Effects of crop sanitation on banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), populations and crop damage in Uganda

M. Masanza[1], C.S. Gold[1*], A. van Huis[2] & P. E. Ragama[1]

[1]*International Institute of Tropical Agriculture, P.O. Box 7878, Kampala, Uganda*
[2]*Laboratory of Entomology, Wageningen University, P.O. Box 8031, Wageningen, 6700 EH, the Netherlands*

Crop sanitation, *i.e.* destruction of crop residues, has been hypothesized to lower banana weevil damage by removing adult refuges and breeding sites. Although it has been widely recommended to farmers, limited data are available to demonstrate the efficacy of this method. The effects of crop sanitation on banana weevil populations and damage were studied in an on-station trial in Uganda. Treatments included low, moderate and high levels of sanitation. Banana weevil populations, estimated by trapping and mark and recapture methods, were lowest in the high sanitation treatment. However, banana weevil damage was either not significantly different among treatments or lower in low sanitation treatments. Similarly, increases in crop sanitation level were not reflected in higher yields. The data from this trial suggest that crop sanitation is not an effective means of managing banana weevil and contrasts with results from an on-farm study in which sanitation reduced both weevil numbers and damage. Possible factors explaining the different outcomes of the two studies are discussed.

Key words: banana weevil, *Cosmopolites sordidus,* crop residues, crop sanitation, highland banana.

INTRODUCTION

Highland cooking banana is an important food and cash crop in Uganda. Most highland banana is grown in small plots by resource-poor farmers with limited inputs. As a perennial, highland banana is important in reducing soil erosion on slopes. Well-maintained stands can last 50 or more years. In recent years, serious yield declines in traditional banana-growing areas in central Uganda have led to the rapid disappearance of banana in this region (Gold *et al.* 1993, 1999a). Early stages of yield decline have also been reported in commercial banana production zones in the country's southwest (Gold *et al.* 1993, 1999b). The decline in yield was attributed, in part, to the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) (Gold *et al.* 1999a). In central Uganda, farmers attributed high levels of banana weevil to abandonment of crop sanitation practices, *i.e.* removal or destruction of crop residues, as these were seen by many as a breeding site for this insect.

Banana weevils oviposit in the base of the plant. The larvae tunnel mostly in the corm but will also attack the true stem and crop residues. Banana weevil damage weakens the stability of the mat and impedes water and nutrient uptake. Damage results in plant loss through snapping and toppling and premature mortality before bunches are developed, reduced bunch weights, mat disappearance and shortened plantation life (Gold *et al.* 2001). Yield losses of up to 100 % have been reported (Sengooba 1986). The insect is disseminated through infested planting material. Population build-up is slow and banana weevil damage and associated yield losses are most pronounced in ratoon crops (Rukazambuga *et al.* 1998).

The adult weevil lives up to four years. It remains reproductive throughout its lifetime, although it produces only a few eggs per week (Abera *et al.* 1999). The adult is free-living and most often found in or near banana plants and crop residues (Gold *et al.* 2004). Treverrow & Bedding (1993) reported crop residues to host 60 % of banana weevil adults in Australia. In Uganda, 25–32 % of adults were found in cut residues, while 10–12 % were associated with standing stumps (Gold *et al.* 2004). Abera *et al.* (1999) found that 33 % of banana weevil oviposition on highland cooking banana was in the stumps, while Vilardebo (1960) reported that infestation of the dessert variety, Gros Michel (AAA), in Ecuador occurred mostly in the residues.

Gold & Bagabe (1997) observed limited infesta-

*To whom correspondence should be addressed.
E-mail: c.gold@cgiar.org

tion on recently harvested plants of the resistant cultivar, Kisubi (Ney poovan subgroup, AB), but that infestation increased over time. Recapture of marked weevils showed considerable movement between adjacent stands of Kisubi and the susceptible highland banana cultivar, Kibuzi. Thus, population build-up in a 'resistant' Kisubi plantation may have contributed to banana weevil damage in the highland banana stand. Similarly, no larvae were found in recently harvested Pisang awak (AB) plants in Sumatra, Indonesia, but high infestations were observed on cut residues left prostrate in the field (C.S. Gold & A. Hasyim, pers. obs.). Antibiosis has been reported as the major means of resistance to banana weevil (Kiggundu 2000; Gold *et al.* 2001). These data suggest that antibiotic mechanisms may break down after harvest and that cut residues may suffer higher attack because of increased exposure of the corm and true stem.

