Evaluation of Different Options: Host Plant Resistance, Weed Management, and Fertilization for the Development of an Integrated Pest Management Strategy for the Sweet Potato Weevil in Burkina Faso

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Summary

*The sweet potato weevil (SPW) (*Cylas puncticollis*) is a destructive pest feeding on the sweet potato in Burkina Faso. This weevil causes severe damage to the tuber, and the infested tuber is unsuitable for human consumption or animal feed. This problem calls for effective control management, especially for non-chemical approaches. A field experiment was carried out from 2012 to 2015 with the aim to develop management methods. Different control methods, including host-plant resistance, weeds management and crop fertilization, were tested. The results showed that two varieties, Zappalo-1 and Resisto were free of any SPW damage (0%). Similarly, when plots were not weeded tubers of the BF11 variety were free of any SPW damage (0%). Finally, the combination of manure and mineral fertilizer significantly reduced the damage due to the SPW to score as low as 1 compare to 3.5 in the absence of manure. From the current study, it can be concluded that an integrated approach combining resistant varieties, good weeding practices and fertilizer application could be implemented to control the SPW in Burkina Faso.*

Résumé

Evaluation de différentes options : résistance variétale, gestion des mauvaises herbes et fertilisation pour le développement d'une stratégie de gestion intégrée du charançon de la patate douce au Burkina Faso

*Le charançon de la patate douce (*Cylas puncticollis*) est un insecte ravageur de la patate douce au Burkina Faso. Il cause de sérieux dégâts sur les tubercules, les rendant impropres à la consommation humaine et à la nutrition animale. Ce problème nécessite des moyens de lutte efficaces, en particulier des méthodes de contrôle non chimique. Dans le but de développer de telles méthodes, des expérimentations au champ ont été conduites de 2012 à 2015. Différentes méthodes de lutte incluant la résistance variétale, la gestion des mauvaises herbes et la fertilisation ont été testées. Les résultats ont montré que deux variétés, Zappalo-1 et Resisto, étaient immunes de tout dégât (0%) du charançon. En outre, lorsque les parcelles n'étaient pas désherbées, on n'enregistrait aucun dégât (0%) du charançon sur la variété BF11. Enfin, la combinaison de la fumure organique et de l'engrais minéral a significativement réduit les dégâts causés par le charançon à un score aussi bas que 1 comparé à un score de 3.5 en absence de fumure organique. Ainsi, à partir de cette étude, on peut conclure qu'une approche intégrée combinant des variétés résistantes, de bonnes pratiques de désherbage et une application de fertilisants pourrait être mise en place pour contrôler le charançon de la patate douce au Burkina Faso.*

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Introduction

The sweet potato is the major tuber crop in Burkina Faso followed by yam and potato (12). Sweet potato production is scattered across the country, but the major production area includes the Nahouri and Sissili provinces in the south and Kénédougou province in the southwest. Sweet potato constitutes a major source of revenue for women, who are the main actors in the post-harvest activities. There is a growing interest in sweet potato production in Burkina Faso, especially as the orange-fleshed sweet potato reduces vitamin A deficiency, which affects over 30% of infants under 5 years old (19). The national production of sweet potato in Burkina Faso has risen from approximately 50,000 tons in the late 90s to over 160,000 tons in 2013 (12). However, this production increase is mainly due to the extension of the cultivated area. The national yields are below 15t/ha with a potential yield of at least 25t/ha given the currently available varieties. This yield gap is due to many production constraints, mainly poor soils and cultural practices, water stresses, diseases and insect pests. Among insect pests, weevils from the genus Cylas are of major concern for farmers (20). Weevil species from the genus Cylas are the major worldwide sweet potato insect pests (16). In Africa, the major species include *Cylas puncticollis* Boheman and *Cylas brunneus* F (33), while in America and Asia, *Cylas formicarius* is the major species encountered (36). The species present in Burkina Faso is Cylas puncticollis (20). The sweet potato weevil feeds on different parts of the host plant. The females use their mouthparts to dig small cavities in the roots, stems and tubers, and they then deposit eggs. When the egg hatches, the larva usually tunnels directly into the stem and/or tuber and feeds on the stems and/or tubers as they grow. Developing larvae cause plant wilting or complete senescence. Field damages lead to significant yield losses and a reduction of the marketability of the infested tubers (36, 39). Additionally, in response to the insect attacks, the plants produce terpenes, which render the tuber unsuitable for human consumption (45). The weevils continue to feed on the tuber after the harvest and are able to destroy the tuber within a few months of storage (21). Damage, which appears as holes in the tuber, leads to a significant loss in tuber weight, and reduces the market value (37). The challenges in storing tubers in the presence of weevils has led farmers to sell their sweet potatoes at low harvest-time prices shortly after harvest, whereas the most profitable prices could be achieved if they were able to extend storage to a few more months. Different control strategies have been developed to control the sweet potato weevil, including chemical control, cultural management, biological control, and host plant resistance (6, 29, 42). Most of the challenges with these management practices are related to their applicability and economic costs. For instance, in South-East Asia and the West Indies, a mass-trapping pheromone appeared promising (1) but failed in Africa mainly because of the cost of the technology, which was not affordable for smallholder farmers (38). So far, the management strategy in Africa relies on the development of tolerant/resistant varieties and crop management practices (23, 29, 43). The current paper reports on host plant resistance to the SPW, the effect of crop weeding on SPW damage, and the effect of crop fertilization on SPW damage for application in Burkina Faso. The different management practices were tested separately and if conclusive will serve as a basis for the development of an integrated management strategy for the SPW in Burkina Faso.

Materials and Methods

Study Environment

The experiments included on-farm field trials and on-station trials.

The on-station trials were carried out at the research station of the *Institute of Environment and Agricultural Research* (INERA) in Kamboinse in central Burkina Faso (latitude: 12°28’N, longitude: 32°1’W). The on-station fertilizer application trials were carried out over two successive years in 2012 and 2013, and the weeding management practice trials were carried out over two successive years in 2014 and 2015. A total rainfall of 699.9 mm, 762.9 mm, 550.7 mm and 904.9 mm was recorded in 2012, 2013, 2014 and 2015, respectively. For all years, the average relative humidity reached 78% during the rainy season and dropped to 21% during the dry season. The temperature ranged from 24-34 °C during the cropping season.

