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Effect of Climate Change Resilience Strategies on Common Bacterial Blight of Common Bean (*Phaseolus vulgaris* L.) in Semi-arid Agro-ecology of Eastern Ethiopia

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Abstract

Common bacterial blight (CBB) caused by Xanthomonas axonopodis pv. phaseoli is the most important biotic production constraint to common bean in eastern Ethiopia. Climate change could have an impact on the disease epidemiology by influencing both common bean growth and the pathogen reproduction. The effects of climate change needs to be mitigated using climate change resilience strategies. Field experiments were conducted in the 2012 and 2013 cropping seasons at Haramaya and Babile research stations in eastern Ethiopia to assess the effects of integrating climate change resilience strategies on CBB of common bean. Gofta (G2816) and Mexican 142(11239) common bean varieties were used. Eight climate change resilience strategies used were compost application, row intercropping and furrow planting alone and in combination. Factorial combinations of two common bean varieties and eight climate change resilience strategies totally 16 treatment combinations were studied in randomized complete block design (RCBD) with three replications and repeated once. Disease severity data were recorded from 10 randomly tagged plants from four central rows per plot. Disease severity, area under disease progress curve (AUDPC) and disease progress rate were significantly different among climate change resilience strategies, between varieties, cropping seasons and locations. Disease severities, AUDPC and disease progress rate were consistently less on row intercropping + compost application + furrow planting and row intercropping + compost application compared to singly applied climate change resilience strategies and sole planting plots in both locations and seasons. The disease epidemic was relatively higher on Mexican 142 than Gofta and during 2012 than 2013 at Babile than Haramaya. Integrated climate resilience strategies reduced CBB epidemics and could be applied as a component in management of CBB in eastern Ethiopia and in areas with similar agro-ecological zones.

Keywords: *Climate Change Resilience, Phaseolus vulgaris, Xanthomonas axonopodis pv. phaseoli*

Introduction

There are several biotic and abiotic production constraints on common bean (*Phaseolus vulgaris* L.) in semi-arid agro-ecologies of eastern Ethiopia. Diseases, insect pests, low soil fertility and periodic water stress are the major constraints [1,2]. The major diseases of common bean in the tropical regions, including Ethiopia that should be targeted for management are common bacterial blight (CBB) caused by *Xanthomonas axonopodis* pv. *phaseoli*, halo blight caused by *Pseudomonas syringae* pv. *phaseolicola,* bacterial brown spot caused by *Pseudomonas syringae* pv. *syringae,* rust caused by *Uromyces appendiculatus*, anthracnose caused by *Colletotrichum lindemuthianum* and other viral and root rot diseases [3-6]. These diseases are frequently occurring and widely distributed in Ethiopia and are destructive agents of common bean production causing heavy yield loss and decreasing seed quality [6-9].

Common Bacterial Blight (CBB) is one of the major diseases and the most important constraint to common bean production in eastern Ethiopia. When environmental conditions are favourable for the pathogen during long periods of warm and humid weather causing reductions CBB becomes the most destructive in both yield and seed quality [10]. Common bacterial blight incidence (53%) and severity (63%) were recorded in sole cropping system of common bean in eastern Ethiopia [8] and the relative yield loss of 22-40% was found in pure stand cropping system.

Change in rainfall pattern, soil moisture, soil temperature, and soil fertility has direct impact on the disease epidemiology by influencing host plant growth and susceptibility; pathogen reproduction, spread,

survival, activity and host-pathogen interaction [11]. According to International Panel for Climate Change, the average global surface temperature will increase by 2.8°C ranging from 1.8 to 4.0°C during 2050 assuming no emission control policies. Climate models suggest that Ethiopia will see further warming in all seasons of +2.2 (1.4°C-2.9°C) by the 2050's [12]. It is likely that this warming will be associated with higher heat waves and higher evapotranspiration rate. Nowadays, the doubt on climate change is not on its occurrence and effects, but rather on how to mitigate the ever-happening effects of climate change to manage properly crop production and protection to ensure food security of the ever-growing population and the proper functioning of the natural ecosystem. This needs to set resilience strategies that can mitigate the existing and ever happening effects of climate change.

The effect of increased temperature, rainfall variability and decreased soil moisture on plant diseases depend on the nature of their effects on both the host and the pathogens [13,14]. Those variables

could first affect disease directly by changing the encounter rate between pathogens and hosts.

Because disease and environment are closely related, climate change may create favourable conditions for pathogens and alter the spatial and temporal distribution of disease epidemics [15]. The host plant agro-climate will be altered and pathogens will be affected negatively or positively [13]. To this effect, new diseases may arise in certain regions, and other diseases may cease to be economically important, especially when the host plant is introduced into new areas [15]. Pathogens tend to follow the host plant in their geographical distribution, but the rate at which pathogens become established in the new environment is a function of the mechanism of pathogen dispersal, suitability of the environment for dispersal, over seasoning, and physiological and ecological changes in the host plant [15]. Climate variability has the potential to modify host physiology and disease resistance and to change the stages and rates of pathogens development. The most likely impacts would be shifts in the spatial distribution of host and pathogen, changes in the physiology of host-pathogen interaction, alteration in crop loss and changes in the efficacy of management strategies [16,17]. Climate variability itself may be an important factor of pathogen selection pressure [13].

Inspite of crop diseases reducing crop productivity and food supply, there has been limited field based empirical research to assess the potential effect of climate change on plant disease [11,17,18]. Most research on how climate change influences plant disease has concentrated on the effects of one or two of the changing climatic factors on the host, pathogen, or the interaction of the two under controlled conditions that are very different from those in the real field. Other situational studies are based on modelling of data from controlled experiments [16].

Research in climate change related issues could result in improved understanding and management of crop diseases in the face of current and future climate extremes [13,16]. Understanding the effect of climate change resilience strategies such as plant nutrients through compost application [19,20], soil and water conservation [20,21], and species mixture combinations [8] management practices on disease intensities will assist identification of the most important variables and focus efforts in developing integrated management packages. The epidemics of CBB needs to be assessed under sole and integrated field based climate change resilience strategies such as intercropping, compost application and furrow planting. The objective of this study, therefore, was to assess the effects of climate change resilience strategies against CBB epidemiology of common bean in eastern Ethiopia.

