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MAIZE COB-BORER ABUNDANCE AND INFLUENCE ON YIELD IN CÔTE D'IVOIRE

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Abstract—Studies were conducted in several ecological regions of Côte d'Ivoire from 1986 to 1990 to monitor maize cob-borer populations and to investigate losses in maize grain yield due to this pest. The relationship between borer abundance and crop losses was studied using regression analyses, in which two regression models were developed. One model related the yield loss per cob to the pest density and the other related the number of damaged grains to the pest density. *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) was the dominant pest in most localities. Its population density was particularly high in the semi-deciduous rain forest and decreased westwards and northwards. These models explained 85.6% (yield loss per cob vs pest density) and 72.5% (number of damaged grains vs pest density) of the observed variation. Moreover, they showed that the weight loss due to cob-borers was much lower than that due to stem borers and also that the number of damaged grains increased rapidly with borer density.

Key Words: maize cob-borers, West Africa, *Mussidia nigrivenella*, yield losses, statistical models

Résumé—Des études ont été réalisées en Côte d'Ivoire de 1986 à 1990 afin d'estimer les densités de population des foreurs de l'épi de maïs et de déterminer les pertes de récoltes occasionnées par ces ravageurs. La relation entre les densités des populations de foreurs et les pertes de récolte a été étudiée au moyen d'analyses de régression, dans lesquelles deux modéles de régression ont été développés. L'un des modèles a établi un rapport entre la perte de rendement par épi par rapport à la densité du ravageur et l'autre a établi un rapport entre le nombre de grains endommagés par rapport à la densité du ravageur. *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) fut le ravageur dominant dans la plupart des localités. Sa densité de population était particulièrement forte dans la forêt semi-décidue et diminuait à mesure que l'on se dirigeait vers l'ouest ou le nord du pays. Les modèles ont expliqué 85.6% (perte de rendement par épi contre densité du ravageur) et 72.5% (nombre de grains endommagés contre densité du ravageur) de la variation observée. De plus, les modèles ont montré que la perte de poids en grain due aux foreurs d'épi était bien moindre que celle occasionnée par des foreurs de tige, mais aussi que le nombre de grains attaqués augmentait rapidement avec la densité d'insectes.

Mots Clés: foreurs de l'épi de maïs, Afrique de l'Oeust, *Mussidia nigrivenella*, pertes de récoltes, modèles statistiques

INTRODUCTION

Seven maize borers have been identified in Côte d'Ivoire to date (Pollet et al., 1978; Dabiré, 1980; Moyal and Tran, 1991a and 1992). Of these, two species are only cob-borers: *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) and *Cryptophlebia leucotreta* (Meyrick) (Lepidoptera: Tortricidae). The other species are mainly stem borers. Some of them, such as *Busseola fusca* (Fuller) and the *Sesamia* species (Lepidoptera: Noctuidae), lay eggs only on the stem. Their larvae may, however, be found in the cob where they enter from the stem. Another species, *Eldana saccharina* Walker (Lepidoptera: Pyralidae), lays eggs either on the stem or on the cob, and can then sometimes enter the cob directly.

Initial studies (Moyal, 1988; Moyal and Tran, 1991b) on the cob-borer densities of populations were carried out in the northern part of Côte d'Ivoire. In this paper, the results of studies on cob-borer abundance in other regions of the country are reported, and models of the crop losses due to these pests are developed.

+See Editor's Note on page v at the end of this issue.

