Original article

# A farmer participatory research approach to assess the effectiveness of field sanitation and regular trapping on banana weevil populations

**Ole Tobias Rannestad[1,2], Amon P. Maerere[2], Torfinn Torp[1], May-Guri Sæthre[1]***

[1] Plant Health Plant Prot. Div., Bioforsk (Nor. Inst. Agric. Environ. Res.), Ås, Norw.

[2] Dep. Crop Sci. Prod., Sokoine Univ. Agric., Morogoro, Tanzania, may-guri.saethre@bioforsk.no

* *Correspondence and reprints*

*Received 11 January 2012*
*Accepted 29 March 2012*

*Fruits,* 2013, vol. 68, p. 83–93

DOI: 10.1051/fruits/2012054
www.fruits-journal.org

***Resumen Español**, p. 93*

## A farmer participatory research approach to assess the effectiveness of field sanitation and regular trapping on banana weevil populations.

**Abstract – Introduction**. Small-scale banana producers in Tanzania are facing constraints caused by the destructive activities of the banana weevil (*Cosmopolites sordidus* Germar). Many currently used methods of addressing the problem are ineffective or too expensive for local farmers to implement. **Materials and methods**. A combination of two integrated pest management (IPM) tools (regular trapping in combination with field sanitation) was tested at two farmer-managed sites (Bujela and Kyimo) and one researcher-managed site (SUA-Morogoro). Treated areas were surrounded by untreated control areas where no trapping and limited sanitation was done. Changes in population densities were estimated by the mark-recapture procedure and the Lincoln index. **Results and discussion**. After eight months, weevil populations in the cleaned and trapped areas had been reduced by 33% (Bujela), 33% (Kyimo) and 74% (SUA). The change in population sizes in the control areas differed greatly, possibly due to discrepancies in field management between farmers' and researchers' practice. Trap types, areas and sites affected the number of weevils captured. Disc-on-stump (DOS) traps captured more weevils than corm disc (CD) and pseudostem (PS) traps. Weevils responded more strongly to traps in the clean area at SUA compared with the other two sites, probably because the more rigid sanitation practices at SUA meant that volatiles from the traps were less likely to be masked by volatiles from surrounding residues. **Conclusion**. Regular trapping with field sanitation can greatly reduce populations of banana weevils, but strict adherence to method execution is required in order to gain favourable results.

**Tanzania / *Musa* / integrated pest control / *Cosmopolites sordidus* / traps / pseudostems / corms / farmer participation / cultivation / weeding**

## Recherche participative avec les agriculteurs pour évaluer l'efficacité de l'assainissement en champ et du piégeage régulier des populations de charançons du bananier.

**Résumé – Introduction**. En Tanzanie, les petits producteurs de bananes sont confrontés à des contraintes liées aux activités destructrices du charançon du bananier (*Cosmopolites sordidus* Germar). De nombreuses méthodes actuellement utilisées pour résoudre ce problème sont inefficaces ou trop coûteuses à mettre en œuvre pour les agriculteurs locaux. **Matériel et méthodes**. Une combinaison de deux outils de lutte intégrée (IPM) (piégeage régulier combiné avec un assainissement du terrain) a été testée sur deux sites gérés par des agriculteurs (Bujela et Kyimo) et sur un site géré par des chercheurs (SUA-Morogoro). Les zones traitées ont été entourées de zones témoins non traitées où aucun piégeage ou assainissement n'ont été faits. Les variations de densité de la population ont été estimées par marquage-recapture et par utilisation de l'indice de Lincoln. **Résultats et discussion**. Après huit mois, les populations de charançons dans les zones nettoyées et équipées de pièges ont été réduites de 33 % (Bujela), 33 % (Kyimo) et 74 % (SUA). Le changement de taille de la population dans les zones de contrôle a considérablement différé, probablement en raison de divergences dans la pratique de gestion en champs par les agriculteurs et les chercheurs. Les types de pièges, les zones et les sites ont affecté le nombre de charançons capturés. Les pièges constitués de disques de souches (DOS) ont capturé plus de charançons que les pièges constitués de disques de rhizomes (CD) ou de pseudotroncs (PS). Les charançons ont réagi plus fortement aux pièges dans la zone nettoyée à la SUA qu'à ceux des deux autres sites, probablement parce que les pratiques d'assainissement plus rigoureuses de la SUA ont fait que les substances volatiles des pièges ont été moins susceptibles d'être masquées par des substances volatiles provenant de résidus environnants. **Conclusion**. Le piégeage régulier associé à l'assainissement en champ peut grandement réduire les populations de charançons du bananier, mais un strict respect de l'exécution des méthodes est nécessaire afin d'obtenir des résultats satisfaisants.

**Tanzanie / *Musa* / lutte intégrée antiravageur / *Cosmopolites sordidus* / piège / pseudotige / cormus / participation des agriculteurs / pratique culturale / désherbage mécanique**

## 1. Introduction

In rural Tanzania, banana (*Musa* spp.) is a staple food crop for a large part of the human population. The majority of those engaged in banana production are small-scale farmers with a farm size of 0.5 ha or less. They grow several banana varieties and make very little use of chemical fertilisers or synthetic pesticides [1, 2]. Like in most banana-growing areas of the world, the banana weevil *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) is a common pest in East Africa [3, 4]. The weevil is nocturnally active [5] and attracted to the host plant by volatiles emanating from fresh and decomposing banana materials [6, 7]. These weevils can live for two to four years [3] and have low fecundity [8]. The females place the eggs singly in chambers excavated at the base of the host plant, and the emerging larvae tunnel into the corm, pseudostem and true stem [5]. The tunnelling activity leads to a reduction in the plants' water and nutrient uptake abilities, resulting in reduced plant size and vigour, toppling and snapping, lower number of suckers, delay in flowering, and thereby shorter banana stand life [3–5].

