intercropping integrated climate change resilient cultural practices (furrow planting in row intercropping and/or compost fertilization in row intercropping and/or furrow planting with compost fertilization in row intercropping or referred as intercropping integrated treatments hereafter unless stated) had the lowest mean disease severity records on both varieties and locations over years in comparison to sole planting. On the final disease severity assessment days, intercropping integrated treatments treated plots recorded up to 23.14% compared to 36.42% of sole plot in 2012 and 32.72% compared to 45.06% of sole plot in 2013 on both faba bean varieties at Haramaya. At Arbarakate, the trend was 16.67% as compared to 22.84% of sole plot on both varieties in 2013.

Thus, intercropping integrated treatment treated plots were found to highly reduce disease severity of rust compared to control plots. The highest mean disease severity reductions reached 36.46% (2012) and 27.39% (2013) on both varieties at Haramaya. Similarly, the reduction was up to 27.01% on both varieties studied at Arbarakate. Although there was no consistent significant variation among compost fertilization, furrow planting, furrow planting along with compost fertilization and sole planting, compost fertilization and furrow planting with compost fertilization had lower faba bean rust severity on both varieties in 2012 and 2013 at Haramaya. In 2012, compost fertilization and furrow planting with compost fertilization lowered the final mean disease severity of faba bean rust in the range between 9.31 and 10.16% at Haramaya. A similar trend was also indicated in 2013 on both varieties at both locations (Table 3). Moreover, at both locations and seasons, the overall mean disease severity records showed that the two faba bean varieties were varied significantly. Degaga variety had lower mean disease severities than Bulga-70 variety studied. The interaction between faba bean varieties and climate change resilient cultural practices used was not significant during both cropping seasons at both locations.

Standardized area under disease progress curve (rAUDPC)

rAUDPC values calculated from disease severity assessed at different DAP on both faba bean varieties for both locations and cropping seasons significantly ($P \leq 0.05$) varied between some of the climate change resilient cultural practices and the control, among some of the climate change resilient cultural practices used and between faba bean varieties studied (Table 4). rAUDPC values were lower on intercropped and intercropping integrated treatments treated plots than on other treatments. In 2012, sole plots had the highest (29.50%-days) rAUDPC values, while the lowest (19.84%-days) rAUDPC values were calculated from compost fertilization in row intercropping treated plots. The overall values indicated that intercropping and intercropping integrated treatments treated plots showed consistent reduction in rAUDPC values. In 2013, a similar trend was also calculated for the sole cropped and integrated climate change resilient cultural practices treated plots for both varieties and locations. Compost fertilization with or without furrow planting also lowered rAUDPC values of faba bean rust on both faba bean varieties in 2012 and 2013 at Haramaya and in 2013 at Arbarakate areas.

Disease progress rate

Disease progress rates and parameter estimates of faba bean rust are tabulated in Tables 5-7. The disease progress rates computed from mean disease severity records showed variations among treatments used in both faba bean varieties, locations and seasons. Disease progress rates of Degaga variety ranged from 0.0182 to 0.0288 units/day in 2012 and from 0.0340 to 0.0456 units/day in 2013 (Table 5); whereas for Bulga-70, the rates ranged from 0.0234 and 0.0331 units/day in 2012 and 0.0461 and 0.0546 units/day in 2013 at Haramaya (Table 6). The rates were also from 0.0158 to 0.0309 units/day for Degaga and 0.0279 to 0.0412 unit/day for Bulga-70 in 2013 at Arbarakate (Table 7). The disease progress rate was relatively higher at Haramaya in 2013 and relatively fast on both varieties in 2012 and 2013 at Haramaya than at Arbarakate. The variety Bulga-70 had higher disease progress rate than the variety Degaga in both cropping seasons at both locations. It was also observed that disease progressed relatively at faster rates on sole and non-intercropped and non-intercropping integrated treatments treated plots across locations and over years for both faba bean varieties. The results indicated that the rate at which faba bean rust progressed was slower when climate change resilient cultural practices were applied in integration than the untreated plots.

