Agro Bali : Agricultural Journal
Vol. 5 No. 3: 414-421, November 2022
e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

Management of Ginger Bacterial Wilt (*Ralstonia solanacearum*) Epidemics through Soil Solarization and Botanical Mulch at Tepi, Southwestern Ethiopia

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Article history: submitted: March 4, 2022; accepted: August 3, 2022; available online: November 26, 2022

Abstract. Ginger is a valuable revenue crop for Ethiopian farmers in many sections of the country. In Ethiopia, bacterial wilt disease is a serious constraint to ginger output. Heavy losses are common as a result of the disease, with extra losses happening as a result of the disease's boundaries, which prevent continued production in infested areas. To investigate the impact of soil solarization and botanical mulch on epidemics of bacterial wilt of ginger in Tepi, Southwestern Ethiopia, field studies were done throughout the 2019 and 2020 main cropping seasons. Four different soil solarization periods were used: two weeks, four weeks, six weeks, and eight weeks before planting, with four different botanical mulches: vetivar grass, lemon grass, Chinese chive, and lantana camara added after planting. The control plots were not solarized nor mulched. Treatments were placed in factorial arrangements with three replications using a randomized full block design. In comparison to the control, soil solarization combined with lemon grass mulch treatment dramatically reduced bacterial wilt mean severity by 22.1 percent to 42.2 percent. These treatments also significantly lowered the rate of AUDPC and disease progression. When compared to control, soil solarization for eight weeks combined with lemon grass mulch resulted in the lowest disease severity (42.2%) and AUDPC (33.8%). Overall, the findings of this study showed that using a mixture of soil solarization and botanical mulches to slow down bacterial wilt outbreaks and recover ginger production and productivity, along with other crop management strategies, was effective.
Keywords: bacterial wilt; botanical mulch; epidemics; ginger; soil solarization

INTRODUCTION

Ginger contributes significantly to Ethiopia's local economy. It has export potential, adds value to the economy, creates a lot of local job opportunities, has an impact on women empowerment, is accessible, and the Ethiopian government prioritizes small farmers (Vijayalaxmi and Sreepada, 2012). Bacterial wilt of ginger, caused by the soil-borne bacteria Ralstonia solanacearum, is a serious issue in Ethiopia's ginger-growing regions. This disease is common in the late rainy season. The infected plant had inward curling, yellowing, and browning across the entire branch, and was nearly dead. The base of the yellow stem (shoot) is water-soaked and readily torn off from the underground rhizome, and the cut stem or rhizome exudes a milky bacterial slime (Habtewold *et al*., 2015).

Once Ralstonia solanacearum has established itself in the field, controlling the bacterial wilt is difficult. Because of its wide host range, lengthy existence in the soil, feast in a variety of ways (planting materials, irrigation water, farm instruments, and vectors), and lives in vegetation as a dormant infection with hereditarily diverse strains (APS, 2005). Knowing these characteristics of the disease, on the other hand, is critical for examining the variables that regulate disease development and developing an effective disease management strategy. Soil solarization is a non-chemical method of reducing soil-borne pests by trapping radiant energy from the sun at high temperatures, and a 5% increase in soil temperature lowers bacterial infections (Kumar et al., 2003).

During the hot season, soil solarization raises soil temperature to levels that kill many disease-causing organisms (Elmore et.al., 1997). It accelerates the breakdown of organic matter in the soil, which has the extra benefit of increasing the availability of soluble nutrients including nitrogen (N03-, NH4+), calcium (Ca++), magnesium (Mg++), potassium (K+), and fulvic acid to plants (Wilen *et al*., 2007). Plants cultivated on solarized soil develop faster and provide greater and better quality yields, according to a study by Stapleton and Wilen (2010). Depending on the site, the top 6 inches of soil can reach temperatures of up to 140°F when done appropriately. The plastic sheets protect the soil for 4 to 6 weeks, allowing the sun's radiant energy to be trapped in the soil,

 e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

heating the top 12 to 18 inches and eradicating a range of soil-borne pests like weeds, diseases, nematodes, and insects (Wilen and Elmore, 2007).

