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Evaluation of various fungicides and soil solarization practices for the management of common bean anthracnose (*Colletotrichum lindemuthianum)* and seed yield and loss in Hararghe Highlands of Ethiopia

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The study was undertaken to evaluate the effect of integrated management of bean anthracnose through soil solarization and various fungicides applications on epidemics of the disease and to determine the effect of integrated management of bean anthracnose on seed yield and loss of common bean variety Mexican-142. Field experiments were conducted at Haramaya and Hirna in 2010 main cropping season of Ethiopia. Soil solarization was integrated with mancozeb and carbendazim seed treatment and with foliar sprays of carbendazim at the rate of 0.5 kg/ha at 10 and 20 days intervals. The experiment was arranged in 2 × 3 × 3 split-split plot design with three replications. A total of 18 treatments were evaluated. There was a significant difference in the anthracnose incidence, severity, seed yield and yield loss. At Haramaya, severe epidemics of anthracnose developed. Seed treatments, foliar sprays and soil solarization alone as well as their interactions did not significantly affect pods per plant and seeds per pod at both locations. The combinations of solarized soil + mancozeb seed treatment + carbendazim foliar spray at 10 days intervals produced seed yield of 3.8 t ha^{-1} at Haramaya and 3.6 t ha^{-1} at Hirna over the control. Integrations of soil solarization, seed treatments and foliar spray were found to be effective in reducing bean anthracnose epidemics and increasing yield.

Key words: Carbendazim, foliar spray, Mancozeb, *Phaseolus vulgaris,* seed treatment.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an important legume crop in the daily diet of more than 300 million of the world's population and an important food and cash legume in the East and the Great Lakes region of Africa (Hadi et al., 2006). In Ethiopia, common bean is mainly grown in Hararghe highlands (eastern), southern, south-western, and the Rift Valley regions (Habtu et al., 1996; CSA, 2005). In Ethiopia, the national average yield of common beans is low ranging from 0.615 to 1.487 tons/ha between 2004 and 2010 (CSA, 2010), which is far below the corresponding yield recorded at research sites (2.5 to 3 tons ha^{-1}) using improved varieties (EPPA, 2004). The major biotic constraints to common bean production in Ethiopia are anthracnose, rust, bacterial blight, angular leaf spot, ascochyta blight and bean common mosaic virus (Habtu, 1987). Anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. and Magnus) Lams-Scrib is one of the most devastating

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seed-borne diseases of common bean in Ethiopia (Schwartz et al., 1983). The crop is vulnerable to the attack of the pathogen at all the stages, from seedling to maturity, depending on the prevalence of favorable environmental conditions that are essential for the initiation and further development of the disease and causes an estimated yield loss of 63% in Ethiopia (Beshir, 1997).

The management of primary inoculum sources is key strategy in controlling bean anthracnose (Hall, 1994). The use of seed treatment is an important tactic for disease control in general and for anthracnose management in particular (Freeman et al., 1997). However, seed treatment alone could be inefficient and would often require follow-up applications of contact or systemic foliar fungicides (Koch, 1996; Tesfaye and Pretorius, 2005). Furthermore, chemical disease control should form part of integrated disease management system including physical practices and manipulation of environmental conditions. Soil solarization has been identified as hydrothermal process and its success depends on moisture for maximum heat transfer to soil-borne organisms; it is a function of time and temperature relationships. The thermal decline of soil-borne organisms during solarization depends on both the soil temperature and exposure time, which are inversely related. The effectiveness of solarization for disinfesting soil and increasing plant growth and development depends on soil colour and structure, air temperature, soil moisture, length of day, intensity of sunlight, and the thickness and light transmittance of the plastic film (Stapleton and DeVay, 1982).

Although bean anthracnose is rampant in *Phaseolus* beans of Hararghe highlands, its economic impact has not been evaluated. In addition to assessment of various management methods like chemical and use of physical practices are urgently needed in order to provide an alternative to other control methods. However, management of bean anthracnose through the effect of soil solarization has not been studied so far in Ethiopia. Much work still needs to be done in Ethiopia, particularly in Hararghe highlands, especially with the bean anthracnose through various fungicides and the effect of soil solarization, since the disease is still causing much devastation on the crop. Therefore, the present study was undertaken to evaluate the various fungicides and the effect of soil solarization for the integrated management of common bean anthracnose and on seed yield loss in Hararghe highlands of Ethiopia under field condition.