Treatment [1]	Haramaya				Arbarakate	
	2012		2013		2013	
	PSI [2]	rAUDPC [3]	PSI [2]	rAUDPC [3]	PSI [2]	rAUDPC [3]
Variety						
Bulga-70	31.79a	26.07a	42.67a	24.59a	21.99a	16.20a
Degaga	27.01b	22.18b	34.34b	20.92b	17.60b	14.30b
Mean	29.40	24.13	38.51	22.76	19.80	15.25
LSD (0.05)	1.09	0.76	1.14		0.57	0.46
Cultural practice						
SP	36.42a	29.50a	45.06a	26.48a	22.84a	18.06a
FP	34.57ab	28.30ab	44.45b	25.68a	22.22ab	16.87b
CA	32.72b	27.01b	41.98b	24.54b	21.60b	16.36b
RI	25.00cd	20.37cd	33.95c	20.56c	17.90c	13.94c
FP + CA	33.03b	27.59b	41.98b	24.35b	21.60b	16.05b
FP + RI	26.55c	21.30c	34.57c	20.77c	18.21c	13.99c
CA + RI	23.14d	19.07d	32.72c	19.60d	16.67d	13.17c
FP + CA + RI	23.77d	19.84cd	33.34c	20.05cd	17.29cd	13.58c
Mean	29.40	24.12	38.51	22.75	19.79	15.25
LSD (0.05)	2.19	1.52	2.27	0.93	1.15	0.91
CV (%)	6.31	5.36	5.00	3.48	4.92	5.07

[1]SP: Sole Planting (Control); FP: Furrow Planting; CA: Compost Application; RI: Row Intercropping; FP+CA: Furrow Planting with Compost Application; FP+RI: Furrow Planting in Row Intercropping; CA+RI: Compost Application in Row Intercropping; and FP+CA+RI: Furrow Plating with Compost Application in Row Intercropping.

[2]Percent severity index on 85 days after planting (DAP) in 2012 and 79 DAP in 2013 at Haramaya and on 86 DAP at Arbarakate during 2013 main cropping season.

[3]rAUDPC, standard area under disease progress curve of faba bean rust.

Means in each column followed by the same letter are not significantly different according to the least significant difference test at 5% probability level.

Table 4: Effects of climate change resilient cultural practices on faba bean rust (*Uromyces viciae-fabae*) severity (%) and standard area under disease progress curve (%-days) at Haramaya during 2012 and 2013 and at Arbarakate during 2013 main cropping seasons.

Year	Treatment[1]	Percent severity[2]		Intercept[3]	SE of intercept[4]	Disease progress rate (Logit/day)	SE of Rate[4]	R^2 (%)[5]
		PSI_i	PSI_f					
	SP	14.19	33.33	-3.14	0.2439	0.0288	0.0033	81.4
	FP	15.43	31.48	-2.85	0.2131	0.0244	0.0029	80.4
	CA	14.19	29.63	-3.05	0.2036	0.0256	0.0028	83.2
	RI	12.34	22.84	-3.03	0.1647	0.0212	0.0022	83.8
2012	FP+CA	13.58	30.25	-3.07	0.2586	0.0265	0.0035	76.6
	FP+RI	11.73	24.69	-3.23	0.2213	0.0246	0.0030	79.4
	CA+RI	11.73	21.60	-3.03	0.1762	0.0200	0.0024	80.2
	FP+CA+RI	12.96	22.22	-2.83	0.1817	0.0182	0.0025	75.8
	SP	12.96	39.51	-4.36	0.1477	0.0438	0.0020	96.5
	FP	11.73	38.89	-4.54	0.1257	0.0456	0.0017	97.7
	CA	11.73	37.04	-4.41	0.0951	0.0431	0.0013	98.5
	RI	11.11	30.86	-4.22	0.1193	0.0375	0.0016	96.9
2013	FP+CA	11.73	37.04	-4.42	0.1187	0.0432	0.0016	97.7
	FP+RI	11.73	31.48	-4.13	0.1636	0.0365	0.0022	94.0
	CA+RI	11.73	29.63	-4.01	0.1684	0.0340	0.0023	92.8
	FP+CA+RI	11.11	30.25	-4.15	0.1369	0.0362	0.0019	95.7

[1]SP: Sole Planting (Control); FP: Furrow Planting; CA: Compost Application; RI: Row Intercropping; FP+CA: Furrow Planting with Compost Application; FP+RI: Furrow Planting in Row Intercropping; CA+RI: Compost Application in Row Intercropping; and FP+CA+RI: Furrow Plating with Compost Application in Row Intercropping. Parameter estimates are from a linear regression of ln(y/(1-y)) disease severity (PSI) proportions at different days after planting (DAP). [2]Initial and final disease severity (PSI) of rust recorded at 50 DAP and 85 DAP in 2012 and at 44 DAP and 79 DAP in 2013, respectively. [3]Intercept of the regression equation. [4]Standard error of parameter estimates. [5]Coefficient of determination of the logistic model.

