Uganda Journal of Agricultural Sciences, 2004, 9:274-280

ISSN 1026-0919

Selection of assessment methods for evaluating banana weevil damage on highland cooking banana

C.S. Gold, P.E. Ragama, R. Coe[1] and N.D.T.M. Rukazambuga[2]

International Institute of Tropical Agriculture, P. O. Box, 7878 Kampala, Uganda
[1] World Agroforestry Center, P.O. Box 30677, Nairobi, Kenya
[2]Rural Sector Support Project, Ministry of Agriculture, P.O. Box 6961, Kigali, Rwanda

Abstract

The banana weevil *Cosmopolites sordidus* (Germar) is an important pest on bananas and plantains (*Musa* spp.). Population build-up is slow and weevil problems become increasingly important in successive crop cycles (ratoons). Yield loss results from plant loss (death, snapping, toppling), mat disappearance (failure to sucker) and reduced bunch size. Damage assessment requires destructive sampling and is most often done on the corm periphery or corm cross sections of recently harvested plants. A wide range of damage assessment methods exist and there are no agreed upon assessment protocols. In this context, it is critical to know what types of damage best reflect weevil pest status through their relationships with yield loss. Multiple damage assessment parameters were employed in two long duration yield loss trials (cv Atwalira, *Musa* spp. AAA-EA) and a cultivar screening trial in Uganda. Parameters included two estimates of peripheral damage on pared corms and estimates of damage to the central cylinder and cortex (plus a derived total damage score) observed in cross sections. In the first two trials, estimated yield losses to banana weevil exceeded 40% in latter cycles. Damage to the central cylinder had a greater effect on plant size and yield loss than damage to the cortex or corm periphery. In some cases, a combined assessment of damage to the central cylinder and cortex showed a better relationship with yield loss than an assessment of the central cylinder alone. Regression (linear and logistic) and correlation analyses showed weak to modest relationships between damage to the corm periphery and damage to the central cylinder. Thus, damage to the corm periphery (less labour intensive to assess) is not a strong predictor of the more important damage to the central cylinder. Therefore, banana weevil damage assessment should be made for the central cylinder and cortex.

Key words: Cosmopolites sordidus, Musa spp., ratoons, Uganda

Introduction

The banana weevil *Cosmopolites sordidus* (Germar) is the most important insect pest on bananas and plantains (*Musa* spp.). The adults are free-living (not confined to the banana plant) but most often found at the base of the banana mats or associated with crop residues (Gold *et al*., 1999). Oviposition is in the base of the banana mat. The larvae tunnel in the corm and lower pseudostem. Most attack occurs below the soil surface. Pupation is within the plant.

Population build-up is slow and weevil problems become increasingly important in ratoon crops. Damage is caused entirely by larval feeding. Weevil attack can prevent crop establishment, cause significant yield reductions in ratoon cycles and contribute to shortened plantation life. Yield loss results from plant loss (death, snapping, toppling), mat disappearance (failure to sucker) and reduced bunch size (Rukazambuga *et al*., 1998; Gold *et al*., 2004).

Accurate assessments of banana weevil population levels and damage are necessary to understand the weevil's pest status and are a prerequisite in evaluating the impact of any intervention. Knowing what types of damage are most important is also important in screening cultivars and developing new varieties through both conventional and non-conventional means. Sampling of banana weevil is difficult and there is no agreed upon assessment protocol. The reclusive behavior of the banana weevil adult and the difficulties in measuring larval damage to the interior of the corm has resulted in a multitude of scoring and evaluation systems.

The most widely used methods have been (1) estimates of peripheral damage (Vilardebo, 1973; Mitchell, 1980, Gold *et al*. 1994b); (2) estimates of internal damage found in cross sections (Gold *et al*., 1994b); and (3) estimates of the proportion of plants attacked (Mestre, 1997). All existing assessment methods measure cumulative weevil attack throughout the life of the plant and cannot determine when this attack occurred.The weevil is an indirect pest and it is not clear what types of damage have the greatest impact on yield. In this paper, we examine and compare the relationships between a range of different banana weevil damage parameters and yield for two long-term trials previously reported on by Rukazambuga *et al*., (1998) and Gold et al. (2004). We seek to determine the parameters that can best estimate the impact of banana weevil attack on plant growth and yield.