MATERIALS AND METHODS

Description of the study sites

The study was conducted at Haramaya University experimental field in the main campus and Hirna Sub-Research Station. Haramaya is located at 9°26'N latitude, 42°30'E longitude and at an altitude of 1980 m. a. s. l. The site receives mean annual rainfall of 780 mm, with mean minimum and maximum temperatures of 8.25 and 24.4°C, respectively. On the other hand, Hirna is located at 9°12'N latitude, 41°4'E longitude and at an altitude of 1870 m. a. s. l. The site receives a mean annual rainfall of 990 to 1010 mm with an average temperature of 24°C.

Experimental design and materials

A split-split plot design with three replications was used at both experimental sites. Total of 18 treatment combinations were evaluated. Main plots were assigned to soil solarization, sub-plots to frequencies of foliar sprays and sub-sub plots to seed treatments. Each sub-sub-plot (2.4 × 2 m) consisted of six rows, and distance between rows and between plants were 40 and 10 cm, respectively. There were 20 plants per row and the four central rows were harvested for determining yield. There were 0.8 m space between sub-sub plots, 1 m between sub-plots and 1 m between main plots. The bean variety Mexican-142, which is susceptible to anthracnose (Beshir, 1997) was used for both experiments; in addition, mancozeb was used for seed treatment at 3 g/kg while carbendazim was used for seed treatment at 2 g/kg and as foliar spray at 0.5 kg/ha.

Soil solarization treatment was performed as follows: After ploughing the plots, the area to be solarized was leveled and made free from weeds, debris, or large clods that could raise the plastic-off ground. The soil was turned over by hand and raked smooth to provide an even surface. Transparent plastic sheeting that was 0.0254 mm thick laid by hand (that is, close to the soil), and anchored to the soil by burying the edges in trench around the treated area. The plastic was kept in place from last week of May to last week of June for 1 month to allow the soil to heat to the greatest depth as possible.

Foliar spray with carbendazim (Bavistin DF) at the rate of 0.5 kg ha^{-1} (CIAT, 1988), and at three frequencies (including control) was used as the third component of the experimental treatments. Frequencies consisted of spraying at 10 day-interval as of disease onset, spraying at 20 day-interval and no spray. Spraying of fungicide was started 42 days after sowing (DAS) at Haramaya and 50 DAS at Hirna, that is, when the first symptoms of the diseases appeared. The experiments relied entirely on natural infection, because both sites are hot spot areas for the disease. Two seed treatments, namely mancozeb (contact) and carbendazim (systemic) were tested at doses of 3 and 2 g/kg of seeds, respectively. Seeds were treated with mancozeb or carbendazim 24 hours before sowing and untreated seeds served as control. Planting was done on July 5, 2010 at Haramaya University and July 13, 2010 at Hirna Sub Research Station on previous plots sown of common bean to get increased disease pressure.

Data collection and analysis

Anthracnose incidence was assessed as of disease onset at 10 day-intervals at both locations. Using 10 randomly pre-tagged bean plants in the four central rows, severity was rated using standard disease scales of 1-9 (CIAT, 1988), where, 1= no visible disease symptoms and 9= more than 25% of leaf surface area with large coalescing and generally necrotic lesions resulting in defoliation. The severity grades were converted into percentage severity index for analysis (Wheeler, 1969).

$$PSI = \frac{\text{Sum of numerical ratings} \times 100}{\text{No.of plants scored} \times \text{maximum score on scale}}$$

Seed yield was obtained from the four central rows of each

Table 1. Average temperatures of soil during four weeks of soil solarization at different depth at Haramaya and Hirna.