Several methods to control weevil damage have been developed or explored, including pesticides [9], botanicals [10], biological control [11], endophytes [12], entomopathogenic fungi [13] and entomopathogenic nematodes [14]. Only a few methods are at the applied stage, and most methods are impractical for small-scale farmers in countries such as Tanzania due to the lack of distribution systems and high costs. Improved crop and habitat management through integrated pest management (IPM) and cultural control have been suggested under such conditions [5, 15].

Because the immature stages of the weevil are spent within the host plant, most cultural control methods target adult weevils only. Reports of high variation in weevil infestation levels on neighbouring farms growing the same banana varieties suggest that field management may affect weevil population size and distribution [15–18]. Trapping of weevils with banana tissue has been suggested as an affordable control method, and even though achievements have been inconsistent [5], weevil trapping has under certain conditions appeared to be a promising way of reducing weevil populations [19–21]. As reviewed in Gold *et al*., most authors conclude that traps containing corm material are more attractive to banana weevils compared with those made from pseudostem tissue [5]. However, since pseudostem tissue is more readily accessible than corm tissue under normal farming conditions, a better understanding of the relative effectiveness of different trap types would be helpful.

The weevils use both fresh and decomposing banana tissue as food sources and for oviposition [4, 22]. Larval survival may be higher in residues due to the breakdown of plant antibiotic resistance in decaying tissue [22]. There has been some concern about possible immigration of weevils from neighbouring fields into areas where control methods are employed [16, 18, 23]. Weevils have recently proven to be able to move considerable distances by nocturnal crawling [24]. Field sanitation, through removal of post-harvest banana residues and weeds, is a cultural control method which seeks to discourage weevil oviposition, and could lead to the emigration of weevils, such as occurs in fallows [18]. By removing resources attractive to the weevils, a dispersal of weevils into neighbouring fields could be promoted. Field sanitation has shown promising results, but so far these have been inconclusive [20, 25, 26].

Few producers in Tanzania actively combat weevil infestations. Since farmers' involvement is essential in the execution of control measures at the local level, a participatory study, involving both farmers and researchers, was designed. The main goals were to: 1) test the effects of field sanitation and regular trapping on three separate weevil populations, 2) compare the relative efficiency of three trap types, and 3) compare differences between farmers' and researchers' managed fields in relation to weevil population densities.

## 2. Materials and methods

### 2.1. Study sites

This study was conducted in the eastern (one site) and southern (two sites) zones of Tanzania. The eastern site was located at Sokoine University of Agriculture (SUA) (6°84´ S, 37°66´ E, 525 m a.s.l.), outside Morogoro town. The average temperature in the area is 25 °C, and the coldest months are July to September. The seasonal rainfall pattern is bimodal, with rain normally falling from late October to December, and from March to May. Annual precipitation is 700–900 mm. The research field was 1900 $m^2$ and contained 207 banana mats, with a spacing of (3 to 4) m between them.

In the Southern Highlands, one site was located in Kyimo village (09°13´ S, 33°34´ E, 1300 m a.s.l.), north of Tukuyu town. The average temperature in the area is 19 °C, and the coldest months are June and July. The rainy season starts in October and lasts until May. Annual precipitation is approximately 2500 mm. The research field was approximately 4500 $m^2$, owned by a local farmer, and contained 300 banana mats. The spacing between mats was (3 to 7) m. The second site was located in Bujela village (09°19´ S, 33°41´ E, 1215 m a.s.l.), southeast of Tukuyu town. The climatic conditions are similar to those in Kyimo. The research field was owned by a local farmer and covered approximately 2600 $m^2$, containing 200 mats. The spacing between the mats was (2 to 6) m.

### 2.2. Experimental design

Farmer participatory methods were applied in Bujela and Kyimo, while the plot at Sokoine University of Agriculture was researcher-managed. In April 2008, an area of rectangular shape, constituting 20–30% of the total field, was marked in the central part of the field at all three sites; hereafter referred to as "the clean area". The clean area was cleaned of banana residues and thoroughly weeded. It was agreed that this would be done continuously throughout the study period every time plants were harvested, and when weeds started to reappear. The remaining area, *i.e.*, the area surrounding the clean area, was not modified. This was hereafter referred to as "the dirty area". It was agreed with the farmers that the clean area should be kept clean of residues and weeded throughout the experimental period. All post-harvest residues should be left undisturbed in the dirty area, and only very limited weeding should be done there.

### 2.3. Traps

Three types of traps – made from fresh and untreated banana tissue – were used. Pseudostem (PS) traps were made by splitting an approximately 30-cm-long piece of banana pseudostem longitudinally. The traps were put on the ground with the cut surface facing the soil. Corm disc (CD) traps were made by slicing a 5–10-cm-thick disc of the corm (rhizome), and placing this with one cut surface facing down. Disc-on-stump (DOS) traps were made by cutting a harvested or broken banana plant through the corm at ground level, and digging a depression in the stump for sap to accumulate. The material used for traps was always inspected to make sure it was not infected with weevils or larval galleries. Since the weevils favour dark and moist conditions [27, 28], all traps were covered with banana leaves after placement.

