Statistical Model of Crop Losses Caused by Maize Stem Borers (Lepidoptera: Noctuidae, Pyralidae) in Côte d'Ivoire

PASCAL MOYAL

ORSTOM, B.P. 1434, Bouaké, Côte d'Ivoire

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ABSTRACT Six experiments were conducted in the savanna and forest areas of Côte d'Ivoire to study the influence of stem borers on maize crop yield components and production. Statistical models showed the effect of the oldest preimaginal instars of 2 stem borers, *Eldana saccharina* Walker (Pyralidae) and *Busseola fusca* (Fuller) (Noctuidae). Plant destruction was mainly caused by early attack of *B. fusca*. Attack by both borers on or about the 60th d after emergence induced plant sterility. Stem borers had no direct effect on number of grains per cob-carrying plant: the level of this yield component was set according to the level of the previously determined components through a compensation phenomenon. The last yield component, average weight of grain, decreased with attack by *E. saccharina* occurring on or about the 80th d after emergence. Effects of borer aggregation, maize variety, and maize streak virus incidence were studied. The statistical model of crop loss, which explains 81.7% of the variation in yield, was validated from the results of 3 trials that were not included in the regression analysis. It enables one to estimate accurately crop losses in most of Côte d'Ivoire with only 2 samplings during the growing season, on the 40th and 80th d after emergence.

KEY WORDS maize borers, crop loss, statistical model, West Africa

CROP LOSSES OF MAIZE, *Zea mays* (L.), in Côte d'Ivoire are mainly caused by borers and by maize streak virus (Moyal 1988a). Seven species of borers, all Lepidoptera, are known to attack maize (Moyal and Tran 1992). Two of them, mainly stem borers, are dominant: *Eldana saccharina* Walker (Pyralidae), which generally begins attack from 50–60 d after emergence; and *Busseola fusca* (Fuller) (Noctuidae), a species that lays its eggs on maize between 20 and 40 d after emergence. These 2 species, which are restricted to Africa (Usua 1977, Betbeder-Matibet 1983), are major pests of maize in most countries south of the Sahara Desert.

Studies on yield reduction caused by attacks of *B. fusca* have been carried out in eastern and southern Africa (Walker 1960, Van Rensburg et al. 1988a–c, Assefa et al. 1989) as well as in western Africa, in Nigeria (Usua 1968). The only studies on the effect of *E. saccharina* on maize yield in Africa have also been carried out in Nigeria (Bosque-Pérez and Mareck 1991). In Côte d'Ivoire, the 1st study of the statistical relationship between borer attack and crop loss was performed based on the results of experiments conducted previously in the savanna area (Moyal 1988b). The aim of this study was to find a relationship applicable to both savanna and forest areas and to get a better insight into the processes by which crop loss occurs. The incidence of maize streak disease was also included in the model of crop loss. This disease, caused by a gemini-virus (Fauquet and Thouvenel 1987), is transmitted by leafhoppers belonging to the genus *Cicadulina* (Homoptera: Cicadellidae). It infects many graminaceous plants (Soto et al. 1982, Damsteegt 1983) in African countries south of the Sahara Desert, in Egypt, in islands of the Indian Ocean, and in India (Guthrie 1976, Soto et al. 1982, Fajemisin et al. 1984). Important epidemics have been reported recently in western Africa: in 1971 in Bénin and Nigeria (Le Conte 1974, Fajemisin et al. 1984) and in 1983 in Côte d'Ivoire, Mali, Burkina Faso, and northern Nigeria (Keyser 1983, Sere and Diémé 1986, Moyal 1988a). In Côte d'Ivoire, when no outbreak occurs, the disease incidence is low during the 1st part of the year and increases throughout the year up to very high levels at the beginning of the dry season (November–December) (Moyal 1991).

Materials and Methods

Experimental Designs. Six insecticide trials were conducted in the southern savanna and in the northern forest areas of Côte d'Ivoire: 3 experiments in 1984, 2 in 1988, and 1 in 1989 (Fig. 1; Table 1). Plots were arranged either in split-plot or in randomized complete-block designs. The 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 insecti-

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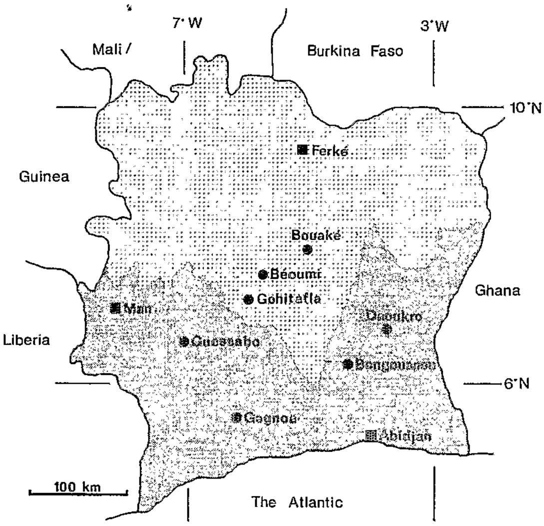

Fig. 1. Map of Côte d'Ivoire showing experimental localities (black circles), the forest region (shaded area), and the savanna region (stippled area).

cides were used, as follows: carbamates, organophosphates, and pyrethroids (Table 1). The main variety of maize used 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). Another variety, 'Ferké 7526', with a growing season ≈10 d shorter and a potential yield of 6,700 kg/ha, was also used in the split-plot experiments. Fertilizing of the soil was done with 300 kg N:P:K (10:18:18) per hectare before sowing and 75 kg urea per hectare at the beginning of male flowering. At each location, rainfall was abundant and no water stress was observed.

