Compost enriched with effective microorganism and bordeaux mixture on ginger bacterial wilt (*Ralstonia solanaceurum*) epidemics in southwestern, Ethiopia

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A B S T R A C T

Ginger is one of the most widely distributed spices grown in various cropping systems and locations throughout the southwestern Ethiopia. Bacterial wilt, caused by *Ralstonia solanacearum,* is one of the serious diseases of ginger in Ethiopia. Field experiments were conducted during 2019 and 2020 to assess effects of soil amendments on bacterial wilt development and epidemics at Tepi, Ethiopia. Three soil amendments practices: compost, effective microorganisms and Bordeaux mixture alone and in integration were evaluated. Treatments were arranged in a randomized complete block design with three replications. Compost at the rate of 7 ton ha^{-1} enriched with effective and Bordeaux mixture treatment significantly reduced ginger bacterial wilt severity, AUDPC and disease progress rate. This treatment reduced bacterial wilt mean severity by up to 21.08% as compared to untreated control plot. Compost at the rate of 7 ton ha^{-1} application also slowed down epidemic progression of bacterial wilt and significantly reduced the disease parameters when integrated effective microorganisms and Bordeaux mixture. The overall results indicated that integrated compost enriched with effective microorganisms and Bordeaux mixture was effective to slow down the epidemics of bacterial wilt and to sustain ginger production and productivity. Hence, integrated compost enriched with effective microorganisms and Bordeaux mixture along with other crop management systems are recommended for improved ginger production and productivity.

Keywords: Bordeaux mixture, bacterial wilt, Compost, Effective microorganism, Epidemics, Ginger

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Introduction

Ginger (*Zingiber officinale* Rosc.), is an important commercial crop grown for its aromatic rhizomes, which are used as both spice and medicine (Sharma *et al.,* 2010). Ginger rhizome is typically consumed as a fresh paste, dried powder, slices preserved in syrup, candy, as a beverage or as flavoring agent. India is the largest producer of ginger in the world accounting for about one-third of the total world output. The crop is known to have been introduced to Ethiopia as early as in the 13th century (Jansen, 1981). It is cultivated in South, Southwestern and Northwestern parts of the country as cash crop, and is among the important spices used in every Ethiopian kitchen for the preparation of pepper powder, stew, bread, and others. It has also some use in traditional medicine for the treatment of flu and stomachache (Girma and Digafie, 2004).

One of the most devastating plant diseases in the tropics is bacterial wilt, caused by the bacterium *Ralstonia solanacearum*. In susceptible host plants, this pathogen disrupts water transport, alters physiology and induces a severe, usually fatal wilt. One plant species that is seriously affected by bacterial wilt is ginger, and efforts to grow ginger widely in Ethiopia have been hampered by this disease (Habetewold *et al.,* 2015).

The pathogen has a very wide host range. The very extensive host range includes several hundred species of plants representing 44 families. Among the common hosts are chili,

eggplant, irish potato, ginger, groundnut, tomato and tobacco. In Ethiopia, the disease caused losses of 51.94% (Guji *et al.*, 2019). Habetewold *et al.* (2015) reported that the disease became the major constraint in the ginger production in Ethiopia and cause losses up to 80-100%.

Effective Microorganisms (EM) with compost was found effective in improving soil and plant health there by improved the quality and productivity of crops (APNAN, 1995; Higa and Parr, 1994). EM may have an advantage of low ecological pollution rather may conserve the environment and sustainable in managing soil borne diseases. Singh *et al.* (2016) indicated that application of EM found the most effective bio control agents; it promotes microbial activity that suppresses *R. solanacearum* by competition. Therefore, the purpose of this study is to know effect of compost amended with Effective Microorganisms (EM) in reducing ginger bacterial wilt incidence and enhancing yields.