Materials and Methods

Experimental location

Field experiments on CBB of common bean were conducted at Haramaya University experimental field stations at Babile and Haramaya, eastern Ethiopia during 2012 and 2013 main cropping seasons (June to November each year). Haramaya is located at 09° 26′ N and 42° 3′ E. The altitude of the area is 1980 meters above sea level with average annual rainfall of 786.8 mm, mean minimum temperature of 10.4°C, maximum temperature of 23.4°C and mean temperature of 16.8°C. The soil of Haramaya is alluvial type with organic matter content of 6.8%, total nitrogen of 0.34%, available phosphorus of 2.2 mg kg soil^{-1}, pH of 7.13 with percent sand, silt and clay content of 62.9, 19.6 and 17.5, respectively. Babile is situated at 09°13′ N and 42°19′ E, with altitude of 1655 meters above sea level with annual total rainfall of 719.2 mm. The mean minimum and maximum temperatures are

15.4 and 28.3°C, respectively, with an average temperature of 21.83°C. The soil of Babile is characterized with organic matter content of 2.95%, total nitrogen of 0.1%, available phosphorus of 1.28 mg kg soil^{-1}, pH of 6.6 with percent sand 45%, silt 24% and clay 31%.

Both locations represent important common bean growing areas and are conducive for CBB disease development of common bean. Babile is a representative of semi-arid agro ecology whereas Haramaya is a representative of midland agro ecology. The weather variables (mean maximum and minimum monthly temperature, monthly total rainfall) for 2012 and 2013 for both locations during experimental months are presented in Figure 1.

Experimental design and management

Three field based climate change resilience strategies such as compost application, row intercropping, and furrow planting were used solely and in combination (Table 1) in two common bean varieties Gofta (G2816) and Mexican 142 (G11239). Gofta is moderately resistant while Mexican 142 is susceptible to CBB. Sorghum variety, Teshale (3442-2OP) developed for the semi-arid environment as moisture stress and striga weed tolerant was used.

Totally 16 treatment combinations were arranged in a randomized complete block design in three replications on a plot size of 3.4 m × 3.6 m (12.24 m^2). Compost was applied two weeks before sowing at a rate of 8 tons per hectare, about half the rate recommended for cereals [22] for both crops. Compost was produced from the maize straw, teff straw and khat remaining (3:1:2 V/V) ratio in well-prepared composting pits. The selection of proportions was based on the availability of crops remaining in the study area. The chops of those materials were watered and allowed to decompose for four months through intermittent mixing up. Its chemical properties were also analyzed.

Close-ended furrows were prepared by digging 20 centimeters deep rows two weeks before sowing in order to harvest the rainwater. Sorghum (variety Teshale) seeds were sown on 21 June 2012 and 28 June 2013 at Babile, 20 June 2012 and 02 July 2013 at Haramaya by drilling seeds at the seed rate of 5 Kg ha^{-1}. Common bean seeds were sown on 11 July 2012 and 05 July 2013 at Babile, 07 July 2012 and 09 July 2013 at Haramaya manually by planting two seeds per hill. A standard intra and inter-row spacing for both crops were used according to the recommended spacing. Sorghum was planted in 0.8 m inter-row and 0.25 m intra-plant spacing. In row intercropping, a row of common bean was planted in the center of sorghum rows at 0.1 m intra-plant and 0.4 m inter-row spacing. Simultaneous planting was used in row intercropping. Similarly, in sole planting of common bean 0.4 m inter-row and 0.1 m inter-plant spacing with 9 rows per plot were used. Spacing between blocks was 1.2 m and between plots was 1 m [23].

After emergence and establishment of seedlings, the rows were thinned to one plant per hill. Recommended agronomic practices such as hand weeding and hoeing were used for both crops [23]. Fertilizer application and artificial inoculation were not applied for common bean. Plants were hand weeded three times at Haramaya and two times at Babile and cultivated once during the growth periods at both locations and seasons.

Disease data

All disease data were collected from central four rows. Disease severity (leaf area showing characteristic CBB symptom) was assessed six times at an interval of seven days during the experimental periods beginning from 48-51 days after planting (DAP) until physiological maturity. Disease severity rating was performed on 10 randomly pre-
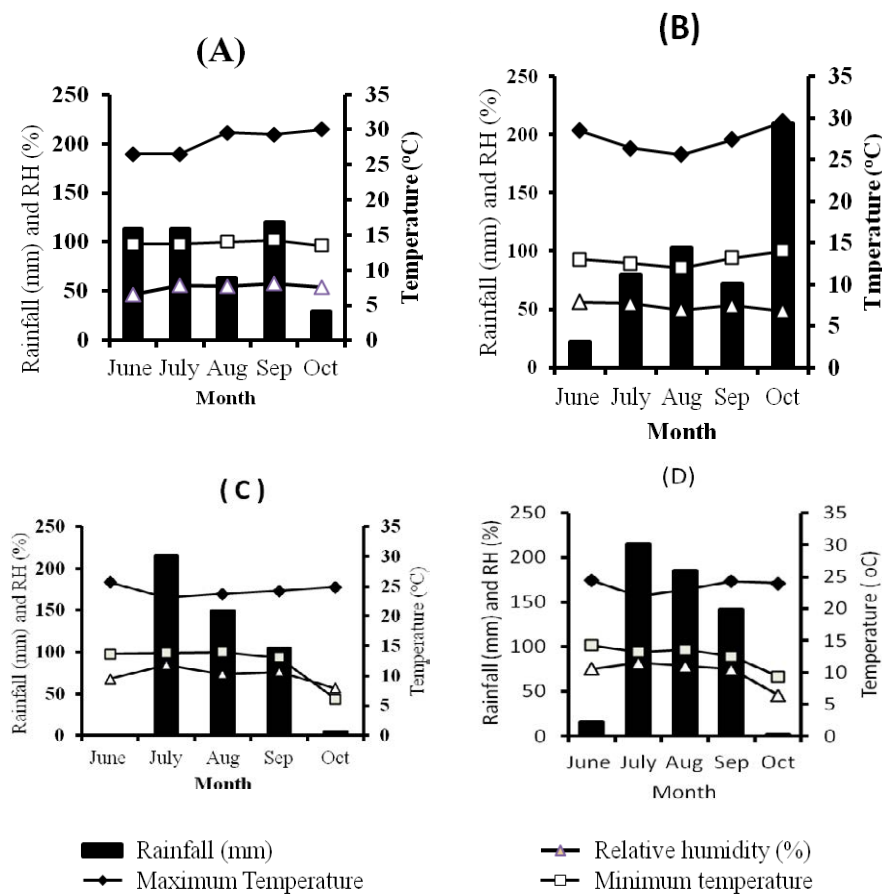
Figure 1: The weather variables (mean maximum and mean minimum temperature (°C), mean relative humidity (%) and total monthly rainfall (mm) at Babile in 2012. (A), in 2013. (B), at Haramaya in 2012. (C) and in 2013. (D).