Materials and methods

Site description, field establishment and trial designs

Trial 1: The first trial was undertaken at Kawanda Agricultural Research Institute, 13 km north of Kampala at 0^{o} 19" N, 1195 m.a.s.l with constant 12h day-length throughout the year. Rainfall, temperatures and soils for the site are described by Rukazambuga *et al*. (1998). The trial was planted in November 1991 in a field that had not been used for banana for at least 10 years.

The trial investigated the effects of different levels of weevil damage on plant growth and yield. The highland cooking banana cultivar Atwalira (AAA-EA), obtained from nearby farmers' fields, was used. Details of the experimental design are presented by Rukazambuga *et al*. (1998). Weevils were released in August, 1992 during the first rainy season following crop establishment. Weevils could not be excluded from control plots. Therefore, the original analysis was conducted for each crop cycle by grouping individual plants into damage categories. The trial ran for 4 crop cycles.

Trial 2: The second trial was conducted at the International Institute of Tropical Agriculture's Sendusu Farm (0^{o} 32' N., 32^{o} 32' E; 1260 m.a.s.l.), 25 km NE of Kampala. Rainfall, temperatures and soils for the site are described by Gold *et al*. (2004). The trial was planted in June 1994 in a field that had been in bush fallow for 4 years, previously planted with maize. The trial consisted of two treatments (1) no weevils (control) (6 replicates); and (2) weevil-infested plots (18 replicates). The original design called for three different levels of weevil pressure, but these could not be maintained under field conditions. Experimental plots (25 x 15 m) consisted of 50 highland banana plants (cv Atwalira). arranged in 10 rows of five mat. Plots were separated by 15 m grass alleys to minimize weevil movement between treatments. Banana weevil adults were released into the trial in March 1995 during the first rainy season following plant establishment. Weevils were excluded from control plots by chemical insecticides starting in 1996. The trial ran for 7 years.

Yield parameters

Bunches were harvested when at least one finger on the first hand began to ripen. Bunch weight was measured with a Salter balance (precision = 0.5 kg). The fate of each plant (harvested, snapped, toppled, broken or dead) was recorded. A plant was considered a complete loss if it did not produce a bunch or if its life was terminated before the bunch reached an edible stage. In such cases a bunch weight of zero was assigned to the plant.

Weevil damage parameters

In all trials, weevil damage was scored immediately after harvest and represented attack that occurred throughout the vegetative phase of the plant. Damage assessment was also conducted on plants that died or were lost through toppling and snapping without producing a bunch.

Banana weevil damage was assessed on the corm periphery and in cross sections at the collar (i.e. corm:pseudostem junction) and 5 cm below the collar. Surface damage was estimated through a modified PCI (c.f. Mitchell, 1980) and consisted of pressing a template grid of 10 sections (covering 180°) on the corm 5 cm below the base of pseudostem and assessing presence or absence of weevil galleries in each 5-cm section above and below the template (giving scores of 0 to 20). "Peripheral damage" (PD) was an estimate of the percentage of corm surface tissue consumed by weevil larvae in the same area used for PCI measurements. In each of the cross section cuts, the percentage corm tissue consumed by weevil larvae was estimated separately for the central cylinder (XI) and cortex (XO). Surrounding rots, emanating from the galleries, were included in cross section damage estimates in trial 1 but not in trial 2. The mean of the two central cylinder and two cortex estimates was calculated to form a derived total cross section score (XT). PCI was scored in trial 1 only, while the other damage parameters were measured in both trials.