Soil amendments can improve crop production through promoting the growth of plants and enhance microbial activity that may suppress soil borne diseases by completion and/or antibiosis. According to Ayana *et al.* (2011), the application of the organic amendment and compost released biologically active substances from crop residues and soil microorganisms such as allele-chemicals. The application of the organic amendment and compost released biologically active substances from crop residues and soil microorganisms such as allele-chemicals (Bailey and Lazarovits, 2003).

Islam and Toyota (2004) demonstrated that the bacterial wilt of tomato was suppressed in the poultry and farmyard manure (FYM) added soils. Compost made from corn stalk, rice straw and tree bark suppressed bacterial wilt caused by *R. solanacearum* and gave lowest disease incidence compared to the control plot (Masyitah, 2004). Cow manure fertilization household compost suppressed *R. solanacearum* in most soils with a clear shift in rhizosphere bacterial community. Silicon amendment significantly reduced bacterial wilt incidence expressed as area under the disease progress curve for tomato genotypes L390 (susceptible) by 26.8% and King Kong2 (moderately resistant) by 56.1% compared to non-treated plants grown in hydroponic culture (Ayana *et al.*, 2011). Therefore, these fertilizer soil amendments may have efficacy not only in respect to increase of crop yield but also in respect to its direct effects on plant pathogens and /or indirect stimulation of soil suppressions.

Apart from all efforts to manage bacterial wilt in different parts of the world, ginger bacterial wilt is still highly distributed and severe in Southwestern areas of the country, and farmers in these areas considered the disease as a major production constraint, which limits the production as well as quality of rhizome. Thus, the use of integration of compost enriched with effective microorganisms and Bordeaux mixture could be alternative options at the disposal of growers in managing ginger bacterial wilt. However, there is very little or no information and research done so far on the effects of soil amendments with compost enriched effective microorganisms and Bordeaux mixture to control the disease in Ethiopia. Therefore, this study was designed to determine the effect of compost enriched with effective microorganism and Bordeaux mixture on the epidemics of ginger bacterial wilt in Southwestern, Ethiopia.

Materials and Methods

Experimental sites

The experiment was conducted at Tepi Agricultural Research Centre (TARC), Ethiopia during 2019 and 2020 main cropping season. TARC is located in Yeki district, Southern Nations Nationalities and Peoples' Regional State, which is 600 km away from southwest of the capital, Addis Ababa. It is found between $35^{\circ}08'$ longitude and $7^{\circ}08'$ latitude and at an altitude of 1200 m.a.s.l. The average maximum and minimum temperatures are 15 and $30^{\circ}C$, respectively. It receives an average annual rainfall of 1630 mm (Guji *et al.*, 2019).

Experimental materials and treatments

Boziab (37/79) variety of ginger released by Tepi Agricultural Research Center was used for all treatments including the control. Compost soil amendments @ 3, 5, and 7 ton ha⁻¹ before planting was evaluated for their response to bacterial wilt alone and integration with effective microorganism and Bordeaux mixture. Compost enriched with effective microorganism and Bordeaux mixture was applied as cultural management practice to reduce pathogen inocula and prevent disease epidemics.

After compost was prepared by enriched with effective microorganism (EM) and alone, the plot to be amended was thoroughly cultivated mixed with compost integrated EM and Bordeaux mixture for one month before planting. The first soil amendment was done at one month before the time of planting with compost enriched with EM and Bordeaux mixture @ 3, 5, 7 tones ha⁻¹ and un-amended plot used as control or check. The experiment was relied entirely on natural epidemics of bacterial wilt, because the sites are hot spot areas of the disease and the previous history of the field confirmed it.

Experimental design and management

A total of 9 treatments including controls were laid out in a randomized complete block design in a factorial arrangement with three replications. Planting was made on a gross plot size of 6 m² (2 m width and 3 m length) with six rows of ginger and four harvestable central rows. A recommended spacing of 0.15 m between plants and 0.3 m between rows were used. Spacing between plots and blocks were 0.5 and 1 m, respectively. Total area allocated for the experiment was 30.5 m x 8.0 m (244 m²). The four central rows were considered for data collections. All other cultural practices for growing ginger under field conditions were done uniformly following recommended practices.