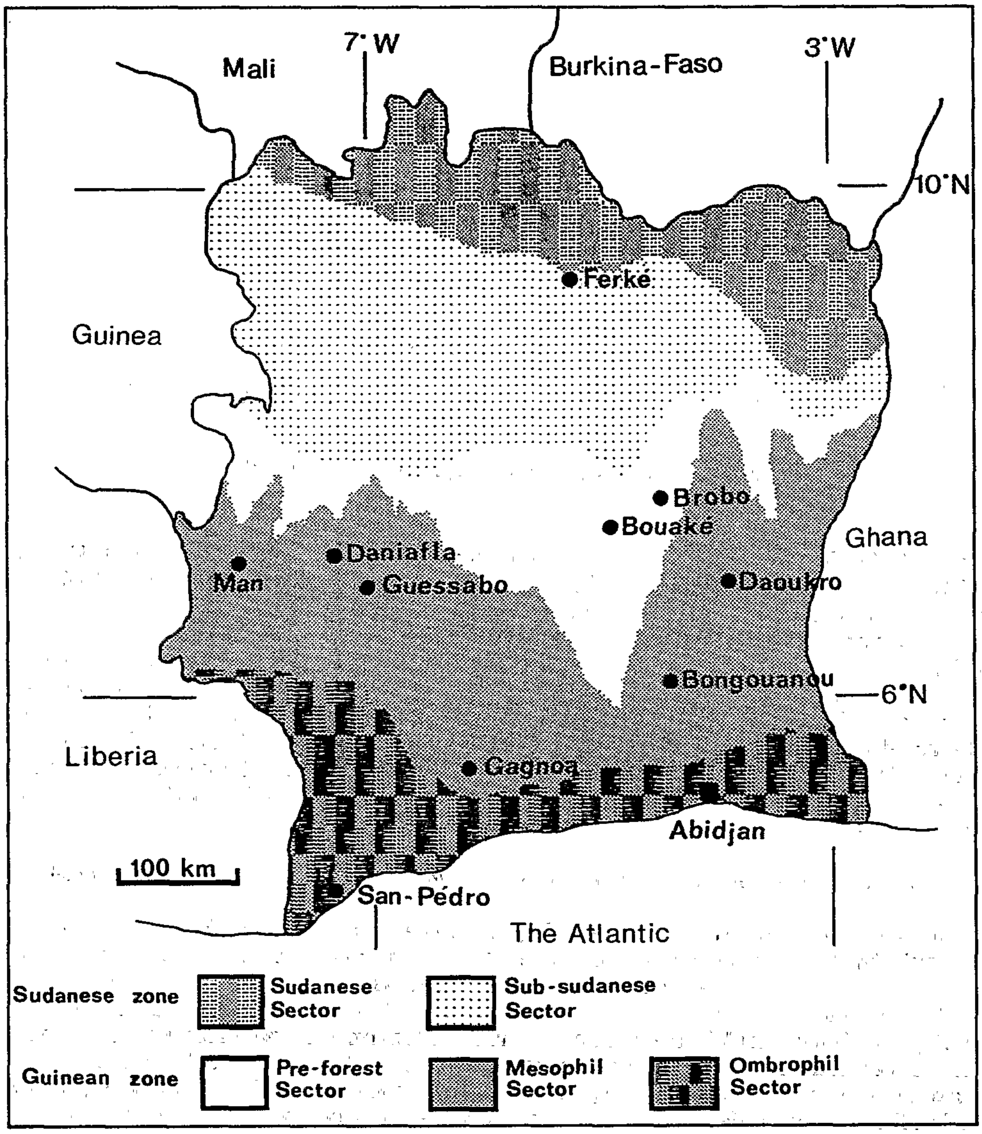

Fig. 1. Map of Côte d'Ivoire showing the ecological zones and the trial localities (black circles)

MATERIALS AND METHODS

The abundance of maize cob-borers was studied from 1986 to 1990 in various ecological areas, mainly in the southern part of Côte d'Ivoire. The country may be divided into two main ecological regions: the Guinean zone in the southern part and the Sudanese zone in the northern part (Fig. 1) (Guillaument and Adjanohoun, 1971; Monnier, 1978). The Guinean zone is divided into three sectors, which are, from south northwards: (i) the ombrophil sector, which is the region of the evergreen forest; (ii) the mesophil sector, which is the region of the semi-deciduous rain forest, and (iii) the pre-forest sector, which is a forest-savannah mosaic region. The Sudanese zone, which is the actual savannah area, is divided into two sectors: the Sudanese sector, restricted to a small fringe in the north of the country, and the sub-Sudanese sector between the Sudanese sector and the Guinean zone.

The maize-growing seasons vary, depending on rainfall. The timing and duration of rainy seasons are due to the movements of the Inter-Tropical Convergence Zone (ITCZ) (Eldin, 1971). In northern Côte d'Ivoire, only one rainy season occurs, generally from May to October, and only one maize crop can be grown in a year. In southern Côte d'Ivoire, a long rainy season from February–March to November may be observed, but usually the ITCZ reaches a sufficiently high latitude degree in July-August to give rise to a short dry season. Two rainy seasons are then, experienced, which permit the growing of maize twice in a year. In central Côte d'Ivoire, one or two rainy seasons occur, depending on the maximum latitude degree reached by the ITCZ. Thus, three rainfed maize crops can be grown in the country. The first crop, which is planted from March to May, is generally grown in central and southern Côte d'Ivoire. The second crop is planted from June to August; it is the only crop grown in northern and western Côte d'Ivoire and can also be grown in most other regions. The third crop which is planted in September or October, can be grown during the second rainy season in the regions where the dry season does not begin too early.