Data analysis

Correlations were calculated between different damage parameters using data from individual plants. When analyzing the relationship between yield and damage parameters, data from individual plants was also used. Plants that died before fruiting had zero yields, leading to a discontinuous distribution of yields. The relationship between yield and the various damage parameters was therefore done in two stages:

1. Logistic regression was used to model the chance of a plant of damage D producing a yield. The model is $\log(p/1-p)=a+bD$, where p is the chance of producing non-zero yield *a* is an intercept and *b* is a slope
2. Linear regression was used to model the dependence of non-zero yields on damage using the model $y=a+bD+residual$, where *y* is a non-zero yield,

Statistics such as r^2 show that the models have poor performance for predicting the yield of individual plants with a given level of damage. The slope parameters b characterizes the strength of the relationship between D and the average value of *y* or *p* across a large number of plants. All damage parameters are expressed on the same scale of 0 to 100 before analysis, so the values of b can be directly compared between different damage parameters to identify those that show the strongest relationship with average *y* or *p*. All calculations where done on SAS (SAS Institute Inc, 1990).

Table 2. Summary statistics for bunch weight that had low weevil damage level (XI < 5%) by cycle in trial 1 at Kawanda Agricultural Research Institute and in control plots in trial 2 at IITA Sendusu Farm, Namulonge, Uganda

A. Trial 1*: plants with low weevil damage (Kawanda)*

Crop Cycle	N	Bunch wt mean±SD	Range (kg)	Coefficient of variation
1	328	9.4 ± 2.7	0-16.0	29%
2	183	10.6 ± 5.1	0-21.5	48
3	122	10.9 ± 5.3	0-24.0	49
4	17	16.7 ± 6.8	6-32.0	41

B. Trial 2: control plots (Sendusu)

Crop Cycle	N	Bunch wt mean±SD	Range	Coefficient of variation
1	1160	12.9 ± 3.0	0.5-28.5	23%
2	1087	19.4 ± 4.5	3.5-32.5	23
3	1025	20.0 ± 5.5	4.0-44.0	28
4	972	21.2 ± 6.5	1.5-40.0	31
5	934	20.1 ± 5.8	1.5-40.0	29
6	817	17.0 ± 5.9	0.5-37.0	35
7	727	16.4 ± 5.2	0.5-37.0	32
8	561	18.0 ± 4.7	0.5-31.0	26
9	250	18.8 ± 7.0	1.0-54.0	37

Results

Damage parameters

In trial 1, all banana weevil damage levels increased over time (Table 1a). The PCI scale saturated quickly with mean scores reaching 90% by the second crop cycle, while other banana weevil damage parameters continued to increase in each of the three ratoon cycles. In trial 2, damage parameters increased over the first five crop cycles and fluctuated in weevil infested plots thereafter (Table 1b). Cross section damage scores in trial 1, based on the area damaged by weevils (i.e. galleries and surrounding rots), were considerably higher than in trial 2 where damage estimates were confined to the surface area consumed by larvae (i.e. galleries) only.

Relationship between damage parameters

For trial 1, PCI showed only a modest relationship with cross section damage ($r = 0.43$ for entire trial, 0.11 to 0.54 for individual crop cycles).PD was a better predictor of total internal damage than PCI ($r = 0.68$ for entire trial, 0.48 to 0.65 for individual crop cycles). In trial 2, a stronger relationship was found between PD and XT ($r = 0.81$ for entire trial, 0.37 to 0.71 for individual crop cycles). However, the relationship between PCI or PD with XI was consistently weaker than with XT (e.g. PCI and XI: $r = 0.36$ for trial 1; PD and XI: $r = 0.60$ for trial 1 and 0.66 for trial 2). These data suggest that PCI is a weak predictor of internal damage, while PD is a modest predictor.

Relationship between damage parameters, plant growth and yield: r^2 for goodness of fit

In trials 1 and 2, low and non-significant r^2 values suggested only poor fits of the data to regression lines indicating weak relationships between the different damage parameters, plant size and bunch weight. This is because banana weevils cause yield loss, not yield. Expected yields, however, could not be determined for individual plants due to the high intrinsic variability in bunch weights for bananas grown from suckers. Suckers used as planting material are not uniform with respect to age, size and general vigour, while within field variation in soils and other constraints will also contribute to variability in bunch weights. For example, bunch weights for plants with low damage levels in trial 1 had coefficients of variation of 29 to 48% (Table 2a), while bunch weights in control plots in trial 2 had coefficients of variation of 23 to 37% (Table 2b).

