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Integrated Management of Sweetpotato Weevil, *Cylas puncticollis* (Boheman) (Coleoptera: Curculionidae) in Eastern Ethiopia

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ABSTRACT
Sweetpotato weevil, *Cylas puncticollis*, is the most destructive insect pest that ranks as the number one constraints for the production of sweetpotato in Eastern Ethiopia. A field experiment with the aim to develop compatible integrated management methods for sweetpotato weevil was conducted in 2011 cropping season at Haramaya University Horticultural Research Field (Rare) in Eastern Ethiopia. The experiment consisted of three factors: Cropping system at three levels (sole cropping of sweetpotato, sweetpotato intercropped with maize and sweetpotato intercropped with haricot bean), earthing-up at three levels (1,2 and 3 times earthing-up) and harvesting time at two levels (prompt and delayed harvesting) making up 18 treatment combinations. The treatments were replicated thrice and laid out in Randomized Complete Block Design (RCBD). Results of the studies revealed that the interaction effect of cropping systems, earthing-up and harvesting periods significantly ($p<0.05$) reduced sweetpotato percentage infestation and storage root damaged, number of unmarketable roots, number of weevils/kg of damaged roots. On the other hand, the interaction effect increased the number of marketable roots/plant and the total yield. Hence, from the current study it can be concluded that the integration of three times earthing-up at monthly interval starting from one month from planting; prompt harvesting, harvesting exactly at the physiological maturity of the roots; and mixed cropping of haricot bean at the ratio of three rows of sweetpotato to one row of haricot bean can sufficiently off set the risk of sweetpotato weevil (*C. puncticollis*) in Eastern Ethiopia.

Key words: *Cylas puncticollis*, earthing-up, harvesting period, integrated management, intercropping, sweetpotato weevil

INTRODUCTION
Sweetpotato (*Ipomoea batatas* (L) Lam.) is one of the world's most widely grown crops and it is an important crop in East Africa where it is grown as a staple food (Stevenson *et al*., 2009). Globally, the crop ranks the seventh among the most important food crops after wheat, rice, maize, potato, barley and cassava. It serves as animal feed and raw material for industries in the world (Ray and Tomlins, 2009).

In Ethiopia sweetpotato has been cultivated for many years and is important in diet where population growth is highest, land holding is least and threat of large-scale starvation is ever present (Habtu, 1995). The crop is most important root and tuber crops as one of the major traditional food crops of the country (Endale *et al*., 1994), where it is a major source of sustenance and food security (CIP, 2004). In eastern Ethiopia sweetpotato is mainly produced for human consumption, as income generator and to feed livestock. However, in Eastern Ethiopia sweetpotato weevil (SPW) (*C. puncticollis*) ranks the number one constraint for sweetpotato production. *C. puncticollis* limit sweetpotato production by damaging vines, tubers and occasionally the foliage, thereby reducing both the yield and quality of the crop. The cryptic feeding nature of the pest made some control practices like chemical control and biological control ineffective (Smit *et al*., 2001). The crop is also considered as a poor man crop which does not call for expensive investment like the use of chemical control for pest management. *C. puncticollis* causes 60-70% yield loss in East Africa (Kabi *et al*., 2001) and 21-78% in Ethiopia (Emana, 1990). Often producers relay on chemical control for *C. puncticollis* management, however, it caused frequent pest outbreaks, pesticide resistance, contamination of the environment, pest resurgence and less pest suppression among others.

Some cultural practices like earthing-up, prompt harvesting and intercropping were found to be more effective in the management of *C. puncticollis* (Emana, 1990). Nevertheless, each component of these cultural practices only suppresses the population and the effect of *C. puncticollis* to certain extent which is well above the economic injury level. The hypothesis now is if these cultural practices are combined in the form of integrated pest management there is a possibility that effective management of *C. puncticollis* can be attained.

Integrated Pest Management (IPM) has emerged as an important approach of pest control strategy, which encourages applying measures that causes least disruption of agro-ecosystem. IPM is effective, economical, environmentally benign alternative to chemical pest control (Schalk *et al*., 1991; Lawrence *et al*., 1997). Among the integrated pest management methods, cultural pest management tools are very useful and effective; economically and environmentally friendly.