Weeks	Depth (cm)	Haramaya (°C)		Hirna (°C)	
		Solarized	Non solarized	Solarized	Non solarized
1	5	58.2	31.6	61.8	33.2
	15	58.0	31.2	59.1	32.9
2	5	54.7	29.7	57.9	31.1
	15	52.5	28.9	55.3	30.5
3	5	53.5	26.1	56.7	28.8
	15	53.9	27.6	55.2	26.7
4	5	48.2	25.1	53.1	25.2
	15	45.7	24.7	52.4	23.3

experimental plot; it was converted into tons per hectare (after adjusting to 10% seed moisture content using moisture meter). In addition, soil temperature for periods of soil solarization was recorded using digital soil thermometer by inserting into the soil at 5 and 15 cm depths (Table 1).

All data were subjected to analysis of variance using General Linear Model (GLM) procedure of SAS statistical version 9.2 software (SAS, 2009) except mean separation for significant interaction effects which was carried out using GenStat version 12.1 software (GenStat, 2009). Least Significant Difference (LSD) was used to separate means.

RESULTS AND DISCUSSION

Solarization was undertaken from last week of May to last week of June and soil temperature for period of solarization was recorded using soil thermometer. Average temperatures of soil during four weeks of soil solarization at different depth at both sites were described in Table 1. Average temperatures of soil were variable across sites, solarization and depth. Soil temperatures were warmer at Hirna than at Haramaya, because there was a cloud and rainfall was more variable across sites during period of solarization. According to Stapleton (1997), soil solarization is based on utilizing the solar energy for heating soil mulched with a transparent sheet, reaching a level of 40 to 55°C in the upper soil layer. There is a gradient of temperatures from the upper to lower soil layer during the appropriate season. The temperature elevation is facilitated by wetting the soil before and/or during mulching with the transparent sheet. The main factor involved in the pest control process is the physical mechanism of thermal killing.

Incidence of anthracnose

Incidence of bean anthracnose showed significant difference between solarized and non-solarized plots at 52 days after sowing (DAS) ($P<0.05$) and highly significant difference at 62, 72, 82 and 92 DAS ($P<0.01$) at Haramaya and all four successive disease assessments at Hirna ($P<0.01$). In these experiments, disease incidence in solarized soil decreased as compared with non-solarized soil, this might be due to anthracnose pathogen population in the soil were reduced by heat. As reported by Dillard and Cobb (1993), in areas where beans are consecutively cropped, over seasonal inoculum can initiate epidemics of bean anthracnose. The primary inoculum from infested debris was relatively more damaging than other inoculum source, causing early epidemic development and yield reduction (Fininsa and Tefera, 2002). The different seed treatments showed highly significant ($P<0.01$) difference in terms of anthracnose incidence at 52, 62 DAS at Haramaya, 60 days after plantin at Hirna, and showed significant difference ($P<0.05$) 72 DAS at Haramaya, 70, 80 and 90 DAS at Hirna (Table 2). At Hirna, the maximum incidence was recorded from control. While, lower levels of incidence were encountered for seed treatments with mancozeb and carbendazim, respectively at final date of incidence assessment. This might be due to the above fungicides able to reduce primary source of anthracnose inoculum on/in the seeds.

There was no significant variation in disease incidence between frequencies of carbendazim foliar sprays at 62, 72, 82 and 92 DAS dates of disease assessment at Haramaya except initial date 52 DAS ($P<0.01$), while significant differences were observed at all dates of assessment at Hirna ($P<0.01$) (Figure 2). Lower mean incidence was calculated from carbendazim foliar sprays at 10 (16.1%) and 20 (17.2%) days' intervals at initial date of incidence assessment 60 DAS. The difference in incidence might be due to the fact that frequent fungicides spraying could reduce spreading of secondary inoculum between beans. Pastor-Corrales and Tu (1989) reported that preventive spraying of foliage at flower initiation, late flowering and pod-filling with protective systemic fungicides like maneb, zineb, benomyl, carbendazim, and fentin hydroxide have been used to

Table 2. Effect of soil solarization, seed treatment and foliar sprays on incidence of common bean anthracnose at Haramaya and Hirna during 2010 main cropping season.