Mulching the beds with green botanical leaves/organic wastes is necessary to prevent soil splashing and erosion caused by heavy rain, which reduces bacterial disease feasts. It also adds organic matter to the soil, inhibits weed growth, and keeps moisture in the soil throughout the cropping season. It can help restore soil structure by increasing the availability of nitrogen and other critical elements for healthy plant growth and disease management. Soil solarization and mulching, in most cases, leaves no chemical residue and is a straightforward way for reducing bacterial wilt pathogen inoculum in the soil. As a result, the goal of this research was to prevent the spread of ginger bacterial wilt epidemics and increase ginger yield rhizome by soil solarization and botanical mulching.

METHODS

Experimental sites

During the 2019 and 2020 main cropping seasons, the trial was conducted at Tepi Agricultural Research Centre (TARC) in Ethiopia. TARC is in Yeki District, Southern Nations Nationalities and Peoples' Regional State, 600 kilometers southwest of Addis Ababa, Ethiopia's capital. It is situated at an altitude of 1200 meters above sea level, between 35o08' longitude and 7o08' latitude. The average maximum and minimum temperatures are 15 and 30 degrees Celsius, respectively. The annual rainfall averages 1630 mm (Guji et al., 2019).

Experimental materials and treatments

Solarization of the soil for 2, 4, 6, and 8 weeks before planting was tested for its effect on bacterial wilt alone and in combination with botanical mulch made up of Vetiver grass, Lemongrass, Chinese chive, and Lantana camara at a rate of 10 tons per hectare. Cultural management strategies such as soil solarization for various weeks prior to planting and mulching after planting with various botanicals were used to minimize pathogen inocula and prevent disease epidemics.

To prevent the sheet from ripping during soil solarization, the solarized plot was well cultivated and smoothed. After that, all plots were moistened and covered with a clear and transparent polyethylene sheet of 15 mm thickness for 2, 4, 6, and 8 weeks under direct sunlight, with un-solarized plots serving as a control (Stapleton and Wilen, 2010). All free ends were buried and then the soil around them was compressed to prevent leakage of heated air or moisture from solarized plots. The first mulching was done at the time of planting using green leaves of Vetiver grass, lemongrass, chinese chive and Lantana camara (please be consistent, check all the use of capital alphabet) @ 10 tons/ha and the un-mulched plots were used as control. The experiment was depend on natural epidemics of bacterial wilt, since the sites are hot spot areas of the disease and the previous history of the field also confirm it.

Experimental design and trial management

A total of 17 treatments including controls were laid out in a randomized complete block design in a factorial arrangements with three replications. Planting was conducted on a gross plot size of 4 m^2 (2 m width and 2 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 44.5 m x 8 m (356 m^2). The four central rows were used 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 evaluated at 15-days interval starting from 60 days after

 e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

planting DAP). Plants that displayed either whole or partial wilting were considered as wilted and staked to avoid double counting in succeeding assessments. Wilt incidence for each treatment was then counted as percentage of total number of plants emerge. Disease progress was plotted as the disease incidence against time. The area under diseases progress curve (AUDPC) from disease incidence was calculated using the formula recommended by Campbell and Madden (1990):

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

Where, n is total number assessment times, t_i is time of the i^{th} assessment in days from the first assessment date, x_i is percentage of disease incidence at i^{th} assessment. AUDPC was expressed in %-days since incidence (x) was expressed in percent and time (t) in days (Campbell and Madden, 1990). AUDPC values were standardized by dividing the values to the epidemic periods (Campbell and Madden, 1990).

Data Analysis

Data on bacterial wilt incidence was scrutinized. Analysis of variance (ANOVA) was done for disease incidence and r AUDPC to see the outcome 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 converted disease incidence data were regressed over time (DAP) to decide the rate. The golly of fit of the models was established based on the degree of the coefficient of determination (R^2) and residuals (SE) reached using the model (Campbell and Madden, 1990). The slope of the regression line foreseeable the disease progress rate.