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 [62,500 plants per hectare]). To estimate borer populations, 5 plants were sampled at random from the 2 rows on each side of the central row in each plot 5 times during the growing season (every 20 d). These plants were dissected and the borer numbers, species, and stages were recorded for each plant. Two yield components were also estimated from the plants of the last sample before harvest (100 d after emergence): the grain number per cob-carrying plant and the average weight of grain. At harvest, the other 2 yield components were estimated from the plants of the central row in each plot: the percentage of harvested plants (number of plants at harvest * 100/number of plants at seedling emergence) and the percentage of cob-carrying plants (number of cob-carrying plants at harvest * 100/number of harvested plants). Yields were estimated from the production of the central 20 m of the center row in each plot.

Table 1. Features of the experiments

Locality, year, and design	Factors
Daoukro, 1984, split-plot 4 replications	1st factor: variety, 2 levels 1: CJB; 2: Ferké 7526 2nd factor: insecticide treatment, 6 levels 1: No treatment 2: Deltamethrin, 12 g (AI)/ha every 10 d, emulsifiable concentrate 3: Cypermethrin, 12 g (AI)/ha 20 and 40 d after emergence, granulates 4: Phoxim, 250 g (AI)/ha 20 and 40 d after emergence, granulates 5: Chlorpyriphos-ethyl, 120 g (AI)/ha 20 and 40 d after emergence, granulates 6: Deltamethrin, 15 g (AI)/ha 20 and 40 d after emergence, emulsifiable concentrate
Gohitafla, 1984, split-plot 4 replications	1st factor: variety, 2 levels 1: CJB; 2: Ferké 7526 2nd factor: insecticide treatment, 6 levels 1: No treatment 2: Deltamethrin, 12 g (AI)/ha every 10 d, emulsifiable concentrate 3: Deltamethrin, 15 g (AI)/ha 60 and 75 d after emergence, emulsifiable concentrate 4: Phoxim, 500 g (AI)/ha and 330 g (AI)/ha, respectively, at 20 and 40 d after emergence, granulates 5: Carbofuran, 200 g (AI)/ha 20 and 40 d after emergence, granulates 6: Deltamethrin, 15 g (AI)/ha 20 and 40 d after emergence, emulsifiable concentrate
Béoumi, 1984, randomized complete-blocks 8 replications	Insecticide treatment, 6 levels 1: No treatment 2: Deltamethrin, 12 g (AI)/ha every 10 d, emulsifiable concentrate 3: Endosulfan, 1,250 g (AI)/ha 20 and 40 d after emergence, emulsifiable concentrate 4: Endosulfan, 1,250 g (AI)/ha 20 and 40 d after emergence, granulates 5: Phoxim, 333 g (AI)/ha 20 and 40 d after emergence, granulates 6: Deltamethrin, 15 g (AI)/ha 20 and 40 d after emergence, emulsifiable concentrate
Bongouanou, and Guessabo 1988, randomized complete-blocks 5 replications	Insecticide treatment, 5 levels 1: No treatment 2: Deltamethrin, 12 g (AI)/ha every 10 d, emulsifiable concentrate 3: Deltamethrin, 15 g (AI)/ha 35 d after emergence, emulsifiable concentrate 4: Deltamethrin, 15 g (AI)/ha 20 and 40 d after emergence, emulsifiable concentrate 5: Deltamethrin, 15 g (AI)/ha 40 and 60 d after emergence, emulsifiable concentrate
Daoukro, 1989, randomized complete-blocks 5 replications	Insecticide treatment, 4 levels 1: Deltamethrin, 15 g (AI)/ha 20 and 40 d after emergence, emulsifiable concentrate 2: Deltamethrin, 15 g (AI)/ha every 14 d, emulsifiable concentrate 3: Carbosulfan, 300 g (AI)/ha every 14 d, emulsifiable concentrate 4: Bifenthrin, 25 g (AI)/ha every 14 d, emulsifiable concentrate

Table 2. Set of contrasts for location and variety (coding by Helmert contrasts)

	Locality				Variety V	
	L1	L2	L3	L4		
Daoukro (2 joined years)	−1	−1	−1	−1	CJB	−1
Bongouanou	1	−1	−1	−1	Ferké 7526	1
Gohitafla	0	2	−1	−1		
Guessabo	0	0	3	−1		
Béoumi	0	0	0	4		

CJB, Composite Jaune de Bouaké.

Grain moisture content, measured with a multigrain moisture tester (Dickey-John, Auburn, IL), was ≈17.0%.