Pest damage is lower in diverse cropping systems suggesting that crop mixtures provide a greater diversity of habitat for arthropods offering a greater abundance and variety of prey and hosts for predators and parasitoids (natural enemies' release hypothesis) or through affecting their ability to find and utilize its host plants. Thus, the non-host plants may mask the herbivore's host-finding stimuli (visual and chemical) so that colonization of the host plant is minimum (resource concentration hypothesis). A number of studies have indicated that the provisioning of floral resources and habitat can increase the density and diversity of natural enemies (Jervis and Heimpel, 2005). Earthing-up is another important *C. puncticollis* management. It prevents exposure of storage roots to weevil infestation by thickening the soils around the storage roots and filling up the soil cracks, so that the adult *C. puncticollis* can not reach storage root to cause damage (Emana, 1990; Palaniswami and Mohandas, 1994). Timely harvesting is another cultural practice that has been used for sweetpotato weevil management. It has been reported that weevil's populations build up when harvesting is delayed because it allows continuous reproduction on available food (Kabi *et al*., 2001). Delay in harvesting increases infestation by SPW (Emana, 1990) and damage to sweetpotato roots (Ebregt *et al*., 2004). Therefore, the general objective of this study was to investigate and develop integrated sweetpotato weevil's management (IPM) methods for Eastern Ethiopia.

MATERIALS AND METHODS

Description of the study area: A field experiment was conducted during the rainy season of 2011 (June to November) in Eastern Ethiopia (East Hararge) at Haramaya University field experimental station (Rare). Haramaya University field experimental station is located at an altitude of 1197m above sea level and lies at coordinates of 9°6'N and 41°8'E. The station lies in the semi-arid belt of the eastern rift valley escarpment with a long-term average rainfall of 612 mm. The soil is classified as Eutric Regosol with a gentle slope (3 to 8%). The texture and structure of the topsoil (0 to 30 cm) are sandy loam and sub angular blocky, respectively. The soil has an average pH of 8.54 and organic matter content of 1.94% (0 to 15 cm) and 1.84 (15 to 30 cm). The mean annual rainfall is 520 mm and means maximum and minimum temperatures range from 28.1-34.6°C and 14.5-21.6°C, respectively (Belay, 2002).

Planting material: Three planting materials namely: A sweetpotato variety, Barkume; an early maturing variety of maize, Katumani and haricot bean variety, Kufanzihki were used for this experiment. Top or middle vine parts of Barkume variety of sweet potato at 30 cm length with 3-4 nodes was used as planting materials. The intercrops (maize and haricot bean) were planted on the two sides within sweetpotato rows (as mixed intercropping) on the same day after plowing, disking and ridging of the experimental field.

Land preparation and its managements: The experimental land was prepared twice. First and second land preparations were done at two week's interval to facilitate organic matter decomposition of the soil. Land was prepared by ploughing using tractor and any residuals of the pervious remains were collected from the plowed land and buried, seed bed were also prepared as per the recommendation for the crops. After planting, hand and light hoeing was used to remove weeds, diseased plants and off types.

Treatments and experimental design: The combined treatments (Table 1) consisted of three levels of cropping systems (sole sweetpotato (as a control), sweetpotato with maize and sweetpotato with haricot bean intercropping), three levels of earthing-up (1, 2 and 3 times earthing-up) and two levels of harvesting periods (prompt and one month delayed harvesting). The treatment combinations were laid-out using Randomized Complete Block Design (RCBD) in factorial arrangement with three replications. Each plot size was 3 m width and 3.6 m length. The spacing was 60 cm between rows and 30 cm between plants for sweetpotato, 10 cm between plants and 60 cm between rows for haricot bean and 15 cm between plants and 60cm between rows for maize. The spacing between blocks and plots were 2×1 m, respectively. Except the treatment combinations all the other agronomic and management practices were applied to each experimental plot in the same way as per the recommendations for the area.