Regression was considered using Minitab (Release 15.0 for windows®, 2007). Least significant difference (LSD) was used for mean separation at 5% level of significance. ANOVA was executed using General Linear Model (GLM) of SAS procedure version 9.3 (SAS, 2014). Association of final disease incidence and rAUDPC with yield and yield constituents was examined using correlation analysis. The two years were reflected as the same because of homogeneity of variances as confirmed using Bartlett's test (Gomez and Gomez, 1984) and the F-test was non-significant for most of the parameters calculated in each year. Thus, data were pooled for analysis.

RESULTS AND DISCUSSION

Disease incidence

Pooled analysis of disease incidence data revealed non-significant (P>0.05) variation between 2019 and 2020 main cropping season. Therefore, data of both years were pooled and analyzed. Interaction effect of soil solarization with botanical mulch on disease incidence showed highly significant (P<0.001) difference at the last date of assessment. The maximum (50.02%) disease incidence was documented from un-solarized and un- mulched control plots, followed by soil solarization for six weeks plots and mulched with lantana camara, which scored 40.14% at final date of assessment (120 DAP). Meanwhile, the lowest (29.0%) level of disease incidence was obtained from plots that were solarization for eight weeks and mulched with lemon grass at 120 DAP. Similar trend was found on the rAUDPC (Table 1). This might be attributed to soil solarisation increased the tilth and nutrient status of soil. It was previously reported that microorganisms beneficial to plant growth were motivated (*Rhizobium spp.* and *Trichoderma spp.*) or were fewer affected (*Bacillus spp*. and Actinomycetes) through soil solarization compared to pathogenic organisms (Stapleton and Devay, 1982; Pokharel, 2013).

Lower wilt incidence and rAUDPC values found in plots treated with soil solarization for eight weeks and mulched with lemon grass might be credited to accessibility of nutrients, relief of essential oils and boosted population of beneficial soil microorganisms. Available nutrients might increase crop potency and essential oils might

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

incorporate lethal chemicals that consequently reduced wilt epidemics. In line with this result, study conducted by Guji *et al*. (2019) reported that addition of potassium fertilizer (100 kg ha^{-1}) combination with soil solarization and lemon grass abridged bacterial wilt incidence by 42.5% over the control. Another study found that bio-fumigation with Brassica spp., palmarosa, and lemongrass amended by mulching released volatiles of essential oils into pathogen-infected fields, which reduced the incidence of bacterial wilt (Arthy et al., 2005). Those plants have high glucosinolate and upon mulching they hydrolyse to antimicrobial isothiocyanates, nitriles or thiocyanates, thereby reducing *R. solanacearum* populations in the soil and wilt incidence on the crops (Blok *et al*., 2000).

Disease Progress Rate

The rates of disease development and bacterial wilt parameter estimates differ depending on the soil solarization time and mulch type. Disease progress rates measured in the vetivar grass mulch ranged from 0.024 to 0.028 units/day (Table 2), whereas in the lemon grass mulch, the rates ranged between 0.011 and 0.025 units/day. In Chinese chive mulch, the rates were 0.012 to 0.025 units/day and 0.015 to 0.027 unit/day in lantana camara mulch. It was also obvious that the rate of disease progressed relatively lower on non-solarized and non-mulched plots (0.032 units/day) than solarized and mulched plots over years. The results indicated that the rate of bacterial wilt progressed was slower when the soil solarization for four weeks was applied in integration with the lemon grass mulch. This strategy could aid in increasing the synergistic effect of each management practice in preventing the spread of the wilt epidemic.

Previous research has also shown that combining soil solarization with other cultural techniques slows disease progression by increasing plant resistance to the pathogen. Soil solarization mixed with potassium fertilizer and lemon grass, for example, increases plant resistance and slows disease progression in this situation (Guji *et al*., 2019).