Crop sanitation has been widely recommended as a measure for managing banana weevil in Uganda. Indeed, in a survey of banana farms in Ntungamo district, Uganda, crop sanitation appeared to be the agronomic factor most strongly related to reduced banana weevil damage (Gold *et al.* 1999b). However, survey data for banana-based cropping systems are rarely conclusive because of the complexity of banana stands including differences in topography, soils, intercrops, banana cultivars and agronomic practices. Therefore further studies are needed to determine the role of crop sanitation on banana weevil populations and damage. Crop residues could reduce banana weevil damage by acting as a 'trap crop' for ovipositing females and drawing them away from standing plants; and by providing a habitat for natural enemies, especially arthropod predators that thrive in banana debris.

The primary objective of this research was to study the effects of crop sanitation on banana weevil population levels and damage to growing plants through a controlled on-station study.

MATERIAL AND METHODS

A field trial was conducted at the Kawanda Agricultural Research Institute (KARI) (0º25'N 32°32'E, 1190 m a.s.l.), 13 km north of Kampala, Uganda, with 12-hour day length throughout the year, a mean annual precipitation of 1190 mm, and an average daily temperature range of 16 to 29 °C. The soil is an isohyperthermic Kandiudalfic Eutrodox (USDA taxonomy) with high water holding capacity, medium acidity (pH 5.9–6.3), low organic matter content and nitrogen and phosphorus deficiency (McIntyre *et al.* 2001; O. Semalulu, pers. comm.).

Four strips of land, one hectare each, were used in the study. Two strips had been in fallow for two years, following earlier plantings of maize and beans. The other two strips, 200 m distant, had supported a banana germplasm collection for 10 years (1989–1998). The plants were uprooted several months prior to our field trial and, based on observations of fresh damage in crop residues, appeared to have a small residual banana weevil population at the time of ploughing.

Experimental design

The experiment had two sets of variables: sanitation level and plant stress. The original design had six treatments: (1) low sanitation, low plant stress; (2) moderate sanitation, low plant stress; (3) high sanitation, low plant stress; (4) low sanitation; high plant stress; (5); moderate sanitation, high plant stress; (6) high sanitation, high plant stress. These were laid in a randomized block design with four replications.

Low levels of sanitation involved leaving both the residual pseudostems and corms in the field; pseudostems of harvested plants were cut 1 m above the collar, the cut portion placed prostrate on the ground. Moderate sanitation involved cutting the pseudostem 1 m above the collar and shredding the cut portion so that it would dry out rapidly. High sanitation involved digging stumps from the soil and chopping both residual pseudostems and corms, denying ovipositing banana weevils access; moderate sanitation prevented access only to residual pseudostems; while low sanitation did not prevent access to pseudostem and corm residues. In all treatments, the corms were left *in situ,* but under high sanitation, the corms were covered with 3–5 cm of soil. Sanitation treatments were implemented with harvest of first bunches in the first crop cycle, April 2000, and continued until the end of the trial.

High plant stress was created by infesting the plots with the banana nematodes, *Heliocotylenchus multicinctus* (Cobb) Golden and *Radopholus similis* (Cobb) Thorne. Subsequent monitoring of root necrosis levels on flowered plants showed that nematode infestations were low and not signifi-

cantly different from those in non-innoculated plots. Therefore, we reduced the treatments to three sanitation levels, high, moderate and low sanitation, with eight replicates.

The four strips were ploughed in February 1999. Plots (787.5–900 m^2) contained 105–140 plants spaced at 3 × 2.5 m. Blocks and plots within blocks were separated by grass alleys of 11 to 15 m. These alleys minimized banana weevil movement between plots (Gold *et al.* 1998).

The trial was planted in March 1999 at the onset of the rainy season. Two highland cooking banana cultivars, Atwalira and Namwezi, susceptible to banana weevil (Kiggundu 2000) were selected from banana farms near KARI. The suckers were pared to remove nematodes and weevil eggs and dipped in a solution of 30 ml emulsifiable Chloropyriphos (480 g/l) in 150 l of water for one hour before planting to disinfest the suckers of weevils and nematodes. The two cultivars were planted alternately within and between the rows. Gap filling was done continually through the subsequent rainy season to replace young suckers that died.