The on-farm varietal screening for host plant resistance were carried out in Southern Burkina Faso in the district of Leo in the Sissili province.

This province is one of the top three sweet potato producers in the country. This location belongs to the South-Sudanian agroecology with a unimodal rainfall pattern, and the rainy season lasts from May to October. A total rainfall of 1024.8 mm was recorded in 2013 in the district of Leo.

The average relative humidity reached 80% during the rainy season and dropped to 19% during the dry season, and temperatures ranged from 25.6 °C to 33 °C. Two villages were selected for conducting the field varietal screening: Mouna (latitude: 11°9’ 16,437” N; longitude: 2° 4’ 58,818” W), which is 4 km north of Leo, and Benaverou (latitude: 11° 3’ 59,664” N; longitude: 2° 9’ 28,204” W), which is 10 km South of Leo. Both locations are hotspots for the sweet potato weevil.

Screening for host-plant resistance to the sweet potato weevil

A total of 30 sweet potato varieties were selected for the host plant resistance screening. The material was selected from the Burkina Faso national collection maintained at different research stations of the Institute of Environment and Agricultural Research (INERA). Because of the growing interest in the orange-fleshed sweet potato our material included 13 orange-fleshed varieties in addition to the white-fleshed varieties. The material included 8 local landraces, 12improved INERA varieties, and 10 exotic varieties. The 30 varieties were planted in a randomized complete bloc design with 4 replications. The planting occurred in late September 2013 towards the end of the rainy season, and the plants were watered every 7 days. Within each replication, each variety was planted on ridges of 5 m long with an intra-ridge spacing of 1 m and an inter-ridge spacing of 30 cm. A space of 2 m was left between adjacent blocks. The mineral fertilizer NPK 15-15-15 was applied to the entire plot three weeks after planting at a dose of 350 kg per ha. All the plots were kept free of any insecticide application and fenced to prevent cattle damage. Data on the sweet potato weevil population were collected 6 weeks and 17 weeks after planting. The number of weevils was recorded on all plants of the central ridges of each variety. Along with number of weevils, we also counted the number of holes per stem on the principal stem of the same plants. At harvest, the damage from the SPW on the tubers was recorded using (40) 1-5 scoring, where in 1=0% damage; 2=1-25% damage; 3=26-50% damage; 4=51-75% damage; and 5=>75% damage. The tubers were then sorted, and tubers with weights below 100 g and/or signs of weevil damage were considered unmarketable. The yields of marketable tubers and unmarketable tubers were computed.

Investigating the effect of different fertilizer applications on SPW damage

The trial was carried out with the orange-fleshed sweet potato variety, TIB 440060, which is moderately tolerant to the SPW. The material was transplanted in early July in both 2012 and 2013 under a split plot design including 3 principal treatments: i) no application of manure; ii) application of manure at a dose of 20 t/ha per year; and iii) application of manure at a dose of 20t/ha every two years. The sub-plots included 4 different NPK mineral fertilizer doses: i) 15-0-45; ii) 30-0-90; iii) 0-30-100; and iv) 30-30-0. Each subplot had an area of 8 m2 and included 4 ridges of sweet potato plants of 2 m long, an intra-ridge spacing of 1 m, and an inter-ridge spacing of 0.80 cm. A space of 1 m was left between adjacent plots and replications.

The manure was applied before planting, and the NPK fertilizer was applied three weeks after planting.

Investigating the effect of sweet potato weeding on SPW damage and yields

The plant materials included two sweet potatoes varieties: BF 11 and Ejumula-2, all sensitive to the sweet potato weevil. The two varieties were planted in mid-July in a randomized complete bloc design with 4 replications. For each replication, each of the two varieties was planted in six different plots of 10.5 m2 on ridges of 3.5 m long, with an intra-ridge spacing of 1 m and an inter-ridge spacing of 0.30 cm. A space of 1 m was left between adjacent plots and replications. The mineral fertilizer NPK 15-15-15 was applied to the entire plot three weeks after planting at a dose of 350 kg per ha. Tomatoes preceded the sweet potatoes. All the plots were kept free of any insecticide application. Within each replication, the 12 plots of the 2 sweet potato varieties were randomly selected for the application of the following weeding management practices: 1) No weeding throughout the cropping season=Control; 2) One single hand-weeding of plots 4 weeks after planting (WAP); 3) One single hand-weeding of plots 6 WAP; 4) One single hand-weeding of plots 8 WAP; 5) One single hand-weeding of plots 10 WAP; 6) Five hand-weeding occurrences of plots at 2-week intervals from 2 WAP onwards. The data were recorded for all plants in the central ridges of each plot and included the following: i) Number of holes/stem; ii) Number of damaged tubers; iii) Number of marketable tubers; and iv) Yield of marketable tubers using the same method as above.

Data analysis

All of the data were subjected to ANOVA (PROC GLM) using the SAS software version 9.1 (SAS 2003). When ANOVAs were significant, the means were separated using the Student–Newman–Keuls test at the 5% level. For the experiment on weeding management, we first compared different weeding treatments and then compared each combination of variety, weeding and seasonal effects. For the experiment on fertilizers, we compared the different manure treatments, then the mineral fertilizers treatments, and finally the effects of combining manure and mineral fertilizer. T-test was used for comparison of locations.

Résultats

Sweet potato weevil damage in the field and effects on yield

The average number of weevils per plant ranges between 0.2-0.71 with significant differences in location ($t_{1,238}$ =-5.58, P<0.0001). The SPW damaged up to 55% of the sweet potatoes stems at both locations ($t_{1,238}$=0.31, P=0.75; Figure 1). However, a significantly higher proportion of tubers were damaged at the Mouna location (40.5%) than at Benaverou (10.52%) ($t_{1,238}$=-7.87, P<0.0001; Figure 1).