Treatments	Incidence at Haramaya (%)		Incidence at Hirna (%)	
	Initial (52 DAS)	Final (92 DAS)	Initial (60 DAS)	Final (90 DAS)
Soil solarization				
Solarized	19.6	60.7	15.9	45.6
Non-solarized	24.4	72.2	21.5	50.7
CV (%)	9.1	9.6	7.3	11.9
LSD (5%)	3.6	6.5	3.1	3.7
Foliar spray				
CFS10	18.9	63.9	16.1	45.6
CFS20	19.4	66.1	17.2	47.2
Control	24.4	72.2	22.8	51.7
CV (%)	15.7	13.0	16.1	12.4
LSD (5%)	4.4	7.9	3.8	4.4
Seed treatment				
MST	18.9	63.3	15.6	43.3
CST	22.8	66.7	17.8	47.2
Control	24.4	72.2	22.8	53.9
CV (%)	14.2	13.4	11.8	15.8
LSD (5%)	4.5	7.9	3.8	4.5

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and; DAS=Days after sowing; 20=Carbendazim foliar spray at 10 and 20 days interval; LSD=Least significant difference.

control bean anthracnose. As reported by Sindhan and Bose (1981), carbendazim was effective as seed dressing and foliar sprays, and these treatments increase seed germination and seed yield, while reducing disease incidence. Study conducted by Gwary (2008) support present experiment in that sorghum anthracnose can best be managed on the early susceptible variety by integrating seed dressing treatment supplemented with foliar sprays.

Severity of anthracnose

Percent severity index was higher in non-solarized soil as compared to solarized soil at both locations. There were significant interaction effects (*P<0.01*) between levels of soil solarization and seed treatment in reducing PSI at 52, 62 72 DAS at Haramaya and non significant difference at 82, 92 DAS at Haramaya and all dates of severity assessment at Hirna. There were significant interaction effects between soil solarization × foliar sprays (*P<0.01*) at 52, 62 and 92 DAS at Haramaya and (*P<0.05*) 70, 80 and 90 DAS at Hirna. Percentage severity index was not significantly different at the remaining dates of severity assessment at both locations. At final date of assessment, the combination of solarized soil with carbendazim sprays at 10 and 20 days intervals minimum over the control at Haramaya. Soil solarization alone or with low dosages of a fungicide, biocide and bio-agent resulted in complete reduction of the pathogen; soil solarization integrated with applications of *T. harzianum*, carbendazim and neem was the most effective treatment (Chakraborty et al., 2008).

There were significant interaction effects between seed treatment × foliar sprays in reducing severity (*P<0.01*) at Haramaya which were no significant at all dates of severity assessment at Hirna. The combination of mancozeb seed treatment with spray frequencies of carbendazim at 10 and 20 day intervals showed much lower over the control at final date of disease assessment at Haramaya. Likewise, the interactions of carbendazim seed treatment with carbendazim spray at intervals of 10 and 20 days much minimum over the control on the final date of severity assessment at Haramaya (Table 3). In connection with this, Jenny (2010) reported that the seed treatment alone provide effective control for a maximum of four to six weeks after sowing, but do not provide absolute control. Current study also showed that combination of seed treatment with foliar spray was more effective in reducing severity than seed treatment or foliar applications of fungicides alone.

There were significant interaction effects among soil solarization × seed treatment × foliar sprays (*P<0.01*) at 52, 72 and 82 DAS at Haramaya and non significant at the remaining dates at Haramaya and all dates disease assessment at Hirna. The interactions of solarized soil × mancozeb seed treatment × carbendazim foliar sprays at 10 and 20 days gaps reduced PSI at initial date of

Table 3. Effect of soil solarization x seed treatment, soil solarization × foliar sprays and seed treatment × foliar sprays interactions on percentage severity index (PSI) of anthracnose at Haramaya and Hirna during 2010 main cropping season.