Table 1: Lists of the different factors, their levels and treatment combinations

		Earthing-up frequencies		
Cropping systems	Harvesting periods	1×, i.e., 30 DAP** (E_0)	2×, i.e., 30 and 60 DAP (E_1)	3×, i.e., 30, 60 and 90 DAP (E_2)
Sole sweetpotato (S_0)	Prompt harvesting (P_0)	$S_0P_0E_0$*	$S_0P_0E_1$	$S_0P_0E_2$
	Delayed harvesting (P_1)	$S_0P_1E_0$	$S_0P_1E_1$	$S_0P_1E_2$
Sweetpotato+maize	Prompt harvesting (P_0)	$S_1P_0E_0$	$S_1P_0E_1$	$S_1P_0E_2$
(S_1)	Delayed harvesting (P_1)	$S_1P_1E_0$	$S_1P_1E_1$	$S_1P_1E_2$
Sweetpotato+haricot	Prompt harvesting (P_0)	$S_2P_0E_0$	$S_2P_0E_1$	$S_2P_0E_2$
bean (S_2)	Delayed harvesting (P_1)	$S_2P_1E_0$	$S_2P_1E_1$	$S_2P_1E_2$

*Treatment combinations with their respective codes given in parenthesis for each level of a factor, **DAP: Days after planting

Table 2: Scale used to differentiate the tubers harvested in to damaged and normal tubers based on external damage

Scale (No. of external damage)	Percentage of damage
1	0
2	1-25
3	26-50
4	51-75
5	76-100

Data collected

Number of adult *C. puncticollis* and percentage infestation: The infestation level (colonization) of sweetpotato by *C. puncticollis* was determined by visual counting of the adult *C. puncticollis* from 12 randomly selected plants. The same sample plants were considered as infested when damage was evident on the stem base starting 30 Days After Planting (DAP). Record was made at about 2:00 pm when the insects were active. Total percentage infestation was calculated as follows:

$$I = \frac{N}{T} \times 100$$

where, I is percentage infestation of the sweetpotato plant by *C. puncticollis* in a plot, N is number of sample plants infested per plot and T is total number of sample plants per plot.

Number of tubers with *C. puncticollis* damage: Weevil's damaged/infested roots of each sample was separated based on the external damage symptoms as indicated in Table 2 on scale basis (Mtunda *et al*., 2001), then the percentage of infested tubers was calculated using the formula:

$$I = \frac{a}{a+b} \times 100$$

where, I is percentage damaged tubers, a is number of infested tubers, b is number of healthy tubers.

Number of marketable and unmarketable tubers: Harvested tubers were separated depending on the size and healthiness of the tuber into those of marketable if the weight of tuber is greater or equal to 100 g and it is healthy and unmarketable (if the weight of tuber is less than 100 g and unhealthy) tubers visually.

Data analysis: Data were checked for normality before analysis. Those which violate normality were transformed (Gomez and Gomez, 1984) using arcsine transformation prior to analysis. Those data which assume normality were subjected to two-way ANOVA using SAS version 9.2 software (SAS, 2008) packages. Significant means ($p<0.05$) was separated using Least Significant Differences (LSD). The cause-effect relationship of sweetpotato weevil's population density and the percent damaged roots was analyzed using regression analysis. The associations between percentage of infestation, damaged sweepotato roots, weight and yield loss, number of weevils per kilogram of storage roots, number of marketable roots and total yield of sweetpotato roots were analyzed using simple correlation analysis.

RESULTS

Percentage infestation of sweetpotato by *C. puncticollis*: The three way interaction effect of the factors on the percentage infestation of sweetpotato by *C. puncticollis* was significant ($p<0.05$) (Table 3). The percentage infestation was significantly reduced by the interaction effect of cropping systems, earthing-up and harvesting period. The lowest (14.33%) *C. puncticollis* infestation on sweetpotato was recorded from the interaction effect of sweetpotato intercropping with maize, prompt harvesting of sweetpotato and three times earthing-up, while the highest (92.33%) percent infestation was recorded from the interaction effect of sole cropping of sweetpotato, delayed harvesting and two times earthing-up, but this treatment combination was statistically on par with the interaction effect of sole sweetpotato cropping, delayed harvesting and one time earthing-up (90.66%).

