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Evaluation of pseudostem trapping as a control measure against banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in Uganda

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Abstract

Controlled studies to determine the efficacy of pseudostem trapping in reducing adult populations of the banana weevil, *Cosmopolites sordidus* (Germar), were conducted under farmer conditions in Ntungamo district, Uganda. Twenty-seven farms were stratified on the basis of *C. sordidus* population density (estimated by mark and recapture methods) and divided among three treatments: (i) researcher-managed trapping (one trap per mat per month): (ii) farmer-managed trapping (trap intensity at discretion of farmer); and (iii) controls (no trapping). Intensive trapping (managed by researchers) resulted in significantly lower *C. sordidus* damage after one year. Over the same period, *C. sordidus* numbers declined by 61% on farms where trapping was managed by researchers, 53% where farmers managed trapping and 38% on farms without trapping; however, results varied greatly among farms and, overall, there was no significant effect of trapping on *C. sordidus* numbers. Moreover, there was only a weak relationship between the number of *C. sordidus* removed and the change in population density. Trapping success appeared to be affected by management levels and immigration from neighbouring farms. Although farmers were convinced that trapping was beneficial, adoption has been low due to resource requirements.

Introduction

Highland cooking banana (Musaceae, *Musa* sp., genome group AAA-EA) is the predominant rural and urban staple food in central and southern Uganda. Since the 1970s, reduced management and high levels of damage by banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), in traditional banana growing areas of the central region have resulted in rapid yield decline (Gold *et al.*, 1993, 1999b).

Bananas are rhizomatous herbaceous plants that reproduce vegetatively. A 'mat' consists of an underground rhizome from which one or more plants (shoots) emerge. The shoot is actually a pseudostem comprised of leaf petioles. The true stem arises from the apical meristem after leaf production has terminated and grows through the centre of the pseudostem, eventually producing the flower and, later, the bunch. After the fruit matures, the stem dies back to the rhizome. Farmers normally cut harvested plants between ground level and 1 m. Young shoots (suckers) may be detached and used as planting propagules.

Cosmopolites sordidus larvae bore in the rhizome killing young plants, delaying flowering and reducing bunch weights, the vigour of followers (ratoon crops) and stand life (Rukazambuga *et al.*, 1998). McIntyre *et al.* (2001) found high rates (38–44%) of sucker mortality when highland banana was planted in a previously infested field. In a highland banana field trial, Rukazambuga *et al.* (1998; unpublished data) found yield loss to *C. sordidus* increased from 5% (0.5 tonnes ha^{-1}) in the plant crop to 44% (8.1 tonnes ha^{-1}) in the

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third ratoon. Yield loss was attributed equally to plant loss (toppling, snapping, plant death) and reduced bunch weights. In the third ratoon of a second trial, Rukazambuga (1996) reported yield losses of 26% (2.5 tonnes ha^{-1}) in intercropped banana and 27% (6.3 tonnes ha^{-1}) in mulched monoculture. Five years after planting, Gold *et al.* (unpublished data) found disappearance of 40% of highland banana mats in *C. sordidus* infested plots compared to 2% in controls.

Cosmopolites sordidus displays a classic 'k' selected life cycle (Pianka, 1970) with a long life span (up to four years) and low fecundity (about one egg per week) (Froggatt, 1925; Abera, 1997; Gold *et al.*, 1999c). Population buildup is slow with greatest *C. sordidus* problems occurring in ratoon crops (Mitchell, 1980; Lescot, 1988; Rukazambuga *et al.*, 1998). The adults are free living and reside in the soil, most often in association with banana mats and residues (Gold *et al.*, 1999c). They are relatively sedentary and rarely fly. Most cultural control methods target *C. sordidus* adults rather than the immature stages that are passed entirely within the host plant.

Integrated pest management methods for *C. sordidus* has been reviewed by Gold *et al.* (2001). Insecticides are beyond the means of most highland banana growers. Moreover, *C. sordidus* has developed resistance to dieldrin in Uganda (Gold *et al.*, 1999a) and to a wide range of chemicals elsewhere (Collins *et al.*, 1991). Classical biological control attempts, using generalist predators from the insect's area of origin in southeast Asia, have been unsuccessful (Waterhouse & Norris, 1987) although further searches for parasitoids are warranted (Neuenschwander, 1988). Certain entomopathogenic fungi (e.g. *Beauveria bassiana* (Balsamo) Vuillemin (Hyphomycetales)) have produced high mortality levels in laboratory tests, but cost-effective production and field delivery systems remain to be developed (Nankinga, 1999). Many *Musa* clones appear to be resistant to *C. sordidus*, but most highland clones are susceptible and breeding resistant hybrids remains a long-term strategy (Kiggundu *et al.*, 1999; Kiggundu, 2000). Thus, cultural controls of *C. sordidus* are the only methods currently available for the majority of banana growers in East Africa.