Cob-borer population densities were recorded in maize crops grown over various periods during the rainy seasons, and also in Bouaké (Fig. 1), in irrigated crops grown during the dry season. Maize crops were grown on the research stations of the Institut des Savanes (IDESSA) (Bouaké, Ferké, Gagnoa and Man), on a private firm (Roussel-Uclaf) (Bouaké and Brobo), and on observation sites of the Development Services (other localities) (Fig. 1). The maize variety used was "Composite Jaune de Bouaké", the most widely distributed variety in Côte d'Ivoire (CIDT, 1984). It has a growing season of about 100 days, and a maximum yield of 6200 kg/ha (IDESSA, 1982). In most cases, planting was done at a spacing of 0.80 m between rows and 0.20 m between plants. Fertiliser (300 kg/ha N-P-K (10-18-18)) was applied at planting and 75 kg/ha urea at male flowering.

Random sampling of plants under natural infestation was carried out at harvest, either in observation plots (samples of 100 plants per plot) or in plots of insecticide experiments (samples of 10 plants per plot). The insecticide treatments applied were efficient against stem borers but had no significant influence on cob-borer densities (Moyal, 1988 and 1989). The cobs were dissected and, for each cob, the borer numbers, species and stages were recorded. The whole and the damaged grains were counted, weighed and averaged over plots. The averages were used in the statistical analyses of crop loss. Grain moisture content, measured with a multigrain moisture tester (Dickey-John Dj MGT), was about 17.0%.

Crop losses were analysed using regression analyses. The models were developed from the data collected in seven insecticide trials arranged in randomised complete block designs. These experiments were conducted during the second maize cycle over 4 years in five localities, namely Man (in 1987), Bongouanou (in 1987 and 1988), Guessabo (in 1988), Gagnoa (in 1988 and 1990), and Daoukro (in 1989) (Fig. 1). Two dependent variables were analysed: the number of damaged grains and the weight loss per cob, reckoned as the difference between the potential weight of the cob (weight of one healthy grain multiplied by the number of grains of the cob) and the actual weight. Various regressors were used in the statistical analyses. The significance of several factors (locality and block) and variables (insect numbers, total number of grains, average weight of grain) and of their interactions were tested. For each regression, the homoscedasticity and the normality of residuals was checked by a graphical study (Chatterjee and Price, 1977; Weisberg, 1980; Draper and Smith, 1981). Coding of the factor effects was done using the Helmert's contrasts which are given by default in S-plus (release 3.0), the software used to perform these analyses (Becker et al., 1988; Chambers and Hastie, 1992).

A validation study of the models was performed to test their applicability. Ten trials were used, namely Man 1987, Guessabo 1988, Daoukro 1989, Gagnoa 1990, Bongouanou first cycle 1988, Bongouanou second cycle 1988 (two plots planted two weeks after the trial used in the model), and Gagnoa second cycle 1987, first cycle 1988, second cycle 1988 (observation plot planted two weeks after the trial used in the model) and third cycle 1988.

RESULTS

Population densities

The study of the cob-borer densities during the second cycle from 1986 to 1989 (Figs 2A–D) showed that *M. nigrivenella* was the dominant pest in most trials. *Eldana saccharina* was generally the most abundant of the other borers, particularly in central Côte d'Ivoire (Bouaké and Brobo) where it was dominant in several trials. The density of the other borers at harvest was low, except in San-Pédro in 1988, where the populations of *C. leucotreta* exceeded one borer per cob and in Gagnoa in 1986, where *B. fusca* densities averaged about 0.5 per cob.

The changes in population density of the main cob-borer, *M. nigrivenella*, were recorded in Bouaké and Gagnoa (Figs 3A–B). In most years, the observations in Gagnoa showed an increase in borer density throughout the year up to a maximum during the second cycle (about eight insects per cob in 1987 and 1988); a more or less rapid decrease followed during the third cycle and the dry season. In 1988, however, very high population densities were observed from the first cycle (more than three borers per cob in the planting of 31 March and about 10 borers per cob in the planting of 13 April). The very low population densities observed in the second cycle of 1986 were due to the combined influence of severe water stress and heavy attacks by *B. fusca* (Moyal, 1995a) which resulted in small plants and a high percentage of plant sterility.