Percentage damaged tubers: The percentage damaged storage tubers by *C. puncticollis* was significant ($p<0.05$) due to the three way interaction effect of cropping systems, earthing-up and harvesting periods (Table 4). Minimum (5.52%) percentage damaged storage tubers of sweetpotato due to *C. puncticollis* was recorded from the interaction effect of sweetpotato intercropped with maize, prompt harvesting and two times earthing-up but this treatment combination was statistically non-significantly different from sweetpotato intercropping with maize, prompt harvesting and one or two times earthing-up; sweetpotato intercropping with haricot bean, prompt harvesting and two or three times earthing-up. On the other hand, maximum (59.45%) percentage damaged storage tubers was recorded from sole sweetpotato cropping, delayed harvesting and one time earthing-up and this treatment combination was followed by the combined effect of sole sweetpotato cropping, delayed harvesting and two times earthing-up (31.33%).

Table 3: Interaction effects of cropping systems, earthing-up and harvesting periods on the percentage infestation of sweetpotato by *C. puncticollis*

		Infestation (%)				
		Earthing-up frequencies				
Cropping systems	Harvesting periods (HP)	1x	2x	3x	Mean	Mean (HP)
Sole sweetpotato	Prompt harvesting	84.43 (58.61)^{bc}	79.33 (52.53)^{c}	66.33 (41.55)^{d}	76.69	47.53^{B}
	Delayed harvesting	90.66 (65.24)^{ab}	92.33 (67.63)^{a}	81.66 (54.81)^{c}	88.21	59.66^{A}
	Mean	87.54	85.83	73.99	82.45^{A}*	
Sweetpotato+maize	Prompt harvesting	29.66 (17.25)^{ij}	43.66 (25.88)^{h}	14.33 (8.23)^{k}	29.21	
	Delayed harvesting	35.33 (20.68)^{i}	50.33 (30.28)^{g}	30.00 (17.45)^{i}	38.55	
	Mean	32.49	46.99	22.16	33.86^{C}*	
Sweetpotato+haricot bean	Prompt harvesting	31.66 (18.45)^{i}	55.00 (33.36)^{fg}	23.33 (13.48)^{j}	36.66	
	Delayed harvesting	63.33^{d} (39.34)^{de}	57.33 (34.97)^{ef}	36.00 (21.0)^{i}	52.22	
	Mean	47.49	56.16	9.66	44.44^{B}*	
	Mean (earthing-up)	55.85^{B}	63^{A}	41.94^{C}		
CV (%)					7.25	
p-value					<0.0001	
LSD					6.45	

The No. inside parentheses are the transformed data (arcsine transformation). Means with the same letter within the table is not significantly different at 5% significant level, Small letters within the table indicates mean separation for higher order interaction effects, Capital letters indicates mean separation for main effects, *Means of the main effect of cropping systems

Table 4: Effects of intercropping, earthing-up and harvesting periods on the percentage damaged storage tubers of sweetpotato by *C. puncticollis*

		Damaged storage tubers (%)				
		Earthing-up frequencies				
Cropping systems	Harvesting period (HP)	1x	2x	3x	Mean	Mean (HP)
Sole sweetpotato	Prompt harvesting	19.05^{e}	28.00^{c}	22.33^{d}	23.12	13.00^{B}
	Delayed harvesting	59.45^{a}	31.33^{b}	25.33^{cd}	38.70	22.59^{A}
	Mean	39.25	29.66	23.83	30.91^{A}*	
Sweetpotato+maize	Prompt harvesting	6.72^{gh}	5.52^{h}	6.56^{gh}	6.26	
	Delayed harvesting	15.33^{f}	9.00^{g}	15.00^{f}	13.11	
	Mean	11.02	7.26	10.78	9.69^{C}*	
Sweetpotato+haricot bean	Prompt harvesting	13.85^{f}	8.33^{gh}	6.98^{gh}	9.72	
	Delayed harvesting	15.66^{f}	16.23^{ef}	16.00^{ef}	15.96	
	Mean	14.75	13.28	11.49	12.84^{B}*	
	Mean (Earthing-up)	21.67^{A}	16.4^{B}	15.36^{B}		
CV (%)					10.38	
p-value					<0.0001	
LSD					3.06	

Means with the same letter within the table is not significantly different at 5% significance level, Small letters within the table indicates mean separation for interaction effects, Capital letters indicates mean separation for main effects, *Means of the main effect of cropping systems

Population density of *C. puncticollis* under the different cultural practices: When the main effect of cropping systems were considered, the result indicated that the population density of *C. puncticollis* was found to be significantly correlated with the percentage of storage tubers damaged. More population density of *C. puncticollis* on sole cropping of sweetpotato was positively correlated with more damaged storage tubers and less percentage of damaged storage tubers on intercropped sweetpotato was associated with less number of weevils per kilogram of damaged sweetpotato tubers. The relationship is depicted by the regression equation, $y = 0.624x+6$ ($r^2 = 0.94$) (Fig. 1), which indicate the high dependency of percentage of damaged sweetpotato storage tubers on the population density of *C. puncticollis*.