Disease Assessment

Ginger bacterial wilt incidence (number of plants wilted) were visually assessed at 15-days interval starting from 60 days after planting (DAP). Plants that showed either complete or partial wilting were all considered wilted and staked to avoid double counting in subsequent assessments. Wilt incidence for each treatment was then calculated as percentage of total number of plants emerged. Disease progress was plotted by considering the disease incidence against time. The area under diseases progress curve (AUDPC) from disease incidence was computed using the formula suggested by Campbell and Madden (1990):

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{X_i + X_{i+1}}{2} \right) (t_{i+1} - t_i)$$

Where, n is total number assessment times, t_i is time of the ith assessment in days from the first assessment date, x_i is percentage of disease incidence at i^{th} assessment. AUDPC was expressed in %-days because incidence (x) was expressed in percent and time (t) in days (Campbell and Madden, 1990).

Data Analysis

Analysis of variance (ANOVA) was performed for disease incidence and AUDPC to see the effect of treatments and their interactions. Logistic, ln [(Y/1-Y)], (Van der Plank, 1963) model was used for estimation of disease progression parameters from each treatment. The transformed disease incidence data were regressed over time (DAP) to determine the rate. The goodness of fit of the models was tested based on the magnitude of the coefficient of determination (R^2) and residuals (SE) obtained using the model (Campbell and Madden, 1990). Regression was computed using Minitab (Release 15.0 for windows®, 2007). Least significant difference (LSD) was used for mean separation at 5% level of significance. Relationship of final disease incidence and AUDPC with yield and yield components was examined using correlation analysis. The two years were considered as the same due to homogeneity of variances as tested using Bartlett's test (Gomez and Gomez, 1984) and the F-test was non-significant for most of the parameters studied in each location. Thus, data were combined for analysis.

Results and Discussion

Disease incidence

AUDPC values calculated from disease severity assessed at different days after planting, yield and final disease severity significantly (P<0.05) varied between some of soil amendment bacterial wilt management practices and the control (Table 1). AUDPC and PSI values were lower on compost 7 ton ha⁻¹ enriched with effective microorganisms and Bordeaux mixture treated plots than on other treatments and control. Control plots had the highest (2117.05%-days) AUDPC values, while the lowest (1470%-days) AUDPC values were calculated from compost enriched with effective microorganism and Bordeaux mixture treated plots. The highest yield (16.26 ton ha⁻¹) was obtained from the plots treated with compost enriched with effective microorganism and Bordeaux mixture, whereas the lowest yield (8.43 ton ha⁻¹) was calculated from the untreated control plots. The overall values indicated that compost integrated with effective microorganisms and Bordeaux mixture treated plots showed consistent in increase yield in ton per hectare, reduction in AUDPC and PSI values than other treatments and control. This could be attributed to besides the suppression of the spread of disease at field, compost also provide nutrients and organic matter, thereby eliminating or reducing the need for fertilizer. Compost can also improve soil structure, which allows for better water transmission, thereby decreasing the potential for bacterial wilt disease development.

Compost may alter resistance of plants to diseases. One of the beneficial properties of compost is the microbial induced suppression of soil borne plant pathogens and disease (Hoitink et al., 1997). Singh et al. (2016) reported that suppressive compost possesses a higher microbial activity than conducive ones. They suggested that a high microbial activity causes depletion in essential nutrients for the survival and multiplication of the pathogen, thus preventing infection of the host. The beneficial microbes in compost and other decomposing organic matter can activate certain disease resistance systems in plants. When a pathogen infects a plant, the plant mobilizes certain biochemical defenses, but these are often too late to avoid the disease. Plants grown in compost appear to have these systems already running and this prevents the pathogen from causing disease. This mechanism, called systemic acquired resistance, is somewhat pathogen specific, but it opens the door for enhancing disease control through common farming practices (Hoitink et al., 1997; Baker and Paulitz, 1996).