Knowles & Jepson (1912) noted the association of *C. sordidus* adults with crop residues and first proposed the use of rhizome and pseudostem traps for collecting adults. Since then, trapping has been widely recommended as a means of *C. sordidus* control (Pinto, 1928; Sein, 1934; Yaringano & van der Meer, 1975; Mitchell, 1978; Koppenhofer *et al.*, 1994; Seshu Reddy *et al.*, 1995; Ngode, 1998). Jayaraman *et al.* (1997) and Alpizar *et al.* (1999) suggested that mass trapping (albeit with semiochemicals) could overcome *C. sordidus*' low fecundity and slow population build-up and lead to successful control.

The most common means of trapping *C. sordidus* adults are 'disk-on-stump traps' and 'split pseudostem traps' (Castrillon, 1991). Disk-on-stump traps consist of a rhizome slice or leaf placed on top of a harvested plant cut in cross section through the rhizome. In split pseudostem trapping, harvested pseudostems are cut into 15–60 cm lengths, split in half longitudinally and placed face down on the soil (most often at the base of mats). Traps containing rhizome material are more attractive to *C. sordidus* than those comprised entirely of pseudostems (Hord & Flippin, 1956; Castrillon, 1991). For example, Yaringano & van der Meer (1975), Nanne & Klink (1975), Mitchell (1978) and Cardenas & Arango (1986) variously reported disk-on-stump traps as catching 3–7 times as many *C. sordidus* as pseudostem traps. However, a harvested plant can produce many pseudostem traps (placed where the farmer deems most useful), but only one disk-on-stump trap (fixed in space). In addition, farmers can move pseudostem material from areas with low *C. sordidus* levels (e.g. stands of resistant cultivars such as Pisang awak) into areas with greater *C. sordidus* problems.

Reductions in *C. sordidus* following trapping have been reported by Vilardebo (1950), Yaringano & van der Meer (1975), Arleu & Neto (1984), Arleu *et al.* (1984), Koppenhofer *et al.* (1994), Seshu Reddy *et al.* (1995), Ndege *et al.* (1995), Masanza (1995) and Ngode (1998). For example, Yaringamo & van der Meer (1975) reported a 50% population reduction after four months of rhizome trapping, while Seshu Reddy *et al.* (1995) found a 50% reduction in *C. sordidus* captured following systematic trapping with pseudostem material. Koppenhofer *et al.* (1994) implemented three trapping studies and found reductions of 33–67% over time periods ranging from seven weeks to one year.

In each of these studies, comparisons were made between initial and final populations and, thus, the trials lacked proper controls, making the results inconclusive. For example, reported *C. sordidus* reductions in the Seshu Reddy *et al.* (1995) study and the first two Koppenhofer *et al.* (1994) trials were interpreted from trap capture rates, which may have reflected weather conditions and trap efficiency (Vilardebo, 1973). In a third trial, Koppenhofer *et al.* (1994) released a known number of *C. sordidus* adults and, following systematic trapping, later estimated populations using mark and recapture methods. However, *C. sordidus* population declines of the same magnitude as that reported by Koppenhofer *et al.* (1994) have been found for field populations of marked and released *C. sordidus* in trials where trapping was not conducted (Rukazambuga, 1996; Gold & Night, unpublished data).

The primary objective of this study was to ascertain the potential for controlling *C. sordidus* under farm conditions using pseudostem trapping in controlled studies. Farmer participatory research methods were employed to determine how appropriate the methods might be for use by resource-limited banana growers.

Materials and methods

Site

The study was conducted in Kikoni Parish in Ntungamo District in southwestern Uganda. Kikoni Parish lies immediately to the southwest of the town of Ntungamo (30°26'E, 0°88'S) and 1300–1560 masl. Mean annual rainfall ranges from 800 to 1500 mm with bimodal (March–May and September–December) distribution. Most holdings are small (< 2 ha) with cooking banana the predominant crop at the site. The site is adjacent to the main tarmac road between Mbarara and Kabale.

The study was preceded by a participatory rural appraisal (attended by > 100 farmers) at the trial site in 1995. Farmers expressed concern about recent yield declines. *Cosmopolites sordidus* was identified as a leading constraint. Observations on farmers' fields confirmed high levels of *C. sordidus* damage on many but not all farms. Most farmers were unaware of how to address the *C. sordidus* problem. Interest in participatory research on *C. sordidus* trapping was high and the results of this meeting formed the basis for the current study.