Statistical Analyses. The aim of this study was not only to develop a model of crop losses caused by maize borers, but also to understand the way these insects reduce yield. Hence, in the 1st step, borer effect on each yield component was studied. Then, the regressors selected in the analyses of the yield components were used in the yield loss model. The regressors used included factors (location, block, and variety) and variables. These included borer population mean and dispersion among plants. The latter was measured by the standard error calculated from the insect numbers in each of the 5 plants sampled in each plot. For each regression, residual homoscedasticity and normality were checked by a graphical study (Chatterjee and Price 1977, Draper and Smith 1981). A square-root transformation was needed to stabilize the residual variance in the yield analysis. The coding of the factor effects used the Helmert contrasts, which contrast the 2nd level with the 1st, then the 3rd with the average of the 1st and 2nd, and so on (Table 2). These contrasts are chosen by default when coding the factors with the software used to perform these analyses, S-plus (release 3.0) (Becker et al. 1988, Chambers and Hastie 1992).

Table 3. Results of the analyses of the first 2 yield components

Explanatory variable	No. of harvested plants/no. of emerged plants[a]		No. of cob-carrying harvested plants/ no. of harvested plants[a]	
Constant	1.1260	0.0000	1.0739	0.0000
L1[b]	0.0279	0.1571	0.2700	0.0000
L2[b]	0.0516	0.0000	0.0991	0.0000
L3[b]	−0.0189	0.0141	−0.0062	0.4104
L4[b]	0.0573	0.0000	−0.0320	0.0000
LB40[c]	−0.4902	0.0000		
sLB40[d]	0.0381	0.5705		
LE80[e]	−0.0243	0.0000	−0.0273	0.0000
LB40:sLB40[f]	0.1206	0.0000		
LB80[g]			−0.0856	0.0000
Multiple R^2	0.6583		0.8712	
Residual standard error	0.1278		0.1275	

[a] Arcsine transformation, coefficient P (>|t|).
[b] Locality dummy variables.
[c] Large *B. fusca* (from the 4th instar) 40 d after emergence.
[d] Standard error of the distribution of the LB40.
[e] Large *E. saccharina* (from the 4th instar) 80 d after emergence.
[f] Interaction (=product) between these 2 variables.
[g] Large *B. fusca* (from the 4th instar) 80 d after emergence.

Yield Components. The statistical study was performed as follows. First, analyses (correlations, regressions, charts) were performed for each location, resulting in sets of explanatory variables and factors to be included in the further analyses combining all the locations. The block effect was found to be not significant in these analyses and so was not used in the analyses hereafter mentioned. Second, regression analyses including all the localities were performed. They involved 3 steps. The 1st step consisted of analyzing the effect of total insect populations on each sampling date and the effect of the possible interactions of locality with the number of insects, of variety with the number of insects, and so on. This enabled selection of the most important dates of attack (40 and 80 d after emergence) and removal of the interactions that had no significant effect. The 2nd step consisted of including, for the selected dates, the insect species and developmental instars (arranged into 2 classes: [1] instars younger than the 4th instar, [2] older instars and pupae): it showed that only 2 borer species, *B. fusca* and *E. saccharina,* had sufficiently high population levels to influence significantly the response variables and that, of the developmental instars of these species, only the oldest had significant effects. In the final step, insect dispersion and the interaction of this variable with the previously selected explanatory variables were included. The final regression equations were kept to this precision level of the developmental instars to get models suitable for most kinds of attacks. However, studies with more accurately determined developmental instars were carried out to get a better insight into the borer effect on yield components.

Yield. The regressors selected in the yield component study were used, and 2 additional predictors were introduced: maize variety (as a factor), which had no influence on the yield components, and maize streak virus incidence on the 60th day after emergence.

Model Validation. A validation study of the yield loss model was performed to test its applicability. Three insecticide trials, which were not included in the statistical analysis, were used. Two