Diammonium phosphate fertilizer was applied three months after planting at the rate of 75 g per plant. Mulch consisting of a mixture of swamp grass, *Miscanthidium violaceum* (K. Schum.) Robyns. (Poaceae) and spear grass, *Imperata cylindrica* (L.) Beauv. (Poaceae), was applied six months after planting to conserve soil moisture.

The plants were in the field for four crop cycles (plant crop and three rations). Plant density was maintained at three plants per mat by regular desuckering. Weeding and deleafing were done uniformly across the field as required.

Banana weevil infestation

In September 1999, six months after plant establishment, the plots were artificially infested with banana weevils. Adults of uncertain age were collected from nearby farms using pseudostem traps. These were then placed in the experimental plots at a density of 10 adults/well-established plant and 5 adults/replant. Weevils were released from 18:00–20:00 in small depressions in the soil near the base of the plant.

Nematode infestation

In high plant stress treatments, nematode infestations were established six months after planting. Root segments originating from nematode-infested banana plants in fields at Semuto (50 km NW of Kampala) were used as a source of innoculum. Nematode-infested roots with necrotic discoloration were chopped into 0.5 cm-lengths, mixed thoroughly to obtain a uniform concentration of nematodes, and placed in depressions dug at the base of banana mats near actively growing roots. The nematode populations did not establish well and root necrosis levels (<2 %) determined at flowering were similar among all treatments.

Monitoring banana weevil populations

Banana weevil adult populations were monitored by pseudostem trapping and the mark and recapture method. At nine months and on a monthly basis from 18 to 29 months after banana weevil release, a single split pseudostem trap (Mitchell 1978) was placed with the cut face down at the base of each banana mat in the trial. After two nights, the number of banana weevil adults in each trap was counted.

Banana weevil adult population densities were estimated in each plot at 9, 18, 21, 23, 25 and 28 months after banana weevil release using split pseudostem traps and mark–recapture methods described by Gold & Bagabe (1997). Trapped adults were marked on the thorax with specific marks for each date and released. After one week, new traps were placed in the field and the number of marked and non-marked weevils was recorded. The Lincoln index was employed to estimate the population

$$N = (m^*n)/r$$

where N is the population estimate, m the number of individuals marked and released, n the total number of individuals captured, and r the number of marked individuals recaptured (Southwood 1978).

Corm damage assessment

Corm damage was assessed weekly on all plants within seven days of harvest. Damage in the upper 10 cm of the corm surface was evaluated by estimating the percentage surface tissue consumed by banana weevil larvae (Gold *et al.* 1994). Damage to the central cylinder and cortex was evaluated in two cross sections, at the collar and 10 cm below the collar, by again estimating the percentage of area consumed by larvae (Gold *et al.* 1994).

All described methods for evaluating banana weevil damage, including those used in this study, entail destructive sampling (Gold *et al.* 2001)

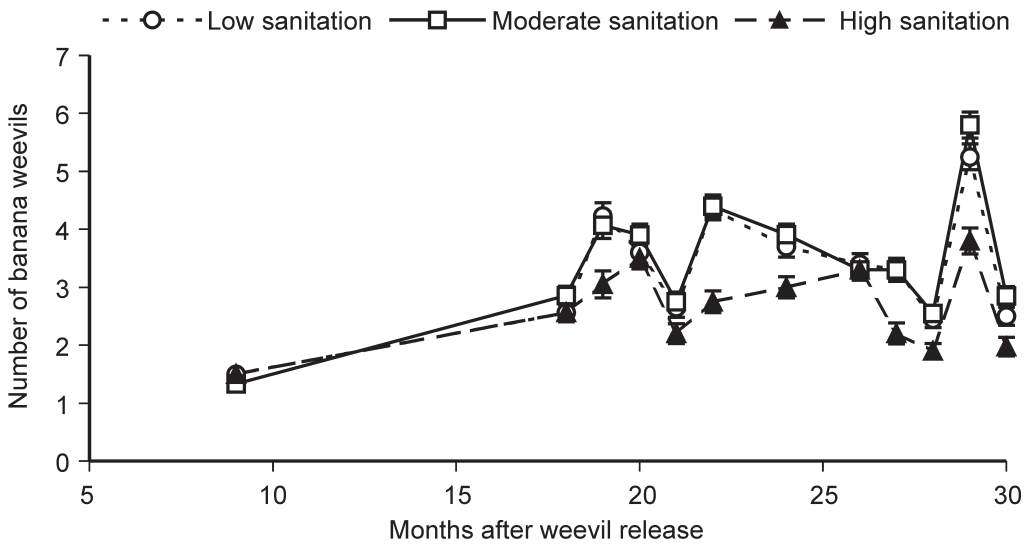

Fig. 1. Mean numbers of banana weevils collected per pseudostem trap in banana plots maintained under low, moderate and high sanitation levels at the Kawanda Agricultural Research Station, Uganda.