Baseline C. sordidus *populations and damage*

Fifty farms were randomly selected with the assistance of the local agricultural extension service (Ntungamo District Agricultural Office, Ministry of Agriculture and Fisheries). Survey farms contained at least one stand of banana > 0.2 ha (i.e. > 100 mats), at least five years old, which were subsequently used for the trapping experiment. None of the selected farms had previously employed trapping to control *C. sordidus*. The banana stands on these farms were mapped and stand area was estimated from the field dimensions.

Populations of *C. sordidus* were estimated on each farm using mark and recapture methods (Southwood, 1978), as adapted for this insect by Price (1993) and Gold & Bagabe (1997). Pseudostem traps (30 cm long) (Mitchell, 1978) were placed at the base of alternate mats and examined for *C. sordidus* adults three days later. These were collected, marked by scratches on the elytra and then released randomly throughout the plantation. Marked individuals were allowed 96 h to disperse within the field before new traps (on alternate mats) were placed for recapture. Adult weevils were again collected from these traps three days after placement. *Cosmopolites sordidus* populations were estimated using the Lincoln index: $N = m*n/r$ where N is the population estimate; m is the number of released (marked) individuals; n is the total number of collected *C. sordidus*; and r is the number of marked individuals which were recaptured (Southwood, 1978). Population estimates of *C. sordidus* were extrapolated from numbers per farm to density per ha using the data on stand size. The farms were classified as having either high (> 20,000 adults ha^{-1}), medium (10,000–19,999 adults ha^{-1}), low (5000–9999 adults ha^{-1}) and very low (1000–4000 adults ha^{-1}) population densities.

Cosmopolites sordidus damage was estimated on 20 recently harvested cooking banana plants per farm using the methods of Gold *et al.* (1994). Cross section cuts were made through the collar (rhizome/pseudostem junction) and through the rhizome 5–10 cm below the collar for each plant. The percentage of surface area occupied by *C. sordidus* galleries was estimated for the central cylinder and cortex. A composite estimate was derived for each plant. Total surface area was estimated by measuring the diameter of the central cylinder and the rhizome. This allowed for estimates of total area (i.e. cm^2) of *C. sordidus* galleries.

Survey results were presented to farmers at a follow-up meeting in May 1996. Farmers reiterated their interest in a participatory research study on pseudostem trapping as a possible means of controlling *C. sordidus*. The proposed study was presented as technology testing rather than technology transfer.

Allocation of treatments

Trapping intensity (i.e. trap number and frequency) is likely to influence the level of *C. sordidus* population and damage reductions. This study was intended to investigate both the effects of intensive trapping on *C. sordidus* populations and the effects of more moderate trapping regimes that might be adopted by farmers. This was done through farmer participatory research. Treatments included: (i) researcher-managed trapping; (ii) farmer-managed trapping; and (iii) control (i.e. no trapping).

Pseudostem trapping targets adult *C. sordidus*. Therefore, the 50 farms were stratified on the basis of estimated *C. sordidus* population density. Twenty-seven farmers, representing nine groups (blocks) of three farms with similar *C. sordidus* density, agreed to participate in the study. Within each group, one farmer volunteered to undertake trapping (farmer-managed treatment). Self-allocation of farmer-managed treatments increased the likelihood of farmer implementation of trapping. The other two farmers in each group were randomly assigned to researcher-managed trapping or controls.

Researchers used pseudostem traps 30 cm long and farmers were recommended to do the same. On researcher-managed farms, trapping was conducted monthly with one trap placed on each mat in the banana stand. In some cases, pseudostem material had to be collected from neighbouring fields to provide sufficient material to maintain this trapping density. In farmer-managed trapping, trapping frequency and density was at the farmer's discretion. In most cases, this was considerably less intense than that of researchers. The farmers relied exclusively on material produced within the farm. Farmers whose banana stands were used as controls were requested not to initiate trapping of *C. sordidus* on their farms for the duration of the experiment. Trapping commenced in June 1996 and continued until July 1997.

Data collection

Each farm was visited monthly to collect *C. sordidus* adults and to record any changes in crop management. On researcher-managed farms, *C. sordidus* were collected, counted and removed from the field three days after trap placement. The traps were then destroyed. In farmer-managed trapping, farmers kept monthly records on the number of traps they placed each month and the number of *C. sordidus* collected. Collected *C. sordidus* were maintained in rearing containers and given to the researchers who verified the accuracy of the counts. At the same time, discussions were held with the farmers to maintain interest in the study and to elicit their perceptions of the value of trapping.

