Crop Losses Caused by Maize Stem Borers (Lepidoptera: Noctuidae, Pyralidae) in Côte d'Ivoire, Africa: Statistical Model Based on Damage Assessment During the Production Cycle

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J. Econ. Entomol. 91(2): 512–516 (1998)

ABSTRACT Eight insecticide experiments were conducted in 7 localities of Côte d'Ivoire to study the feasibility of developing a reliable model of crop losses of maize caused by stem borers based on damage assessment during the growing cycle. The observed damage was the percentage of tunneled internodes and the percentage of dead-hearts 80 d after seedling emergence. Five trials were used to fit the model; the remaining 3 were used to validate it. Sampling throughout the growing cycle revealed that only 2 borer species were involved: *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Dead-hearts were mainly caused by the 1st species, whereas the tunneled internodes resulted from the presence of both pests. The model, which is aimed at estimating crop losses after damage has occurred, explained 81% of the variation in yield. The validation study showed that the model enabled a prediction of yield within a range of approximately ±10% at different localities and under different infestation conditions.

KEY WORDS maize borers, crop loss, damage, statistical model, west Africa

MAIZE, *Zea mays* (L.), is damaged by 5 lepidopteran stem borers in Côte d'Ivoire: *Sesamia calamistis* Hampson (Noctuidae), *Sesamia botanephaga* Tams & Bowden (Noctuidae), *Chilo aleniellus* (Strand) (Pyralidae), *Busseola fusca* (Fuller) (Noctuidae), and *Eldana saccharina* Walker (Pyralidae) (Pollet et al. 1978, Dabiré 1980, Odjo 1984, Moyal and Tran 1992). Of these, only the latter 2 species are major pests, that cause heavy crop losses (Moyal 1996). *B. fusca,* which is primarily restricted to the forest area (Fig. 1) (Moyal 1988), attacks maize during the 1st part of the growing cycle, before male flowering. *E. saccharina,* which attacks maize in the whole of Côte d'Ivoire, is primarily injurious in the central and eastern regions of the country (Moyal 1988). Generally, this pest attacks maize during the 2nd part of the growing cycle (from the beginning of grain filling), but in some rare instances it is found attacking maize shortly after seedling emergence.

The influence of *B. fusca* on maize yield was studied in eastern and southern Africa as well as in western Africa, in Nigeria (Walker 1960, Usua 1968, Van Rensburg et al. 1988a–c, Assefa et al. 1989). Studies on the effect of *E. saccharina* on maize yield have also been carried out in Nigeria (Bosque-Pérez and Mareck 1991). In Côte d'Ivoire, Moyal (1996) developed a model of crop losses of maize caused by these 2 pests based on the number of borers per stem estimated several times throughout the production cycle. The purpose of our study was to examine the feasibility of developing a reliable model for predicting regional crop losses after borer attack has occurred, based on a single damage assessment (percentage of tunneled internodes and of dead-hearts) 80 d after seedling emergence.

Materials and Methods

Experimental Designs. Five insecticide trials were conducted in the southern savanna and in the northern forest areas of Côte d'Ivoire, west Africa: 2 experiments in 1984 (Gohitafla and Beoumi) (Fig. 1), 1 in 1987 (Man), and 2 in 1988 (Bongouanou and Guessabo). Plots were arranged either in split-plot (in 1984) or in randomized complete-block designs (the other trials). The number of replicates ranged from 4 to 7, depending on the trials. In the split-plot experiments, the 1st factor was maize variety (2 levels): the 1st variety was 'Composite Jaune de Bouaké', a 100-d growth cycle composite that is the most commonly used variety in Côte d'Ivoire (CIDT 1984). It produces male flowers between 45 and 50 d after emergence and yields at best 6,200 kg/ha (Idessa 1982). This variety was the one used in the other trials as well. The 2nd variety used in the split-plots was 'Ferké 7526', which has a growing season ≈10 d shorter and a potential yield of 6,700 kg/ha. The 2nd factor, insecticide treatments, consisted of no protection at all (control), complete protection throughout the growing season (plots sprayed every 10 or 14 d), protection either only during the 1st part of the growing season or only during the 2nd part. Various insecticides were applied at different doses and timing. Some treatments were present in all the trials: control, systematic spray every 10 d with deltamethrin 12 g (AI)/ha, and deltamethrin 15 g (AI)/ha 20 and 40 d after seedling emergence.