Number of marketable tubers/plant: The interaction effects of cropping systems, earthing-up and harvesting period on the number of marketable tubers were significant ($p<0.05$) (Table 5). Maximum (9.67 roots plant^{-1}) marketable roots were recorded from the interaction effect of sweetpotato intercropping with maize, prompt harvesting and three times earthing-up which was followed by intercropping sweetpotato with haricot bean, prompt harvesting and three times earthing-up (8.27 tubers plant^{-1}) which is not statistically different from the combined effect of intercropping sweetpotato with maize, prompt harvesting and two times earthing-up (7.25 tubers plant^{-1}). On the other hand, minimum (1.8 roots plant^{-1}) marketable healthy tubers were recorded from sole cropping of sweetpotato, delayed harvesting and one time earthing-up but the difference was statistically non-significant from sole cropping of sweetpotato, delayed harvesting and two times earthing-up (2.89 tubers plant^{-1}); intercropping sweetpotato with maize, delayed harvesting and one times earthing up (2.37 tubers plant^{-1}) and intercropping sweetpotato with haricot bean, delayed harvesting and one/two times earthing up (2.7 and 2.0 tubers plant^{-1}, respectively).

Table 5: Effects of cropping systems, earthing-up and harvesting periods on the number of marketable storage tubers of sweetpotato as affected by *C. pucticollis*

		No. of marketable roots per plant				
		Earthing-up frequencies				
Cropping systems	Harvesting period (HP)	1x	2x	3x	Mean	Mean (HP)
Sole sweetpotato	Prompt harvesting	3.54^{efgh}	3.62^{efgh}	5.00^{cd}	4.00	6.14^{A}
	Delayed harvesting	1.80^{j}	2.89^{ghij}	4.4^{def}	3.33	2.99^{B}
	Mean	3.12	3.25	5.25	3.66^{B}*	
Sweetpotato+maize	Prompt harvesting	4.66^{cde}	7.25^{b}	9.67^{a}	7.19	
	Delayed harvesting	2.37^{ij}	3.57^{efgh}	3.27^{fghi}	3.07	
	Mean	3.51	5.41	6.47	4.13^{A}*	
Sweetpotato+haricot bean	Prompt harvesting	4.00^{defg}	5.73^{c}	8.27^{b}	6.00	
	Delayed harvesting	2.70^{hij}	2.00^{j}	3.3^{fghi}	2.23	
	Mean	3.35	3.86	5.78	4.20^{A}*	
	Mean (earthing-up)	3.95^{B}	4.10^{B}	5.65^{A}		
CV (%)					15.30	
p-value					0.0006	
LSD					1.162	

Means with the same letter within the table is not significantly different at $p<0.05$ Fisher's least significant difference test, small letters within the table indicates mean separation for interaction effects, capital letters indicates mean separation for main effects, *Means of the main effect of cropping systems