The varieties reacted differently to the SPW, with damaged tubers ranging between 2 and 89% (Mouna: F29, 90=5.23, P<0.0001; Benaverou: F29, 90=3.23, P<0.0001). Using the Stather et al. (40) 1-5 damage scoring scheme, and the data of the site with higher SPW infestation, two varieties appeared to be resistant -appalo-1 and Resisto-, 12 were moderately resistant, 6 were Moderately Sensitive and 10 were Sensitive (Table 1).

Overall, the sweet potato tuber yield ranged between 2-93 and 3.48 t/ha with no significant difference between locations (t1, 238= -1.18, P = 0.23). Likewise the proportion of marketable tubers was not affected by locations (t1, 238 =1.82, P = 0.06). The yield of marketable tubers was significantly affected by the variety, the highest yields being BF77*TAINUNG-10, CAROMEX, BF59*TIB-3, and BF 14 (Table 1).

Effect of fertilizers on sweet potato damage

The mineral fertilizer alone did not affect the SPW damage but affected the yield of marketable tubers. There was no effect of manure alone on either damage or yield. However, the combination of manure and mineral fertilizer significantly affected the SPW damage and the yield of marketable tubers (Table 2). This was particularly true when the K content in the mineral fertilizer was very high (Table 2).

Effect of weeding and weeding timing on SPM damage and yields

The percentage of damaged stems varied between 0-82% with no significant difference between varieties (Table 3). However, the weeding of the plots and the timing of the weeding significantly affected the SPW damage to tubers (Table 3). Thus, the plots that were not weeded at all or that were weeded once 10 weeks after planting had a significantly lower amount of damage, especially for the variety BF11 (Table 3). Both varieties had lower tuber yields in 2015 than in 2014 (F=40.92; P<0.0001). For the variety BF11, continuous hand weeding led to a higher yield of marketable tubers (Table 3). In contrast, for the second variety, EJUMULA 2, a delayed weeding at 6 weeks after planting led to a significantly higher tuber yield (Table 3). The yield of marketable tubers followed the same trends as overall tuber yield for each of the two varieties (Table 3).

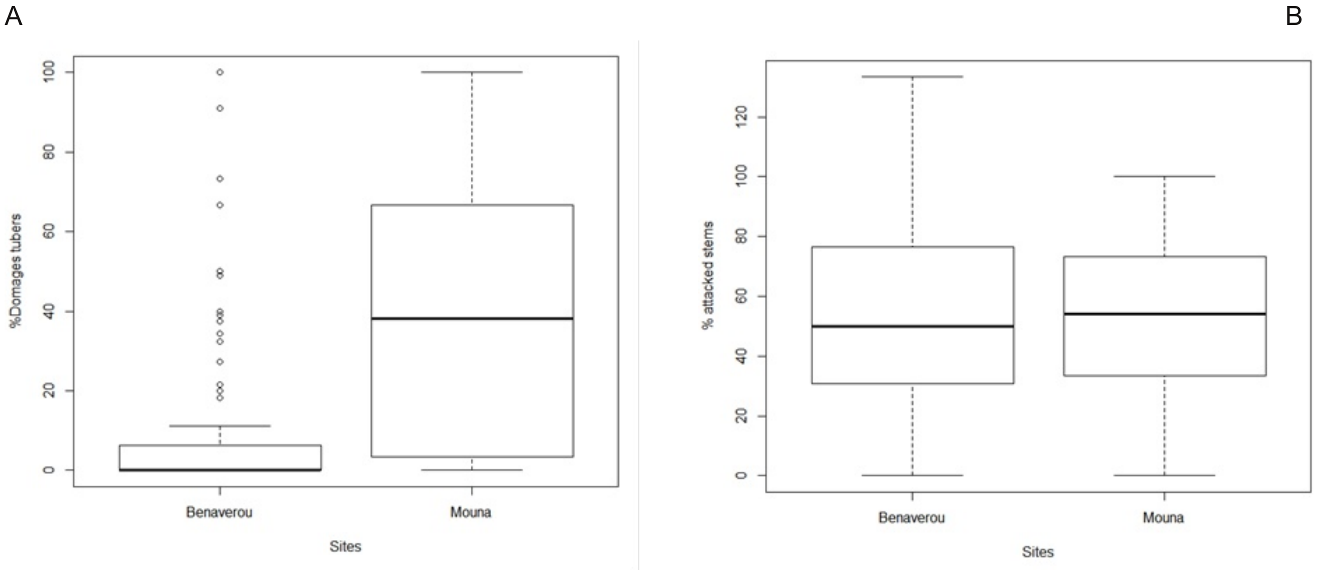

Figure 1: Percentage damaged tubers (A) and attacked stems (B) due to sweet potato weevils *Cylas puncticollis* at two locations in 2013.

Tableau 1
Severity of damages, status of the different sweet potato varieties and yield of marketable tubers.