Treatments interaction		PSI at Haramaya (%)		PSI at Hirna (%)	
		Initial (52 DAS)	**Final (92 DAS)**	**Initial (60 DAS)**	**Final (90 DAS)**
Soil solarization	**Seed treatment**				
Solarized	MST	13.8	28.7	16.3	25.2
	CST	13.1	29.1	16.6	25.7
	US	20.7	38.5	15.6	26.2
Non-solarized	MST	13.9	33.1	20.3	29.4
	CST	14.3	34.8	20.9	31.4
	US	26.9	44.7	21.9	32.1
CV (%)		13.0	12.3	9.6	9.7
LSD at 5% for SS × ST		4.4	NS	NS	NS
Soil solarization	**Foliar spray**				
	CFS10	13.3	30.5	19.0	21.9
Solarized	CFS20	15.1	31.5	15.1	25.2
	UF	19.3	34.4	14.3	29.9
Non-solarized	CFS10	15.1	32.6	21.2	25.2
	CFS20	17.9	32.7	17.5	31.8
	UF	22.1	47.4	24.4	35.8
CV (%)		14.7	12.1	25.8	21.1
LSD at 5% for SS x FS		2.5	4.3	NS	14
Seed treatment	**Foliar spray**				
	CFS10	12.2	28.2	20.0	29.6
MST	CFS20	13.4	29.3	16.3	24.8
	UF	15.9	35.3	18.5	27.4
	CFS10	14.5	31.1	21.1	31.8
CST	CFS20	13.6	30.3	15.9	25.2
	UF	12.9	34.6	19.2	28.5
	CFS10	15.8	35.4	19.3	31.1
US	CFS20	19.8	36.7	16.7	25.6
	UF	33.2	52.8	20.4	30.7
CV (%)		13.0	12.3	9.6	9.7
LSD at 5% for ST x FS		3.6	5.3	NS	NS

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; DAS =Days after sowing; US=Untreated seed; LSD=Least significant difference; FS=Foliar spray; ST=Seed treatment; SS=Soil solarization; NS=Non significant difference.

anthracnose disease assessment. Similarly, the interaction of carbendazim seed treatment with the same fungicide foliar sprays frequencies at 10 and 20 days intervals reduced disease severity at initial (52 DAS) date of severity assessment.

The primary inoculum from infested debris was relatively more damaging, causing early epidemic development and yield reduction, and the difference among severity levels could be influenced by concentration of inoculum harbored and which survived the temperature, relative humidity, and rain during over seasoning and the location of debris could have an effect (Fininsa and Tefera, 2002). Under favorable temperature and relative humidity, the pathogen leads to reduction of the grain quality due to occurrence of the tags, besides to decrease in the productive potential of the common bean

Table 4. Effect of soil solarization x foliar spray x seed treatment interactions on seed yield of common bean during 2010 main cropping season at Haramaya and Hirna.

Treatments interactions			Yield (tons/ha)	
			Haramaya	Hirna
Soil solarization	**Foliar spray**	**Seed treatment**		
Solarized	CFS10	CST	3.6	3.5
	CFS10	MST	3.8	3.6
	CFS10	US	2.5	2.8
	CFS20	CST	2.9	3.1
	CFS20	MST	3.2	3.1
	CFS20	US	2.3	2.6
	UF	CST	2.6	2.9
	UF	MST	2.8	2.9
	UF	US	2.2	2.5
Non-solarized	CFS10	CST	3.2	3.2
	CFS10	MST	3.4	3.5
	CFS10	US	2.4	2.5
	CFS20	CST	2.7	2.8
	CFS20	MST	3.0	3.1
	CFS20	US	2.2	2.4
	UF	CST	2.4	2.6
	UF	MST	2.5	2.8
	UF	US	1.9	2.3
CV (%)			17.1	12.5
LSD at 5% for SS × FS × ST			0.88	0.68

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; US=Untreated seed; LSD=Least significant difference; SS=Soil solarization; FS=Foliar spray; ST=Seed treatment.

(Pastor-Corrales et al., 1995). Generally, variation in severity between locations might have been due to the differences in environmental factors, inoculum load and time of infection. At both study areas, the magnitude of disease severity was significantly different between levels of solarization, it was higher for non-solarized than solarized soil (Figure 1).