Relationship between damage parameters and plant size: slopes of regression equations

Damage parameters showing the greatest significant slopes were considered to have had the greatest effect on growth or yield. Slopes of regression equations suggest that damage to the central cylinder (XI) and total cross section damage (XT) showed the strongest relationships with plant girth in Trials 1 and 2, while damage to the corm periphery (PCI, PD) and cortex (XO) were not consistently related to reduced plant size (Table 3a,b). In trial 1, yield loss resulted from plant loss and reduced bunch weight. Logistical regression for the different damage parameters showed that based on slopes XI, XO and XT were the best predictors of plant loss (especially in the fourth cycle when plant loss was greatest) (Table 4). PD was a weaker predictor of plant loss, while

Table 3. Linear regression slopes for different banana weevil damage parameters as predictor of reduced girth by crop cycle.

a. Kawanda Agricultural Research Institute

Parameter	Crop cycles			
	1	2	3	4
PCI	-0.34±0.091***	-0.06±0.268ns	0.06±0.268ns	0.48±0.550ns
PD	-0.16±0.046***	-0.06±0.035ns	-0.06±0.035ns	-0.03±0.053ns
XI	-0.18±0.116ns	-0.19±0.031***	-0.19±0.031***	-0.07±0.056 ns
XO	-0.15±0.101ns	-0.07±0.047ns	-0.07±0.047ns	-0.04±0.084 ns
XT	-0.23±0.128ns	-0.19±0.041***	-0.19±0.041***	-0.07±0.075 ns

b. Sendusu Farm, Namulonge.

Cycle	PD±SE	XI±SE	XO±SE	XT±SE
1	-0.06±0.063ns	-0.06±0.060ns	0.03±0.064ns	-0.02±0.068ns
2	-0.01±0.040 ns	0.02±0.050ns	-0.29±0.044***	-0.21±0.054***
3	-0.01±0.049ns	-0.29±0.052***	0.09±0.051ns	-0.12±0.060*
4	-0.17±0.038***	-0.20±0.035***	-0.05±0.047ns	-0.20±0.046***
5	-0.03±0.047ns	-0.20±0.043***	0.12±0.057*	-0.12±0.059*
6	0.02±0.053ns	- 0.25±0.044***	-0.07±0.066ns	-0.25±0.060***
7	-0.01±0.049ns	-0.32±0.047***	-0.05±0.064ns	-0.29±0.061***
8	-0.02±0.058ns	-0.34±0.048***	-0.16±0.067*	-0.37±0.064***
9	-0.15±0.083ns	-0.35±0.069***	-0.05±0.107ns	-0.36±0.099***

Table 5. Linear regression slopes for different banana weevil damage parameters as predictor of reduced bunch weight by crop cycle at Kawanda Research Institute.

Parameter	Crop cycles			
	1	2	3	4
PCI	-0.011±0.005*	-0.001±0.015ns	0.013±0.026ns	0.029±0.055ns
PD	-0.029.013*	-0.061±0.025*	-0.044±0.019*	-0.047±0.024*
XI	-0.122±0.033***	-0.124±0.020***	-0.112±0.018***	-0.169±0.023***
XO	-0.061±0.005*	-0.085±0.025***	-0.038±0.025ns	-0.073±0.036*
XT	-0.126±0.037**	-0.130±0.024***	-0.107±0.023***	-0.175±0.031***

the slope for PCI against plant loss was not significantly different from 0 in any crop cycle. The damage parameters XI and XT also showed the strongest relationship with reductions in bunch weight. XO and PD showed more modest effects on yield, while PCI had weakest relationship with yield loss (Table 5).

In trial 2, yield loss was primarily due to disappearance of mats and secondarily to reductions in bunch weight and plant loss. Disappearance of mats occurred mostly between the third and seventh crop cycles. During this period, XI was the most consistent predictor of mat disappearance in the subsequent cycle (Table 6). Logistical regression slopes for PD and XT against mat disappearance were either positive or non-significant, suggesting no meaningful relationship. With the exception of the second crop cycle, XI also had more effect on bunch weight than any other damage parameter (Table 7). In this trial, damage to the corm periphery (PD) and cortex (XO) did not appear to have a meaningful impact on bunch weight.