S. No	Treatment	Treatment combination description
1	SP	sole planting
2	CA	compost application
3	FP	furrow planting
4	RI	row intercropping
5	CA+FP	row intercropping + furrow planting
6	RI+CA	row intercropping + compost application
7	RI+FP	row intercropping + furrow planting
8	RI+CA+FP	row intercropping + compost application + furrow planting

Table 1: Climate change resilience treatments for management of common bean common bacterial blight for both Gofta and Mexican 142 varieties during 2012 and 2013 at Babile and Haramaya, eastern Ethiopia.

tagged plants per plot at both locations and seasons. Severity was rated using standard scales of 1-9 [24-26] where 1=no visible symptom and 9=disease covering more than 25% of the foliar tissue and the severity grades were converted into percentage severity index (PSI) for analysis using:

$$PSI= \frac{\text{Sum of numerical ratings} \times 100}{\text{Number of plants scord} \times \text{maximum score on scale}}$$

Area under disease progress curve (AUDPC) and disease progress rate (r) were calculated from the severity data. AUDPC was computed from PSI data calculated on each date of assessment as described by Madden [27].

$$AUDPC= \sum_{i=1}^{n-1} 0.5\left(xi+1+xi\right)\left(ti+1-ti\right)$$

Where n is the total number of assessments, t_i is the time of the ith assessment in days from the first assessment date, x_i is the percentage of disease severity at i^{th} assessment. AUDPC was expressed in percent-days because the severity (x) was expressed in percent and time (t) in days.

Weather data

Weather variables of minimum temperature (°C) at 09:00 h and maximum daily air temperature (°C) at 18:00 h, relative humidity (%) at 06:00 h, 09:00 h, 12:00 h, 15:00 h and 18:00 h, and daily rainfall (mm) were collected from the meteorological stations of both location and the averages were calculated and presented in Figure 1.

Data analysis

Mean disease severity and yield data from each variety and treatment were examined and used for data analysis. Disease severity at different DAP and AUDPC were subjected to analysis of variance using the PROC GLM procedure of AUDPC or SAS version 9.1 [28] to determine the treatment effects. Homogeneity of variances was tested using the procedure described by Gomez and Gomez [29] and as the test showed heterogeneity of variances, separate analysis of the two-year and two location data was performed. Differences among treatment means were compared using the Fisher's least significant difference (LSD) test at 5% level of significance.

Results

Disease severity

Common bacterial blight epidemics on both varieties during both cropping seasons were varied significantly among the climate change resilience strategies. Disease severity was consistently less on the most integrated plots than sole planted and less integrated plots. During both cropping seasons, the disease severity was significantly different (P<0.01) among climate change resilience strategies throughout the whole disease recording dates while significant difference (P<0.01) of disease severity between the two varieties were recorded at late disease recording days. A higher disease severity was observed in the year 2012 compared with the 2013 cropping season. The interaction between and among the climate change resilience strategies, varieties and location was not significant.

In 2012, the highest initial disease severity (18.5%) at 48 DAP was calculated from sole planted plots of Gofta variety, while lower was recorded in row intercropping + compost application plots of common bean varieties at Babile (Figure 2). Similarly, higher final disease severity at 83 DAP was recorded from sole planting on Mexican 142 (54%) and on Gofta (53.8%) whereas lower final disease severity was recorded from row intercropping + compost application + furrow plating on Gofta (40%) and from row intercropping + compost application on Mexican 142 (40.7%) (Figure 2). During the 2013 cropping season, higher final disease severities at 85 DAP on Gofta (43%) and on Mexican 142 (50.4%) were obtained from sole planting while lower final disease severity on Gofta (27.4%) was obtained from row intercropping + compost application and on Mexican 142 (38.2%) from row intercropping + compost application + furrow planting at Babile (Figure 2). The other climate change resilience strategies reduced CBB severity intermediately and showed similar trend of disease reduction form the first to last date of disease recording and the data were not presented in the Figure 2 for clarity.

At Haramaya, the highest initial disease severity (20%) at 50 DAP was calculated from sole planted plots of Gofta variety, while lower was recorded in row intercropping + compost application + furrow planting plots of Gofta and in row intercropping of Mexican 142 in 2012 cropping season (Figure 3). Similarly, higher final disease severity at 85 DAP was recorded from sole planting on Mexican 142 (56%) and on Gofta (48%) whereas lower final disease severity was recorded from row intercropping + compost application on Gofta (40%) and from row intercropping + compost application + furrow planting on Mexican 142 (42.9%). During the 2013 cropping season, higher final disease severities at 86 DAP on Gofta (43%) and on Mexican 142 (54.8%) were obtained from sole planting followed by furrow planting while lower final disease severity on Gofta (28%) and on Mexican 142 (40%) were obtained from row intercropping + compost application + furrow planting at Haramaya (Figure 3). The other climate change resilience strategies reduced CBB severity intermediately and showed similar trend of disease reduction form the first to last date of disease recording and the data were not presented in the Figure for clarity.

With respect to mean initial and final disease severity of the varieties during 2012 cropping season, the highest mean initial disease severity was 18.2% at Babile and 19.6% at Haramaya in sole planting (Table 2). The row intercropping + compost application had the lowest 13.3% at Babile and row intercropping + furrow planting had the lowest (14.1 %) mean initial disease severity at Haramaya (Table 2). The highest mean final disease severity (53.9%) was recorded in sole planting at Babile and 52.4% at Haramaya (Table 2). The lowest mean final disease severity was from row intercropping + compost application + furrow planting (40.7%) at Babile (Table 2) and 41.8% at Haramaya during 2012 (Table 2).