Effect of integrated management of bean anthracnose on seed yield

There were significant (*P<0.05*) differences in interactions among the levels of solarization × foliar sprays × seed treatments on seed yield both at Haramaya and Hirna. While, the lowest seed yields were recorded on the combinations of non-solarized soil × unsprayed foliar × seed treatments at both study sites (Table 4). Low application rates of fungicide, fumigant, or herbicide have been successfully combined with soil solarization to achieve better pest control (Hartz et al., 1993). However, the interaction effects of soil solarization × seed treatments as well as seed treatments × foliar sprays were no significant both at Haramaya and Hirna.

Yield components

Hundred seed weight was varied significantly (*P<0.01*) between each levels of soil solarization at Hirna and showed no significant differences at Haramaya (Tables 5 and 6). Maximum 100 seed weight was calculated from solarized soil as compared with the non-solarized control at Hirna. Solarization levels had no significant effect on the number of pods per plant and seeds per pod at both locations. Plants often grew faster and produced yields of increased quantity and quality (size and appearance) when grown in solarized as compared to non-solarized soil. Soil solarization was found to be effective against a wide range of soil-borne pathogens that affect many agricultural crops in various regions of the world were reported by Katan et al. (1976), Pullmann et al. (1979) and Camporota et al. (1986). Soil solarization has been used effectively to reduce populations of soil-borne pathogens (Katan et al., 1980). Seed treatments and foliar sprays alone had no significant effect on pods per

Table 5. Effect of soil solarization x foliar sprays interaction on yield and its components of common bean during 2010 main cropping season at Haramaya.

Treatments interaction		Pods/plant	Seeds/pod	100 seed weight (g)	Yield (tons/ha)
Soil solarization	Foliar sprays				
Solarized	CFS10	27.4	3.5	16.8	3.4
	CFS20	24.1	3.8	16.0	2.8
	UF	21.8	3.7	16.6	2.5
Non-solarized	CFS10	21.4	3.7	16.1	3.5
	CFS20	20.6	3.9	16.6	2.4
	UF	21.0	3.8	15.6	2.3
CV (%)		38.4	17.3	7.3	25.0
LSD at 5% for SS × FS		NS	NS	0.99	0.55

CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; LSD=Least significant difference; NS=Non significant difference; SS=Soil solarization; FS=Foliar spray.

Table 6. Effect of anthracnose on yield and its components of common bean under soil solarization, fungicide seed treatments using carbendazim and mancozeb, and foliar applications of carbendazim during 2010 main cropping season at Hirna.

Treatments	Pods/plant	Seeds/pod	100 seed weight (g)	Yield (tons/ha)
Soil solarization				
Solarized	18.5	4.9	16.0	3.0
Non-solarized	18.2	4.8	15.4	2.8
CV (%)	4.4	2.7	1.6	4.1
LSD (5%)	NS	NS	0.41	NS
Foliar sprays				
CFS10	17.6	4.8	15.6	3.2
CFS20	18.1	4.9	15.6	3.0
Control	19.3	4.8	15.9	2.6
CV (%)	21.1	6.0	6.7	15.5
LSD (5%)	NS	NS	NS	0.25
Seed treatments				
MST	17.2	4.8	16.0	3.1
CST	18.6	4.9	15.4	2.7
Control	19.2	4.7	15.7	2.9
CV (%)	19.1	6.9	4.5	12.5
LSD (5%)	NS	NS	NS	NS

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; LSD=Least significant difference; NS=Non significant difference.

plant, seeds per pod and 100 seed weight both at Haramaya and Hirna. Interaction between soil solarization × seed treatments was significant (*P*<0.05) on 100 seed weight at Hirna and non significant at Haramaya (Tables 7). The difference between soil solarization × seed treatments effects was not significant on the pods per plant and seeds per pod at both study areas. According to Beshir (1997), seed treatment with fungicides resulted good disease control which resulted in the high seed weight and low seed yield losses and effective in reducing the severity of anthracnose.

Relative yield loss in seed yield

Estimates of yield loss were made on the basis of field experiments at Haramaya and Hirna, in which fungicides application, particularly, in combination, promoted seed yield gain in each levels of solarization. Yield losses differed among plots treated with different fungicides and spray frequencies in each solarization levels. Highest yield losses were recorded on the control plots of non-solarized and followed by fungicides untreated plots in the solarized soil at both locations (Table 8).