that would interfere with the imposed low- and moderate-sanitation treatments, *i.e.* leaving crop residues undisturbed. Therefore, we assessed damage on a sub-sample of harvested plants in these treatments (35 %, 30 %, 20 % and 10 % in the first four crop cycles, respectively), leaving the corm residues of other harvested plants undisturbed. All recently harvested plants were evaluated for banana weevil damage in high sanitation plots.

Growth and yield parameters

Data on banana plant growth and yield were collected across four crop cycles. Plants were observed daily for flowering, *i.e.* when the first bract leaf emerged from between the flag leaf and the last leaf. Plant girth, height and number of functional leaves were recorded for all plants within one week of flowering. Plant height was defined as the distance between the soil surface and the base of the uppermost leaf. Plant girth was measured at 100 cm above ground level. Plants were harvested after reaching physiological maturity, *i.e.* first ripening of a finger. Bunch weight was measured using a Salter balance (precision = 0.5 kg).

Data analysis

Plant growth parameters (height, girth and number of functional leaves) and corm damage (over four crop cycles) were subjected to mixed model procedures of SAS (SAS Inc. 1997). The sanitation treatments were considered as fixed, and residuals as random effects. Prior to analyses, a diagnostic check was carried out and angular transformation (arc sine transformation) on corm damage was carried out to stabilize the variances. Data on each crop cycle were analysed independently. Means separation was carried out using Dunnett's test (SAS Inc. 1997) where moderate and high sanitation levels were compared to the low sanitation.

RESULTS

Banana weevil trap catches fluctuated over time, with treatment means ranging from 1.5 to 6 adults per trap (Fig. 1). Trap catches were significantly lower ($F = 51.7$, d.f. = 7884; $P < 0.05$) in high sanitation plots than in moderate and low sanitation treatments except at 20 and 26 months after weevil release. Trap captures were similar in low and moderate sanitation treatments.

Population densities, estimated by the mark and recapture technique, were also significantly lower ($F = 11.4$, d.f. = 100, $P < 0.05$) in high sanitation than in low or medium sanitation plots for all sampling dates (Fig. 2). For example, in 2001 densities were 37 % and 43 % lower in high than low sanitation plots 24 and 27 months after release, respectively. Trap catches and population densities were similar in low and moderate sanitation plots throughout the trial. There was a general increase

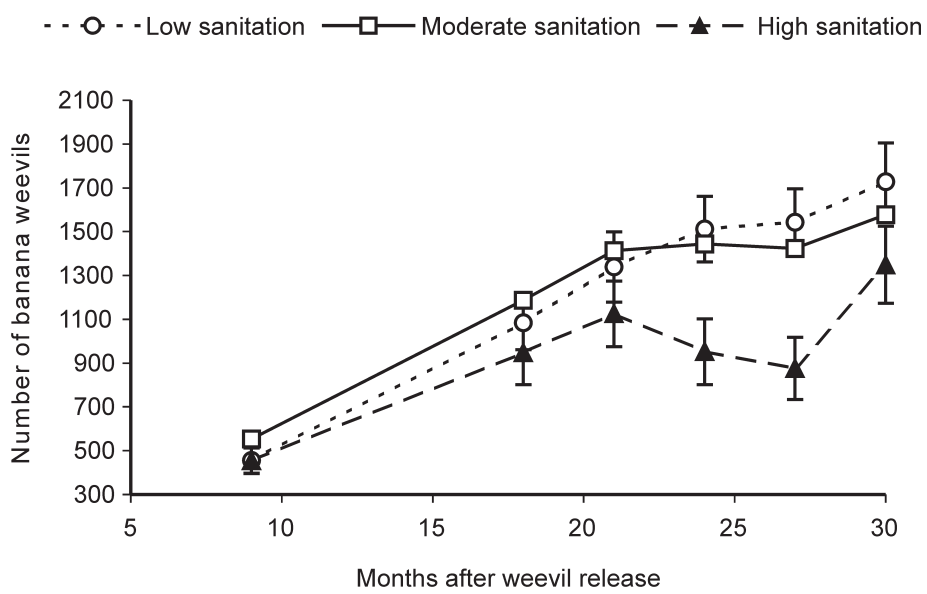

Fig. 2. Population density estimates of banana weevils per plot in banana plots maintained under low, moderate and high sanitation levels at the Kawanda Agricultural Research Station, Uganda.