On all farms, *C. sordidus* populations were estimated at 6 and 12 months after the initiation of the study using the mark and recapture procedure previously described. Trapped *C. sordidus* were then released back into the field. Weevil damage was assessed every three months. Farm management (desuckering and sanitation) levels were also recorded.

In the planning meeting, farmers suggested that the benefits of *C. sordidus* management in their banana stands might not be realized if neighbours did not also employ *C. sordidus* control methods. Neighbouring farms could thus serve as a source of *C. sordidus* reinfestation, counteracting any benefits from trapping. It was hypothesized that trapping would be most effective in isolated systems. Therefore, *C. sordidus* damage was assessed in fields neighbouring study farms to determine their possible role in influencing changes in *C. sordidus* status from the trapping plots.

Response/derived variables were: (i) percentage change in population density; (ii) overall change in population; (iii) impact of trapping on population density; and (iv) trap efficiency variable index.

Statistical analysis

The analysis of variance to detect differences in treatments for four response variables was performed using the mixed model procedure in SAS (1997), with the categories or blocks as random and treatment effects as fixed. Where appropriate covariates such as farm sizes and initial population densities were included in the model. These were derived as follows:

Efficiency of trapping under different population densities (den) and treatment (trt) was for instance modelled as:

$$\text{Transformed total trap catches} = \mu + trt + den + trt{*}den + N2 + error \quad (1)$$

where the covariate N2 is the estimated population density after the first six months of trapping, i = 1, 3; j = 1, 4.

Per cent change in population density over time was computed as follows:

Assume that the initial population in June 1996 is n_1. Then percentage change in population between June 1996 and January 1997 is given as

$$P_{12} = (n_2 - n_1)/n_1{*}100 \quad (2)$$

while change between January 1997 and July 1997 is

$$P_{23} = (n_3 - n_2)/n_2{*}100 \quad (3)$$

with n_2 = population after trapping for six months and n_3 = population after trapping for 12 months.

The overall change (%) was simply calculated as

$$OC = (n_3 - n_1)/\ n_1{*}100. \quad (4)$$

Adjusted percentages for population change in farmer and researcher managed farms were computed as

$$[1 - (100 - \%C)/100] * \%F \quad (5)$$

where %C = overall change recorded in control field and %F represent overall change in farmer or researcher managed field.

The response variable assessing the impact of trapping (I) on population was obtained as:

$$I = n_3 - [(n_1 - tc_1) + (n_2 - tc_2)]/n_3{*}100 \quad (6)$$

where tc_1 is *C. sordidus* caught between June 1996 and January 1997; and tc_2 represent *C. sordidus* caught between January 1997 and July 1997. Where $I \leq 0$ this signifies impact. The rejection of the hypothesis LSmeans = 0 (in favour of LSmeans < 0) indicates substantial impact. The smaller the probability the greater the impact of the treatment concerned.

Rhizome damage over time was assessed using repeated measures analysis of variance.

Results

Survey

Farm-holdings averaged 0.85 ha (range 0.4–5.9 ha), with banana occupying > 60% of the cultivated land. Banana stands ranged in age from 5 to 75 years (mean 33 years) and most plantations were contiguous with other holdings. Densities of *C. sordidus* ranged from 1600 to 149,000 ha^{-1} (median 9300 ha^{-1}), while damage ranged from 1 to 19% (median 3.1%). For the 27 farms selected for this study, the mean *C. sordidus* population per farm was 6479 (= 13,389 ha^{-1}) for controls, 10,804 (= 13,556/ha^{-1}) for farmer-managed plots and 7565 (= 13,944 ha^{-1}) for researcher-managed plots (table 1A).

Trapping efficacy

For farmer-managed plots, two farmers placed between 0.3 and 0.6 traps per mat per month, while trapping on other farms was commonly < 0.3 traps per mat per month. After one year of trapping, farmers had removed, on average, 19% (2798 ha^{-1}) of the baseline *C. sordidus* population. Trapping efficiency ranged from 3 to 51%. In contrast, placement of one trap per mat per month in researcher-managed plots for

Table 1. Changes in adult population density of *Cosmopolites sordidus* in farm trapping study, Ntungamo district, Uganda (June 1996 to July 1997).

A. Mean density per hectare (± S.E) (extrapolated).

Trapping intensity[1]	Months after initiation of trapping		
	0 (start)	6	12
None (control)	13389 ± 8439	10622 ± 6665	11356 ± 10067
Moderate (farmer-managed)	13556 ± 8900	7155 ± 4692	7133 ± 6814
Intensive (researcher-managed)	13944 ± 9379	7111 ± 4694	4177 ± 2957

B. Mean per cent changes in population

Treatment	June 1996 to January 1997	January 1997 to July 1997	Overall change
Population changes			
Control	−42	12	−38± 10
Farmer-managed	−50	−9	−53± 10
Researcher-managed	−49	−42	−61± 10
Adjusted reductions			
Farmer-managed	−14	−19	−27
Researcher-managed	−12	−52	−38

[1]n = 9 farms for each treatment.