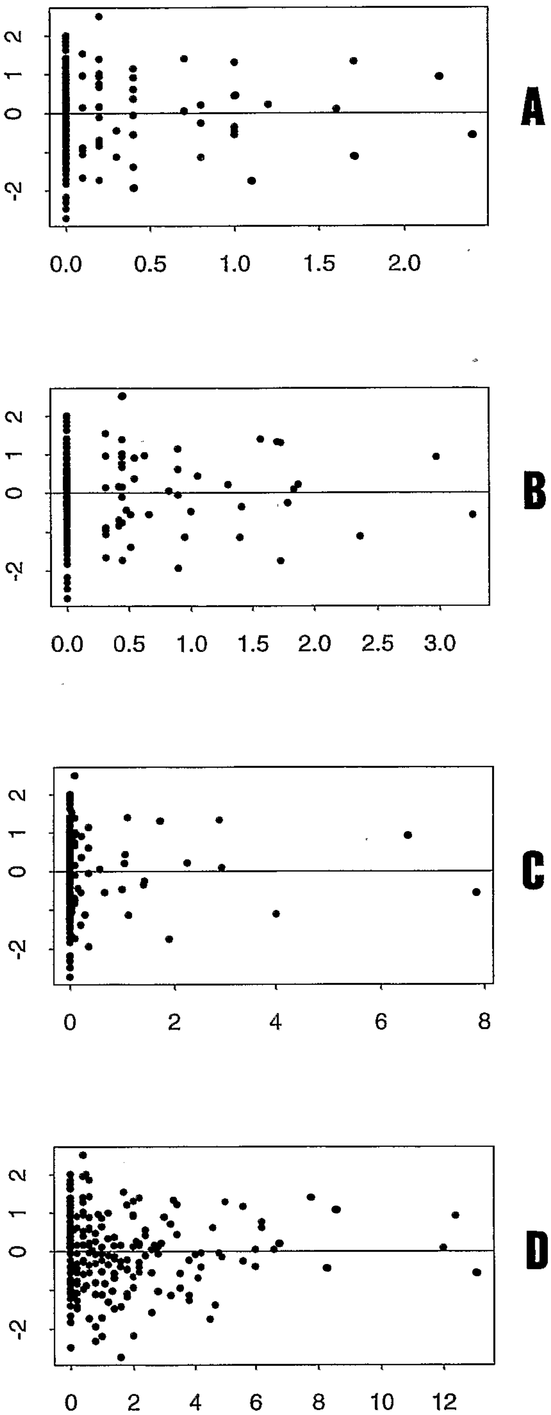

Fig. 2. Percentage of harvested plants: residual study. (A–E) Standardized residuals versus: (A) larvae older than the 3rd instar and pupae of *B. fusca* 40 d after emergence (V1); (B) standard deviation of V1 (V2); (C) V1 * V2; (D) larvae older than the 3rd instar and pupae of *E. saccharina* 80 d after emergence; (E) fitted percentage of harvested plants upon 100; (F) residuals versus quantiles of standard normal.

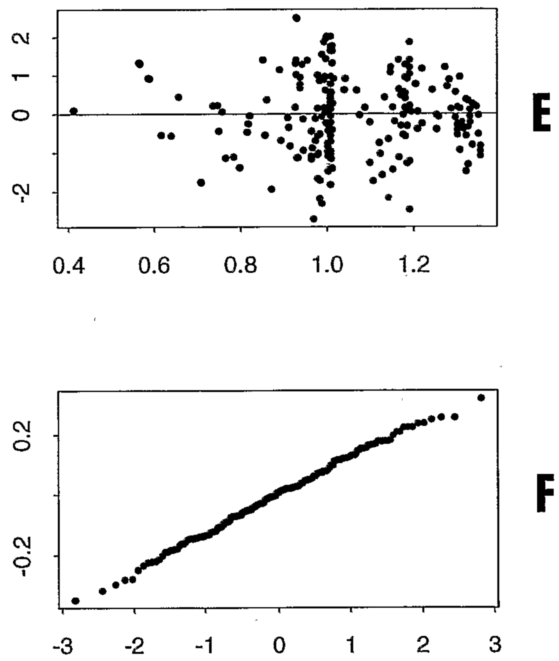

Fig. 2. Continued.

of them were laid out as randomized complete-block designs: the 1st was conducted in 1983 in Bouaké, in the savanna area (Fig. 1), and the other in 1987 in Gagnoa, in the forest area (Fig. 1). The 3rd trial consisted of the comparison of 2 fields, the 1st receiving no insecticide treatment, and the 2nd receiving 4 insecticide treatments throughout the growing season. This trial was conducted in 1988 in Bongouanou and was planted 2 wk after the trial that was used in the statistical analysis.

Results and Discussion

Tables 3–8 present the equations of the final models. Insect numbers were entered as numbers per maize stem. The column "$P(>|t|)$" gives the level of significance of the Student t-test. Figs. 2–5 show that the model residuals have constant variance and are distributed according to the normal distribution.

Yield Components. Plant destruction during the growing season was caused mainly by early attacks of *B. fusca*, which resulted from oviposition occurring before the 25th day after emergence (*LB40*, Table 3). The coefficient of the significant interaction between *LB40* and *sLB40* is positive, which means that these attacks produced more dead-hearts (destruction of the growing point) as the insects were more widely spread. This can be explained by the fact that very few larvae of *B. fusca* are needed to destroy young maize plants (Usua 1968, Brénière 1971). This 1st yield component was also decreased by the earliest attacks of *E. saccharina* (*LE80*, Table 3). A more detailed