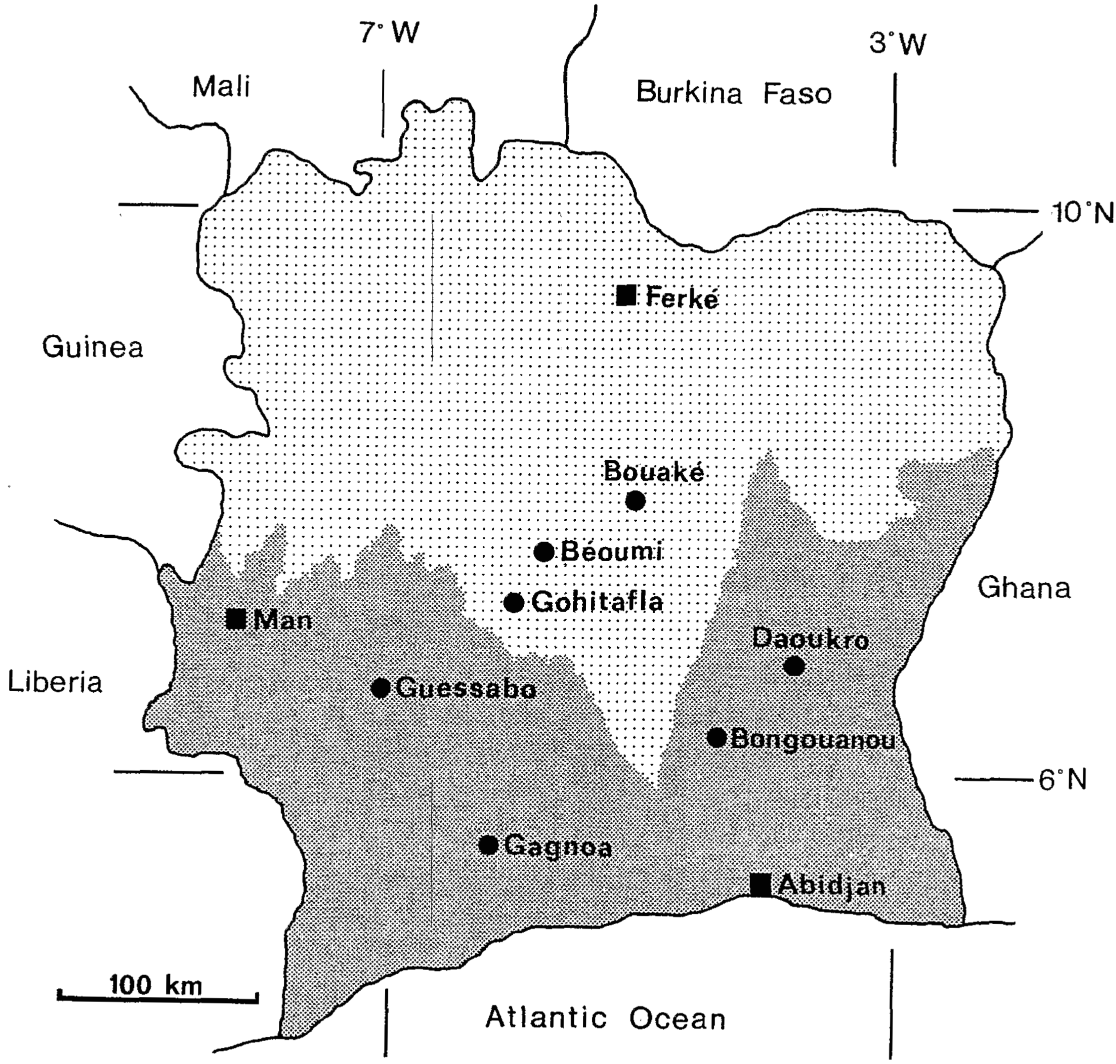

Fig. 1. Location of study sites (black circles) in the forest (shaded area) and the savanna (stippled area) regions of Côte d'Ivoire.