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Table 2. Analysis of variance for effects of treatments and time on *Cosmopolites sordidus* adult population changes, with farm size as covariate (using arcsine transformed unextrapolated data).

Source	NDF	DDF	F	P > F
Treatment	2	44	1.94	0.15 ns
Time	2	16	106	0.0001***
Linear time	1	16	114.63	0.0001***
Quadratic time	1	16	97.70	0.0001***
Treatment × time	4	44	1.35	0.26 ns
Farm size	1	44	14.94	0.0003***

ns, not significantly different at $P > 0.05$; ***significantly different at $P \leq 0.001$.

Table 3. Impact of different levels of trapping on *Cosmopolites sordidus* population in Ntungamo district, Uganda (June 1996 to July 1997).

Treatment	LS means	S.E.	Pr > t*
Control	–372	1309	0.78
Farmer-managed	–335	1408	0.81
Researcher-managed	–2717	1308	0.06

*The smaller the Pr > t or the larger the LS means the greater the impact.

one year resulted in a mean removal of 91% (16,679 ha^{-1}) of the estimated initial *C. sordidus* population. Weevil removal ranged from 39 to 234% of the baseline population.

Population change

A general reduction in the *C. sordidus* population occurred during the first six months of the trial, with similar levels of decline found in all treatments (table 1A – population extrapolated to density per ha). Analysis using unextrapolated data, with farm sizes as covariate showed that, over the next six months, *C. sordidus* populations on control farms increased by 12%, while densities on researcher-managed and farmer-managed farms declined by 42% and 9%, respectively. Over the entire trial, populations declined by 61% in researcher-managed plots, by 53% in farmer-managed plots and by 38% in controls (table 1B). Adjusting for the overall decline in *C. sordidus* populations in Ntungamo during the course of the study suggests that trapping reduced *C. sordidus* populations by 38% in researcher-managed plots and by 27% in farmer-managed stands (table 1B). The effects of trapping on *C. sordidus* levels were highly variable across farms so that these changes were not significantly different among treatments (table 2). Tests on significance of least square means indicated that researcher-managed trapping had the greatest impact (table 3).

Intensive trapping greatly reduced *C. sordidus* populations on most but not all farms (table 4). In researcher-managed plots, seven farms experienced *C. sordidus* population reductions of > 50% (maximum 98%), while two farms had reductions of only 5% and 28%, respectively. In farmer-managed plots, population changes ranged from a 3% increase to an 88% decrease, with five farms having > 50% reductions. Thus, the data suggest that trapping can but will not always reduce *C. sordidus* numbers.

The number of *C. sordidus* captured per trap was correlated with initial population density in researcher- ($r = 0.67$, $P = 0.003$) and farmer-managed trapping ($r = 0.51$, $P = 0.01$). On farmer-managed fields, the proportion of *C. sordidus* removed was highly correlated with number of traps ($r = 0.90$, $P = 0.001$). Under constant trapping conditions (i.e. researcher-managed systems), the proportion of *C. sordidus* trapped showed a moderate inverse relationship with population size ($r = -0.48$, $P = 0.15$). This suggests that trapping may be more efficient at lower *C. sordidus* densities and that extended periods of trapping might be required to reduce populations at higher densities.

Moreover, there was no clearly defined trend in *C. sordidus* removals and subsequent reductions in populations ($r = -0.21$, $P = 0.20$). For example, in one researcher-managed field, *C. sordidus* removal was > 2.3 times the estimated original population (9300 ha^{-1}), yet after one year, the farm only had a population reduction of 5%. In contrast, 39% of *C. sordidus* were removed from one researcher-managed plot, but the net population decline was 98% (from 18,000 ha^{-1}), while only 3% of *C. sordidus* were removed from another field, but the population declined by 80% (from 23,600 ha^{-1}).