in population with time in all plots, but the rate was higher in plots maintained at low and moderate sanitation levels than in plots maintained at high sanitation. On all sampling dates, <4 % of marked weevils was recovered in plots other than where they had been released.

Corm damage

In this study, higher levels of crop sanitation did not reduce banana weevil damage. Post-harvest assessment showed that banana weevil corm damage in moderate and high sanitation treatments were either higher or similar to damage levels in low sanitation treatments for all damage parameters in all crop cycles (Table 1). Although banana weevil adult populations increased over time, damage levels were relatively stable across crop cycles. By comparison, in a study at the same site, Rukazambuga *et al.* (1998) found damage to the central cylinder to increase seven-fold over four crop cycles.

Growth parameters

Plant height and girth at flowering tended to increase with the crop cycle (Table 2). Plant height, girth and the number of functional leaves were not significantly affected by sanitation level during the first three crop cycles ($P > 0.05$) (Table 2). In the fourth crop cycle, plants in the high sanitation treatment were shorter, had smaller girth and fewer functional leaves than plants in the other treatments ($F = 2.9$, d.f. = 81, $P < 0.05$).

Yield

Bunch weights were similar among treatments in the first and second crop cycles and lowest in high sanitation plots in the third and fourth cycles ($F = 9.8$, d.f. = 69, $P < 0.05$) (Table 3). In the fourth crop cycle, bunches from plots maintained at high and moderate sanitation were 34 % and 20 % smaller than bunches from plots maintained at low sanitation. Toppling, most likely caused by weevil attack to the corm periphery, ranged from 6.2 % in the first cycle to 10.5 % in the fourth with no treatment effects found in any cycle. Stem breakage by wind ranged from 9.3 % in the first cycle to 14.3 % in the fourth cycle and was not affected by sanitation level.

DISCUSSION

In a study of 60 highland banana plantations in southwestern Uganda, Masanza *et al.* (2004) found fields with higher levels of crop sanitation had lower banana weevil population densities and damage. Farmers who increased their level of sanitation management during the study had lower numbers of banana weevil adults and less weevil damage to plants compared to baseline levels. By contrast, farmers who maintained low

Table 1. Banana weevil corm damage in plots maintained at low, moderate and high sanitation levels during four crop cycles at the Kawanda Agricultural Research Institute, Kampala, Uganda (1999–2002). Damage indices are expressed in percentages

	Crop cycle			
	First	Second	Third	Fourth
a. Corm periphery damage				
Sanitation level				
Low	14.4 ± 1.49	14.3 ± 1.49	15.2 ± 1.59	13.9 ± 2.09
Moderate	17.3 ± 1.50*	17.9 ± 1.50*	19.1 ± 1.60*	16.6 ± 2.09
High	14.3 ± 1.50	14.6 ± 1.50	15.3 ± 1.50	20.2 ± 2.11*
b. Central cylinder damage				
Sanitation level				
Low	5.5 ± 1.08	4.5 ± 1.08	4.3 ± 1.15	5.4 ± 1.52
Moderate	8.2 ± 1.09*	8.6 ± 1.09*	7.4 ± 1.16*	8.1 ± 1.52*
High	5.5 ± 1.09	5.3 ± 1.09	4.8 ± 1.09	8.7 ± 1.53*
c. Cortex damage				
Sanitation level				
Low	8.2 ± 0.94	7.4 ± 0.94	9.0 ± 1.00	8.5 ± 1.28
Moderate	9.4 ± 0.95	11.0 ± 0.95*	9.3 ± 1.00	11.6 ± 1.28*
High	9.0 ± 0.96	8.4 ± 0.96	8.7 ± 0.96	8.4 ± 1.30

*Significantly different ($P < 0.05$) by Dunnett test adjusted to the low sanitation treatment within the column for each type of damage.

levels of sanitation had similar levels of banana weevil adults and damage at the onset and conclusion of the study. The on-farm study, however, dealt with complex systems including between farm differences in topography, soil fertility, cropping systems, cultivar mixtures and management practices. In the current study, banana weevil populations were consistently lower in banana plots with high levels of sanitation. Banana plantations littered with crop residues appear to provide

Table 2. Banana growth parameters at flowering for four crop cycles in plots maintained under low, moderate and high sanitation levels at the Kawanda Agricultural Research Institute, Kampala, Uganda (1999–2002).