Varieties	*Damage score	Status	Yield of marketable tubers (t/ha)	
			MOUNA	BENAVEROU
RESISTO	1.0±0.0e	R	0.1±0.0b	0.4±0.2de
ZAPPALO -1	1.0±0.0e	R	0.2±0.1b	0.5±0.0de
BF138	1.5±0.2ed	MR	0.1±0.6b	0.2±0.1de
BF59*CIP-1	1.5±0.2ed	MR	0.5±0.5b	0.9±0.3cde
BF59*RESISTO-3	1.5±0.2ed	MR	0.5±0.2b	0.2±0.0de
BF59*TIB-1	1.5±0.2ed	MR	0.9±0.2b	2.1±0.2cdbe
BF77*TAINUNG-10	1.5±0.2ed	MR	7.3±1.7a	6.3±1.4ab
BF80-3	1.5±0.2ed	MR	0.1±0.1b	2.1±1.9cdbe
BF92*CIP-6	1.5±0.2ed	MR	0.5±0.2b	0.2±0.0de
BF59*RESISTO-10	2.0 ±0.4ed	MR	2.9±1.7ab	1.3±0.5cde
BF59*TIB-3	2.0±0.0ed	MR	4.3±0.9ab	5.1±1.2cadb
BF82*TAINUNG22	2.0±0.4ed	MR	2.7±1.6ab	1.6±1.0cde
TIB440060	2.0±0.4ed	MR	1.6±0.5b	3.1±1.1cdbe
TIEBELE-2	2.0±0.0ed	MR	3.5±1.1ab	3.0±0.4cdbe
BF14	2.5±0.2ced	MS	3.9±1.0ab	2.1±1.1cdbe
BF51	2.5±0.61ced	MS	3.9±2.8ab	1.7±0.8cdbe
BF59*CIP-4	2.5±0.2ced	MS	0.8±0.6b	0.6±0.6de
EJUMULA-1	2.5±0.6ced	MS	0.1±0.0b	0.1±0.1^{e}
BF77*TAINUNG-2	3.0±0.8cedb	MS	3.3±1.0ab	1.2±0.3cde
ZAPPALO 3-1-3	3.0±0.8cedb	MS	0.15±0.06b	0.0±0.0^{e}
BF 10	3.5±0.2cadb	S	2.2±1.04ab	5.2±1.3cadb
BF 59	3.5±0.6cadb	S	3±2.86ab	8.1±0.9a
CAROMEX	3.5±0.6cadb	S	4.95±1.74ab	4.2±1.5cadbe
EJUMULA-2	3.5±0.6cadb	S	0.6±0.6b	2.3±0.8cdbe
BF-3	4.0±0.4cab	S	1.2±0.8b	5.7±1.1cab
BF59*RESISTO-4	4.0±0.0cab	S	1.7±0.4b	5.1±1.3cadb
BF59*RESISTO-7	4.0±0.0 cab	S	1.0±0.4b	1.9±0.0cdbe
CIP199062-1	4.0±0.0cab	S	1.5±1.0b	4.5±1.3cadbe
JEWEL	4.5±0.2ab	S	2.8±0.5ab	0.3±0.1de
BF 18	5.0±0.0a	S	0.5±0.2b	5.6±2.1cab

*(40) 1-5 damage scoring
R= Resistant, MR=Moderately Resistant, MS=Moderately Sensitive, S=Sensitive

Tableau 2
Combine effect of manure and mineral fertilizers on sweet potato weevils damage and yields in two consecutive seasons.

		Damage score		Marketable tubers (T/ha)	
Manure	NPK doses	2012	2013	2012	2013
No manure	15-0-45	2.75±0.25ab	3.50±0.25a	1.10±0.44b	2.06±0.84a
	30-0-90	1.25±0.25b	1.75±0.47ab	8. 87±1.77ab	8.69±3.54a
	0-30-100	2.00±0.40ab	2.25±0.47ab	3.10±1.26ab	7.12±3.34a
	30-30-0	3.25±0.47a	3.20±0.475a	3.70±1.51ab	3.37±1.37a
20 t/ha of manure per year	15-0-45	2.50±0.86ab	2.25±0.25ab	1.50±0.61b	1.37±0.47a
	30-0-90	2.50±0.28ab	2.00±0ab	10.00±2.00a	8.44±3.44a
	0-30-100	1.25±0.25b	1.75±0.25ab	7.80±3.18ab	11.62±4.74a
	30-30-0	1.00±0.00b	1.00±0.00b	3.40±1.38ab	2.19±0.89a
20t/ha of manure every two years.	15-0-45	2.25±0.47ab	1.75±0.47ab	3.10±1.26ab	4.44±1.81a
	30-0-90	1.75±0.25ab	1.75±0.25ab	4.62±0.92ab	5.69±2.17a
	0-30-100	1.50±0,28ab	2.00±0ab	6.60±2.69ab	9.56±3.90a
	30-30-0	2.25±0.47ab	2.00±0.57ab	1.75±0.66b	1.56±0.66a
		$F_{11,84}$=2.80; P=0.0097	$F_{11,84}$=3.21; P=0.0039	$F_{11,84}$= 3.17; P=0.0043	$F_{11,84}$=1.74; P=0.1000
Season effect		$F_{1, 94}$= 10.62; P=0.0016		$F_{1, 94}$= 1.20; P=0.27	
Manure effect		$F_{3, 93}$= 0.62; P=0.5400		$F_{3, 93}$= 0.71; P=0.4900	
Mineral fertilizer effect		$F_{3, 92}$= 1.91; P=0.1300		$F_{3, 92}$= 6.42; P=0.0005	
Manure x Mineral fertilizer		$F_{3, 84}$= 3.14; P=0.0014		$F_{3, 84}$= 2.93; P=0.0025	

Tableau 3

Percentage of tubers damaged by weevil and yield of marketable tubers on two sweet potato varieties under different weeding regimes in 2014 and 2015.

		Damaged tubers (%)		Marketable tubers (T/ha)	
		2014	2015	2014	2015
BF11	No weeding	0.00±0.00c	0.00±0.00b	0.30±0.21b	0.59±0.42b
	Continuous hand weeding	42.12±11.02cab	66.14±10.00a	2.25±0.56a	1.47±0.05a
	4 WAT	68.30±7.67a	60.42±13.95a	0.89±0.49b	0.11±0.02b
	6 WAT	32.09±9.35cab	42.69±20.92ab	1.15±0.26b	0.04±0.02b
	8 WAT	49.34±13.48ab	81.94±11.86a	0.54±0.12b	0.11±0.01b
	10 WAT	27.04±11.33cab	29.12±7.9ab	0.60±0.05b	0.23±0.05b
EJUMULA-2	No weeding	30.83±10.83cab	33.89±9.7ab	0.16±0.06b	0.00±0.00b
	Continuous hand weeding	31.91±6.33cab	62.98±13.11a	0.48±0.14b	0.00±0.00b
	4 WAT	35.14±11.65cab	82.61±17.39a	0.13±0.01b	0.21±0.04b
	6 WAT	16.58±4.78cb	61.50±18.31a	0.55±0.27b	0.00±0.00b
	8 WAT	35.24±11.41cab	77.31±10.46a	0.74±0.3b	0.06±0.01b
	10 WAT	34.09±7.54cab	0±0b	0.21±0.06b	0.00±0.00b
		P=0.0059	P=0.0022	P=0.0003	P<0.0001
		F=3.03	F=3.48	F=4.49	F=11.25
		DF=11	DF=11	DF=11	DF=11
Varietal effect		$F_{1, 94}$=0.03; P=0.87		$F_{1, 94}$=6.67; P=0.01	
Season effect		$F_{1, 94}$=9.92; P=0.0020		$F_{1, 94}$=14.77; P=0.0002	
Weeding effect		$F_{5, 90}$=6.54; P<0.0001		$F_{5, 90}$=1.79; P=0.1200	
Weeding x variety		$F_{11,84}$=3.28; P=0.0009		$F_{11,84}$=1.94; P=0.0400	
Weeding x season		$F_{11,84}$=6.69; P<0.0001		$F_{11,84}$=2.94; P=0.0025	
Varieties x season		$F_{3, 92}$=3.25; P=0.0200		$F_{3, 92}$=7.91; P=0.0001	
Weeding x variety x season		$F_{23, 72}$=3.29; P<0.0001		$F_{23, 72}$=2.26; P=0.0040	