### 2.4. Data collection

To estimate the initial absolute population in clean and dirty areas in each plot, the mark-recapture procedure as described by Southwood and Henderson was applied [29]. In April 2008, one trap was placed on every banana mat in both the clean and dirty areas at the three sites. The ratio of the three trap types was always similar in the clean and dirty areas in every trapping session at each site. The traps were left in the field for three days. Trapped weevils were collected and marked differently with a shallow depression on the elytra with a hobby drill (model 800; Dremel, Racine, Wisconsin, USA), corresponding to whether they were caught in the clean or in the dirty area. It was ensured that the weevils suffered no damage during the marking process, and shortly after they were released in the banana mat where they had been caught. The marked weevils were left to mix with the rest of the population for two weeks before recapture. Recapture was carried out by placing one trap on every banana mat in both clean and dirty areas. All captured weevils were examined and recorded as marked or unmarked. It was also recorded whether the marked weevils originated from the clean or dirty area. The initial population estimates for both clean and dirty areas at the three sites were then calculated using the Lincoln index [29]: $N = (a \times n) / r$, where N = number of individuals in the population, $a$ = total number of individuals marked in sample 1; $n$ = total number of individuals caught in sample 2; $r$ = number of recaptures (*i.e.*, individuals marked in sample 1 and recaptured in sample 2).

In December 2008 (for SUA) and January 2009 (for Kyimo and Bujela), the weevil populations in the clean and dirty areas were again estimated by the mark-recapture procedure and the Lincoln index. This was done to investigate if the field sanitation and trapping in the clean areas had had any impact on population size. Due to differences in field size, and a slight difference in the relative size between clean and dirty areas within the sites, population estimates were transformed from number of weevils per treatment (clean/dirty) to numbers per $m^2$. A total of 2215 weevils were marked during the initial and final population estimates.

Between the initial and final population estimates, regular trapping was conducted in the clean areas only, by placing one trap within every banana mat. The relative number of PS, CD and DOS traps was kept at a similar level for each trapping session at each of the three sites. The traps were checked for weevils in the morning three days after placement. The number of weevils per trap, whether the weevils were marked or unmarked, and the trap type were recorded. All trapped weevils were subsequently removed from the field. Trapping was carried out nine times at SUA and seven times in Kyimo and Bujela.

### 2.5. Statistical analysis

A generalised linear mixed model was used to predict the effect of trap types (CD, DOS and PS) and area (clean and dirty) on the number of weevils captured (analysed by the GLIMMIX procedure [30]). The number of weevils captured in a trap was modelled by a negative binomial distribution, with the natural log-function, *ln*, as the link function. The model is expressed as follows: $\ln(\mu_{ijk}) = \ln[E(Y_{ijk}|\gamma_k)] = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k$, where $\mu_{ijk}$ = the expected value of $Y_{ijk}$ being the number of weevils captured in trap type $i$, area $j$ and site $k$; and $\mu$ = the general mean; $\alpha_i$ = the main effect of trap type $i$; $\beta_j$ = the main effect of area $j$ (clean or dirty); $(\alpha\beta)_{ij}$ = the interaction effect between trap type $i$ and area $j$; $\gamma_k$ = the random effect of site $k$.

A mixed linear model was used to predict the effect of trap types (CD, DOS and PS) and month (May 2008–February 2009) on the average number of weevils captured per trapping month in the clean areas (analysed by the MIXED procedure [30]). The average number of weevils captured in a trap per month was assumed to have a normal distribution. The model is expressed as follows: $y_{ijt} = \mu + \alpha_i + \beta \cdot t + (\alpha\beta)_i \cdot t + S_j + (\alpha S)_{ij} + (\beta S)_j \cdot t + \varepsilon_{ijt}$ (where $y_{ijt}$ is the average number of weevils captured in a trap of type $i$ [$i$ = 1 (CD), $i$ = 2 (DOS), $i$ = 3 (PS)], at site $j$ [$j$ = 1 (SUA), $j$ = 2 (Kyimo), $j$ = 3 (Bujela)], and in month $t$ ($t$ = 5, 6, 7, 8, 9, 10, 11, 12, 13, 14)). Observations (= average number of weevils per trap per month) was weighted according to the number of traps the average capture was based on.

## 3. Results and discussion

### 3.1. Initial and final population estimates

During the study period, the densities of weevils in the three clean areas decreased from 3.20 weevils·$m^{-2}$ to 0.83 weevils·$m^{-2}$ at SUA, from 0.75 weevils·m$^{-2}$ to 0.50 weevils·m$^{-2}$ in Kyimo, and from 2.60 weevils·m$^{-2}$ to 1.76 weevils·m$^{-2}$ in Bujela, giving a change in weevil populations in the clean areas of –74%, –33% and –33% at the three sites, respectively.

In the dirty areas, weevil densities increased from 2.40 weevils·m$^{-2}$ to 2.99 weevils·m$^{-2}$ at SUA, remained unchanged at 1.00 weevils·m$^{-2}$ in Kyimo, and decreased from 3.20 weevils·m$^{-2}$ to 2.18 weevils·m$^{-2}$ in Bujela, giving a change in weevil populations in the dirty areas of +23%, 0% and –31% at the three sites, respectively (*figure 1*).