During 2013 cropping season, the highest mean initial disease severity at 50 DAP was 16.3% in sole planting at Babile and at 51 DAP was 17.8% in sole planting at Haramaya, while the row intercropping

Figure 2: Disease progress curve of common bean common bacterial blight on (A) Gofta in 2012 (B) Gofta in 2013, (C) Mexican 142 in 2012 and (D) Mexican 142 in 2013 at Babile. RI + CA + FP, row intercropping + compost application + furrow planting; RI + FP, row intercropping + furrow planting; SP, sole planting.
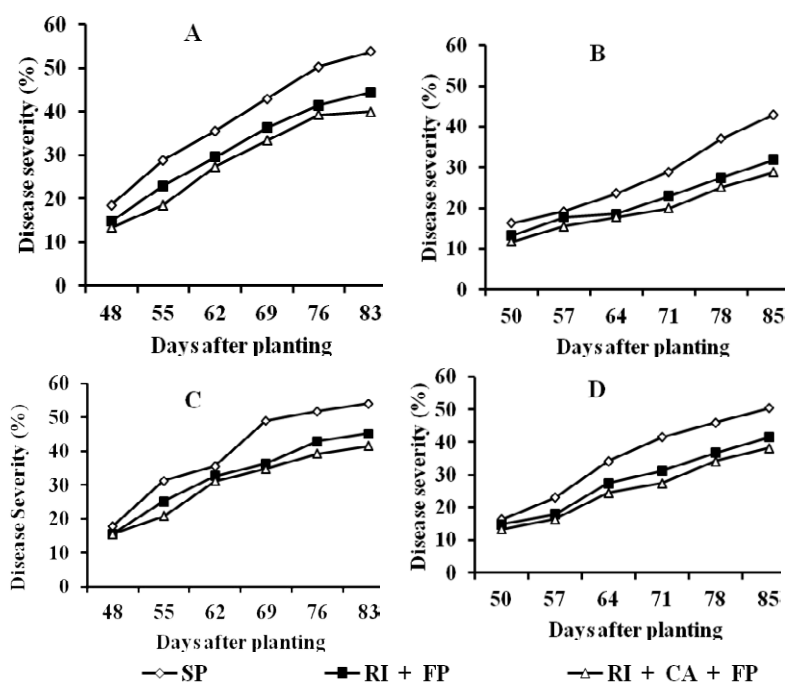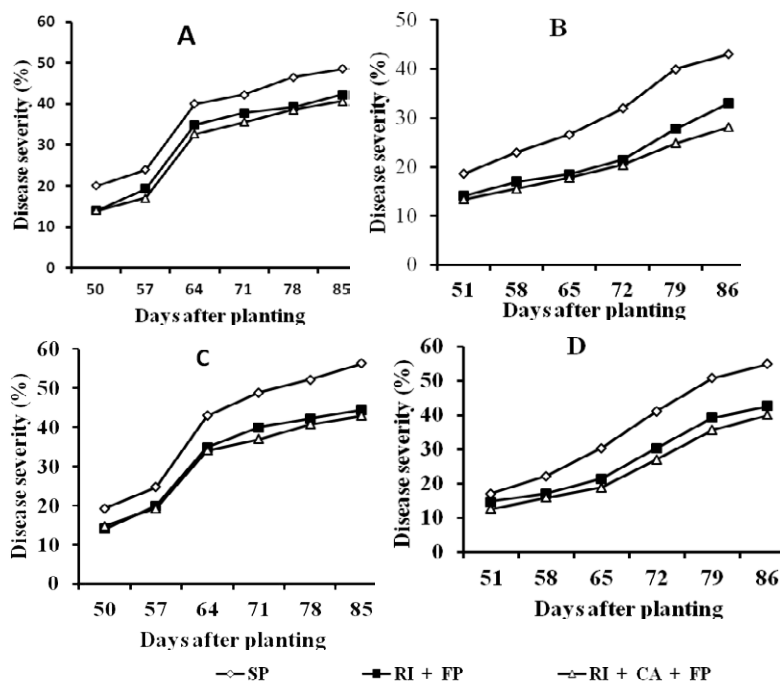
Figure 3: Disease progress curve of common bean common bacterial blight on (A) Gofta in 2012 (B) Gofta in 2013, (C) Mexican 142 in 2012 and (D) Mexican 142 in 2013 at Haramaya. RI + CA + FP, row intercropping + compost application + furrow planting; RI + FP, row intercropping + furrow planting; SP, sole planting.

Location	Babile				Haramaya			
Year	2012		2013		2012		2013	
PSI	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Variety								
Mexican 142	15.8a	47.5a	15.3a	42.7a	15.8a	48.7a	15.2a	47.2a
Gofta	15.1a	46.8a	13.9b	34.1b	15.8a	43.4b	15.1a	34.3b
LSD (0.05)	1.32	1.59	1.04	2.26	1.28	2.42	1	2.1
Strategy								
SP	18.2a	53.9a	16.3a	46.7a	19.6a	52.4a	17.8a	48.9a
CA	14.8c	51.0ab	15.6ab	39.3bc	17.4ab	52.8a	16.3ab	46.3ab
FP	17.8ab	51.1ab	15.9ab	42.6ab	16.7bc	44.8bc	15.7b	43.3bc
RI	15.2bc	44.6cd	14.4abcd	36.7cd	14.4cd	44.1bc	14.4bc	38.0de
CA+FP	14.8c	49.7b	14.8abc	38.5bc	15.bcd	47.0b	15.9ab	41.3cd
RI+CA	13.3c	41.5de	12.9cd	33.2d	14.8cd	41.8c	13.7c	36.1e
RI+FP	15.2bc	44.8c	14.1bcd	36.7cd	14.1d	43.3bc	14.4bc	37.8de
RI+CA+FP	14.4c	40.7e	12.6d	33.5d	14.4cd	41.8c	13.0c	34.1e
LSD (0.05)	2.65	3.18	2.07	4.52	2.55	4.83	2	4.2
CV (%)	14.5	5.71	12.05	9.99	13.68	8.91	11.2	8.7

PSI= percentage severity index, LSD=Least Significant difference, CV= Coefficient of Variance, CV= Coefficient of variation, CA=compost application, FP=furrow planting, RI=row intercropping, CA + FP=compost application + furrow planting, RI + CA=row intercropping + compost apllication , RI + FP=row-intercropping + furrow planting, RI + CA + FP=row intercropping + compost application + furrow planting, SP= sole planting.