Table 1. Interaction effects of soil solarization and botanical mulch on disease incidence (%) of bacterial wilt (*R. solanacearum*) and standardized area under disease progress curve (%-days) at Tepi, Ethiopia during the 2019/20 cropping season

Treatment combination[1]	Disease incidence (%) and rAUDPC (%-days) centered							
	Week 2		Week 4		Week 6		Week 8	
	PDI_f [2]	rAUDPC [3]	PDI_f [2]	rAUDPC [3]	PDI_f [2]	rAUDPC [3]	PDI_f [2]	rAUDPC [3]
VG	34.68^{defg}	23.05^{fgh}	38.26^{bcd}	25.46^{cde}	39.41^{bc}	24.08^{efg}	33.76^{efgh}	24.7^{6def}
LG	39.1^{bc}	24.17^{efg}	33.27^{fghi}	22.54^{gh}	30.33^{hi}	21.63hi	29.0^{i}	20.3^{i}
Ch	37.57^{bcde}	25.18^{cde}	36.06^{cdef}	28.95^{b}	31.56ghi	24.38^{ef}	29.53^{i}	22.10^{h}
LC	39.85^{bc}	26.42^{cd}	39.08^{bc}	26.63^{c}	40.14^{b}	25.6^{cde}	38.13^{bcd}	24.86^{cde}
Control	50.2^{a}	33.43^{a}	50.2^{a}	33.43^{a}	50.2^{a}	33.43^{a}	50.2^{a}	33.43^{a}
LSD (0.05)	3.87	1.8						
CV (%)	6.37	4.34						

[1] VG = vetivar grass; LG = lemon grass; Ch = Chinese chive; LC = lantana camara. [2]Percent disease incidence at 120 days after planting (DAP). [3]rAUDPC = standardized area under disease progress curve

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

of ginger bacterial wilt. Means followed by same letter(s) within a column are not significantly different at 5% level of significance.

Table 2. Effect of soil solarization and botanical mulch on the rate of disease progression (r) of ginger bacterial wilt (*R. solanacearum*) and parameter estimations at Tepi, Ethiopia during the 2019/20 cropping season.

Botanical mulch	Soil solarization period [1]	Disease progress rate (r) at Tepi			
		Disease progress rate (unit day^{-1}) [2]	SE of rate [3]	SE of intercept [4]	R^2 (%) [5]
Vetivar grass	Control	0.032	0.278	0.278	90.7
	W2	0.025	0.138	0.138	96.2
	W4	0.028	0.078	0.078	98.7
	W6	0.024	0.124	0.124	96.0
	W8	0.024	0.140	0.140	94.6
Lemon grass	Control	0.032	0.278	0.278	90.7
	W2	0.025	0.063	0.063	98.9
	W4	0.020	0.107	0.107	95.5
	W6	0.018	0.118	0.118	93.4
	W8	0.011	0.073	0.073	93.8
Chinese chive	Control	0.032	0.278	0.278	90.7
	W2	0.012	0.066	0.066	95.4
	W4	0.022	0.057	0.057	98.9
	W6	0.025	0.042	0.042	99.5
	W8	0.022	0.202	0.202	89.5
Lantana camara	Control	0.032	0.278	0.278	90.7
	W2	0.015	0.155	0.155	88.0
	W4	0.027	0.134	0.134	96.6
	W6	0.026	0.125	0.125	97.0
	W8	0.024	0.117	0.117	96.8

[1]W2 = soil solarization for two weeks; W4 = soil solarization for four weeks; W6 = soil solarization for six weeks; W8 = soil solarization for eight weeks; [2]Disease progress rate obtained from regression line of disease incidence with time of assessment (days). [3]Standard error of rate. [4]Standard error of parameter estimates. [5]Coefficient of determination of the Logistic model.