The results from this study show that trapping with pseudostem and corm material, combined with field sanitation, can greatly reduce weevil populations. Koppenhöfer *et al.* and Seshu Reddy *et al.* obtained a 33–50% reduction in weevil catches after systematic trapping with pseudostem tissue [19, 31]. However, these studies were based on trap capture rates and not on population size estimates, thus making the results difficult to interpret. Estimates based on mark-recapture data from Uganda showed that one year of intensive trapping reduced weevil populations by up to 61% [16]. The low fecundity of and slow increase in weevil populations means that regular trapping can potentially remove enough of the population to overcome their reproductive capacity, and eventually contribute to successful weevil suppression [16]. However, trapping without field sanitation may prove to be counterproductive since residues could act as loci for weevil breeding [15, 22], with volatiles from residues mixing with volatiles from the traps and thereby reducing the effectiveness of the latter. Rannestad *et al.* showed that banana weevils are more mobile than previously thought, indicating that the increase in population size in the dirty area at SUA may also be explained by migration of weevils from the clean to the dirty area [24]. Unfortunately, the present study could not provide a clear answer to whether migration occurred from the clean to dirty area because the populations in the three dirty areas were not monitored between the initial and final population estimates. Rhino *et al.* found that, by leaving banana fields fallow, weevil migration into adjacent active banana fields was initiated [18]. This indicates that weevil migration from clean to dirty areas might have contributed to the changes in populations in our experiment.

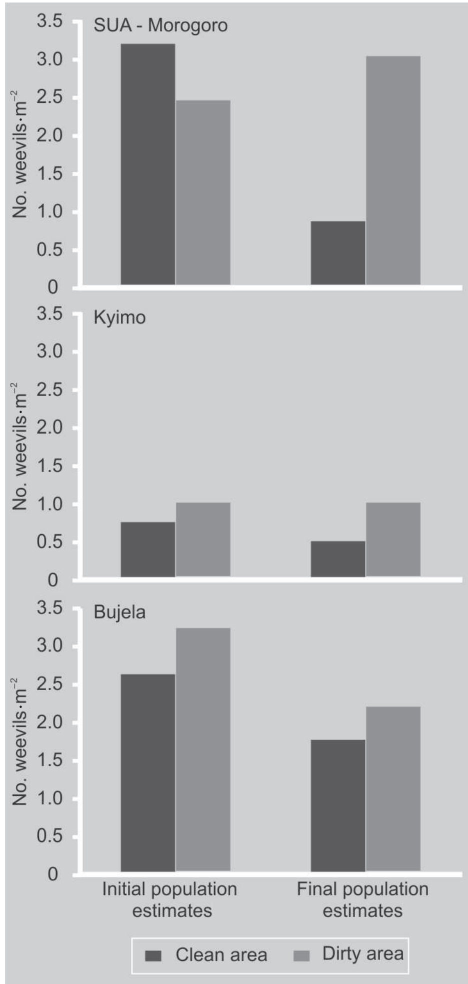


**Figure 1.**
Initial (May 2008) and final (Dec. 2008/Jan. 2009) population estimates (weevils per m$^2$) in clean and dirty areas of the banana fields at Sokoine University of Agriculture (SUA), Bujela and Kyimo (Tanzania). Measured by the mark-recapture procedure and calculated using the Lincoln index.

The farmers' participatory research approach used in the experiments was at times a challenge to the study, and this may at least partly explain the higher reduction in weevil population in the clean area at SUA compared with the clean areas in Kyimo and Bujela (*figure 1*). Even though the clean areas in Kyimo and Bujela were at all times kept cleaner on average than their adjacent dirty areas, the relative difference between the two treatments was - through more rigid researcher management - maintained at a visibly more pronounced level at SUA. This

**Table I.**
SAS Type III tests of the effect of three trap types and two area types (clean or dirty) on the number of weevils captured in banana fields, modelled by the generalised linear mixed model. The trap types were disc-on-stump (DOS), corm disc (CD) and pseudostem (PS) traps (Tanzania).

| Effect | Num DF[1] | Den DF[2] | F value | *P* > F |
|---|---|---|---|---|
| Trap type | 2 | 3895 | 142.42 | < 0.0001 |
| Area | 1 | 3895 | 1.23 | 0.2677 |
| Trap type × area | 2 | 3895 | 6.85 | 0.0011 |

[1] Numerator degrees of freedom.
[2] Denominator degrees of freedom.