Means within a column followed by the same letters are not significantly different by the mean comparison test of Student-Newman-Keuls (α = 0,05).

Tableau 4
Combine effect of manure and mineral fertilizers on sweet potato weevils damage and yields in two consecutive seasons.

		Damaged tubers (%)		Marketable tubers (T/ha)	
		2014	2015	2014	2015
BF11	No weeding	0.00±0.00c	0.00±0.00b	0.30±0.21b	0.59±0.42b
	Continuous hand weeding	42.12±11.02cab	66.14±10.00a	2.25±0.56a	1.47±0.05a
	4 WAT	68.30±7.67a	60.42±13.95a	0.89±0.49b	0.11±0.02b
	6 WAT	32.09±9.35cab	42.69±20.92ab	1.15±0.26b	0.04±0.02b
	8 WAT	49.34±13.48ab	81.94±11.86a	0.54±0.12b	0.11±0.01b
	10 WAT	27.04±11.33cab	29.12±7.9ab	0.60±0.05b	0.23±0.05b
EJUMULA-2	No weeding	30.83±10.83cab	33.89±9.7ab	0.16±0.06b	0.00±0.00b
	Continuous hand weeding	31.91±6.33cab	62.98±13.11a	0.48±0.14b	0.00±0.00b
	4 WAT	35.14±11.65cab	82.61±17.39a	0.13±0.01b	0.21±0.04b
	6 WAT	16.58±4.78cb	61.50±18.31a	0.55±0.27b	0.00±0.00b
	8 WAT	35.24±11.41cab	77.31±10.46a	0.74±0.3b	0.06±0.01b
	10 WAT	34.09±7.54cab	0±0b	0.21±0.06b	0.00±0.00b
		P=0.0059	P=0.0022	P=0.0003	P<0.0001
		F=3.03	F=3.48	F=4.49	F=11.25
		DF=11	DF=11	DF=11	DF=11
Varietal effect		$F_{1, 94}$=0.03; P=0.87		$F_{1, 94}$=6.67; P=0.01	
Season effect		$F_{1, 94}$=9.92; P=0.0020		$F_{1, 94}$=14.77; P=0.0002	
Weeding effect		$F_{5, 90}$=6.54; P<0.0001		$F_{5, 90}$=1.79; P=0.1200	
Weeding x variety		$F_{11,84}$=3.28; P=0.0009		$F_{11,84}$=1.94; P=0.0400	
Weeding x season		$F_{11,84}$=6.69; P<0.0001		$F_{11,84}$=2.94; P=0.0025	
Varieties x season		$F_{3, 92}$=3.25; P=0.0200		$F_{3, 92}$=7.91; P=0.0001	
Weeding x variety x season		$F_{23, 72}$=3.29; P<0.0001		$F_{23, 72}$=2.26; P=0.0040	

Means within a column followed by the same letters are not significantly different by the mean comparison test of Student-Newman-Keuls (α=0,05).

Discussion

In our experiment, damage likely due to the infestation levels of the sweet potato weevil varied with location and varieties due to environmental characteristics and plant genetic attributes. Several factors had an impact, including:

- the physical attributes of the sweet potato;
- the age of stem cutting; and
- the influence of season and altitude on SPW infestation (35).

Among these attributes, the first and the last seem to play key roles in our case.

The physical attributes, including flesh colour, neck length, shape, thickness, and skin colour, are related with infestation of sweet potatoes by weevils. Certain studies have shown that oval- and round-shaped sweet potato tubers were more attacked in the field by SPW compared to elongate, spindle, and long-stalked tubers (44). The ability of some varieties to form tubers deeper in the soil reduces weevil damage (29). Also, the sweet potato rooting characteristic, especially root size can significantly affect tuber infestation by SPW (24).

The content of some chemical compounds in the tubers is also a factor that can make sweet potato varieties resistant to the SPW (4, 42). Compounds such as caffeic acids, coumaric acid esters inhibit SPW feeding and reduce egg-laying capacity (42). The volatiles emitted by sweet potato aerial parts and roots, especially sequiterpene can make some genotypes less attractive for SPW (25, 47).

Weevil damage due to infestation has a relationship with the location, altitude and planting season of the sweet potatoes (35). The temperature and humidity may influence the infestation and level of damage in the field. Several studies have concluded that higher temperatures may increase the growth rate of the insect's population as well as the risk and severity of the outbreaks (17). The development of weevils from egg stage to adults is faster in the environments where the temperature is ranged between 25 °C and 30 °C (30). In our study area, the temperature ranged from to 25.6 °C to 33 °C, likely more than sufficient to stimulate growth in the insect population and allow the development of more than three generations of SPW during the cultural season. The planting date may also increase the pest population. When sweet potatoes were planted late, the incidence of weevil infestation is higher than when they were planted early from June to July (20). In our region September planting date is considered late (20) and this period is not conducive to the development of the main natural enemies such as nematodes and entomopathogenic fungi (41).