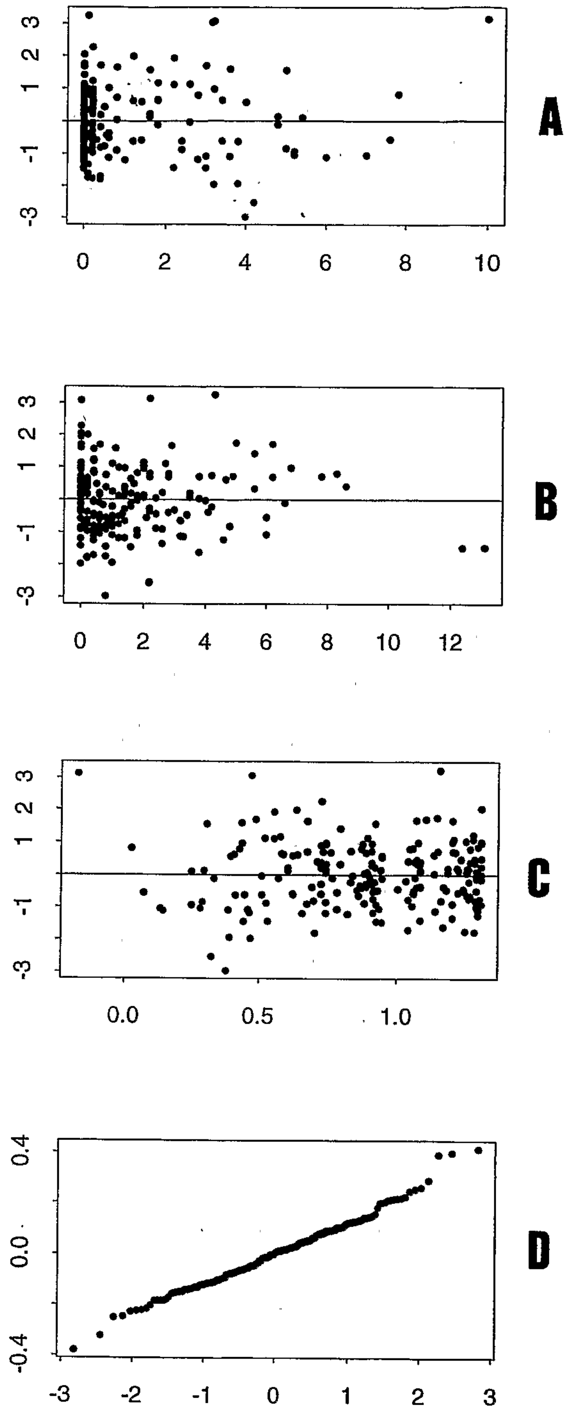

Fig. 3. Percentage of cob-carrying plants: residual study. (A–C) Standardized residuals versus: (A) larvae older than the 3rd instar and pupae of *B. fusca* 80 d after emergence; (B) larvae older than the 3rd instar and pupae of *E. saccharina* 80 d after emergence; (C) fitted percentage of cob-carrying plants upon 100; (D) residuals versus quantiles of standard normal.

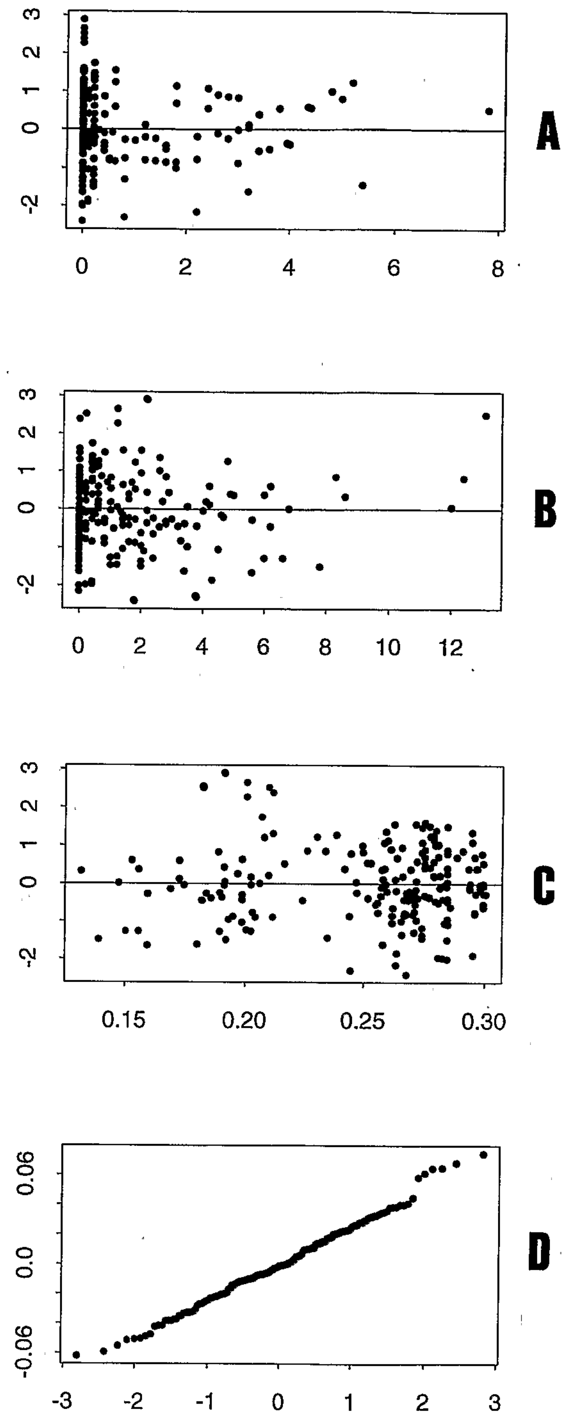

Fig. 4. Average weight of grain: residual study. (A–C) Standardized residuals versus: (A) larvae older than the 3rd instar and pupae of *B. fusca* 80 d after emergence; (B) larvae older than the 3rd instar and pupae of *E. saccharina* 80 d after emergence; (C) fitted average weight of grain; (D) residuals versus quantiles of standard normal.