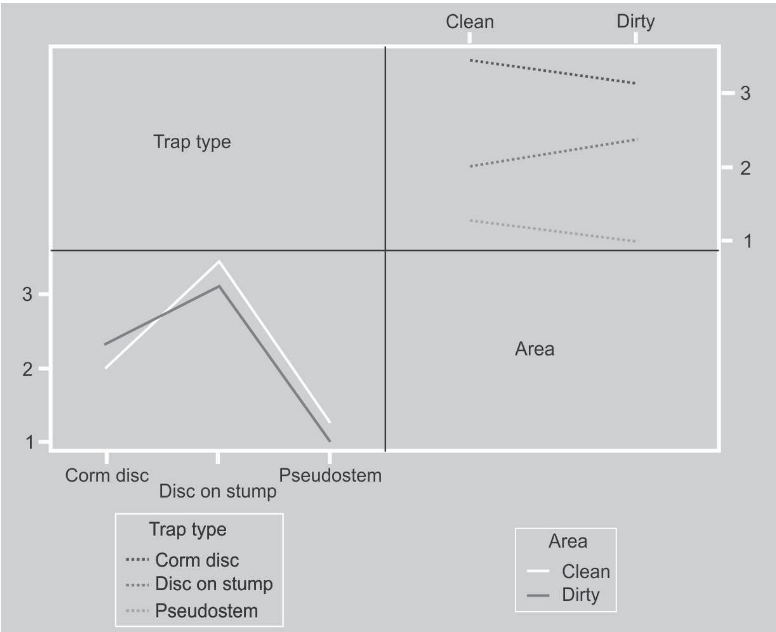


**Figure 2.**
Interaction plot of three trap types [disc-on-stump (DOS), corm disc (CD) and pseudostem (PS) traps] and two areas (clean and dirty) on captured banana weevils [estimated E(Y)], analysed by a generalised linear mixed model (with a negative binomial response variable and the natural log-function, *ln*, as the link function).

indicates that management may have been a distinguishing factor.

Moreover, in Bujela, the dirty area was modified by the farmer who, in September, cleaned 25% to 30% of the area of all banana residues, and replanted this area with banana suckers. Consequently, weevil food sources and oviposition sites were lost, and an unknown number of eggs, larvae and adult weevils were probably removed with the tissue. This modification is likely to have contributed to the decrease in weevil numbers in the dirty area in Bujela, while the stable and increasing trend in the dirty areas in Kyimo and SUA, respectively, reflects population dynamics better when little or no sanitation is practised.

### 3.2. Effects of trap types in clean versus dirty areas

A total of 3913 traps were used during the study, of which 335 were DOS, 855 were CD and 2723 were PS. The generalised linear mixed model gave a good description of the effect of trap types (DOS, CD and PS), and areas (clean or dirty) on the number of weevils captured (*table I, figure 2*). Trap types and areas affected the number of weevils captured. Trap type had a significant effect on the number of weevils captured. There was no significant main effect of area, but there was a significant interaction effect between trap type and area on the number of weevils captured (*table I*). The variance of the random factor site was different from zero (Estimate = 0.2408, ChiSq = 309, and Pr > ChiSq < 0.0001), showing that there were significant differences among sites.

DOS traps captured more weevils than CD and PS traps across sites and areas (clean and dirty), and CD traps captured more weevils than PS traps across sites and areas (*figures 2–4*). Even though trap catches on their own, for reasons related to, *e.g.*, trap design and seasonality, do not always reflect the actual size of a weevil population [5], our catches corresponded well with the calculated populations at all three sites, with Kyimo yielding both the lowest population estimates and the lowest trap catches (*figures 1–4*). It should be noted that the stand in Kyimo was younger than those at the other sites. According to Gold *et al*., the increase in weevil populations is a slow process which often leads to higher densities in older stands [5].

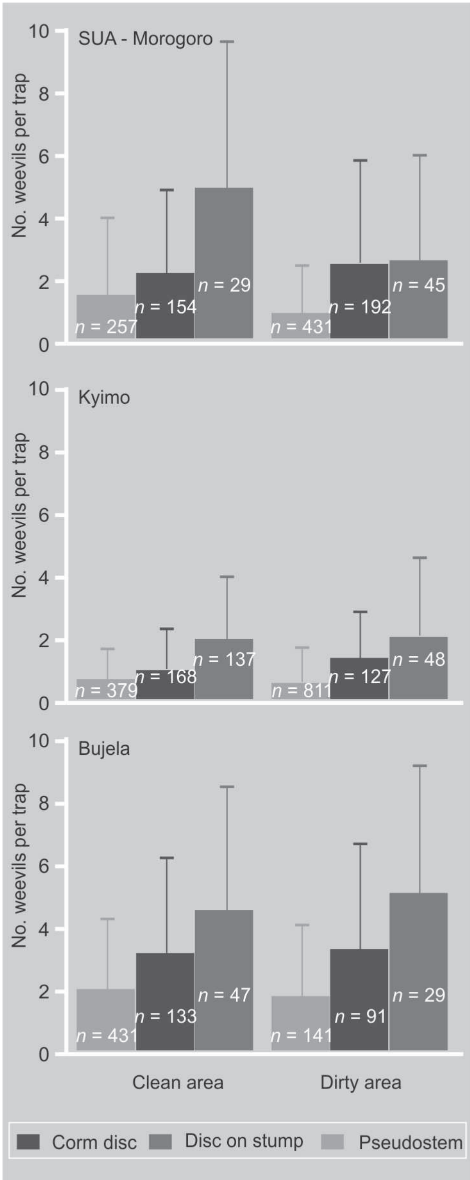


**Figure 3.**
Average number of banana weevils caught per trap type and trapping date (+ standard deviation) in banana fields, in the clean and dirty areas, at Sokoine University of Agriculture (SUA), Bujela and Kyimo (Tanzania).