Disease Progress Curve

For each mulch type, disease development curves of bacterial wilt incidence vs DAP) were made independently with varying weeks of soil solarization before planting (Figure 1). Disease severity rose from the outset to the end severity documented during the study periods, according to each curve for soil solarization duration and mulch type. The disease progression curve for each solarization period also revealed that disease progression differed slightly depending on the type of mulch employed. In control plots, disease incidence was quite high, with relatively steep progressive curves and the highest levels of bacterial wilt severity. Soil solarization for two weeks, both alone and in combination with lantana camara treated plots, resulted in curves that were identical to control plots. The disease progression curves of plots treated with soil solarization for eight

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

weeks and lemon grass mulching treatments, on the other hand, moved slowly and showed the lowest levels of bacterial wilt severity at various days after planting. A recent study found that during soil solarisation, beneficial changes occur in the structure of the soil, the solubility of mineral elements accessible for plant and microbial growth, and the populations of soil-borne microbes, all of which are consistent with this direction (Katan et al., 1990). Plant pathogens' inoculum concentration, as well as their aggressiveness and survival, are affected by these changes. During and after soil solarization, changes in the populations of other soil-borne microorganisms may influence disease control and plant development.

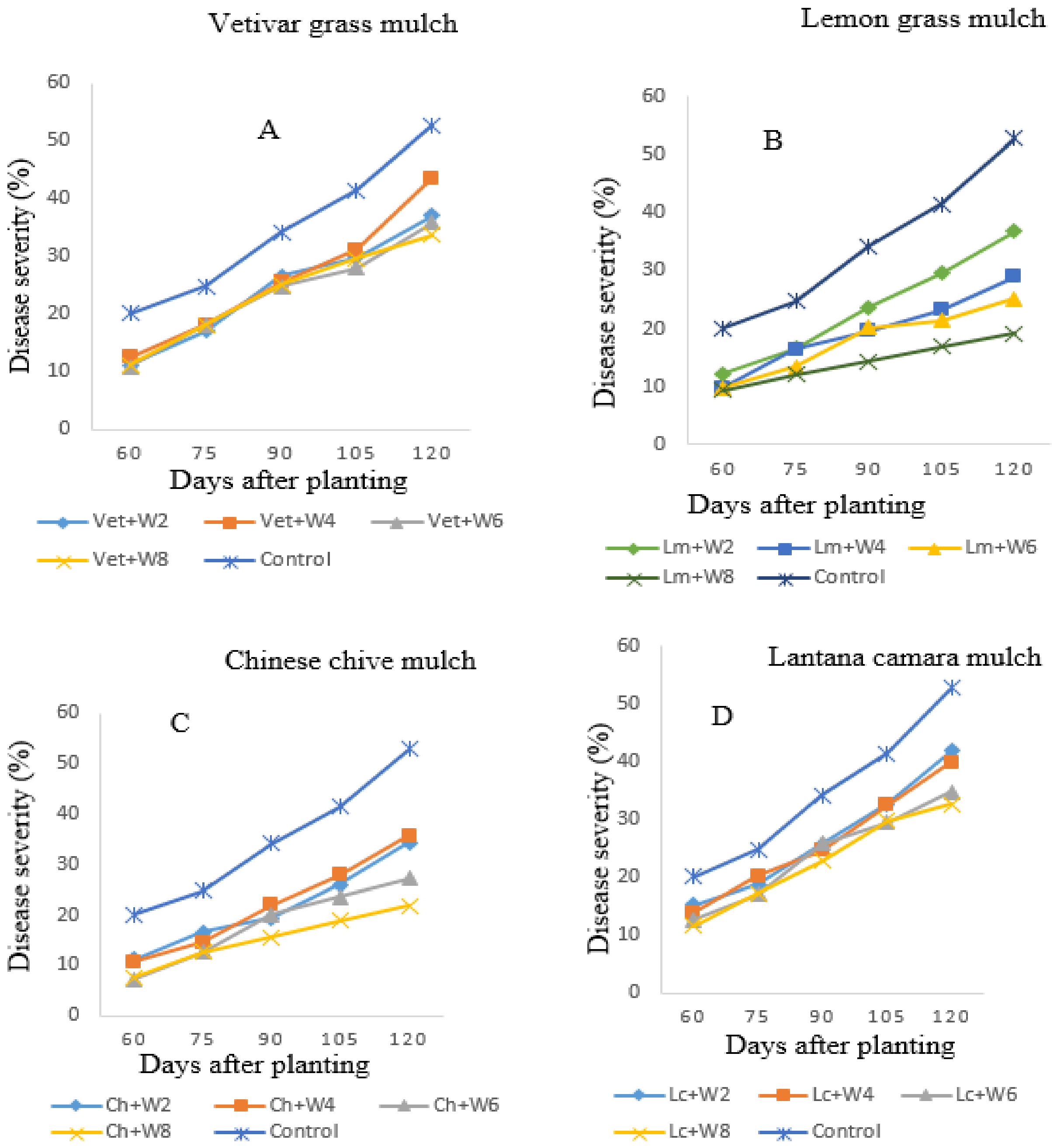

Figure 1. Ginger bacterial wilt (*Ralstonia solanacearum*) disease progress curves as affected by soil solarization for (two weeks (W2), four weeks (W4), six weeks (W6) and eight weeks (W8), and botanical mulch with (Vet (vetivar grass), Lm (lemon grass), Ch (chinase chive), and Lc (lantana camara) at Tepi in 2019 and 2020 main cropping seasons.

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

Association of Yield and Disease Parameters

It was critical to calculate the link between and among final disease incidence, rAUDPC, disease progression rate, yield, and yield-related components, because changing one of the parameters throughout the trial will affect the reaction of the other parameters. Simple correlation analysis was utilized to investigate the association between disease and yield measures. Tables 3 show the various levels of relationships found between disease incidence, rAUDPC, disease progression rate, yield, and yield-related components.