Discussion

The banana weevil causes reduced plant size, bunch weight, delayed maturation rates, plant loss, or disappearance of mats through failure to produce suckers. Weevil damage is indirect and difficult to assess. For this reason a multitude of damage parameters have been developed. These use not only different scoring systems, but evaluate damage on different parts of the banana corm. To date, there has been no basis for selecting one assessment method over another (Gold et al. 1994a). Assessment of damage to the corm

Table 4. Logistic regression slopes for different banana weevil damage parameters as predictor of plant loss by crop cycle Kawanda Agricultural Research Institute.

Parameter	Crop cycles							
	1		2		3		4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
PCI	5.00	-0.09±0.053ns	2.67	-0.06±0.051ns	4.09	-0.14±0.089ns	11.63	-0.54±0.443ns
PD	3.86	-0.01±0.013ns	2.13	-0.03±0.012**	1.87	-0.02±0.008*	1.75	-0.03±0.007***
XI	4.91	-0.18±0.040***	2.04	-0.04±0.009***	2.25	-0.05±0.007***	3.25	-0.07±0.008***
XO	4.45	-0.09±0.053ns	2.31	-0.05±0.011***	2.36	-0.05±0.010***	2.19	-0.05±0.01***
XT	5.51	-0.23±0.053**	2.34	-0.05±0.011***	2.48	-0.06±0.010***	3.53	-0.09±0.011***

Table 6. Logistic regression slopes for different banana weevil damage parameters as predictor of plant loss by crop cycle at IITA's Sendusu Farm, Namulonge, Uganda

Cycle	PD±SE		XI±SE		XO±SE		XT±SE	
	intercept	slope	intercept	slope	intercept	slope	intercept	slope
1	5.74	-0.07±0.035*	4.89	-0.13±0.029***	5.63	-0.12±0.027***	5.67	-0.17±0.034***
2	0.98	0.10±0.025***	2.60	-0.04±0.020ns	2.73	-0.09±0.017***	2.93	-0092±0.020***
3	1.41	0.03±0.019ns	2.06	-0.04±0.014**	0.70	0.10±0.022***	1.68	0.02±0.022ns
4	0.40	0.05±0.014***	1.62	-0.01±0.009ns	0.49	0.06±0.016***	1.32	0.01±0.014ns
5	0.23	0.05±0.013***	1.76	-0.03±0.009**	-0.03	0.09±0.016***	1.21	0.01±0.014ns
6	1.26	-0.01±0.011ns	1.57	-0.04±0.008***	0.61	0.02±0.014ns	1.47	-0.03±0.011**
7	1.01	-0.00±0.012ns	1.47	-0.04±0.010***	0.65	0.02±0.016ns	1.38	-0.03±0.014*
8	2.97	-0.08±0.017***	2.20	-0.07±0.012***	1.80	-0.03±0.019ns	2.42	-0.08±0.017***
9	2.05	-0.03±0.023ns	1.94	-0.05±0.017**	1.48	-0.00±0.029ns	2.01	-0.05±0.023*

Table 7. Linear regression slopes for different banana weevil damage parameters as predictor of bunch weight reductions by crop cycle at Senduso Farm- Namulonge

Cycle	PD±SE	XI±SE	XO±SE	XT±SE
1	-0.04±0.019*	-0.14±0.031***	-0.06±0.025*	-0.11±0.031***
2	-0.09±0.039*	-0.07±0.053ns	-0.35±0.043***	-0.32±0.056***
3	-0.01±0.056ns	-0.23±0.068**	0.11±0.058ns	-0.04±0.071ns
4	-0.16±0.042***	-0.24±0.039***	0.01±0.051ns	-0.19±0.052***
5	-0.04±0.041ns	-0.25±0.038***	0.06±0.049ns	-0.18±0.051***
6	0.03±0.048ns	- 0.30±0.038***	0.03±0.058ns	- 0.27±0.054***
7	-0.08±0.048ns	-0.35±0.046***	-0.03±0.063ns	-0.28±0.060***
8	-0.02±0.068ns	-0.36±0.061***	-0.08±0.080ns	-0.33±0.080***
9	-0.10±0.114ns	-0.34±0.095***	-0.06±0.154ns	-0.35±0.136***