The other treatments aimed at controlling pests either before male flowering (spraying emulsifiable concentrate or application of granulates in the whorl at 20 and 40 d after seedling emergence with organophosphates [phoxim 333 or 500 g (AI)/ha], carbamates [carbofuran 200 g (AI)/ha, endosulfan 1,250 g (AI)/ha]) or after male flowering (spraying deltamethrin 15 g (AI)/ha either at 40 and 60 d after seedling emergence or at 60 and 75 d after seedling emergence). Fertilizer was applied at 300 kg N:P:K (10:18:18) per hectare before sowing and 75 kg urea per hectare at the beginning of male flowering. In each experiment, plots were 25 m long and 4 m wide. Five rows of maize were planted in each plot (0.80 m between rows, 0.20 m between plants in each row [i.e., 62,500 plants per hectare]). No water stress was observed in the experiments. Between 25 and 85 d after emergence, rainfall exceeded 300 mm, which is needed in Côte d'Ivoire to ensure effective availability of fertilizer by the maize varieties used (Chabalier 1985).

Two different ways of estimating borer damage 80 d after seedling emergence were used. First, a visual estimation of the number of plants with dead-hearts in each plot was done on the central row, which was afterward used to estimate yield. Second, the percentage of tunneled internodes was assessed through dissection of 5 plants per plot, which were sampled at random from the 2 rows on each side of the central row. The same sampling methods were used more frequently (every 20 d) to monitor borer populations so that it was possible to relate the observed damage to borer species and abundance. This fairly low sample size (2%) was chosen to prevent a too large reduction in plant density, which could have changed the attractiveness of the crop to the pest and the relationship between damage and yield (Moyal 1995a).

The central 20 m of the middle row in each plot were harvested. Cobs were dried and shelled, and the weight of the grain yield was estimated. Grain moisture content after drying, measured with a multigrain moisture tester (Dickey-John, Auburn, IL), was ≈17.0% and it was adjusted in the analyses to a common moisture of 15.5%.

Statistical Analyses. A statistical model of crop losses of maize was developed using 2 different kinds of regressors: factors (block, locality, variety) and the variables (percentage of dead-hearts and of tunneled internodes observed 80 d after seedling emergence). The coding of the factor effects used the Helmert contrasts (Chambers and Hastie 1992), which contrast the 2nd level with the 1st, then the 3rd with the average of the 1st and 2nd, and so on. For instance, the 1st indicator variable for the location factor, L1, has the value −1 for the 1st location (Bongouanou), 1 for the 2nd location (Gohitafla), and 0 for the other locations. The 2nd indicator variable, L2 has the values −1, −1, 2, 0, and 0 for the 5 locations, respectively. The order of the 5 locations was Bongouanou, Gohitafla, Guessabo, Man, and Béoumi. The 1st variety was 'CJB' (coding = −1), the 2nd 'Ferké 7526' (coding = 1), and the blocks were ordered from the one with the highest soil potential to the one with the lowest soil potential. These contrasts are chosen by default when coding factors with the software used to perform these analyses, S-plus (release 3.0) (Becker et al. 1988, Chambers and Hastie 1992). Plots of model residuals were constructed to ensure that the model assumptions (residual homoscedasticity and normality) were not violated (Chatterjee and Price 1977, Draper and Smith 1981).

Model Validation. A validation study was performed to test the applicability of the yield loss model. Three insecticide trials, which were not included in the regression analysis, were used. Two of them were laid out as randomized complete-block designs. The 1st was conducted in 1983 in Bouaké, in the savanna area (Fig. 1). It included 11 treatments replicated 5 times: a control (without any insecticide treatment), 8 treatments that consisted of application of pyrethroids (mainly deltamethrin) at different dosages and timing, 1 treatment with application of carbofuran, and 1 treatment with application of *Bacillus thuringiensis* Berliner. The 2nd was conducted in 1987 in Gagnoa, in the forest area (Fig. 1), and included 4 treatments replicated 8 times: a control and 3 treatments that consisted of application of deltamethrin at different dosages and timing. In both trials the agronomic features (plot size, variety, fertilizers) were the same as in the trials used in the regression analysis. The 3rd trial, which was conducted in Bongouanou in 1988, was planted 2 wk after the experiment used in the regression analysis. It included 2 plots (each 25 m long and 30 m wide): a control, and a treated plot (application of deltamethrin 4 times during the growing cycle, every 20 d). Borer damage and populations were recorded in the same way as in the experiments used in the regression analysis. These trials were selected for the validation study to keep the same procedure as in the study of the relationship between borer density and yield (Moyal 1996). Indeed, in that case, the study regarded the influence of borers not only on yield but also on yield components. Data on yield components were however not available for these 3 trials, which were then chosen to validate the yield loss model.