Table 7. Effect of soil solarization x foliar sprays, soil solarization × seed treatments interactions on yield and yield components of common bean during 2010 main cropping season at Hirna.

Treatments interaction		Pods/plant	Seeds/pod	100 seed weight (g)	Yield (tons/ha)
Soil solarization	Seed treatments				
Solarized	MST	16.8	4.7	15.5	3.1
	CST	18.6	4.8	14.9	2.8
	US	19.9	4.8	15.8	3.1
Non-solarized	MST	17.5	4.7	16.5	3.2
	CST	18.5	5.0	15.9	2.8
	US	18.4	4.7	15.6	2.7
]CV (%)		19.1	6.9	4.5	12.5
LSD at 5% for SS × ST		NS	NS	0.64	NS
Soil solarization	Foliar sprays				
Solarized	CFS10	17.9	4.7	15.3	3.4
	CFS20	17.8	4.8	15.3	2.9
	UF	19.6	4.8	15.6	2.6
Non-solarized	CFS10	17.3	4.8	15.8	3.5
	CFS20	18.3	5.0	15.9	2.6
	UF	18.9	4.7	16.3	2.5
CV (%)		21.1	6.0	6.7	15.5
LSD at 5% for SS x FS		NS	NS	NS	0.47

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CFS10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; LSD=Least significant difference; NS=Non significant; SS=Soil solarization; FS=Foliar spray; ST=Seed treatment

Table 8. Relative seed yield losses caused by bean anthracnose under soil solarization, fungicide seed treatments using mancozeb and carbendazim and carbendazim foliar spray during 2010 main cropping season at Haramaya and Hirna.

Treatments		Haramaya		Hirna	
Soil solarization	Fungicides	Yield (tons/ha)	RYL (%)	Yield (tons/ha)	RYL (%)
Solarized	CST+UF	2.6	25.7	2.9	17.1
	MST+UF	2.8	20.0	2.9	17.1
	MST+CFS20	3.2	8.6	3.1	11.4
	CST+CFS20	2.9	17.1	3.1	11.4
	US+CFS20	2.3	34.3	2.6	25.7
	MST+CFS10	3.8	-8.6	3.6	-2.9
	CST+CFS10	3.6	-2.9	3.5	0.0
	US+CFS10	2.5	28.5	2.8	20.0
	Control	2.2	37.1	2.5	28.6
Non-solarized	MST+CFS20	3.0	9.1	3.1	8.8
	US+CFS20	2.2	33.3	2.4	29.4
	CST+CFS20	2.7	18.2	2.8	17.7
	MST+CFS10	3.4	-3.0	3.5	-2.9
	CST+CFS10	3.2	3.0	3.2	5.9
	US+CFS10	2.4	27.3	2.5	26.5
	MST+UF	2.5	24.2	2.8	17.7
	CST+UF	2.4	27.3	2.6	23.5
	Control	1.9	42.4	2.3	32.4

MST=Mancozeb seed treatment; CST=Carbendazim seed treatment; CST10 and 20=Carbendazim foliar spray at 10 and 20 days interval; UF=Unsprayed foliar; US=Untreated seed; RYL=Relative yield loss.

Figure 1. Infected pods by *C. lindemuthianum* on control plant at Haramaya.

Figure 2. Healthy plants on treated plot with MST+CFS10 at Hirna.

Conclusions

Differences in epidemics occurred within each level of solarization due to fungicide applications under natural infection. Plots treated with combinations of mancozeb seed treatment and carbendazim spray frequencies at 10 days' intervals obtained the best protection in terms of disease severity and increased seed yield at bothlocations. Therefore, this study contributes to integrated bean anthracnose management options using soil solarization seed treatment and foliar spray is justified. Bean growers should be encouraged to use seed treatment and other cultural practices applicable in the area against anthracnose when growing susceptible bean cultivars. And the use of resistant varieties and producing pathogen free seeds would be a cheap means of controlling the anthracnose disease and need to be explored.

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