In addition, the infestation and damage recorded may be reliant on the nature of the soil. The two locations where the study was carried out belong to the same agroecology but had different soil characteristics. In fact, at MOUNA, the soil is clayey, while it is sandy at BENAVEROU. When the tubers begin to grow, the clayey soil cracks, especially when dry. As SPW cannot dig a hole into the soil, these cracks facilitate SPW entering the soil and damage the tubers. The damage that occurred late did not affect the overall tuber yields, which were not significantly different between the two sites. However, the damage affected the yield of marketable tubers. Overall, the varieties CAROMEX, BF18, BF59 and BF-3 appeared to be tolerant to the SPW with good tuber yield despite significant damage. The varieties ZAPPOLO-1 and RESISTO could constitute a good source of resistance for breeding programmes. Both varieties exhibited low yields at both sites. Low-yielding varieties are generally less affected by sweet potato weevils (5). Resistance and / or tolerance to the SPW are attributed to different features, including pest preference. Sweetpotato resistance to weevils has been reported in the laboratory and the field (9; 31; 46). Sweet potato resistance to weevil adults should be examined in terms of the preference of the SPW for ovipositing on specific cultivars, which may be related to the potential of latex produced by the sweet potato as a defense mechanism (13) However, according to Okada *et al.* (32), few studies have considered the preference of weevil adults for some cultivars or the suitability of the preferred cultivars for juvenile development. For these reasons, further investigations are needed to better understand the mechanisms of resistance of the identified varieties.

Regarding fertilizers, our findings indicate a positive effect of manure in combination with a high K content on reducing SPW damage and increasing the yield of marketable tubers. The effectiveness of some fertilizers as compost or manure associated with synthetic fertilizers in reducing pest populations has been reported on the spotted tentiform leafminer *Phyllonorycter blancardella* and the migrating woolly apple aphid *Eriosoma lanigerum* (10) and for *Colorado potato* beetle (3). The negative effects of K fertilizer on the SPW that were observed in the present study were also reported for different insect species in other settings (14). In fact, nitrogen and potassium influence the accumulation of chemicals in the tubers, affecting the resistance of the varieties to the SPW (28). Organic fertilization alone had no effect on weevil damage or yields. This result is in accordance with the findings of Alyokhin *et al.* (3), who report that synthetic fertilizers applied alone did not reduce the Colorado potato beetle population in the treated plot. However, this result differs from those of other authors (6), which showed that for the weevil *Cylas puncticollis*, damage increases with high doses ofpoultry manure.

Indeed, for soils rich in organic matter or manure, the infiltration rate and the water retention capacity improve, making these soils supple and loose (18). This feature increases the porosity of these soils and facilitates the penetration of adult SPW, causing significant damage to the tubers. In our study, the presence of mineral fertilizers could reduce the effects of organic manure on the soil porosity. It has been reported that mineral fertilizers without organic amendment cause the hardening of some soils, making it difficult for SPWs to enter these soils to attack sweet potato tubers (36). The fertilization of plants improves their growth and increases the rate of organic matter in the soil. Fertilization is the main determinant of biological activity and influences the physical and chemical properties of the soil (8). The action of some organic and mineral fertilizers could reduce soil cracks and improve tuber yields.
The evaluation of the effects of weeding on SPW management showed that the crops were less damaged by the SPW when the plot was not weeded at all or when it was weeded once 10 weeks after planting. To the best of our knowledge, this is the first time such a finding is reported on *C. puncticollis* in Africa. This result is very interesting for sweetpotato producers because they will be able to choose the best times for weeding their sweet potato field.
Several cultural practices have been identified as being effective in SPW management in terms of reducing the infestation level in the field, and reports have been published on combining potato varieties, harvesting dates and mulching levels (26); potato cultivars in relation to different mulching levels (27); host plant resistance/tolerance, mulching and varying harvesting dates (11); combinations of 3 earthing-up events and prompt harvesting (48). The decreasing effect of weeds in terms of the number of crops attacked in the fields may be due to the favourable microenvironment that they create for natural enemies of the SPW. As reported in other settings, the non-crop habitats may harbour beneficial organisms such as predators of the pest (7). The natural enemies of the SPW include fungi and nematodes (49), the development of which could be enhanced by the microclimate created by the weeds. Similarly ants and carabids, which are potential predators of weevils, are more prevalent in not weeded plots (22). In addition to the better development of natural enemies, the weeds helped increase the soil humidity, which reduces soil cracking and could make it difficult for SPW to enter the soil (35). Finally weeds itself can make it difficult for SPW to walk on soil and spread in the crop.
However, the positive effect of weeds on SPW infestations could be lowered by the negative effects of weeds on crop development.

In fact, the weed species encountered included mainly *Cyperaceae* species, which are competitors for nutrients. These weeds can cause a yield loss if their density is high (34). The option to weed once 10 weeks after planting could be a good trade-off. Another option is to associate the sweet potato with edible cover crops, as crop association seems to be effective for controlling SPW (15).
The next step is to combine the best fertilizer combination and weeding practice with resistant varieties in an IPM approach for controlling the SPW.

Conclusion

At the end of this study, two varieties (RESISTO and ZAPPALO-1) were identified as resistant to the weevils' attacks and four varieties (Caromex, BF77 Tainung * -10, BF14, BF59 * TIB-3) which were more productive. Also, weevils' damages were lowered in the no weeding plots than in continuous hand weeding plots. Finally, the application of the N30P0K90 and N0P30K100 was given the high yields and considerably reduced the damage of the sweet potato weevils. In the context of a sustainable and effective management of sweet potato weevils, it is critical to combine the various cultural control methods implemented during this study. For that we recommend the use of resistant and high yielding varieties combined with good cultural practices including the applying of mineral fertilizers (high rate of nitrogen and potassium), organic fertilizers (20 t/ha) and a delay weeding 10 weeks after planting.