The standardized area under the disease progression curve (r = 0.792**) was absolutely and highly substantially (P≤0.01) linked with the final disease incidence. The epidemiological indices PSI and AUDPC were highly associated, which agrees with Biniam *et al*. (2014). In furthermost cases, the negative alliance of rhizome yield with bacterial wilt progress was found to be stronger with rAUDPC than with final disease incidence. Yield and rAUDPC were significantly (P≤ 0.01) correlated (r =-0.663**). Such result indicated the presence of robust negative effects of bacterial wilt on rhizome yield of ginger. Yield and final disease incidence (r = -0.522**) also shows negative association. Similar results was noted for the correlation between disease parameters and ginger yield associated components. This study corroborated Guji et al (2019) results that bacterial wilt severity, AUDPC, and infection rates are all strongly and negatively related to ginger rhizome yields.

Table 3. Coefficients of correlation ® 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 (t ha^{-1})	PSI f (%)[1]	rAUDPC[1]	Dpr (units day^{-1})
RL (cm)	1					
NFPR	0.069^{ns}	1				
Yield (t ha^{-1})	0.423**	0.334**	1			
PSI f (%)	-0.366**	-0.538**	-0.522**	1		
rAUDPC[1]	-0.549**	-0.516**	-0.663**	0.792	1	
Dpr (units day^{-1})	0.026^{ns}	-0.065^{ns}	0.184^{ns}	-0.078^{ns}	-0.081^{ns}	1

[1] RL= rhizome length, NFPR= no. of finger per rhizome, PSI f= final disease severity index, rAUDPC = standardized 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.

CONCLUSIONS

Based on the findings of this study, it can be stated that soil solarization and botanical mulch had a substantial impact on bacterial wilt severity, AUDPC, progress rates, and curves. Soil solarization for eight weeks before planting and botanical mulching with lemon grass after planting significantly reduced bacterial wilt of ginger. As a result, it has been confirmed that soil solarization for several weeks prior to ginger planting and the application of lemon grass mulch for several weeks after planting, in addition to other crop management strategies to manage bacterial wilt of ginger, can be one strategy for overcoming current and future climate dynamics in Southwestern Ethiopia. Additional or new research on the combined

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v5i3.935

management of ginger bacterial wilt is needed.

ACKNOWLEDGEMENTS

The Ethiopian Institute of Agricultural Research supported the research. We thank the spice section of the Tepi Agriculture Research Center for all of their technical and field help throughout field preparation, observation, and data collecting.

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