Table 2: Effects of integrated climate change resilience strategies on CBB disease severity at Babile and Haramaya during 2012 and 2013 cropping seasons.

+ compost application + furrow planting had the lowest mean initial disease severity 12.6% at Babile and 13% at Haramaya (Table 2). The highest mean final disease severity at 85 DAP (46.7%) was recorded in sole planting at Babile and at 86 DAP was 48.9% at Haramaya while the lowest mean final disease severity was from row intercropping + compost application + furrow planting (33.5%) at Babile and 34.1% at Haramaya (Table 2).

In both cropping seasons while CBB occurred on both varieties it did not vary at early stage. However, significant variations in the disease severity between varieties started from 55 to 69 DAP at Babile and from 64 to 83 DAP at Haramaya during 2012, whereas 50 to 85 DAP at Babile and 65 to 86 DAP at Haramaya during 2013 (Figure 3). At both locations and during both cropping seasons significantly higher disease severity was recorded from Mexican 142 than Gofta variety. Likewise, higher mean initial disease severity (15.8%, 15.3%) and final disease severity (45.5%, 42.7%) were recorded on Mexican 142, during 2012 and 2013 respectively than on Gofta variety at Babile (Table 2).

Considering the range of disease severity and percentage of

disease severity reduction, the solely applied climate change resilience strategies had higher disease severity and lower reduction compared to most integrated and integrated ones. The most integrated climate change resilience strategy i.e. row intercropping + compost application + furrow planting and row intercropping + compost application caused higher CBB severity reduction. The resilience strategies reduced the mean final disease severity of both varieties from 5.2-24.5% (mean 14.3%) during 2012 at Babile (Table 2). Similarly, the resilience strategies reduced the mean final disease severity from 12.1-34.5% (mean 20.3%) on Gofta (Figure 3B) and from 10.8-27% (mean 13.9%) on Mexican 142 (Figure 3D) at Haramaya during 2013.

Area under disease progress curve

There were significant differences (P<0.001) among the climate change resilience strategies in both locations and seasons for mean AUDPC (Figures 4 and 5). There was significant difference (P<0.01) between the two varieties of common bean, with the mean AUDPC value (1230%-days) higher on the Mexican 142 variety than Gofta (1158%-days) during 2012 cropping season and mean AUDPC value (1041%-days) higher on the Mexican 142 variety than Gofta (807%-days) during 2013 at Babile. At Haramaya, the mean AUDPC value (1253%-days) was higher on Mexican 142 variety than (1153%-days) on Gofta during 2012 cropping season and mean AUDPC value was higher (1057%-days) on Mexican 142 variety than (822%-days) on Gofta during 2013.