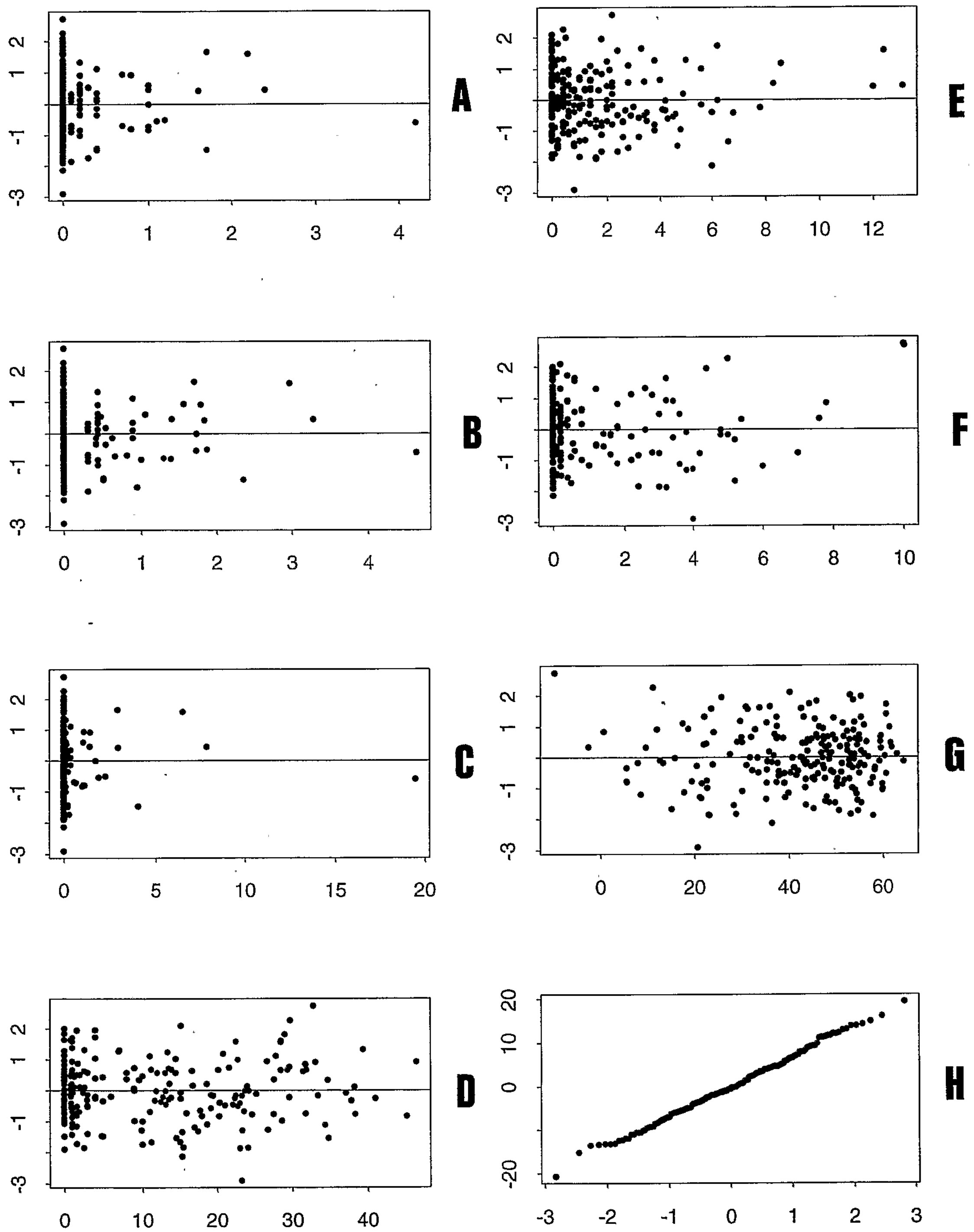

Fig. 5. Yield: residual study. (A–E) Standardized residuals versus: (A) larvae older than the 3rd instar and pupae of *B. fusca* 40 d after emergence (V1); (B) standard deviation of V1 (V2); (C) V1 * V2; (D) incidence of maize streak virus 60 d after emergence; (E) larvae older than the 3rd instar and pupae of *E. saccharina* 80 d after emergence; (F) larvae older than the 3rd instar and pupae of *B. fusca* 80 d after emergence; (G) fitted yield (square root transformation); (H) residuals versus quantiles of standard normal.

Table 4. Correlation coefficients between the yield component "number of grains per cob-carrying plant" and the other yield components and yield (*P* value in parentheses)

Locality	Yield	% harvested plants	% cob-carrying plants	Avg wt of grain
Daoukro	0.12 (0.3297)	0.11 (0.3719)	−0.14 (0.1552)	0.22 (0.0733)
Bongouanou	−0.53 (0.0064)	−0.54 (0.0053)	−0.62 (0.0009)	−0.61 (0.0012)
Gohitafla	0.12 (0.4166)	0.16 (0.2773)	0.08 (0.5889)	0.25 (0.0868)
Guessabo	−0.07 (0.7395)	0.04 (0.8494)	−0.56 (0.0036)	−0.12 (0.5678)
Béoumi	−0.10 (0.4987)	0.06 (0.6854)	0.02 (0.8927)	−0.04 (0.7872)

study showed that only the pupae found 80 d after emergence had a significant effect, not so much by their number but by their aggregation: these borers had the greatest effect in plots where they were the most aggregated. It can be concluded from this that the effect of *E. saccharina,* which attacks rather late in the growing season, was particularly noticeable on plants already damaged by *B. fusca.*

The 2nd yield component, the percentage of cob-carrying plants at harvest, was reduced by the large borers sampled at 80 d after emergence. A more detailed study showed that both pupae and old instars of *B. fusca* and only pupae of *E. saccharina* decreased this yield component significantly. The main injuries that caused this reduction occurred then at ≈60–70 d after emergence, because of old instars that gave rise to the pupae sampled at 80 d after emergence. The dispersion rate of these insects had no effect on this component.