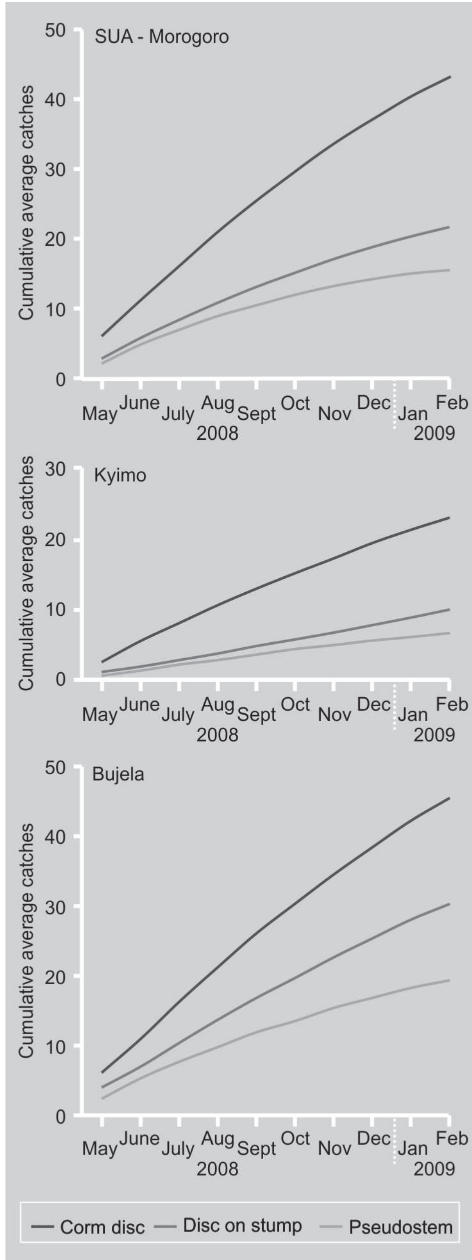


**Figure 4.**
Cumulative average catches of banana weevils in clean areas of banana fields per trap type and month, at each of three sites in Tanzania [Sokoine University of Agriculture (SUA), Bujela and Kyimo].

When assessing the efficiency of trap types in the clean areas only, the mixed linear model gave a good description of the effect of trap types (DOS, CD and PS) and month (May 2008 to February 2009) on the average number of weevils captured per trap and month (*table II, figure 4*). Trap type had a significant effect on the number of weevils captured. There was no significant main effect of month, and no interaction effect between trap type and month on the number of weevils captured. Based on the observed data and the predicted values from the analysis, the cumulative catches for each

**Table II.**
SAS Type III tests of the effect of three trap types and month (May 2008–February 2009) on the average number of weevils captured per trap and month in the clean areas of banana fields, modelled by the mixed linear model. The trap types were disc-on-stump (DOS), corm disc (CD) and pseudostem (PS) traps (Tanzania).

| Effect | Num DF[1] | Den DF[2] | F value | *P* > F |
|---|---|---|---|---|
| Trap type | 2 | 4 | 5.44 | 0.0724 |
| Month | 1 | 2 | 3.79 | 0.1845 |
| Trap type × month | 2 | 54 | 0.88 | 0.4197 |

[1] Numerator degrees of freedom.
[2] Denominator degrees of freedom.

**Table III.**
Differences of least squares means for three trap types from SAS Type III tests of the effect of trap types and month (May 2008–February 2009) on the average number of weevils captured per trap and month in the clean areas of banana fields. P-values adjusted by Tukey's method. The trap types were disc-on-stump (DOS), corm disc (CD) and pseudostem (PS) traps (Tanzania).

| Effect | Estimate | Degrees of freedom | *t* value | *P* > t |
|---|---|---|---|---|
| CD *versus* DOS | – 1.6535 | 4 | – 3.41 | 0.0276 |
| CD *versus* PS | 0.6784 | 4 | 1.66 | 0.1722 |
| DOS *versus* PS | 2.339 | 4 | 5.00 | 0.0075 |

[1] Numerator degrees of freedom.
[2] Denominator degrees of freedom.

trap type and site and their estimated development over ten months underline the superiority of the DOS traps over CD and PS traps in the clean areas (*figure 4*, *table III*).

Generally, our results are in agreement with other studies, showing that traps containing rhizome material (*i.e.*, CD and DOS) are more attractive to weevils compared with those made entirely from pseudostem tissue (reviewed in [5]). However, since the latter is by far the most accessible in the field, farmers who decide to carry out trapping on their farms will continue to have to rely more on PS traps than on CD and DOS traps.

The ratio between average total catches per trap in the clean versus the dirty areas was higher at SUA (1.41 weevils *vs.* 1.0 weevil) compared with Kyimo (0.91 weevils *vs.* 1.0 weevil) and Bujela (0.96 weevils *vs.* 1.0 weevil). It is likely that the weevils responded more strongly to the traps in the clean area at SUA because of the more rigid sanitation regime executed there. The almost total absence of banana residues in the clean area at SUA means that volatiles from residues had very little masking effect on the traps here, while the traps in the dirty area at SUA were probably masked to a greater extent by volatiles from banana residues present in the field. This indicates that field sanitation, by reducing the weevils' focal feeding and breeding loci in the field, could even enhance the effectiveness of regular trapping. Similar trends have been found in Uganda, where weevil population decline was greater in fields subjected to high levels of sanitation [16, 26]. However, it has been argued that the removal of residues may force weevils to oviposit on standing plants, thereby causing no net benefit on fruit production from reduced weevil populations [27]. Sanitation combined with determined trapping would address this, since trapping would exhaust the adult weevil population around banana mats.