Table 5: Mean initial (PSI_i) and final (PSI_f) severity index and parameter estimates of faba bean rust (*Uromyces viciae-fabae*) on Degaga variety at Haramaya, Ethiopia during 2012 and 2013 main cropping seasons.

Year	Treatment[1]	Percent severity[2]		Intercept[3]	SE of intercept[4]	Disease progress rate (Logit/day)	SE of Rate[4]	R^2 (%)[5]
		PSI_i	PSI_f					
	SP	15.43	39.51	-3.23	0.3264	0.0331	0.0044	76.2
	FP	14.81	37.66	-3.18	0.3053	0.0314	0.0042	76.8
	CA	14.81	35.81	-3.07	0.2959	0.0296	0.0040	75.7
	RI	15.43	35.81	-3.01	0.2880	0.0289	0.0039	75.8
2012	FP+CA	12.96	27.16	-3.21	0.1912	0.0261	0.0026	85.4
	FP+RI	14.20	28.40	-2.98	0.2199	0.0237	0.0030	78.4
	CA+RI	12.34	24.68	-3.09	0.1990	0.0234	0.0027	81.3
	FP+CA+RI	11.73	25.31	-3.20	0.2264	0.0251	0.0031	79.4
	SP	12.96	50.62	-4.93	0.1512	0.0546	0.0021	97.6
	FP	12.96	50.00	-4.92	0.1645	0.0538	0.0022	97.1
	CA	12.34	46.92	-4.90	0.1376	0.0527	0.0019	97.9
	RI	11.11	37.04	-4.74	0.1700	0.0471	0.0023	96.1
2013	FP+CA	12.34	46.91	-4.97	0.1246	0.0534	0.0017	98.3
	FP+RI	11.11	37.66	-4.78	0.1443	0.0480	0.0020	97.2
	CA+RI	11.11	35.80	-4.72	0.1627	0.0461	0.0022	96.2
	FP+CA+RI	11.11	36.42	-4.74	0.1475	0.0467	0.0020	97.0

[1]SP: Sole Planting (Control); FP: Furrow Planting; CA: Compost Application; RI: Row Intercropping; FP+CA: Furrow Planting with Compost Application; FP+RI: Furrow Planting in Row Intercropping; CA+RI: Compost Application in Row Intercropping; and FP+CA+RI: Furrow Plating with Compost Application in Row Intercropping. Parameter estimates are from a linear regression of ln(y/(1-y)) disease severity (PSI) proportions at different days after planting (DAP). [2]Initial and final disease severity (PSI) of rust recorded at 50 DAP and 85 DAP in 2012 and at 44 DAP and 79 DAP in 2013, respectively. [3]Intercept of the regression equation. [4]Standard error of parameter estimates. [5]Coefficient of determination of the logistic model.

Table 6: Mean initial (PSI_i) and final (PSI_f) severity index and parameter estimates of faba bean rust (*Uromyces viciae-fabae*) on Bulga-70 variety at Haramaya, Ethiopia during 2012 and 2013 main cropping seasons.

Discussion

The overall results of the study indicated that severity of rust was higher and rapidly increasing at the later stages of the epidemic period at Haramaya both in 2012 and 2013. However, in both cropping seasons at Haramaya and Arbarakate, rust severity, rAUDPC and disease progress rate were reduced and grain yield per unit area was increased by integrated climate change resilient cultural practices compared to sole planting. Among the resilient cultural practices, intercrops and intercropping integrated treatments had the lowest disease parameters of faba bean rust and chocolate spot as well [35] as compared to sole cropping. Such effects could be reduced faba bean density due to intercropping and maize acting as a physical barrier that might hamper inoculum spread and disease progress. In addition, intercrops might have also modified the microclimate by modifying the density of host plants thereby changing canopy microenvironment.