Farm management, stand isolation and trapping effects

In researcher-managed farms, stand management and surrounding land-use appeared to influence trapping effects (table 5). The plot in which a high level of *C. sordidus* removal resulted in only a 5% reduction in *C. sordidus* population had low levels of management (i.e. sanitation and desuckering), was smaller in size (i.e. 0.2 ha) than the other farms and was surrounded on all sides by banana plantations with high *C. sordidus* incidence (average damage 5.1%). This suggested continuous immigration of *C. sordidus* from neighbouring farms and availability of a habitat favourable (i.e. abundant residues) for *C. sordidus* population growth. The farm in which trapping resulted in a 28% reduction in *C. sordidus* population also had low management levels. In contrast, six of the seven farms registering major reductions in *C. sordidus* population levels had moderate to intensive levels of crop management. The single farm that had low levels of management and

Table 4. Number of farms showing different levels of change in *Cosmopolites sordidus* adult populations following one year of pseudostem trapping, Ntungamo district, Uganda (June 1996 to July 1997).

Trapping management	Number of farms in each category			
	Increase (>+10%)	No change (+10 to –15%)	Medium reduction (–15 to –50%)	Major reduction (>–50%)
Control	2	3	2	2
Farmer	0	1	3	5
Researcher	0	1	1	7

Table 5. Farm size, management level and surrounding vegetation of banana stands on researcher-managed farms.

Farm no.	Farm size (ha)	Management level		Weevil population change	Surrounding vegetation[1]		
		Sanitation	Desuckering		Banana	Coffee	Grass
1	0.2	Intensive	Intensive	−93	High	None	None
2	0.3	Moderate	Intensive	−91	High	None	None
3	0.3	Moderate	Moderate	−78	High	Low	None
4	1.1	Moderate	Moderate	−68	High	Low	None
5	0.7	Moderate	Moderate	−68	High	None	Low
6	1.3	Moderate	Moderate	−67	High	None	Low
7	0.5	Low	Moderate	−53	None	High	Low
8	0.8	Low	Low	−28	Low	Low	High
9	0.2	Low	Low	− 5	High	None	Low

[1] High, primary crop or vegetation; low, secondary crop or vegetation in area surrounding study plot.

registered high population decline was isolated and surrounded by coffee and bush-fallow.

Rhizome damage

During the course of the study, there was a decrease in *C. sordidus* damage in all treatments (fig. 1). Damage levels began to diverge among treatments between 4 and 8 months after trapping commenced. The level of rhizome damage from *C. sordidus* was influenced by both time and treatment ($F = 7.78$; $P < 0.01$ and $F = 3.66$; $P < 0.001$, respectively) (table 6). There was a significant linear and quadratic trend in decline in rhizome damage during the course of the study in all the treatments, but the decline was greatest in researcher-managed farms. Damage in controls and farmer-managed plots were not significantly different from each other. During the course of the study, damage on researcher-managed farms had declined by 49%, compared to 24% in farmer-managed farms and 19% in controls.

Post-trial evaluation

A meeting was held in December 1997 to evaluate the trapping study. The farmers who trapped summarized what they did and presented their observations on trapping as a means of *C. sordidus* control. The researchers then presented the results in graphic form. The farmers concluded that trapping can control *C. sordidus*, but also expressed concerns about (i) the labour and resource requirements; and (ii) the immigration of weevils from neighbouring plantations that were not employing *C. sordidus* control measures. Thus, farmers suggested that trapping could not be adopted as a primary control method but, rather, could be used to supplement other possible controls such as crop sanitation.

Discussion

Trapping to control *C. sordidus* has been widely recommended by national research and extension