Table 1. Effects of compost enriched with microorganism (EM) and Bordeaux mixture on bacterial wilt (*R. solanacearum*) final disease incidence (%), yield (ton ha^{-1}) and area under disease progress curve (%-days) at Tepi, Ethiopia during the 2019-2020 main cropping season.

Treatments	Yield (ton ha^{-1})	PSI (%)[1]	AUDPC (%-days)[2]
Compost @ 3 ton ha^{-1}	12.33[c]	55.00[cd]	1675.14[c]
Compost @ 5 ton ha^{-1}	12.53[c]	55.16[cd]	1582.24[cd]
Compost @ 7 ton ha^{-1}	13.40[bc]	53.06[de]	1540.52[d]
Sole Bordeaux mixture	9.83[d]	60.00[b]	1919.94[b]
Sole EM	9.43[de]	58.06[bc]	1964.78[b]
Compost @ 3 ton ha^{-1} + EM + Bordeaux mixture	13.26[bc]	50.50[ef]	1688.35[c]
Compost @ 5 ton ha^{-1} + EM + Bordeaux mixture	14.13[b]	46.76[f]	1495.06[d]
Compost @ 7 ton ha^{-1} + EM + Bordeaux mixture	16.26[a]	42.53[g]	1470.00[d]
Control	8.43[e]	66.86[a]	2117.05[a]
LSD (5%)	1.30	4.10	124.09
CV (%)	6.18	4.37	4.17

[1]*Percent disease incidence at 120 days after planting (DAP).* [2]*AUDPC = standardized area under disease progress curve of ginger bacterial wilt. Means followed by same letter(s) within a column are not significantly different at 5% level of significance.*

Disease progress rate

The disease progress rates calculated from mean disease severity records showed variations among some of soil amendments treatments used and control. The lowest disease progress rates was calculated from the plot treated with compost 7 ton ha^{-1} enriched with effective microorganisms and Bordeaux mixture (0.030 units day^{-1}), while the highest disease progress rates was recorded from untreated control plot (0.041 units day^{-1}) (Table 2). It was also observed that disease progressed relatively at faster rates on sole effective microorganisms, Bordeaux mixture and untreated control plots. The results indicated that the rate at which bacterial wilt progressed was slower when compost integrated with effective microorganisms and Bordeaux mixture to manage the disease was applied in integration than the untreated plots. Possibly the treatment could enhance the health and vigor of plants that might increase plant chances to withstand pathogen attack and to activate the host defense system in addition to benefits gained from the intercrops. In agreement with this study, Neher *et al.* (2014) found that compost amended soils reduced disease severity of ear blight on brassicas compared to the bare soil. Haggag and Saber (2007) 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.

Sang *et al.* (2010) also noted a similar result 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. In addition, composted paper mill residuals suppressed leaf spot of field-grown cucumber and bacterial spot of field-grown snap bean and anthracnose in greenhouse grown snap beans likely due to induced systemic resistance (Stone *et al.*, 2003). Sang *et al.* (2010) showed the same result on the suppression of *Colletotrichum coccodes* in pepper leaves and *C. orbiculare* in cucumber leaves.

Table 2. Effect of soil solarization and botanical mulch on disease progress rate (r) and parameter estimates of bacterial wilt (*Ralstonia solanacearum*) of ginger at Tepi, Ethiopia during the 2019-2020 main cropping seasons.