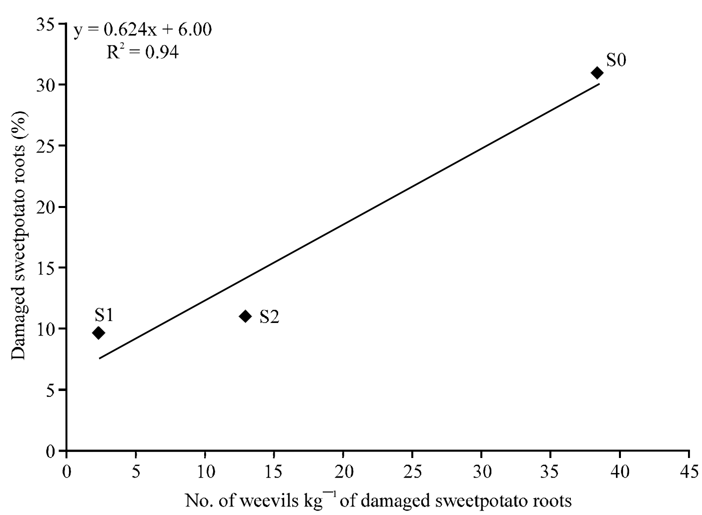

Fig. 1: Cause-effect relationship of population density of *C. puncticollis* per kilogram damaged storage tubers, S_0: Sole sweetpotato, S_1: Sweetpotato+maize, S_2: Sweetpotato+haricot bean

Number of unmarketable tubers/plant: The two way effects (cropping systems and harvesting periods (Fig. 2), cropping systems and earthing-up (Fig. 3) showed a significant ($p<0.05$) difference for number of unmarketable sweetpotato tubers per plant. Considering cropping systems and

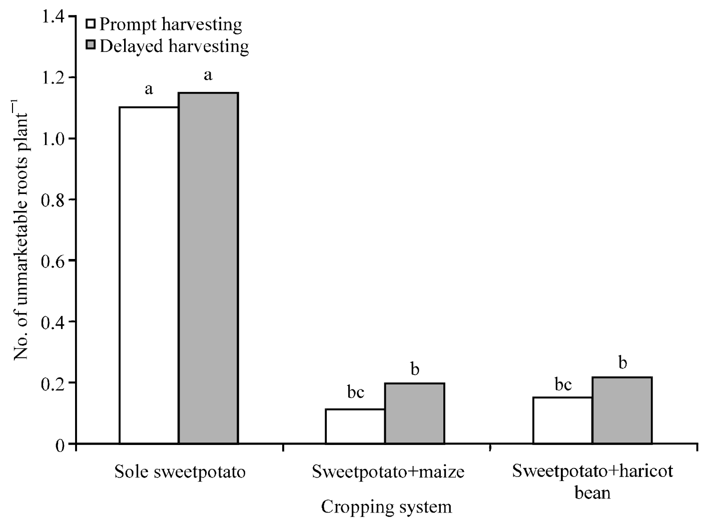

Fig. 2: Interaction effects of cropping systems and harvesting periods on the number of unmarketable tubers/plant

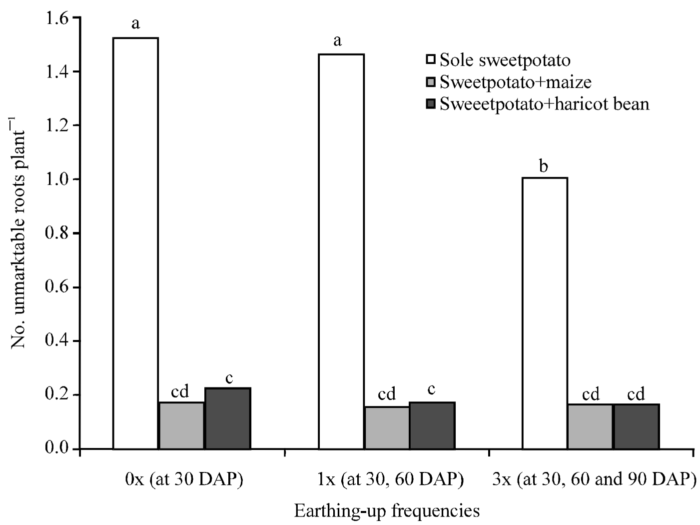

Fig. 3: Interaction effects of cropping systems and earthing-up on the number of unmarketable sweetpotato tubers/plant

harvesting periods, the highest number of unmarketable tubers/plant was obtained from sole sweetpotato cropping integrated with delayed harvesting but it was non-significantly different with sole sweetpotato cropping integrated with prompt harvesting where as the lowest number of unmarketable tubers per plant were obtained when sweetpotato was intercropped and harvested promptly which was on par with intercropping of sweetpotato with both intercrops and delayed harvesting. Among the two intercrops tested, maize intercropping reduced the number of unmarketable storage tubers in comparison to haricot bean but statistically non-significant difference was observed among the two crops. The result also revealed that delay in harvesting time