## 4. Conclusions

Our study shows that trapping with pseudostem and corm tissue combined with field sanitation can, if executed regularly and strictly, greatly reduce banana weevil populations. Weevil populations also decreased by 33% after seven trapping sessions under farmer-managed conditions with lower levels of sanitation. While corm tissue is shown to be more attractive to weevils, the plant's large pseudostem-to-corm ratio means that pseudostem tissue will play an important part for farmers who wish to implement regular trapping as an IPM tool.

## Acknowledgements

We thank Daison Malinga and James Mwaipungu for allowing us to use their farms as study sites, and for their participation in the experimental work. The assistance of the people at the Horticulture Unit at Sokoine University of Agriculture was appreciated. The study was partly funded by Fredskorpset (The Norwegian Peace Corps) via Utviklingsfondet (The Development Fund), and the PANTIL programme.

## References

[1] Karamura E., Frison E., Karamura D.A., Sharrock S., Banana production systems in eastern and southern Africa, in: Picq C., Fourè E., Frison E.A. (Eds.), Int. Symp. Bananas and food security, INIBAP, Douala, Cameroon, 1998, pp. 401–412.

[2] Ouma G., Intercropping and its application to banana production in East Africa: a review, J. Plant Breeding Crop Sci. 1 (2009) 13–15.

[3] Rukazambuga N.D.T.M., Gold C.S., Gowen S.R., Yield loss in East African highland banana (*Musa* spp., AAA-EA group) caused by the banana weevil, *Cosmopolites sordidus* Germar, Crop Prot. 17 (1998) 581–589.

[4] Gold C.S., Kagezi G.H., Night G., Ragama P.E., The effects of banana weevil, *Cosmopolites sordidus*, damage on highland banana growth, yield and stand duration in Uganda, Ann. Appl. Biol. 145 (2004) 263–269.

[5] Gold C.S., Peña J.E., Karamura E.B., Biology and integrated pest management for the banana weevil, *Cosmopolites sordidus* (Germar) (*Coleoptera: Curculionidae*), Int. Pest Manag. Rev. 6 (2001) 79–155.

[6] Budenberg W.J., Ndiege I.O., Karago F.W., Hansson B.S., Behavioural and electrophysiological responses of the banana weevil *Cosmopolites sordidus* to host plant volatiles, J. Chem. Ecol. 19 (1993) 267–277.

[7] Braimah H., van Emden H.F., Evidence for the presence of chemicals attractive to the banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in dead banana leaves, Bull. Entomol. Res. 89 (1999) 485–491.

[8] Koppenhöfer A.M., Observations on egg-laying behaviour of the banana weevil, *Cosmopolites sordidus* (Germar), Entomol. Exp. Appl. 68 (1993) 187–192.

[9] Polidoro B.A., Dahlquist R.M., Castillo L.E., Morra M.J., Somarriba E., Bosque-Pérez N.A., Pesticide application practices, pest knowledge, and cost-benefits of plantain production in the Bribri-Cabécar indigenous territories, Costa Rica, Environ. Res. 108 (2008) 98–106.

[10] Musabyimana T., Saxena R.C., Kairu E.W., Ogol C.K.P.O., Khan Z.R., Powdered neem seed and cake for management of the banana weevil, *Cosmopolites sordidus*, and parasitic nematodes, Phytoparasitica 28 (2000) 321–330.

[11] Abera-Kalibata A.M., Hasyim A., Gold C.S., van Driesche R., Field surveys in Indonesia for natural enemies of the banana weevil, *Cosmopolites sordidus* (Germar), Biol. Control 37 (2006) 16–24.

[12] Paparu P., Dubois T., Coyne D., Viljoen A., Dual inoculation of *Fusarium oxysporum* endophytes in banana: effect on plant colonization, growth and control of the root burrowing nematode and the banana weevil, Biocontrol Sci. Tech. 19 (2009) 639–655.

[13] Godonou I., Green K.R., Oduro K.A., Lomer C.J., Afreh Nuamah K., Field evaluation of selected formulations of *Beauveria bassiana* for the management of the banana weevil (*Cosmopolites sordidus*) on plantain (*Musa* spp., AAB group), Biocontrol Sci. Tech. 10 (2000) 779–788.

[14] Mwaitulo S., Haukeland S., Sæthre M.-G., Laudisoit A., Maerere A.P., First report of Entomopathogenic nematodes from Tanzania and their virulence against larvae and adults of banana weevil *Cosmopolites sordidus* Germar 1824 (Coleoptera: Curculionidae), Int. J. Trop. Insect Sci. 31 (2011) 134–161.

[15] Gold C.S., Night G., Ragama P.E., Kagezi G.H., Tinzaara W., Abera A.M.K., Field

distribution of banana weevil *Cosmopolites sordidus* (Germar) adults in cooking banana stands in Uganda, Int. J. Trop. Insect Sci. 24 (2004) 242–248.

[16] Gold C.S., Okech S.H., Nokoe S., Evaluation of pseudostem trapping as a control measure against banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in Uganda, Bull. Entomol. Res. 92 (2002) 35–44.

[17] Rukazambuga N.D.T.M., Gold C.S., Gowen S.R., Ragama P., The influence of crop management on banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) populations and yield of highland cooking banana (cv. Atwalira) in Uganda, Bull. Entomol. Res. 92 (2002) 413–421.