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Literature

1. Alcazar J., Cisneros F. & Morales A., 1997, *Large-scale implementation of IPM for sweet potato weevil in Cuba: A collaborative effort*, Program Report 1995-1996. International Potato Center, Lima, Peru. 185-190.
2. Altieri M.A. & Nicholls C.I., 2004, *Biodiversity and pest management in agro ecosystems*. 2nd edn. New York: Food Products Press. 252 p.
3. Alyokhin A., Porter G., Groden E .& Drummond F., 2005, Colorado potato beetle response to soil amendments: A case in support of the mineral balance hypothesis. A*gri., Ecosyst. Environ.*, **109**, 234-244.
4. Anyanga M.O., Muyinza H., Talwana H., Hall D.R., Farman D.I., Ssemakula, G.N., Mwanga R.O.M. & Stevenson P.C., 2013, Resistance to the weevils *Cylas puncticollis* and *Cylas brunneus* conferred by sweet potato root surface compounds. *J. Agric. Food Chem*., **61**, 8141-8147.
5. AVRDC, 1990, *Screening for sweet potato weevil resistance*. Progress Report 1988, Asian Vegetable Research and Development Center, Taiwan. 175-176.
6. Bamaiyi L.J., Dauji L.Z., Gabriel V.K., Lyocks W.S.J. & Tanimu J., 2011, Effect of poultry manure rates and vine staking on the incidence and severity of *Cylas puncticolis* (Curculionidae: Brentidae) on sweetpotato (*Ipomea batatas* Lam). *J. Agric. Biol. Sci.*, **2**, 049-053.
7. Bianchi F.J., Booi C.J.& Tscharntke T., 2006, Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings. R. Soc. Lond., *B. Biol. Sci.*, **273**, 1715-1727.
8. Bi voko D.R.R., Ahonzo-Niamke S.L., & Zeze A., 2013, Impact des propriétés physicochimiques des sols de culture du manioc sur l'abondance et la diversité des communautés de champignons mycorhiziens à arbuscules dans la zone agro écologique d'Azaguie, sud-est de la Côte d'Ivoire. *Agron. Afr.*, **25**, 251-264.
9. Bottega D.B., Rodrigues C.A. & Peixoto N., 2010, Selection of sweet potato clones (*Ipomoea batatas*) resistant to *Euscepes postfasciatus* under field conditions in Ipameri, State of Goiás, Brazil. *Rev. Agri.*, 85, 179-184.
10. Brown M.W. & Tworkoski T., 2004, Pest management benefits of compost mulch in apple orchards. *Agric. Ecosyst. Environ.*, **103**, 465-472.
11. Devi M., Niranjana R.F. & Kalieswari N., 2016, Evaluation of cultural control practices in the management of sweet potato weevil (*Cylas formicarius*) (Apionidae: Coleoptera). *Int. J. For. Crop Improvement*, **7**, 24-28.
12. DGESS, 2014, *Résultats définitifs de la campagne agricole et de la situation alimentaire et nutritionnelle en 2013/2014*. MASA. 77 p.
13. Emma S., Data S.F., & Nottingham S.J.K., 1996, Effect of Sweet potato Latex on Sweet potato Weevil (Coleoptera: Curculionidae) Feeding and Oviposition. J*. Econ. Entomol.*, **89**, 544-549.
14. Facknath S. & Lalljee B., 2005, Effect of soil-applied complex fertilizer on an insect-host plant relationship: *Liriomyza trifoliion - Solanum tuberosum*. *Entomol. Exp. Appl.*, **115**, 67-77.
15. Fite T., Getu E. & Sori W., 2014, Integrated management of sweet potato weevil, *Cylas puncticollis* (Boheman) (Coleoptera: Curculionidae) in Eastern Ethiopia. *J. Entomol.*, **11**, 225-237.
16. Fuglie K.O., 2007, Priorities for sweet potato research in developing Countries: Results of a survey. *Hort Science*, **42**, 1200-1206.
17. Gomi T., Nagasaka M., Fukuda T. & Higahara H., 2007, Shifting of the life cycle and life-history traits of the fall webworm in relation to climate change. Entomol. *Exp. Appl.*, **125**, 179-184.
18. Grandy A.S., Porter G.A. & Erich M.S., 2002, Organic amendment and rotation crop effects on the recovery of soil organic matter and aggregation in potato cropping systems. *Soil Sci. Soc. Am. J.*, **66**, 1311-1319.
19. INSD, 2013, *Annuaire statistique 2011. Ministere de l'Economie et des finances*. 420 p.
20. Institute de l'Environnement et de Recherche Agricole. Rapport de la campagne 2012-2013.
21. Issa A.H., Doumma A. & Toufique B.M., 2015, Inventaire des variétés, des méthodes locales de stockage et de protection contre les ravageurs de la patate douce (Ipomea batatas L.) dans la bande Ouest du Niger. *Int. J. Biol. Chem. Sci.*, **9**, 1962-1971.
22. Jackson D.M. & Harrison, H.F., 2008, Effects of a killed-cover crop mulching system on sweetpotato production, soil pests, and insect predators in South Carolina. *J. Econ. Entomol.*, **101**, 1871-1880.
23. Jackson D.M., Harrison J.H.F. & Ryan-Bohac J.R., 2012, Insect resistance in sweet potato plant introduction accessions. *J. Econ. Entomol.*, **105**, 651-658.
24. Kabi S., Ocenga-Latigo M.W., Smit N.E.J.M., Stathers T.E. & Rees D., 2001, Influence of Sweet potato Rooting Characteristics on Infestation and Damage by *Cylas* Spp., *Afr. Crop Sc. J.*, **1**, 165-174.
25. Korada R.R., Naskar S.K., Prasad A.R., Prasuna A.L., & Jyothi K.N., 2010, Differential volatile emission from sweet potato plant: mechanism of resistance in sweet potato for weevil *Cylas formicarius* (Fab.). *Current Sc.*, **99**, 1597-1601.
26. Mansaray A., Sundufu A.J., Yilla K. & Fomba S., 2014, Evaluation of cultural control practices in the management of sweet potato weevil (Cylas puncticollis) Boheman (Colepotera: Curculionidae), *Sc. Connect*, **44**, E-ISSN: 2223-506X.
27. Mansaray A., Sundufu A.J., Moseray M.T. & Fomba S.N., 2015, Sweet potato weevil (*Cylas puncticollis*) Boheman infestation: cultivar differences and the effects of mulching. *Open Entomol. J.*, **9**, 7-11.
28. Marti H.R., Mills H.A., Severson R.F. & Kays S.J., 1993, Nutritional effects on sweet potato storage root surface chemistry. *J. Plant Nutr.*, **16**, 653-665.
29. Muyinza H., Talwana H.L., Mwanga R.O.M.& Stevenson C., 2012, Sweet potato weevil (Cylasspp.) resistance in Africa sweet potato germplasm. *Int. J. Pest Manag.*, **58**, 73-81.