	Crop cycle			
	First	Second	Third	Fourth
a. Plant height (cm)				
Sanitation level				
Low	242.7 ± 5.13	261.7 ± 5.13	269.6 ± 5.13	272.5 ± 5.48
Moderate	234.5 ± 5.13	257.3 ± 5.13	264.5 ± 5.13	284.2 ± 5.92
High	239.8 ± 5.13	257.8 ± 5.13	260.8 ± 5.13	256.8 ± 5.13*
b. Plant girth (cm)				
Sanitation level				
Low	38.0 ± 1.09	42.4 ± 1.09	45.3 ± 1.09	46.8 ± 1.16
Moderate	36.3 ± 1.09	41.1 ± 1.09	44.3 ± 1.09	48.5 ± 1.26
High	37.5 ± 1.09	41.7 ± 1.09	43.9 ± 1.09	42.2 ± 1.09*
c. Functional leaves (number)				
Sanitation level				
Low	6.7 ± 0.09	6.8 ± 0.09	6.8 ± 0.10	6.6 ± 0.10
Moderate	6.4 ± 0.09	6.6 ± 0.09	6.6 ± 0.09	6.7 ± 0.10
High	6.6 ± 0.09	6.6 ± 0.09	6.6 ± 0.09	6.1 ± 0.09*

*Significantly different ($P < 0.05$) by Dunnett adjusted to the low sanitation treatment within the column for each type of damage.

Table 3. Banana bunch weights and plant loss in plots maintained under low, moderate and high sanitation levels at the Kawanda Agricultural Research Institute, Kampala, Uganda (1999–2002).

	Crop cycle			
	First	Second	Third	Fourth
a. Bunch weight (kg)				
Sanitation level				
Low	5.9 ± 0.41	8.1 ± 0.41	8.9 ± 0.41	9.2 ± 0.55
Moderate	5.3 ± 0.39	7.4 ± 0.39	9.0 ± 0.39	7.4 ± 0.39*
High	5.9 ± 0.39	7.3 ± 0.39	7.4 ± 0.39*	6.1 ± 0.55**
b. Plants toppled per plot				
Sanitation level				
Low	4.4 ± 1.55	7.8 ± 1.34	7.5 ± 1.10	11.0 ± 1.90
Moderate	7.7 ± 0.95	7.9 ± 1.01	8.7 ± 0.95	11.0 ± 1.90
High	6.4 ± 1.10	7.8 ± 0.95	7.9 ± 1.02	9.5 ± 1.34
c. Plants broken by wind per plot				
Sanitation level				
Low	9.3 ± 2.26	7.4 ± 3.19	16.6 ± 2.26	11.0 ± 5.53
Moderate	7.7 ± 1.96	10.0 ± 2.26	13.2 ± 2.77	17.0 ± 5.53
High	11.0 ± 2.26	9.8 ± 3.19	13.2 ± 2.77	15.0 ± 3.91

*Significantly different ($P < 0.05$) by Dunnett test adjusted to the low sanitation treatment within the column for each type of damage.
**Significantly different ($P < 0.01$).

a suitable habitat for weevil multiplication (Wallace 1938; Abera 1997; Masanza *et al.* 2004). In high sanitation plots, shredding of banana residues resulted in elimination of potential oviposition sites and destruction of banana weevil immatures already in the plant.

Banana weevils are attracted to banana plants and residues by kairomones (Budenberg *et al.* 1993; Rwekika 1996). Cut corms and pseudostems are especially attractive to ovipositing banana weevil adults (Abera 1997; Gold *et al.* 2001). For example, Gold *et al.* (2004) found more than 30 % of adults to be associated with cut residues and stumps and Abera (1997) found 30 % of oviposition within banana mats to occur on stumps. The data also suggest that larval survivorship may be greater on residues, possibly due to the breakdown of plant antibiotic resistance mechanisms (Gold & Bagabe 1997). Thus, it appears that crop residues contribute to increased populations of banana weevils by providing additional substrates for oviposition and larval development.