surface (PCI, PD), however, requires less work and may have less negative impact on the stability of the mat. In our studies in Uganda using the East African highland banana cultivar Atwalira, internal damage has a greater effect on plant performance than other damage parameters, especially those measuring damage to the corm periphery (e.g. CI, PCI, PD scoring methods). This was demonstrated by the frequency and size of significant negative slopes in logistical and regression equations of damage versus plant size, plant loss, rate of disappearance of mats and bunch weight. Estimating damage to both the central cylinder and cortex improved the relationship between attack and yield, but damage to the cortex by itself showed a much weaker relationship with bunch weight than damage to the central cylinder.

Damage to the corm periphery showed inconsistent relationships with reductions in plant size and yield. Of the two damage peripheral damage parameters, PD provided a much better predictor than PCI. Although we did measure the widely used CI of Vilardebo (1973), we believe that it is likely to perform somewhere between PCI (a grid) and PD (an estimate of surface area damaged)

Moreover, damage to the corm periphery tended to show only weak to modest relationships with damage to the corm interior. For example, trial-wise correlations for PD and XI of r=0.6 and 0.66 clearly show a relationship between these two parameters, they are not strong enough for PD to give an accurate prediction of damage to the central cylinder. This suggests that assessment methods measuring corm surface damage, though easier to employ, are neither good predictors of more important damage indicators nor good direct estimators of yield loss. We therefore conclude that damage estimates on the corm periphery are not utile parameters for assessing pest status.

Our study indicates that internal damage revealed in cross sections is the most important. Further work can be done to determine if our own means of estimating cross section damage are the most precise and most accurate means of estimating this damage. Like all other assessment methods, these are somewhat subjective and also suffer from a compressed score (reported damage levels are often less than 10%).

Acknowledgement

This research was funded by grants from the Rockefeller Foundation to IITA.

References

Gold, C.S., Kagezi, G.H., Night, G. and Ragama, P.E., 2004. The effects of banana weevil, *Cosmopolites sordidus* (Germar), damage on highland banana growth, yield and stand duration in Uganda. *Annals of Applied Biology*: In press.

Gold, C.S., Karamura, E.B., Kiggundu, A., Bagamba, F. and Abera, A.M.K., 1999. Geographic shifts in highland cook ing banana (*Musa* spp., group AAA-EA) production in Uganda. *International Journal of Sustainable Develop ment and World Ecology*, 6: 45-59.

Gold, C.S., Speijer, P.R., Karamura, E.B. and Rukazambuga, N.D. 1994a. Assessment of banana weevils in East African highland banana systems and strategies for control. In: R.V. Valmayor, R.G. Davide, J.M. Stanton, N.L. Treverrow and V.N. Roa (Editors) *Proceedings of Banana Nematode/Borer Weevil Conference. Kuala Lumpur, 18-22 April 1994*, Los Banos, Philippines, pp 170-190.

Gold, C.S., Speijer, P.R., Karamura, E.B., Tushemereirwe, W.K. and Kashaija, I.N., 1994b. Survey methodologies for pest and disease assessment in Uganda. *African Crop Science Journal*, 2, 309-321.

Mestre, J., 1997. Les recherches recentes sur le charancon des bananiers, *Cosmopolites sordidus* (Germar, 1824) (Coleoptera: Curculionidae). *Fruits*, 52, 67-82.

Mitchell, G. 1980. *Banana Entomology in the Windward Islands. Final Report 1974-1978*. Windward Island Banana Growers Association (WINBAN), St. Lucia. 216 pp.

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*, 17, 581-589.

SAS Institute., 1990. SAS/STAT Users guide, Version 6, 4th Edition Vol 2. Cary, CN, USA. 895 pp.

Vilardebo, A**.**, 1973. Le coefficient d'infestation, critere d'evaluation du degre d'attaques des bananeraies par *Cosmopolites sordidus* Germ. le charancon noir du bananier. *Fruits*, 28, 417-431.