30. Nteletsana L., Schoeman A.S. & Geoch M., 2001, Temperature effects on development and survival of sweet potato weevil, *Cylas puncticollis* Boheman (Coleoptera: Aionidae), *Afr. Entomol.*, **9**, 1-3.
31. Okada Y.K., Yasuda T.S. & Ichinose K., 2014, Sweetpotato resistance to *Euscepes postfaciatus* (Coleoptera: Curculionidae): larval preference adversely effected by adult's preference to tuber for food and oviposition. *J. Econo. Entmol.*, **107**, 1662-1673.
32. Okada Y., Kobayashi A., Tabuchi H. & Kuranouchi T., 2017, Review of major sweet potato pests in Japan, with information on resistance breeding programs. *Breed Sci*., **67**, 73-82.
33. Okonya J.S. & Mujica N., Carhuapoma P. & Kroschel J. 2016, S*weetpotato weevil, Cylas puncticollis (Boheman 1883)*. In: Kroschel J., Mujica N., Carhuapoma P. & Sporleder M. (Eds.). *Pest distribution and risk atlas for Africa. Potential global and regional distribution and abundance of agricultural and horticultural pests and associated biocontrol agents under current and future climates*. Lima (Peru). International PotatoCenter (CIP). ISBN 978-92-9060-476-1.
34. Seem J.E., Creamer G.N. & Monks D.W., 2003, Critical weed free period for Beauregard sweet potato (*Ipomoea batatas*). *Weed Technol.*, **17**, 686-695.
35. Seow-Mun H. & Min-Yang L., 2015, *An insight into sweet potato weevils management: A Review.* Psyche, 849560, doi:10.1155/2015/849560
36. Smit N.E. & Matengo L.O., 1995, Farmers' cultural practices and their effects on pest control in sweet potato in south Nyanza, Kenya. *Int. J. Pest Manag.*, **41**, 2-7.
37. Smit N.E.J.M., 1997, *Integrated pest management for sweet potato in Eastern Africa*. PhD Thesis, Wageningen University, The Netherlands, 151 p.
38. Smit N.E.J.M., Downham M.C.A., Laboke P.O., Hall D.R., & Odongo B., 2001, Mass trapping male Cylas spp. with sex pheromones: A potential IPM component in sweet potato production in Uganda. *Crop Prot.*, **20**, 643-651.
39. Sorensen K.A., 2009, Sweet potato insects: *identification, biology and management.* In: *The sweet potato*. Loebenstein G. & Thottappilly G. (Eds.). Springer-Verlag New York Inc., USA. Pp 157-184.
40. Stathers T.E., Rees F., Kabi S., Mbilinyi L., Smith N.M., Koizya H., Jeremiah S.A. & Nyanjio D. J., 2003, Sweet potato infestation by *Cylas* species in East Africa: I. Cultivar differences in field manifestation and the role of plant factors. *Int. J. Pest Manag.*, **49**, 131-140.
41. Stathers T., Namanda S., Mwanga R.O.M., Khisa G. & Kapinga R., 2005, *Manual for sweet potato Integrated Production and Pest Management Farmer Field Schools in Sub-Sahara Africa*. International Potato center Kampala, Uganda. 168 p.
42. Stevenson P.C., Muyinza H., Hall D.R., Porter E.A., Farman D.I., Talwana H. & Mwanga R.O.M., 2009, Chemical basis for resistance in sweet potato *Ipomoea batatas* to the sweet potato weevil *Cylas puncticollis*. *Pure Appl. Chem.*, 8, 57-67.
43. Tarekegn F., Emana G., & Waktole S., 2014, Integrated management of sweet potato weevil *Cylas puncticollis* (Boheman) (Coleoptera: Curculionidae) in Eastern Ethiopia. *J. Entomol.*,**11**, 225-237.
44. Teli V.S. & Salunkhe G.N., 1996, A search for sources of resistance to sweet potato weevil. I. Morphological traits. *J. Maharashtra Agric. Univ.,* **20**, 400-403.
45. Uritani I., Saito T., Honda, H.& Kim W.K., 1975, Induction of furano-terpenoids in sweet potato roots by the larval components of the sweet potato weevils. *Agric. Biol. Chem.*, 37, 1857-1862.
46. Wanderley P.A., Boiça A.L.J., & Wanderley M.J.A., 2004, Resistência de Cultivares de Batata-Doce a *Euscepes postfasciatus* Fairmaire (Coleoptera: Curculionidae). *Neotrop. Entomol.*, **33**, 371-377.
47. Wang Y. & Kays S.Y., 2002, Sweetpotato volatile chemistry in relation to sweetpotato weevil (*Cylas formicarius*) behavior. *J. Am. Soc. Horticultural Sci.*, **127**, 656-662.
48. Wolde W., Getu E. & Sori W., 2014, Integrated Management of Sweet potato Weevil (Cylaspuncticollis (B.)) (Coleoptera: Curculionidae) at Chano Dorga, Southern Ethiopia. *Asian J. Agric Resear.*, **8**, 17-29.
49. Yamaguchi T., Kawasoe K. & Izumi S., 2006, Pathogenicity of steinernematid nematodes on the sweet potato weevil, *Cylas formicarius* (Fabricius) (Coleoptera: Curculionidae) and their feasibility for suppression of the weevil population. *Jap. J. Appl. Entomol. Zool.*, **50**, 217-224.

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