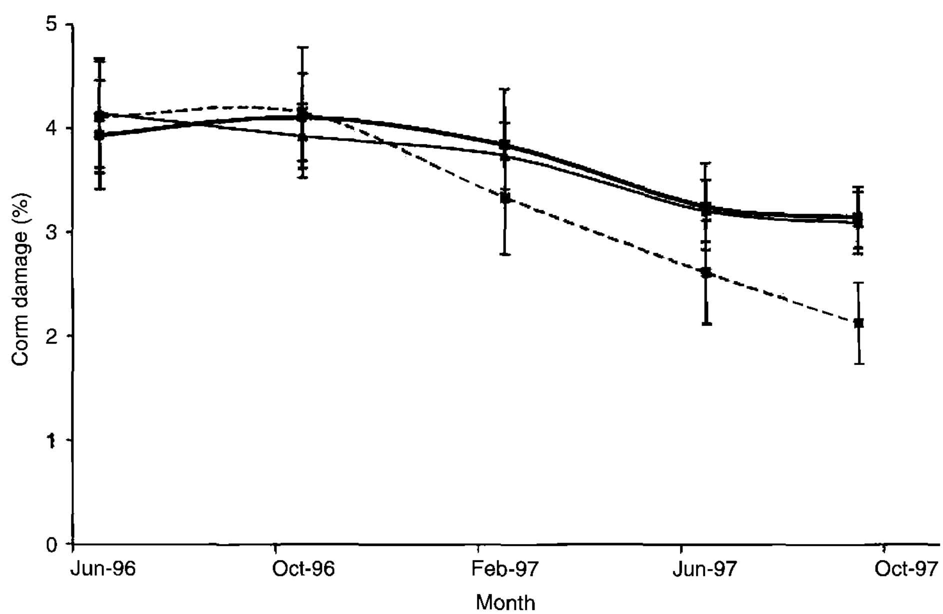

Fig. 1. *Cosmopolites sordidus* damage to banana rhizomes under different pseudostem trapping treatments, Ntungamo district, Uganda (June 1996 to July 1997). Treatments: -■-, control (no trapping); -▲-, farmer-managed (moderate trapping); -■-, researcher-managed (intensive trapping).

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Table 6. Split plot design ANOVA (mixed procedure model) for rhizome damage in a *Cosmopolites sordidus* trapping study, Ntungamo district, Uganda (June 1996 to July 1997).

Source	DF	F	Pr > F
Treatment	2	7.78	0.0007***
Time	4	3.66	0.0076**
Linear time	1	33.5	0.0001***
Quadratic time	1	4.8	0.0388*
Treatment × Time	8	0.31	0.9606 ns

Contrast	Level of significance
Control vs. farmer	0.7849ns
Control vs. researcher	0.0014**
Farmer vs. researcher	0.0006***

ns, not significantly different at $P > 0.05$; *significantly different at $P \leq 0.05$; **significantly different at $P \leq 0.01$; ***significantly different at $P \leq 0.001$.

programmes (Gold *et al.*, 1993; Ndege *et al.*, 1995). Nevertheless, the use of trapping in *C. sordidus* control has been controversial (Jones, 1968; Ostmark, 1974; INIBAP, 1988). For example, Jayaraman *et al.* (1997) and Alpizar *et al.* (1999) argued that, given the low fecundity and slow population build-up of *C. sordidus*, mass trapping (e.g. with semiochemicals) should be able to provide a measure of successful control. In contrast, Mestre (1997) concluded that *C. sordidus* is a poor candidate for mass trapping with semiochemicals because it is soil dwelling, sedentary and rarely flies. Moreover, few data have been available to demonstrate the efficacy of trapping under farm conditions. Although a number of researchers have reported success in reducing *C. sordidus* numbers through pseudostem trapping alone (e.g. Koppenhofer *et al.*, 1994; Seshu Reddy *et al.*, 1995), all of these studies lacked proper controls, making conclusions unreliable. Observations on natural decline of *C. sordidus* reported by Rukazambuga (1996) and on control farms here suggest that these studies may have exaggerated the percent reduction in *C. sordidus* population resulting from a trapping exercise.

The results obtained in this study do, however, suggest that systematic pseudostem trapping in established plantations can greatly reduce *C. sordidus* populations. Large reductions in *C. sordidus* populations were achieved on seven of nine farms. At the same time, less intensive trapping levels implemented by farmers resulted in important reductions of *C. sordidus* in five of nine farms. However, trapping benefits were not realized on all farms.

The data suggest that trapping is most effective at lower *C. sordidus* densities. Moreover, difficulties in interpreting data arise when comparing *C. sordidus* removal rates and changes in population levels. It is unclear how removal of more than twice the estimated baseline population could result in only a 5% decrease on one farm, while removal of 39% of the original population could be accompanied by a 98% reduction in *C. sordidus* numbers on another. Observations during the study period suggest that other factors (e.g. farm management, proximity to neighbouring infested stands) can influence the efficacy of trapping in *C. sordidus* control. It should also be noted that *C. sordidus* densities are not necessarily stable in established plantations, but, rather, fluctuate over time as evidenced, in part, by the population shifts experienced on control farms (tables 1A, 4).

Population estimates were derived from mark and recapture studies. No other methods are currently available for assessing *C. sordidus* populations. One of the assumptions of mark and recapture studies is a complete mixing of marked and unmarked insects prior to recapture. *Cosmopolites sordidus* adults have only limited mobility (Gold *et al.*, 1999c) and many may be sedentary for extended periods of time (S. Lux, personal communication). As a result, complete mixing of marked and unmarked weevils may not be possible. This suggests that mark and recapture studies may underestimate true *C. sordidus* populations. If this is true, such errors in population estimates are likely to be similar for all farms. The baseline census provided important information on *C. sordidus* densities (rarely determined elsewhere) and highlighted the considerable variation in *C. sordidus* status among farms within a single watershed.