Previous studies indicated that deploying crop diversity in the form of intercropping is one way of introducing more biodiversity into agroecosystems; and results from intercropping studies showed that higher species richness may be associated with significant reduction in the negative impacts of diseases [36,37] and weeds [38]. Intercropping also limits the places where pests can find optimal foraging or reproductive conditions [39]. Similarly, mixtures play a major role in

Variety	Treatment[1]	Percent severity[2]		Intercept[3]	SE of intercept[4]	Disease progress rate (Logit/day)	SE of Rate[4]	R^2 (%)[5]
		PSI_i	PSI_f					
Degaga	SP	12.34	20.37	-3.76	0.2052	0.0276	0.0027	90.6
	FP	11.11	19.75	-4.08	0.2319	0.0309	0.0030	90.5
	CA	11.11	19.14	-3.98	0.3233	0.0293	0.0042	81.2
	RI	11.11	16.05	-3.44	0.2021	0.0205	0.0026	84.4
	FP+CA	11.11	19.14	-4.06	0.1770	0.0301	0.0023	93.9
	FP+RI	11.73	16.05	-3.19	0.2609	0.0172	0.0034	69.3
	CA+RI	11.11	14.82	-3.15	0.1490	0.0158	0.0019	85.7
	FP+CA+RI	11.11	15.44	-3.26	0.2021	0.0177	0.0026	80.2
Bulga-70	SP	12.96	25.31	-4.43	0.2423	0.0391	0.0032	93.3
	FP	12.34	24.69	-4.58	0.3533	0.0398	0.0046	87.0
	CA	12.34	24.07	-4.51	0.2838	0.0385	0.0037	90.8
	RI	11.73	19.75	-3.96	0.2796	0.0286	0.0036	84.7
	FP+CA	11.73	24.07	-4.75	0.2097	0.0412	0.0027	95.4
	FP+RI	11.11	20.37	-4.33	0.1676	0.0336	0.0022	95.6
	CA+RI	11.11	18.52	-3.97	0.2360	0.0279	0.0031	88.2
	FP+CA+RI	11.11	19.14	-4.13	0.2865	0.0303	0.0037	85.6

[1]SP: Sole Planting (Control); FP: Furrow Planting; CA: Compost Application; RI: Row Intercropping; FP+CA: Furrow Planting with Compost Application; FP+RI: Furrow Planting in Row Intercropping; CA+RI: Compost Application in Row Intercropping; and FP+CA+RI: Furrow Plating with Compost Application in Row Intercropping. Parameter estimates are from a linear regression of ln(y/(1-y)) disease severity (PSI) proportions at different days after planting (DAP). [2]Initial and final disease severity (PSI) of rust recorded at 65 DAP and 86 DAP in 2013, respectively. [3]Intercept of the regression equation. [4]Standard error of parameter estimates. [5]Coefficient of determination of the logistic model.

Table 7: Mean initial (PSI_i) and final (PSI_f) severity index and parameter estimates of faba bean rust (*Uromyces viciae-fabae*) on Degaga and Bulga-70 varieties at Arbarakate, Ethiopia during 2013 main cropping season.

reducing the efficiency of the pathogen through the dilution effect [40] and mixed crop species can also delay the onset of diseases by reducing the spread of disease carrying spores and by modifying environmental conditions to less favorable to the spread of certain pathogens [9,41]. In addition, under Ethiopian conditions, mixed cropping has also been reported to reduce disease severity of faba bean rust [42].

In faba bean-maize intercrops and intercrop integrated treatments of this study, the population of faba bean per plot was reduced by more than half. This could modify the microclimate of the faba bean canopy in that there was free air-circulation, low leaf wetness and reduced damp sites. Likewise, Biddle and Catline [43] stated that densely planted faba beans encourage humid microclimate within the canopy, thereby, encouraging infection and spore production in the presence of warm temperatures and light film of moisture on the leaf surface. Thus, Fernández-Aparicio et al. [44] noted that intercropping faba bean with cereals has been proposed as a means to lessen the incidence of faba bean rust. The cereal favors aeration and prevents the formation of a dense faba bean canopy that might enhance disease damage. Reddy [45] also indicated that varietal mixtures reduce disease epidemics by reducing the spatial density of susceptible plants where the deposition probability of released spores on susceptible tissue from a lesion is reduced.