In this study, adult populations were on average 40 % higher in low-sanitation than in high-sanitation plots during the last five sampling dates of the trial. Nevertheless, corm damage in banana plots maintained at moderate and high sanitation levels was similar to or even higher than in plots with low sanitation. This suggests that females in plots with low sanitation continued to place many of their eggs on crop residues. As a result, the reduction in banana weevil populations in plots with high sanitation resulted in no net benefit to standing plants. Similarly, high sanitation provided no benefit in terms of better crop growth or yield. Of note, is that the difference in population between high and low sanitation plots appeared to be widening over time, suggesting that damage might ultimately have reached higher levels in low-sanitation plots had the study continued for a longer time.

These results stand in sharp contradiction to the results obtained by Masanza *et al.* (2004) in on-farm sanitation trials. The efficacy of cultural controls of banana weevil and other insects in general are influenced by numerous factors and may not be uniformly successful in all situations (*e.g.* Andow 1983). For example, Gold *et al.* (2002) found that monthly pseudostem trapping in Ntungamo district tended to reduce banana weevil population density and damage, but that these reductions were not realized on all farms. Moreover, methodological differences between this study and that of Masanza *et al.* (2004) may have affected the results. For example, different cultivars were used in the two studies and this may

have affected relative adult attraction, oviposition and larval survivorship in standing plants and crop residues. It is also possible that implementation of crop sanitation requires a longer time before effects on banana damage are realized than that afforded by this study.

Crop sanitation is a widely recommended practice for management of banana weevils (Gold *et al.* 2001). In Uganda, on-farm surveys (Gold *et al.* 1997) and on-farm studies (Masanza *et al.* 2004) suggest that crop sanitation can reduce banana weevil populations and damage. Nevertheless, the poor relationship between crop sanitation level and banana weevil damage found in this study sounds a cautionary note. Clearly more needs to be understood on the relationship between crop sanitation and banana weevil control. Finally, the effectiveness of cultural controls must be monitored rather than provided as a blanket recommendation.

ACKNOWLEDGEMENTS

The Rockefeller Foundation provided financial support for this research through a grant administered by the International Institute of Tropical Agriculture (IITA). We thank I. Serubiri for assisting with data collection.

REFERENCES

ABERA, A.M.K. 1997. Oviposition preferences and timing of attack by the banana weevil (*Cosmopolites sordidus* Germar) in East African highland banana (*Musa* spp). M.Sc. thesis, Makerere University. Kampala, Uganda.

ABERA, A.M.K., GOLD, C.S. & KYAMANYWA, S. 1999. Timing and distribution of attack by the banana weevil (Coleoptera: Curculionidae) in East African Highland Banana (*Musa* spp.). *Florida Entomologist* **82**: 61–64.

ANDOW, D.A. 1983. Plant diversity and insect populations: Interactions among beans, weeds and insects. Ph.D. thesis, Cornell University, Ithaca. NY.

BUDENBERG, W.J., NDIEGE, I.O., KARAGO, F.W. & HANSSON B.S. 1993. Behavioral and electro-physiological responses on the banana weevil *Cosmopolites sordidus* to host plant volatiles. *Journal of Chemical Ecology* **19**: 267–277.

GOLD, C.S. & BAGABE, M.I. 1997. Banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae), infestations of cooking- and beer-bananas in adjacent plantations in Uganda. *African Entomology* **5**: 103–108.

GOLD, C.S., KARAMURA, E.B., KIGGUNDU, A., BAGAMBA, F. & ABERA, A. 1999a. Geographic shifts in the highland cooking banana (*Musa* spp., group AAA-EA) production in Uganda. *International Journal of Sustainable Development and World Ecology* **6**: 45–59.

GOLD, C.S., NIGHT, G., RAGAMA, P.E., KAGEZI, G.H., TINZAARA, W. & ABERA, A.M.K. 2004. Field distribution of banana weevil (*Cosmopolites sordidus* (Germar)) adults in cooking banana stands in Uganda. *Insect Science and its Application* **24**: 242–248.