At Babile, highest AUDPC The values were obtained from sole planting of Gofta and Mexican 142, respectively. The lowest AUDPC value was computed from row intercropping + compost application + furrow planting on Gofta and from row intercropping + compost application on Mexican 142, during 2012 (Figure 4A). The row intercropping + compost application + furrow planting reduced the AUDPC value by 25% on Gofta and row intercropping + compost application reduced AUDPC value by 26.3% on Mexican 142. During 2013 cropping season, on Mexican 142 variety maximum AUDPC value (1244.5%-days) was computed from the sole planting whereas the minimum value (895.9%-days) was from row intercropping + compost application + furrow planting plots followed by row intercropping + compost application (908.7%-days) at Babile (Figure 5A). The resilience strategies reduced AUDPC values from 6.4-30.8% (mean 16.8%) on
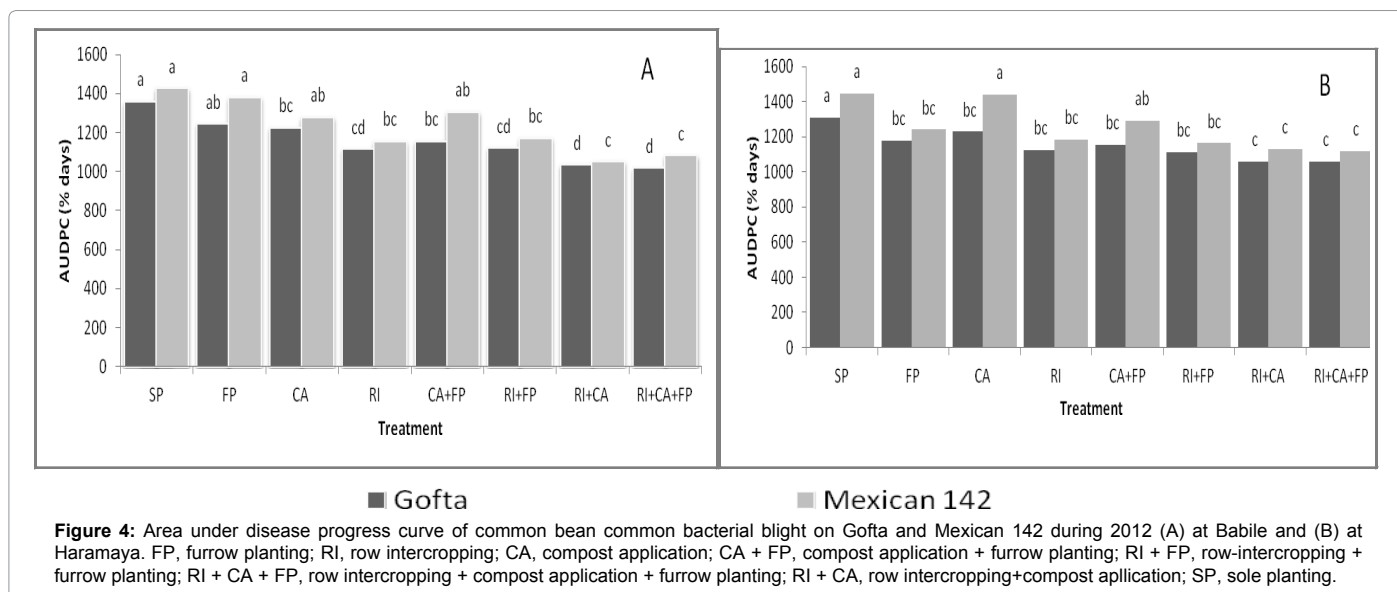
Gofta and from 8.7-28% (mean 16.3%) on Mexican 142 compared to sole planting during 2013 cropping season at Babile (Figure 5A).
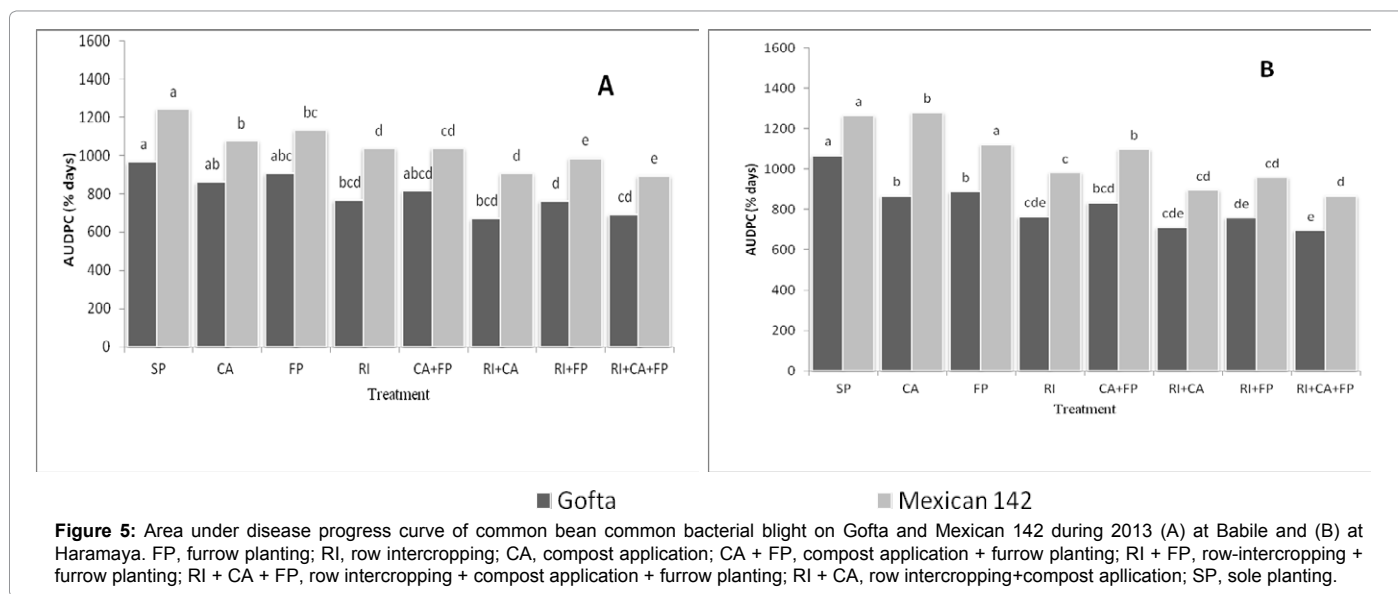
At Haramaya during 2012, the maximum AUDPC value was computed from the sole planting on Mexican 142 and the minimum value from row intercropping + compost application + furrow planting followed by row intercropping + compost application (Figure 4B). In the same year, on Gofta variety, row intercropping + compost application + furrow planting reduced AUDPC by 19.2%, row intercropping + compost application by 19.1% compared to sole planting whereas row intercropping + compost application + furrow planting reduced AUDPC by 22.6%, row intercropping + compost application by 21.7% and row intercropping + furrow planting by 19.5% compared to sole planting on Mexican 142. The climate change resilience strategies reduced AUDPC value by 6-19% (mean 11.9%) on Gofta and 10.6-22.6% (mean 13.4%) on Mexican 142 compared to sole planting during 2012 cropping season at Haramaya.

Higher AUDPC Values were recorded from sole planting of Gofta and Mexican 142 respectively, while lowest AUDPC value on Mexican 142 form row intercropping + compost application + furrow planting during 2013 (Figure 5B). Therefore, row intercropping + compost application + furrow planting reduced the AUDPC values by 34.8% on Gofta and by 31.4% on Mexican 142. All of climate change resilience strategies reduced AUDPC by 16.8-34.8% (mean 22.9%) on Gofta and 11.4-31.4% (mean 16.3%) on Mexican 142 compared to sole planting during 2013 cropping season at Haramaya.

Disease progress rate

Comparisons of disease progress rates were made among treatments based on the Logistic model by fitting disease severity data with dates of assessment. The rates of disease progress were varied among treatments, between locations and seasons. During 2012 cropping season, the highest disease progress rate (0.055-logit day^{-1}) was computed from Mexican 142 variety at Haramaya while the lowest epidemic rate (0.027 logit day^{-1}) was from Gofta variety during 2013 cropping season at Haramaya. The disease progress rates calculated for varieties, climate change resilience strategies, years and locations were different and presented in Table 3 for 2012 and Table 4 for 2013 seasons. During both cropping seasons, the reduction of disease progress rate

Figure 4: Area under disease progress curve of common bean common bacterial blight on Gofta and Mexican 142 during 2012 (A) at Babile and (B) at Haramaya. FP, furrow planting; RI, row intercropping; CA, compost application; CA + FP, compost application + furrow planting; RI + FP, row-intercropping + furrow planting; RI + CA + FP, row intercropping + compost application + furrow planting; RI + CA, row intercropping+compost apllication; SP, sole planting.

Figure 5: Area under disease progress curve of common bean common bacterial blight on Gofta and Mexican 142 during 2013 (A) at Babile and (B) at Haramaya. FP, furrow planting; RI, row intercropping; CA, compost application; CA + FP, compost application + furrow planting; RI + FP, row-intercropping + furrow planting; RI + CA + FP, row intercropping + compost application + furrow planting; RI + CA, row intercropping+compost apllication; SP, sole planting.

achieved through application of climate change resilience strategies have shown similar trend to the disease severity and area under disease progress curve in both varieties and locations.