[18] Rhino B., Dorel M., Tixier P., Riséde J.-M., Effect of fallows on population dynamics of *Cosmopolites sordidus*: toward integrated management of banana fields with pheromone mass trapping, Agric. Forest Entomol. 12 (2010) 195–202.

[19] Seshu Reddy K.V., Prasad J.S., Ngode L., Sikora R.A., Influence of trapping of the banana weevil, *Cosmopolites sordidus* (Germar 1824) on root-lesion nematode, *Pratylenchus goodeyi* (Sher and Allen 1953) population densities and subsequent banana yield, Acta Oecologica 16 (1995) 593–598.

[20] Smith D., Banana weevil borer control in south-eastern Queensland, Aust. J. Exp. Agric. 35 (1995) 1165–1172.

[21] de Graaf J., Govender P., Schoeman A.S., Viljoen A., Efficacy of cultural control measures against the banana weevil, *Cosmopolites sordidus* (Germar) in South Africa, J. Appl. Entomol. 132 (2008) 36–44.

[22] Masanza M., Gold C.S., van Huis A., Distribution, timing of attack, and oviposition of the banana weevil, *Cosmopolites sordidus*, on banana crop residues in Uganda, Entomol. Exp. Appl. 117 (2005) 119–126.

[23] Vinatier, F., Chailleux, A., Duyck, P.-F., Salmon, F., Lescourret F., Tixier P., Radiotelemetry unravels movements of a walking insect species in heterogeneous environments, Anim. Behav. 80 (2010) 221–229.

[24] Rannestad O.T, Sæthre M.-G., Maerere A.P., Migration potential of the banana weevil *Cosmopolites sordidus*, Agric. Forest Entomol. 13 (2011) 405–412.

[25] Masanza M., Gold C.S., van Huis A., Ragama P.E., Okech S.H.O., Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) populations and crop damage in farmers' fields in Uganda, Crop Prot. 24 (2005) 275–283.

[26] Masanza M., Gold C.S., van Huis A., Ragama P.E., Effects of crop sanitation on banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), populations and crop damage in Uganda, Afr. Entomol. 14 (2006) 267–275.

[27] Roth L.M., Willis E.R., The humidity behaviour of *Cosmopolites sordidus* (Coleoptera: Curculionidae), Ann. Entomol. Soc. Am. 56 (1963) 41–52.

[28] Reddy G.V.P., Cruz Z.T., Guerrero A., Development of an efficient pheromone-based trapping method for the banana root borer *Cosmopolites sordidus*, J. Chem. Ecol. 35 (2009) 111–117.

[29] Southwood T.R.E., Henderson P.A., Ecological methods, 3rd ed., Wiley-Blackwell, Oxford, U.K., 2000.

[30] Anon., SAS 9.2 TS level 1 MO, SAS Inst. Inc., Cary, N.C., U.S.A., 2011.

[31] Koppenhöfer A.M., Seshu Reddy K.V., Sikora R.A., Reduction of banana weevil populations with pseudostem traps, Int. J. Pest Manag. 4 (1994) 300–304.

## Investigación participativa con los agricultores para evaluar la eficacia del saneamiento en campo y de la instalación regular de trampas de las poblaciones de gorgojos del banano.

**Resumen – Introducción**. En Tanzania, los pequeños productores de bananas están enfrentados a obstáculos ligados a las actividades destructoras del gorgojo del banano (*Cosmopolites sordidus* Germar). Existen numerosos métodos empleados actualmente para resolver este problema, los cuales son ineficaces o demasiados costosos de ejecutar para los agricultores locales. **Material y métodos**. Se testeó una combinación de dos estrategias de lucha integrada (IPM) (instalación regular de trampas combinada con un saneamiento del terreno) en dos emplazamientos gestionados por agricultores (Bujela y Kyimo) y en un emplazamiento gestionado por investigadores (SUA-Morogoro). Las zonas tratadas se rodearon de zonas testigos no tratadas, donde no se realizó ninguna instalación de trampas o saneamiento. Se estimaron las variaciones de densidad de la población mediante marcaje y recaptura, así como empleando el índice de Lincoln. **Resultados y discusión**. Después de ocho meses, las poblaciones de gorgojos en las zonas limpiadas y equipadas con trampas se redujeron un 33% (Bujela), un 33% (Kyimo) y un 74% (SUA). El cambio de dimensión de la población en las zonas de control difirió considerablemente, probablemente, por divergencias en la práctica de gestión de campos por agricultores e investigadores. Los tipos de trampas, las zonas y los emplazamientos afectaron el número de gorgojos capturados. Las trampas constituidas con discos de cepas (DOS) capturaron más gorgojos que las trampas constituidas con discos de rizomas (CD) o de pseudo troncos (PS). Los gorgojos reaccionaron más fuertemente a las trampas en la zona limpiada en SUA que a las de los otros dos emplazamientos, probablemente, porque las prácticas de saneamiento más rigurosas de la SUA ayudaron a que las sustancias volátiles de las trampas fueran menos susceptibles de taparse por otras sustancias volátiles procedentes de residuos cercanos. **Conclusión**. La instalación regular de trampas asociada al saneamiento práctico puede reducir mucho las poblaciones de gargajos del banano, pero es necesario un estricto respeto de la práctica de los métodos, con el fin de obtener resultados satisfactorios.

**Tanzania / *Musa* / control integrado de plagas / *Cosmopolites sordidus* / trampas / pseudotallos / cormo / participación de agricultores / cultivo / escarda mecánica**