Treatments	Disease progress rate (r) at Tepi			
	Disease progress rate (unit day^{-1}) [1]	SE of rate [2]	SE of intercept [3]	R^2 (%) [4]
Compost @ 3 ton ha^{-1}	0.039	0.085	0.021	99.2
Compost @ 5 ton ha^{-1}	0.036	0.180	0.101	95.6
Compost @ 7 ton ha^{-1}	0.037	0.150	0.068	97.2
Sole Bordeaux mixture	0.039	0.077	0.018	99.3
Sole EM	0.036	0.140	0.058	97.5
Compost @ 3 ton ha^{-1}+ EM + Bordeaux mixture	0.035	0.075	0.016	99.2
Compost @ 5 ton ha^{-1} + EM + Bordeaux mixture	0.034	0.032	0.003	99.8
Compost @ 7 ton ha^{-1} + EM + Bordeaux mixture	0.030	0.020	0.001	99.9
Control	0.041	0.173	0.090	97.0

[1]*Disease progress rate obtained from regression line of disease incidence with time of assessment (days).* [2]*Standard error of rate.* [3]*Standard error of parameter estimates.* [4]*Coefficient of determination of the Logistic model.*

Disease progress curve

The disease progress curves of bacterial wilt (severity versus DAP) were sketched in Figure 1. The curves revealed that disease severity progressed increasingly starting from the onset to the final severity records in all treatments during the study periods. The five disease progress curves for each treatment also indicated that the disease progress was not similar for each soil amendments used. Disease severity in untreated control plots followed relatively high progressive curves and displayed the highest levels of bacterial wilt severity. The sole Bordeaux mixture and effective microorganism's plots followed similar curves as untreated plots but lied intermediate between control and compost @ 5 ton ha-1 enriched with effective microorganisms and integrated with Bordeaux mixture treated plots with intermediate levels of bacterial wilt severity. Whereas disease progress curves of plots treated with compost at @ 7 ton ha-1 enriched with effective microorganisms and integrated with Bordeaux mixture treatments progressed slowly and display the lowest levels of bacterial wilt severity at different days after planting.

The disease progress curves in Figure 1 depicted only for five treatment categories (sole effective microorganism, sole Bordeaux mixture, compost @ 5 ton ha-1 enriched with effective microorganism and Bordeaux mixture, compost 7 ton/ha enriched with effective microorganism and Bordeaux mixture and un treated control) based on bacterial wilt severity levels for the sake of clarity and ease graphic presentation. Accordingly, sole effective microorganism, sole Bordeaux mixture and compost @ 5 ton ha-1 with Em and Bordeaux mixture is treatments lied in between control and compost @ 7 ton ha-1 enriched with effective microorganism and Bordeaux mixture, whereas treatments like compost @ 3 ton ha-1, @ 5 ton ha-1, @ 7 ton ha-1 were intermediate sole effective microorganism and compost @ 5 ton ha-1 with effective microorganisms treatments.
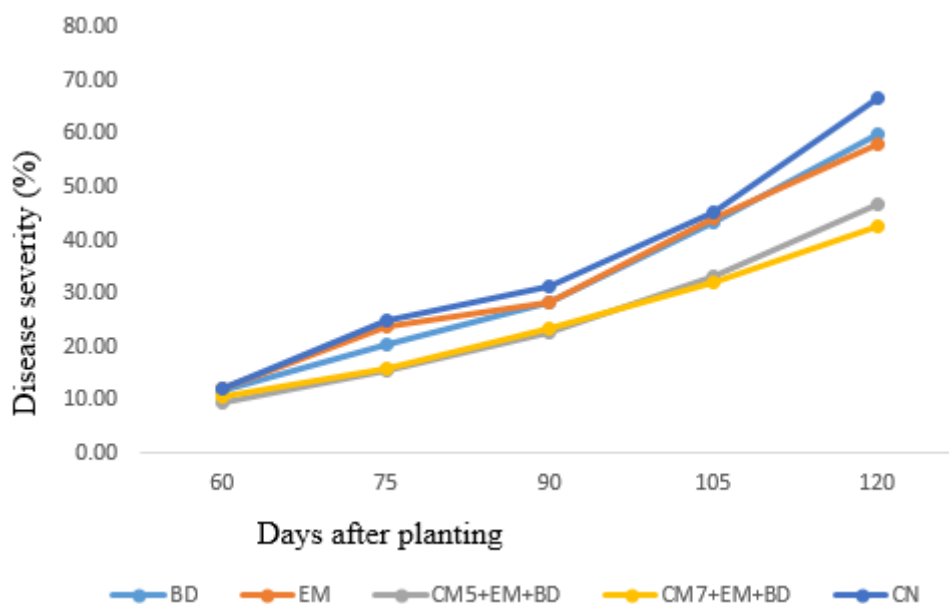