In the 2012 cropping season, the disease progress rate was higher on the Gofta (0.053 logit day^{-1}) treated with compost application, on Mexican 142 (0.050 logit day^{-1}) treated with compost application + furrow planting at Babile and on Mexican (0.055 logit day^{-1}) treated with compost application, at Haramaya (Table 3). Application of row intercropping + furrow planting reduced disease progress rate by 6.5% on Gofta and application of row intercropping + compost application + furrow planting reduced disease progress rate by 18.7% on Mexican 142 compared to sole planting at Babile during 2012 cropping season (Table 3). Lower rate of disease progress was obtained from row intercropping + compost application on Gofta (0.040logit day^{-1}) and from row intercropping + compost application + furrow planting on Mexican 142 (0.44 logit day^{-1}). Generally, application of row intercropping + compost application + furrow planting reduced the rate of disease progress by 12% on Mexican 142 variety at Haramaya during 2012.

In 2013 cropping season, slower disease progress rate was calculated on Gofta (0.029 logit day^{-1}) and on Mexican 142 (0.037 logit day^{-1}) treated with row intercropping + compost application at Babile and on Gofta (0.027 logit day^{-1}) and on Mexican 142 (0.046 logit day^{-1}) treated with row intercropping + compost application + furrow planting at Haramaya compared to sole planting. In 2013 the disease progress rate from compost application was faster (0.055 logit day^{-1}) than the remaining climate change resilience strategies on Mexican 142 (Table 4), and sole planting had faster disease progress rate (0.04 logit day^{-1}) on Gofta and (0.048 logit day^{-1}) on Mexican 142 at Babile. The disease progress rate in compost application was highest in both cropping seasons on Mexican 142 at Haramaya. Application of the most integrated climate change resilience strategy: row intercropping + compost application + furrow planting reduced the rate of disease progress by 22.9% on Gofta variety and by 14.8% on Mexican variety during 2013 cropping season at Haramaya (Table 4).

Discussion

Common bacterial blight epidemics significantly varied among and between climate change resilience strategies, between common bean

varieties, locations and cropping seasons. Variety Mexican 142 had higher disease severity and higher area under disease progress curve (AUDPC) than variety Gofta might be due to the higher resistance level of Gofta than Mexican 142. The result of this study agreed with the findings of Fininsa and Tefera [9] that described Gofta as moderately resistant to common bacterial blight and Mexican 142 as susceptible variety. Higher disease epidemic was found during 2012 cropping season than 2013 cropping season at both locations. In both location higher relative humidity, higher minimum and maximum temperatures (Figure 1) recorded in August and September months during 2012 cropping season could have created conducive environment for increased common bacterial blight severity and progress rate than 2013 cropping season. Similarly, lower relative humidity, higher minimum and maximum temperatures were recorded at Babile than at Haramaya during both cropping seasons (Figure 1), were suitable for common bacterial blight disease development and early disease appearance common bacterial blight. At Haramaya, lower disease severity and lower AUDPC were computed than at Babile during both cropping seasons. The result was similar with the findings of Fininsa [8] as high temperature and low relative humidity favor higher common bacterial blight severity.

Climate change resilience strategies had lower final disease severity (8.6-36.2%) and lower AUDPC than the sole planting on both varieties of common bean during 2012 and 2013 cropping seasons at both locations. The variation of final disease severity was based on the type of climate change resilience strategy, resistance level of common bean, common bacterial blight conduciveness of location and weather variables of two cropping seasons.

Intercropping common bean with sorghum has significantly lowered the severity level of common bacterial blight compared with sole planting. Row intercropping + compost application + furrow planting and row intercropping + compost application showed significantly lower common bacterial blight severity than the sole plantings during both cropping seasons and locations. All types of common bean–sorghum intercropping systems (row intercropping, row intercropping + furrow planting, row intercropping + compost application, row intercropping + compost application + furrow planting) significantly reduced the final disease severity (13-36.2%)

Resilience strategy	Babile				Haramaya			
	Gofta		Mexican		Gofta		Mexican	
	Rate (r)	R^2	Rate (r)	R^2	Rate (r)	R^2	Rate (r)	R^2
SP	0.046	90.8	0.048	88.4	0.04	83.7	0.05	83.1
CA	0.053	92.7	0.048	89.9	0.043	81.7	0.055	86.9
FP	0.046	89.7	0.046	87	0.04	79	0.044	82.1
RI	0.046	89.3	0.042	86.9	0.042	82	0.049	84.2
CA + FP	0.05	93.9	0.05	84.6	0.042	79.5	0.052	85.1
RI + CA	0.048	87.8	0.044	84.1	0.04	81.2	0.045	83.8
RI + FP	0.043	87.6	0.041	86.5	0.043	79	0.046	84.2
RI + CA + FP	0.044	86.7	0.039	86	0.044	80.8	0.044	82.7

CA=compost application, FP=furrow planting, RI=row intercropping, CA + FP=compost application + furrow planting, RI + CA=row intercropping + compost apllication , RI + FP=row-intercropping + furrow planting, RI + CA + FP=row intercropping + compost application + furrow planting, SP= sole planting.

Table 3: Common bean common bacterial blight disease progress rate (r) in logit per day and adjusted coefficient of determination (R^2) on Gofta and Mexican 142 varieties at Babile and Haramaya during 2012 cropping season.

Resilience strategy	Babile				Haramaya			
	Gofta		Mexican		Gofta		Mexican	
	Rate (r)	R^2	Rate (r)	R^2	Rate (r)	R^2	Rate (r)	R^2
SP	0.04	90.3	0.048	90.1	0.035	91	0.054	93.3
CA	0.034	83.5	0.041	86.2	0.033	80.1	0.055	95.3
FP	0.037	87.2	0.044	88.5	0.036	84.7	0.048	93.4
RI	0.031	77.9	0.041	89.7	0.029	82.1	0.047	90.4
CA + FP	0.036	83.6	0.039	88.2	0.033	85.9	0.048	89.2
RI + CA	0.029	87.6	0.037	69	0.028	78.5	0.048	88.4
RI + FP	0.03	77.6	0.042	92.9	0.031	82.9	0.046	88.8
RI + CA + FP	0.031	86.1	0.041	90.7	0.027	82.9	0.046	91.1

CA=compost application, FP=furrow planting, RI=row intercropping, CA + FP=compost application + furrow planting, RI + CA=row intercropping + compost apllication , RI + FP=row-intercropping + furrow planting, RI + CA + FP=row intercropping + compost application + furrow planting, SP= sole planting.