Results and Discussion

The experiments were conducted under high levels of natural infestation by borers in all localities but Man: The maximum percentage of tunneled internodes observed ranged from 28.8% in Guessabo to 76.2% in Béoumi, and the maximum percentage of dead-hearts from 7.7% in Béoumi to 32.3% in Bongouanou. In Man, no dead-hearts were observed and the percentage of tunneled internodes was only up to 6.6%. Damage were caused by *E. saccharina* only in Béoumi and Man, and by both species *E. saccharina*

Table 1. Results of the ANOVA of yield for different localities, varieties, blocks, and damage levels

Factor	Degrees of freedom	Sum of squares	Mean squares	*F* value	*P*(*F*)
Locality	4	115,106,639	28,776,660	106.41	0.0000
Variety	1	6,491,350	6,491,350	24.00	0.0000
Block	7	10,939,272	1,562,753	5.78	0.0000
TIN[a]	1	33,463,036	33,463,036	123.74	0.0000
DH[b]	1	15,642,254	15,642,254	57.84	0.0000
Locality * TIN[c]	4	2,432,747	608,187	2.25	0.0671
Variety * TIN[c]	1	475,394	475,394	1.76	0.1871
Block * TIN[c]	7	2,005,712	286,530	1.06	0.3931
Locality * DH[c]	3	543,437	181,146	0.67	0.5720
Variety * DH[c]	1	219,888	219,888	0.81	0.3688
Block * DH[c]	7	1,652,141	236,020	0.87	0.5299
Residuals	134	36,236,505	270,422		

[a] Tunneled internodes.
[b] Dead-hearts.
[c] Interaction between both factors.

Table 2. Regression analysis of yield on locality, block, variety, and damage

Explanatory variable	Coefficient	$P(>\|t\|)$[a]
Constant	3708.0	0.0000
L1[b]	−542.9	0.0000
L2[b]	−184.8	0.0001
L3[b]	260.2	0.0000
L4[b]	−186.5	0.0000
BL1[c]	−61.7	0.3487
BL2[c]	−64.4	0.0969
BL3[c]	−112.9	0.0001
BL4[c]	−31.29	0.2438
BL5[c]	−42.7	0.1635
BL6[c]	−41.3	0.1098
BL7[c]	−39.3	0.1742
V[d]	362.4	0.0000
TIN[e]	−23.55	0.0000
DH[f]	−65.82	0.0000
Multiple R^2	0.807	
Residual standard error	526.8	
Degrees of freedom	157	

[a] Level of significance of the Student t-test.
[b] Locality dummy variables.
[c] Block dummy variable.
[d] Variety dummy variable.
[e] Percentage of tunneled internodes.
[f] Percentage of dead-hearts.

and *B. fusca* in the other sites. In Béoumi, attacks by *E. saccharina* commenced early (20 d after seedling emergence), in contrast with the other experiments where they started at the beginning of grain filling (50–60 d after seedling emergence), which is usually when the infestation of this pest begins.

The effect of all the variables and factors was significant but not the one of the interactions between variables and factors (Table 1). The fitted model is presented in Table 2. Dead-hearts were the main cause of crop losses, which agrees with the results of the study of the relationship between borer numbers and crop loss (Moyal 1996). This study showed indeed that the main crop losses were caused by early attacks of *B. fusca,* which result in dead-hearts. Early attacks by *E. saccharina,* as observed in Béoumi, produce few dead-hearts, because this species usually enters the stem in the lower internodes (Moyal 1995b). *B. fusca* larvae, in contrast, feed on the leaves of the whorl during the first 4 instars and then enter the stem (Van Rensburg et al. 1987) where they feed in the upper part. This often results when attacks occur early in injury to the growing point, producing dead-hearts.

Because crops suffered no water stress in the experiments, the location and block effects resulted primarily from differences in soil potential. Thus, potential yields are low in 3 localities, Guessabo (3,170 kg/ha), Gohitafla (3,150 kg/ha), and Béoumi (3,000 kg/ha) and high in the other 2, Bongouanou (4,270 kg/ha) and Man (4,670 kg/ha). Usually, savanna soils have lower potentials than forest ones. The case of Guessabo, a forest locality, is rather peculiar, because the land had just been reclaimed from a forest. The models for the first 3 localities enable prediction of yield in savannah localities, whereas the latter 2 can be used for prediction in forest localities.