Figure 1. Ginger bacterial wilt (*Ralstonia solanacearum*) disease progress curves as affected by compost enriched with effective microorganism and Bordeaux mixture (sole Bordeaux mixture (BD), sole effective microorganism (EM), compost @ 5 ton ha-1 enriched with effective microorganisms and Bordeaux mixture (CM5+EM+BD) and compost @ 7 ton ha-1 enriched with effective microorganisms and Bordeaux mixture (CM7+EM+BD) and control (CN) at Tepi in 2019 and 2020 main cropping seasons.

Association of yield and disease parameters

Calculating correlation between and among final disease incidence, AUDPC, disease progress rate, yield and yield related components was important since change of either of the parameters influenced the response of the other during the experiments. For studying relationship between disease and yield parameters, simple correlation analysis was used.

Different levels of associations were observed among disease incidence, AUDPC, disease progress rate, yield and yield related components and presented in Tables 3.

Standardized area under disease progress curve and final disease incidence were positively and highly significantly ($P \leq 0.01$) correlated (r = 0.892**). This is in agreement with Binyam *et al.*

(2014), the epidemiological parameters PSI and AUDPC were highly correlated. In most cases, the negative correlation of rhizome yield with bacterial wilt development was found to be stronger with AUDPC than with final disease incidence. Yield and AUDPC were negatively and highly significantly (P≤ 0.01) correlated (r = -0.951**). Such finding could indicate the presence of strong negative effects of bacterial wilt on rhizome yield of ginger. Yield and final disease

incidence (r = -0.957**). More or less similar phenomenon was noted for the correlation between disease parameters and yield related components of ginger. This complies with the findings of Guji et al. (2019) who found that bacterial wilt severity, AUDPC and infection rates are strongly and negatively correlated with ginger rhizome yields.

Table 3. Coefficients of correlation (r) between yield and disease parameters on ginger at Tepi, Ethiopia during the 2019 and 2020 main cropping season.

Parameter	RL (cm)[1]	NFPR[1]	Yield (ton ha⁻¹)	PSI f (%)[1]	AUDPC[1]	Dpr (units day⁻¹)
RL (cm)	1					
NFPR	0.975**	1				
Yield (ton ha⁻¹)	0.849**	0.885**	1			
PSI f (%)	-0.860**	-0.873**	-0.957**	1		
AUDPC[1]	-0.736**	-0.796**	-0.951**	0.892**	1	
Dpr (units day⁻¹)	-0.922**	-0.835**	-0.824**	0.911**	0.713**	1

[1] RL= rhizome length, NFPR= no. of finger per rhizome, PSI f= final disease severity index, AUDPC = area under disease progress curve of bacterial wilt incidence of ginger. **Level of statistical significance at P ≤ 0.01. ns non-significant at P > 0.05.

Conclusion

Based on the results obtained from this study, it can be concluded that bacterial wilt severity, AUDPC, progress rates and curves were strongly influenced by soil amendments with compost enriched with effective microorganisms and integrated with Bordeaux mixture. Soil amendments with compost at the rate of 7 ton ha⁻¹ enriched with effective microorganisms and Bordeaux mixture before planting highly reduced bacterial wilt of ginger. It is therefore, promising to amend the soil for several weeks before planting with compost at the rate of 7 ton ha⁻¹ along with Bordeaux mixture and other crop management strategies to manage bacterial wilt of ginger in the face of the current and future climate dynamics in southwestern Ethiopia. Further studies on integrated management of bacterial wilt should be continued. In addition, more efforts should be done with compost quality, quantity and its effects on soil physico-chemical properties.

Acknowledgements

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