Table 6: Simple pearson correlation coefficient of some variables measured

	PI	DR	PWL	PYL	WprKG	MHT	Yield t ha^{-1}
PI	1	0.32^{ns}	0.60**	0.38*	0.56*	-0.18^{ns}	-0.002^{ns}
DT		1.00	0.68**	0.61**	0.60**	-0.61**	-0.30**
PWL			1.00	0.75**	0.58*	-0.37*	-0.35*
PYL				1.00	0.45*	-0.29^{ns}	-0.31^{ns}
WprKG					1.00	-0.55**	-0.09^{ns}
MHT						1.00	-0.89^{ns}
Yield t ha^{-1}							1.00

ns: Non-significant at 5% level of significance, *Significant at 5% level of significance and **highly significant at 0.01 level of significant, PI: Percentage infestation, DR: Percentage damaged tubers, PWL: Percentage weight loss, PYL: Percentage yield lose, WprKG: Number of weevils per kilogram of sweetpotato storage tubers, MHT: Number of marketable healthy roots, Yield t ha^{-1}: Total yield of storage tubers of sweetpotato per hectare

resulted in more number of unmarketable storage tubers but statistically non-significant from prompt harvesting indicating the significant effect of cropping system than harvesting periods. Besides, the interaction effect of cropping systems and earthing-up was significant on the number of unmarketable storage tubers of sweetpotato. Maximum number of unmarketable tubers/plant was harvested from sole sweetpotato cropping system with one-time earthing-up. However, statistically no significant different were observed among the two crops intercropping with sweetpotato and two or three times earthing-up. It is the cropping systems which is more influential to the number of unmarketable storage tubers than the earthing up frequencies similar to the harvesting periods.

Simple correlation analysis of the variables: The simple linear association between the variables (Table 6) indicated that, percentage infestation was significantly and positively-correlated with percent weight loss (r = 0.6**), percent yield loss (r = 0.38*), number of weevils per damaged sweetpotato tubers (r = 0.56*) and inversely non-significantly correlated with number of marketable healthy tubers (r = -0.18^{ns}) and total yield of sweetpotato (r = -0.002^{ns}). Percentage damaged tubers was positively and significantly correlated with percentage weight loss (r = 0.68**), yield loss (r = 0.61**) and number of weevils (r = 0.60**) but negatively and significantly correlated with marketable healthy tubers (r = -0.61) and yield (r = -0.30).

DISCUSSION

In the present study, variation was observed on the infestation of sweetpotato by *C. Puncticollis* under the different cultural practices considered for integrated management of sweetpotato weevil. Reduced infestation of sweetpotato by *C. puncticollis,* damaged storage tubers, number of unmarketable tubers, etc and on the contrary an increased number of marketable and healthy tubers in the combined effect of intercropping sweetpotato with maize/haricot bean, prompt harvesting and three times earthing-up was observed when compared with sole cropping of sweetpotato, delayed harvesting and less frequent earthing-up. This result were may be due to the confusing olfactory and visual cues received from intercropped crops (maize and haricot bean) act as physical barriers against *C. puncticollis* movement than sole cropping of sweetpotato. Also, the non-host plants (maize/haricot bean) may increases the number of natural enemies in the field and may be responsible for the lower number of *C. puncticollis* in the intercropped sweetpotato in comparison to sole sweetpotato resulting in positive responses for the growers (less number of weevils, more yield, less loss, less infestation and less damage). The population density of *C. puncticollis* and percentage of damaged storage tubers were lower in the intercropping systems than in the sole sweetpotato cropping. Frank and Liburd (2005) found reduced number of *Bemisia tabaci* and aphid in more diverse cropping systems involving squash and a living mulch, buckwheat indicating the importance of cropping system for the management of crop pests. Funderburk *et al.* (2011) reported that planting of sunflower on the perimeter of pepper field's increase the density of minute pirate bugs (predatory bug) in the pepper, helping to suppress western flower thrip. Suris *et al.* (1995) and Alexander (1992) also reported intercropping of sweetpotato with corn resulted in lower percentage of sweetpotato weevil population and damaged storage tubers than sweetpotato pure stand. Similarly, Rao (2005) and Rao *et al.* (2006) reported low incidence of *Cylas formicarius* in the multiple cropping systems. Christerson (1995) observed a decrease in the number of *Aphis fabae* in an intercropping of beet with phacelia. Hassanali *et al.* (2008) also reported that a low incidence of Striga (*Striga hermontheca*) and maize stem borer (*Chilo partellu*) in maize/desmodium, legume and napier grass intercropping.