Table 4: Common bean common bacterial blight disease progress rate (r) in logit per day and coefficient of determination (R^2) on Gofta and Mexican 142 varieties at Babile and Haramaya during 2013 cropping season.

and AUDPC compared to sole planted plots at both locations and seasons. Similarly, Fininsa [8] reported reduction of 17-40% common bacterial blight severity in bean-maize intercropping. In sorghum-common bean intercropping, common bacterial blight disease epidemics were reduced because the sorghum may be used as physical barrier against bacterial inoculum from reaching to common bean. Changes in microclimate such as temperature and wind velocity reduction may disfavor the pathogen and cause reduction in disease. Higher temperature and relative humidity are favorable conditions for common bacterial blight disease epidemics and a decrease in temperature in the intercropping system might have lowered the severity of common bacterial blight. A cool microclimate in row intercropping + compost application + furrow planting disfavours common bacterial blight pathogen infection that could be initiated from infected seeds, infested soil or infested debris in the soil. The microclimate may also retard proliferation and spread of the bacteria between plants as the result of non-host nature of component crop sorghum for the bacteria.

Intercropping common bean with sorghum therefore could have been reduced the common bacterial blight severity and AUDPC compared to sole planting, during 2012 and 2013 cropping seasons at both location. In addition to disfavor common bacterial blight severity, intercropping can maintain soil fertility and balanced nutrition that might be the case for physiological and morphological fitness of the crop to build resistance to common bacterial blight. The result of this study is in line with the report of Matusso, et al. [30] that the principal reasons for intercropping are soil conservation and improvement of soil fertility, diseases control and balanced nutrition.

Furrow planting reduced the final disease severity during both cropping seasons at both locations when applied singly (2.7-18.4%) or in combination (5.7-34.5%) with other resilience strategies such as compost application and intercropping. Furrow planting could conserve soil moisture and create sufficient water availability in the root system of common bean that might have enabled common bean to reduce disease epidemics due to creation suitable condition for plants might favour the host than the pathogen. The result of this study is in agreement with the findings of Aydinalp and Cresser [21] revealed periodic low soil moisture make plant easily susceptible to diseases. Furrow planting had promising potential of mitigating climate change and reducing disease severity when integrated with intercropping and compost application. Furrow planting was effective when the soil had good water holding capacity similar to soil of Haramaya and less effective in sand soils with high drainage capacity for example soil of Babile.

Compost application reduced the final common bacterial blight disease severity (3.9-17.3) when applied singly and (14.2-36%) of disease severity reduction when combined with other resilience strategies during 2013 cropping season. The result of this experiment is in agreement with the results of Vallad et al. [31] and Abdasi et al. [32] conducted on foliar plant diseases. Vallad et al. [31] revealed that compost had 34-65% of disease symptom reduction of bacterial speck of *Arabidopsis thaliana* caused by *Pseudomonas syringae* pv. tomato compared with non-amended soil. Abbasi et al. [32] found that application of compost resulted in reduced bacterial spot incidence on tomato fruit by 28-33%, compared with non-amended soil. Disease control with compost has been attributed to successful competition

for nutrients by beneficial microorganisms, antibiotic production by beneficial microorganisms and activation of disease-resistant genes in plants. Using compost not only could supply plant nutrients, but also can increase tolerance and resistance to diseases and retains soil moisture [33]. Composts' contribution to nutrient fertility must also be taken into account because nutrient effects may influence the severity of pathogens and consequently reduce greenhouse gas emission largely carbon dioxide emission as the result of carbon sequestration [19].

When the climate change strategies are integrated their synergetic effect significantly reduced disease severity, AUDPC and disease progress rate. Row intercropping + compost application and row intercropping + compost application + furrow planting have shown significant difference in disease severity reduction compared to less integrated climate change resilience strategies and sole planted plots at Babile and Haramaya. Compost application aggravated the diseases severity on the susceptible variety of Mexican 142 when applied solely, at Haramaya during both cropping seasons. This was because of compost application could have enhanced the growth of Mexican 142 variety at fast rate and created closed canopy earlier, consequently increased temperature and humidity, which sequentially could create favorable condition for common bacterial blight development and spread. Generally, there were higher disease progress rates on Mexican 142 than on Gofta during both seasons and both locations. When composting and furrowing are integrated to intercropping, they are highly effective in reducing disease severity, disease progress rate and the AUDPC as the result of synergetic effect.

Comparisons of disease progress rates among climate change resilience strategies, between varieties, locations and cropping seasons have shown different trends when compared to disease severity and AUDPC. The resilience strategies having lower disease severity exhibited higher disease progress rate. High disease rates were observed in some of resilience strategies that had lower disease severity. This could be due to high density of initial inoculum from the infected seeds, infested debris or infested soil that might have increased the initial disease severity. The disease progress rate with higher initial disease severity was higher even though there was lower final disease severity. Experimental studies have shown that the number of initial inoculum [34] considerably influenced the rates of disease increase. In an experiment with southern blight of processing carrot, the rate of disease increase generally increased as the number of initial foci increased [35].

Generally, common bacterial blight severity was reduced due to the reduction of inoculum dispersal and inhibition of inoculum proliferation and creating disfavoring conditions for the bacteria by climate change resilience strategies. These climate change resilience strategies of disease management therefore are cheaper, sustainable and could be easily adopted by small-scale farmers in eastern Ethiopia. The results obtained from this study suggested the importance of climate change resilience strategies applied singly and in combination as management option of common bacterial blight and other common bean diseases in the eastern Ethiopia and in areas with similar agro-ecological conditions. The furrow preparation and compost application rate of common bean should also need further investigation in the study area.

Conclusions and Recommendations

Application of integrated climate change resilience strategies in field experiments enhanced productivity of common bean and reduced disease severity and AUDPC of common bacterial blight compared to solely applied climate change strategies and sole planting common beans over locations and seasons. In addition, the most integrated strategy: row intercropping + compost application + furrow planting, has shown promising results in maintaining soil temperature and moisture. Thus, it could be concluded that farmers in eastern Ethiopia should design a strategy to promote common bean production through the application of row intercropping + compost application + furrow planting and row intercropping + compost application to improve the physico-chemical properties of soil and sustain enhanced production and productivity of common bean. It is strongly believed that integrated climate change strategies through reducing CBB disease epidemics as ecofriendly disease management option and enhancing soil fertility management, contribute substantially to the efforts of increasing food production and household food security in the study area.

Competing interests

The authors declare that they have no competing interests

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