GOLD, C.S., NIGHT, G., SPEIJER, P.R., ABERA, A.M.K. & RUKAZAMBUGA, N.D.T.M. 1998. Infestation levels of banana weevil, *Cosmopolites sordidus* Germar, in banana plants established from treated propagules in Uganda. *African Entomology* **6**: 253–63.

GOLD, C.S., OKECH, S.H. & NOKOE, S. 2002. Evaluation of pseudostem trapping as a control measure against banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in Uganda. *Bulletin of Entomological Research* **92**: 35–44.

GOLD, C.S., PENA, J.E. & KARAMURA, E.B. 2001. Biology and integrated pest management for the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Integrated Pest Management Reviews* **6**: 79–155.

GOLD, C.S., RUKAZAMBUGA, N.D.T.M., KARAMURA, E.B., NEMEYE, P. & NIGHT, G. 1999b. Recent advances in banana weevil biology, population dynamics and pest status with emphasis to East Africa. In: Frison, E.A., Gold, C.S., Karamura, E.B. & Sikora, R.A. (Eds) *Proceedings of a Workshop on Banana IPM held in Nelspruit, South Africa, 23–28 November 1998*. 35–50. International Network for the Improvement of Banana and Plantain, Montpellier.

GOLD, C.S., SPEIJER, P.R., KARAMURA, E.B., TUSHEMEREIRWE, W.K. & KASHAIJA, I.N. 1994. Survey methodologies for pest and disease assessment in Uganda. *African Crop Science Journal* **2**: 309–321.

KIGGUNDU, A. 2000. Host plant reactions and resistance mechanisms to banana weevil, Cosmopolites sordidus (Germar) in Uganda Musa germplasm. M.Sc. thesis. University of the Orange Free State, Bloemfontein, South Africa.

MASANZA, M., GOLD, C.S., VAN HUIS, A., RAGAMA, P.E. & OKECH, S.H.O. 2004. Effect of sanitation on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) population and crop damage in farmers' fields in Uganda. *Crop Protection* **24**: 275–283.

McINTYRE, B.D., GOLD, C.S., KASHAIJA, I.N., SSALI, H., NIGHT, G. & BWAMIKI, D.P. 2001. Effects of legume intercrops on soil-borne pests, biomass, nutrients and soil water in banana. *Biology and Fertility of Soils* **34**: 342–348.

MITCHELL, G. 1978. The estimation of banana borer population and resistance levels. *Technical Bulletin* 2, Windward Island Banana Association, St Lucia.

RUKAZAMBUGA, N.D.T.M., GOLD, C.S & GOWEN, S.R. 1998. Yield loss in East African highland banana (*Musa* spp., AAA-EA group) caused by the banana weevil, *Cosmopolites sordidus* Germar. *Crop Protection* **7**: 581–589.

RWEKIKA, E. 1996. Feeding allelochemicals for the

banana weevil *Cosmopolites sordidus* Germar. Ph.D. thesis, University of Dar es Salaam, Tanzania.

SAS INSTITUTE. 1997. *SAS Institute Inc., SAS/STAT Software: Changes and Enhancement through Release 6.12, Cary, NC.* SAS Institute, Cary, North Carolina.

SENGOOBA, T. 1986. Survey of banana pest problem complex in Rakai and Masaka districts, August 1986: Preliminary trip report. Uganda Ministry of Agriculture, Kawanda Agricultural Research Station, Kampala, Uganda.

SOUTHWOOD, T.R.E. 1978. *Ecological Methods.* Chapman and Hall, London.

TINZAARA, W., KARAMURA, E. & TUSHEMEREIRWE, W. 1999. Preliminary observations on natural enemies associated with the banana weevil *Cosmopolites sordidus* Germar in Uganda. *Infomusa* **8**: 28–29.

TREVERROW, N. & BEDDING, R.A. 1993. Development of a system for the control of the banana weevil borer *Cosmopolites sordidus* with entomopathogenic nematodes. In: Bedding, R., Akhurst, R. & Kaya, H. (Eds) *Nematodes and the Biological Control of Insect Pests.* 41–47. CSIRO, Melbourne.

VILARDEBO, A. 1960 *Los Insectos y Nematodos de las Bananeras del Ecuador.* Instituto Franco-Euatiano de Investigaciones Agromicas, Paris.

WALLACE, C.R. 1938. Measurement of beetle borer migrations in banana plantations. *The Journal of Australian Institute of Agricultural Science* **4**: 215–219.

Accepted 30 March 2006