These studies showed that borers had no direct effect on the number of grains per cob-carrying plant. This 3rd yield component was, in most cases, correlated neither with yield (Table 4) nor with insect attacks, which were responsible for the main part of yield variation in these experiments. Sometimes, it was negatively correlated with yield, as for instance in Bongouanou where a compensation phenomenon was particularly noticeable (Table 4): in plots where many plants were destroyed, the remaining cob-carrying plants produced higher ear and grain numbers (in this locality, the correlation coefficient between the number of cobs per cob-carrying plant and the number of grains per cob-carrying plant equaled 0.95, with a *P* value of 0.0). A further compensation phenomenon occurred for the average weight of grain, which was lower in plants carrying higher grain numbers (Bongouanou, Table 4). The effect of borers on maize crops in these trials was thus quite different from that of water stress, which would have resulted in a reduction of the number of grains per plant (Claassen and Shaw 1970).

Table 5. Results of the analyses of the last yield component and the yield

Explanatory variable	Avg wt of grain, g[a]		Yield, kg/ha[a]	
Constant	0.2749	0.0000	56.9986	0.0000
L1[b]	0.0146	0.0009	10.7427	0.0000
L2[b]	−0.0018	0.3261	0.5511	0.3563
L3[b]	−0.0029	0.0586	−0.4372	0.3344
L4[b]	−0.0158	0.0000	−0.5221	0.1075
LB40[c]			−21.3672	0.0009
sLB40[d]			5.2438	0.1551
LE80[e]	−0.0093	0.0000	−2.1405	0.0000
LB80[f]	−0.0053	0.0086	−4.2060	0.0000
LB40:sLB40[g]			2.4088	0.0042
v[h]			2.2032	0.0427
STR60[i]			−0,3798	0.0000
v:STR60[j]			−0.1540	0.0050
Multiple R^2	0.7276		0.8165	
Residual standard error	0.0257		7.132	

[a] Coefficient P (>|*t*|).
[b] Locality dummy variables.
[c] Large *B. fusca* (from the 4th instar) 40 d after emergence.
[d] Standard error of the distribution of the LB40.
[e] Large *E. saccharina* (from the 4th instar) 80 d after emergence.
[f] Large *B. fusca* (from the 4th instar) 80 d after emergence.
[g] Interaction (=product) between LB40 and sLB40.
[h] Variety dummy variable.
[i] Maize streak virus incidence on the 60th d after emergence.
[j] Interaction (=product) between v and STR60.

The 4th yield component, the average weight of grain, was mainly decreased by the attacks of the oldest preimaginal instars of *E. saccharina* occurring 80 d after emergence, which prevented full grain filling (Table 5). The aggregation rate had no impact on this component.

Yield. To get a better fitting in the yield study, 2 additional variables were introduced: maize variety and maize streak virus incidence. In fact, only the maximum incidence of streak was introduced, and the dynamics of the epidemics, which may be rather variable (Moyal 1991), was not considered. The explanatory variables selected in the yield component study were also found to be significant when studying yield (Table 5). This can be explained by the wide range of borer attacks, which occurred at various times in the growing season and therefore decreased the different yield components more or less at each locality (Table 6). The model, which explains 81.7% of the variation in yield, shows the great effect of attacks by *B. fusca.* In the beginning of the growth cycle, the more these borers were dispersed, the more they reduced the stand density, and consequently yield: thus, when aggregation was minimum, yield reduction due to these attacks was 10 times as great as that due to late attacks by *E. saccharina* (Table 5). Moreover, yield reduction caused by late attacks by *B. fusca* was double that caused by attacks

Table 6. Correlation coefficients between yield and yield components (*P* value in parentheses)

Locality	% harvested plants	% cob-carrying plants	No. grains per cob-carrying plants	Avg wt of grain
Daoukro	0.47 (0.0001)	0.85 (0.0000)	0.12 (0.3297)	0.38 (0.0014)
Bongouanou	0.95 (0.0000)	0.57 (0.0029)	−0.53 (0.0064)	0.60 (0.0015)
Gohitafla	0.69 (0.0000)	0.39 (0.0061)	0.12 (0.4164)	0.46 (0.0010)
Guessabo	0.88 (0.0000)	0.21 (0.3137)	−0.07 (0.7395)	0.52 (0.0077)
Béoumi	0.11 (0.4565)	0.70 (0.0000)	−0.10 (0.4987)	0.75 (0.0000)

by *E. saccharina* occurring at the same time (Table 5).

Because crops suffered no water stress in the experiments, the location effect denotes in fact the soil potentialities: thus, yield estimation for Composite Jaune de Bouaké when no stem borer attack occurs is 4,350 kg/ha in Bongouanou and ≈3,000 kg/ha in Gohitafla, Beoumi, and Guessabo. The case in Daoukro, where the estimated yield is ≈2,000 kg/ha, is different and is a consequence of the combination of climatic conditions (low insolation and heavy rainfall) and termite infestation in many plots. The results in Daoukro are therefore peculiar to this locality, but it is possible to use the equations obtained from the other localities to estimate crop losses in most of Côte d'Ivoire. For instance, to estimate crop losses in a forest locality where the borer-free maize crop yield is considered to be ≈3,500 kg/ha, the mean of the models developed for the localities of Bongouanou and Guessabo can be used. In the savanna area, where less rich soils often yield ≈3,000 kg/ha, the mean of the equations for Gohitafla and Béoumi can be used.