Cosmopolites sordidus females oviposit on all stages of banana plants, although flowered plants are preferred (Abera *et al.*, 1999). Damage estimates on rhizomes of harvested plants reflect *C. sordidus* attack throughout the life of the plant. Thus, plants harvested in the first half of the study had extended exposure to *C. sordidus* populations prior to the onset of trapping. Moreover, removal of adult weevils through trapping is a gradual process with effects increasingly realized over time. Therefore, a lag time would be expected between the onset of trapping and the reduction of *C. sordidus* damage in harvested plants. This is exactly what happened in researcher-managed fields, with the greatest effect in damage reduction found at the conclusion of the trial. By comparison, the more modest population reductions found in farmer-managed fields were not translated into advantages in terms of damage reduction during the course of this study.

Trapping with crop residues is a method readily available to most banana growers. However, systematic trapping requires discipline on the part of the farmer (Nonveiller, 1965) and realistic expectations of how much control trapping might provide in both short and long-term time horizons. In Uganda, the theoretical value of trapping has been widely recognized, yet few farmers actually practice it (Gold *et al.*, 1993). For example, farmers in Kabarole district abandoned trapping after a few weeks because they observed no (immediate) reduction in weevil numbers or crop improvement. Moreover, systematic trapping is labour intensive and limited by availability of sufficient material.

Following a discussion of results (e.g. table 4) in Ntungamo, participating and non-participating farmers alike were convinced that trapping can reduce banana weevil levels. Nevertheless, they expressed two areas of concern that are likely to influence the adoption of trapping at this site: (i) material and labour resource requirements for pseudostem trapping; and (ii) re-infestation via immigration of adult weevils from neighbouring fields. As a result, farmer adoption of weevil trapping in the three years following the conclusion of this study has been limited. Only three of the 27 farmers in the study (all from farmer-managed treatments) and one other farmer at the site have adopted trapping (albeit at irregular intervals) for weevil control. This suggests that pseudostem trapping may not be an appropriate strategy for resource-poor, subsistence growers. In contrast, many small-scale commercial growers in Masaka district have readily adopted pseudostem trapping (J. Ssennyonga *et al.*, unpublished data).

Several methods have been proposed to increase the efficiency of pseudostem and disk on stump traps and, thereby, reduce costs. For example, trapping has been proposed as a means of aggregating weevils which can then be killed with chemical pesticides (Bullock & Evers, 1962; Sotomayor, 1972). Cardenas & Arango (1986) found that treated traps caught twice as many *C. sordidus* adults as untreated ones. This suggests that the insecticides killed many *C. sordidus* that would otherwise enter and leave traps, thereby increasing trap catches. However, it is unclear if treating traps would have been more cost-effective than simply applying chemicals around the base of the mat.

Trapping has also been suggested as a delivery system for biopesticides (e.g. entomopathogens) (Mesquita, 1988; Kaaya *et al.*, 1993; Batista Filho *et al.*, 1994; Nankinga, 1999). For example, Batista Filho *et al.* (1994), Carballo & Lopez (1994) and Nankinga (1999) found *C. sordidus* mortality of up to 60–100% in traps treated with different formulations of *B. bassiana*. Nevertheless, Nankinga (1999) found applications of *B. bassiana* formulations at the base of the plant to be more effective than applications to traps.

Trap efficiency can also be enhanced by the use of semiochemicals that attract *C. sordidus*. These include both male aggregation pheromones and kairomones (Budenberg *et al.*, 1993; Cerda *et al.*, 1994; Jayaraman *et al.*, 1997). In Costa Rica, Alpizar *et al.* (1999) reported that pitfall traps with Cosmolure+ (a pheromone/kairomone mixture produced by Chemtica International, S.A., San Jose, Costa Rica) collected 12 times as many *C. sordidus* as unbaited sandwich traps. Through interference studies, they estimated the effective radius of trap attractivity at 2.5–7.5 m. Applying four traps per ha (changed and moved monthly) over an 18 month period, Alpizar *et al.* (1999) realized a 65% reduction in *C. sordidus* damage in plantain fields.

In summary, pseudostem trapping may not be the most practical means of *C. sordidus* control for resource-poor banana growers. In this study, researcher-managed, intensive pseudostem trapping (i.e. one trap per mat per month) on farmers' fields resulted in major reductions of *C. sordidus* populations on most (but not all) farms and in lower weevil damage levels. Less intensive trapping, as practiced by farmers, had mixed effects on pest populations and no impact on damage levels during the study period. Most farmers expressed doubts on their capacity to employ this method and, in fact, few have adopted it. Research on enhanced trapping through the use of semiochemicals and killing agents (e.g. insecticides, entomopathogens) should be evaluated.

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