Lower number of *C. puncticollis* was recorded in sweetpotato/maize intercropping system (9.31 weevils kg^{-1} of damaged tubers) and sweetpotato/haricot bean cropping system (11 weevils kg^{-1} of damaged tubers). On the other hand sole sweetpotato cropping gave the maximum number of *C. puncticollis* per damaged tubers (33.36 weevil kg^{-1} of damaged tubers) resulting in significant damage (internally/externally) to storage tubers. Less percentage storage tubers damage was recorded from integrated effect of intercropping sweetpotato with maize, prompt harvesting and three times earthing-up. The low percentage damaged sweetpotato tubers from this treatment combination may be due to the low infestation of *C. puncticollis* in plots that received this treatment combination. The report of Alexander (1992) also indicated that high relationship of population density of weevils and damaged storage tubers which confirm the present study.

Besides, lower number of unmarketable tubers in the intercropped cropping systems may be due to efficient use of nutrients and low vine damage resulting in increasing the marketable storage tuberous roots, while the high number of unmarketable storage roots harvested from sole sweetpotato was due to the high competition among the same species (sweetpotato) for the same resources and high infestation on the veins which may result in infested vascular tissues. Low incidence of *C. puncticollis* in the intercropped sweetpotato resulted in high marketable tuberous roots. This finding is in consistency with the finding of Suris *et al.* (1995) who observed lower percentage of sweetpotato weevil damage in sweetpotato intercropped with maize than sweetpotato pure stand in Cuba.

The reduction of soil cracking through earthing-up and prompt harvesting may also caused reduced reproduction/multiplication of sweetpotato weevils and escape of the main crop, respectively from *C. puncticollis* infestation in the field leading to better management of weevils and greater yield responses from the crop. Damage to sweetpotato roots was significantly decreased as the frequencies of earthing-up increased, when sweetpotato was harvested on time and intercropped with maize/haricot bean. Earthing-up the plant three times starting from the first month after planting resulted in high marketable healthy tubers. The role of sweetpotato tuberous root hilling up as a management tools were reported by Emana (1990) and Macfarlane (1987) who reported that earthing-up offers protection against sweetpotato weevils. Rashid (1999) mentioned the advantages of earthing-up and suggested that 2-3 times earthing-up were helpful for Mukhi Kachu production. The result of Qadir (1997) and Qadir *et al.* (1999) also examined that earthing-up at 15 days resulted in better plant and yield performance in potato crop.

Promptly harvesting when sweetpotato reached physiological maturity plays a vital role in managing the infestation of sweet potato weevil resulting in reduced damage to the storage tubers of sweetpotato. On an average, delayed harvesting resulted in significantly higher infestation (59.66%) and tuber damage (22.59%) by *C. puncticollis* and lower number of marketable tubers (2.99 tubers/plant) in the three cropping systems and three frequencies of earthing up. On the other hand, prompt harvesting of sweetpotato gave lower percentage of damaged tubers (13.00%) and infestation (47.53%) of sweetpotato by *C. puncticollis* and more number of marketable tubers (6.14 tubers/plant). The result also revealed that delay in harvesting period resulted in high unmarketable storage tubers may be due to the presence of their host in the field which provide suitable environment for the growth and development of *C. puncticollis*. Similar to this finding Ebregt *et al.* (2007) reported piecemeal harvesting of sweetpotato caused more storage root damage by weevil (*Blosyrus* spp.) than with one-time harvesting.

CONCLUSION

The results of the present study revealed that the interaction effect of intercropping, earthing-up and harvesting period of sweetpotato would be effective in the management of *C. puncticollis* reducing the infestations and other associated damage. Therefore, intercropping sweetpotato with maize/haricot bean, earthing-up two or three times and harvesting of sweetpotato on time at its physiological maturity can be a promising integrated management tools to control *C. Puncticollis* in sweetpotato production systems in Eastern Ethiopia.

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