It was also observed that compost fertilization alone and in integration with furrow planting and row intercropping in particular highly reduced faba bean rust and decreased chocolate spot severity [35]. Slight increase in epidemic development on the most integrated treatment was obtained compared to compost fertilization in row intercropping, which might be due to the presence of furrows that could slightly increase humidity under that canopy late in the cropping season. Compost fertilization might have enhanced the health and vigority of plants that could have increased plant chances to withstand pathogen attack and to activate the host defense system. Neher et al. [46] found that compost amended soils reduced disease severity of ear blight on brassicas compared to the bare soil. Haggag and Saber [47] reported that compost teas significantly reduced disease incidence and population counts of alternaria blight and significantly increased the activities of both peroxidase, β-1,3-glucanase and chitinase that could increase plant resistance both under greenhouse and field planted tomato and onion. Similar results were also observed by Sang et al. [48] against Phytophthora capsici in pepper plants by compost water extracts and the test again activates expression of pathogenesis-related genes and peroxide generation in the leaves and lignin accumulation in the stems.

The epidemics of faba bean rust was appeared early and higher at Haramaya than at Arbarakate areas. This could be associated with the weather conditions and the altitude differences of the two locations. Arbarakate was characterized by many rainy days with extended period of rainfall and mild temperature (15.8 to 16.6°C) during the cropping season which might have delayed the onset of rust and its epidemics. Haramaya was relatively warm (temperature ranging from 14.7 to 19.8 °C) with high relative humidity and fair rainfall distribution. Moreover, the results also demonstrated that rust severity was relatively higher late in the epidemic period during 2013 than 2012 at Haramaya. This might be partially explained by early termination of rainfall that would in turn reduce leaf wetness and infection in 2012.

Supporting the current study, Hawthorne et al. [49] stated that rust infection is favored by humid and warm temperatures. This infection can occur following six hours of leaf wetness. The development of both primary and secondary inoculum sources of faba bean rust are also influenced by environmental factors. Such that cloudy weather with high humidity and 17-22°C favors development of the disease [9]. That is, spore production is encouraged by high humidity and warm temperatures and once spores are released and deposited on a susceptible host crop, germination occurs quickly in the presence of a light film of moisture on the leaf surface to cause infection [43]. Of course, Dipak et al. [50] also found that rainy days are negatively correlated with disease development of *Uromyces viciae-fabae;* which could be the most probably reason for the delayed onset of faba bean rust at Arbarakate in 2013.

Faba bean rust epidemics might also be associated with altitude in which Arbarakate recorded lower rust severity than Haramaya since the former location is more highland than the later. In accordance with this study, a survey conducted by Shifa et al. [51] in Hararghe highlands of Ethiopia in the 2009 cropping season to determine the incidence and severity of faba bean rust, and its association with environmental factors and cultural practices found that the incidence and severity of faba bean rust showed higher association with altitudes. The results indicated that those surveyed locations with an altitude above 2450 m.a.s.l had relatively low incidence and severity than locations below 2450 m.a.s.l. The variation could be partly due to the difference in the relative warmness of locations, as faba bean rust epidemic is lower in lower and intermediate altitudes (<2300 m.a.s.l) and usually late in the season [52].

Conclusions

Climate change resilient cultural practices alone and in integration found effective to slow the epidemic progression of faba bean rust and improve crop productivity in the prevailing climate change effects. Intercropping integrated climate change resilient cultural practices highly reduced disease parameters of faba bean rust. Similarly, compost fertilization of the soil with or without row intercropping also plays an important role to manage faba bean rust. These practices could also be employed as an option in climate resilient agriculture to mitigate climate change and variability impacts in subsistence farming systems. It is, therefore, promising to grow faba bean with these climate change resilient cultural practices (maize row intercropping and compost fertilization in row intercropping in particular) in addition to using host resistance and other crop management strategies to manage faba bean rust in Hararghe highlands. Further studies on integrated control of rust should continue that include host resistance and cultivar mixtures in the system. Moreover, the mechanisms through which compost fertilization reduces severity of foliar diseases should also be thoroughly investigated.

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