The validation study (Table 3) was performed using the model fitted for Guessabo to predict yield in Bouaké, which is a savanna locality where potential yields are low. The model fitted for Man was used to predict yield in Gagnoa, a forest locality and the model fitted for Bongouanou was used to predict yield in this locality. One prediction per treatment was performed. A confidence interval for the observed yield is presented for Bouaké and Gagnoa because there were replications in the experiments. Both *B. fusca* and *E. saccharina* were present in Gagnoa and Bongouanou and the latter species only was found in Bouaké. In Gagnoa, all the observed yields fell within the prediction intervals. In Bouaké, where the variation within treatments was higher than in Gagnoa, 9 observed yields out of 11 lie within the prediction intervals. In Bongouanou, the predicted yield of the plot sprayed with insecticides (the less damaged) is underesti-

Table 3. Observed and predicted yields for 3 insecticide trials at 3 locations, 1983–1988

Site	% tunneled internodes	% deadhearts	Observed yield mean (kg/ha)	Confidence interval[a] (P = 0.05)	Predicted yield (kg/ha)	Prediction interval (P = 0.05)
Bouaké (1983)	1.18	0	3,470	2,995–3,945	3,145	2,873–3,417
	4.64	0	3,352	2,589–4,115	3,063	2,791–3,335
	10.14	6.0	2,414	2,041–2,787	2,539	2,266–2,812
	7.01	4.0	2,727	2,129–3,325	2,744	2,475–3,013
	4.62	0	3,124	2,653–3,595	3,064	2,792–3,336
	4.46	0	3,157	2,665–3,649	3,067	2,795–3,339
	5.36	4.0	2,651	2,360–2,942	2,783	2,513–3,053
	5.44	4.0	2,793	2,522–3,064	2,781	2,511–3,051
	4.32	4.0	2,773	2,344–3,202	2,807	2,536–3,078
	1.44	0	3,048	2,718–3,378	3,139	2,875–3,413
	10.74	8.0	2,216	2,011–2,411	2,393	2,112–2,674
Gagnoa (1987)	31.09	5.8	3,063	2,703–3,423	3,301	2,977–3,625
	11.26	2.5	4,055	3,760–4,350	3,986	3,707–4,265
	15.25	1.6	4,034	3,749–4,320	3,949	3,667–4,231
	20.86	2.5	3,840	3,564–4,116	3,759	3,467–4,051
Bongouanou (1988)	34.20	9.5	2,583	—	2,585	2,309–2,860
	7.70	1.3	4,431	—	3,746	3,415–4,077

[a] A confidence interval is indicated for the yield of the observed treatment when this yield is the mean of several replications.

mated in comparison with the observed yield. In this experiment there were no replications and yield estimation was then less reliable than in the others. Thus, 14 observed yields out of 17 (82.4%) fell within the prediction intervals on the whole, which shows that prediction of crop losses is reliable in most cases. The model reliability was confirmed by a regression of the observed yield versus the predicted yield. The slope (1.21) was not significantly different from 1.0 ($P = 0.06$) but was very close (low values of P mean a slope significantly different from 1.0), because of the presence of the very high yield observed in Bongouanou. If this datum, which can be considered as an outlier caused by an unusual high soil potential, is removed, then the slope is much close to 1.0 (slope = 1.11, $P = 0.17$).

When we compare the precision of the prediction from this model based on damage (Table 2) to that of the model based on borer numbers (Moyal 1996), it appears that the damage model is a little more accurate than the borer model: confidence intervals fall within ±7.0 and ±11.7% versus ±10.9 and ±14.5%, respectively. This may be due to the fact that only the old instars of 2 borer species were significant in the borer–yield relationship study, although some other borers or instars, present but not at a high density, caused injuries that were taken into account in the damage model. The latter model is then more accurate for a prediction of yield after the damage has occurred, whereas the borer model has to be used to predict the crop loss before damage has occurred and to determine if control measures are needed.

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Received for publication 8 May 1997; accepted 30 September 1997.