Model Validation. Study of the confidence intervals computed for various rates of attack (Table 7) shows that accurate estimation of crop losses is generally possible. The worst estimations are observed in the case where very high attacks occur in the beginning of the growing season, perhaps because few instances of this type of attack occurred in the experiments.

Table 8 presents the results of the validation study. In Bouaké and Gagnoa, 1 prediction was performed for each treatment, and this is why a confidence interval for the observed yield is presented (this yield is the mean of the yields of 5 replications in Bouaké and 8 replications in Gagnoa). In Gagnoa and Bongouanou, attacks by both *B. fusca* and *E. saccharina* occurred, but in Bouaké, only *E. saccharina* was present. In Gagnoa and Bongouanou, all the observed yields lie in the prediction intervals. In Bouaké, where the variation within treatments was higher than in Gagnoa, 9 observed yields out of 11 lie in the prediction intervals. Thus, on the whole, 15 observed yields out of 17 (88.2%) lie in the prediction intervals. For the other 2 cases, confidence and prediction intervals overlap. It can be concluded from these tests that the model enables accurate maize yield loss prediction in the savanna and forest areas of Côte d'Ivoire, and likely also in the littoral area, where the main pest of maize is *E. saccharina* (Pollet et al. 1978).

In conclusion, these investigations showed that *B. fusca* was the most damaging pest in our trials. Early attacks by this species resulted in a reduction in the number of harvested plants, whereas later attacks resulted in an increase in plant sterility. The latter was also increased by early attacks by *E. saccharina,* but this species decreased maize yields mainly through a reduction in grain filling.

No effect of borers on the number of grains per cob-carrying plant was noticed, in contrast with what is observed when water stress occurs. Nevertheless, Godfrey et al. (1991) showed that the European corn borer, *Ostrinia nubilalis* Hübner (Lepidoptera: Pyralidae), influenced the maize

Table 7. 95% CI for some kinds of attacks

Attack features	B40[a]	E80[b]	B80[c]	Square root of yield	CI (±this value)	CI in% (±this value)
Low attacks throughout the growing season	0	1.0	0	59.16	3.4	5.7
High attacks throughout the growing season	2.4	13.1	0	22.41	6.59	29.4
Low attacks at the beginning of the growing season, high at the end	0	6.8	0	32.11	3.16	9.8
High attacks at the beginning of the growing season, low at the end	1.7	2.1	0.4	42.19	5.77	13.7

[a] Large *B. fusca* (from the 4th instar) 40 d after emergence.
[b] Large *E. saccharina* (from the 4th instar) 80 d after emergence.
[c] Large *B. fusca* (from the 4th instar) 80 d after emergence.

Table 8. Validation study of the yield loss model

Locality	Year	Observed yield mean[a]	Confidence interval ($P = 0.05$)	Predicted yield[a]	Prediction interval ($P = 0.05$)
Bouaké	1983	53.72	49.60–57.83	53.83	50.89–56.77
		57.46	51.24–63.69	53.62	50.68–56.56
		48.95	45.19–52.71	51.52	48.52–54.52
		51.45	45.88–57.01	52.64	49.70–55.58
		55.69	51.52–59.85	53.41	50.47–56.35
		55.97	51.64–60.31	53.62	50.68–56.56
		51.39	48.58–54.20	53.06	50.12–56.00
		52.77	50.23–55.31	52.89	49.95–55.83
		52.46	48.42–56.50	52.94	50.00–55.88
		55.10	52.08–58.12	53.96	51.02–56.90
		47.01	44.80–49.21	50.58	47.52–53.64
Gagnoa	1987	55.13	51.81–58.45	58.59	55.08–62.10
		63.59	61.22–65.95	64.49	60.41–68.57
		63.43	61.18–65.68	61.65	57.79–65.51
		61.89	59.66–64.11	60.80	57.00–64.60
Bongouanou	1988	47.43		48.53	45.00–52.06
		66.57		62.78	58.78–66.78

[a] Square-root transformation.

plant physiology in a way similar to that of water stress. This difference can be explained by the compensation phenomena occurring between the various yield components. Thus, in our trials, the 1st borer effects were reductions in the number of plants and cobs: these resulted in an increase in the number of grains per cob-carrying plant through a compensation phenomenon. No significant difference between pest-free and attacked plots was then noticeable for this component. This was confirmed by other studies (Moyal 1995), which showed that, when planting densities are low, borers have less influence on the plant and cob number and then reduce the grain number per plant.

From the results obtained, it becomes possible to answer the main questions leading from studies of crop losses caused by pests (Chiarappa 1981, Walker 1987). Thus, it is now possible to understand how yield components are decreased by maize borers, which are the main pests of maize not only in Côte d'Ivoire but also in all of West Africa (Atachi 1989, Bosque-Pérez and Mareck 1990, Gahukar 1990). Next, it is possible to get accurate estimations of crop losses with only 2 samplings during the growing season. Finally, the economic thresholds can now be determined for the 2 main maize borers in West Africa, *B. fusca* and *E. saccharina*.

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