In Bouaké, borer densities were low (between 0 and 0.5 per cob) in the irrigated crops grown during

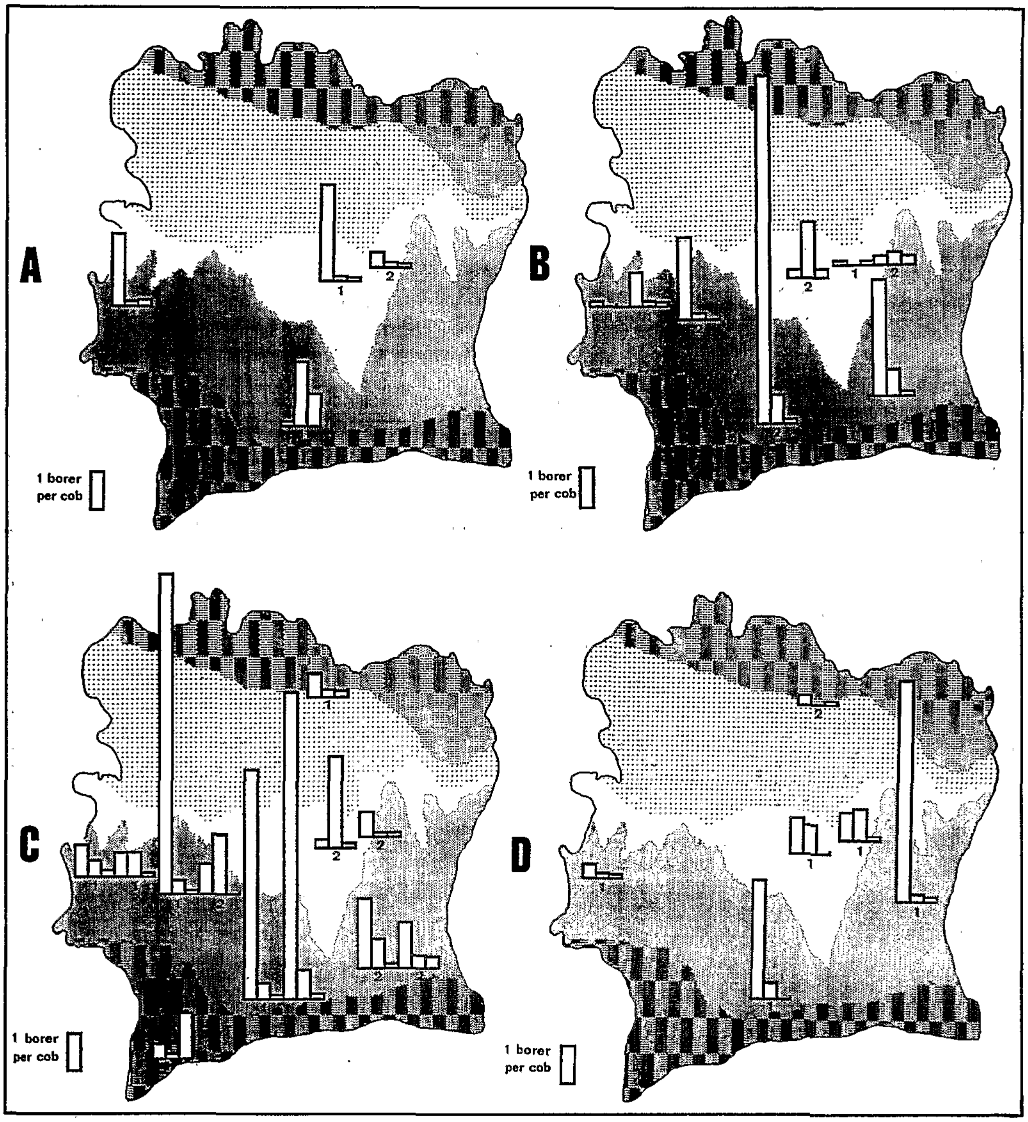

Fig. 2. Abundance of cob-borer populations during the second maize cycle. 1: early plantings (from June to mid-July); 2: late plantings (from mid-July to mid-August) (when two same numbers are mentioned in a locality, the second one corresponds to a planting 2 weeks after the first one). A: 1986; B: 1987; C: 1988; D: 1989. From the left to the right: *M. nigrivenella*, *E. saccharina*, other borers, respectively

the dry seasons. Depending on the year, however, either very little variation was observed throughout the year (1988 and 1989) or an increase occurred resulting in a maximum during the second cycle (1986 and 1990).

Crop loss models

The regression analyses showed that among the factors studied and their interactions with variables, only the locality effect was significant. However, localities that were close to each other did not have significantly different borer densities. Man was therefore joined with Guessabo and Bongouanou with Daoukro (Table 1).

Table 1. Set of contrasts for locality (coding by Helmert's contrasts)

	Factor	
Locality	L1	L2
Man-Guessabo	-1	-1
Bongouanou-Daoukro	1	-1
Gagnoa	0	2

In both models, the insect developmental instars were arranged into two classes: young instars (younger than L4) and older ones. The model fitted for the number of damaged grains explained 85.6% of the observed variation (Table 2). The number of damaged grains increased linearly with the number

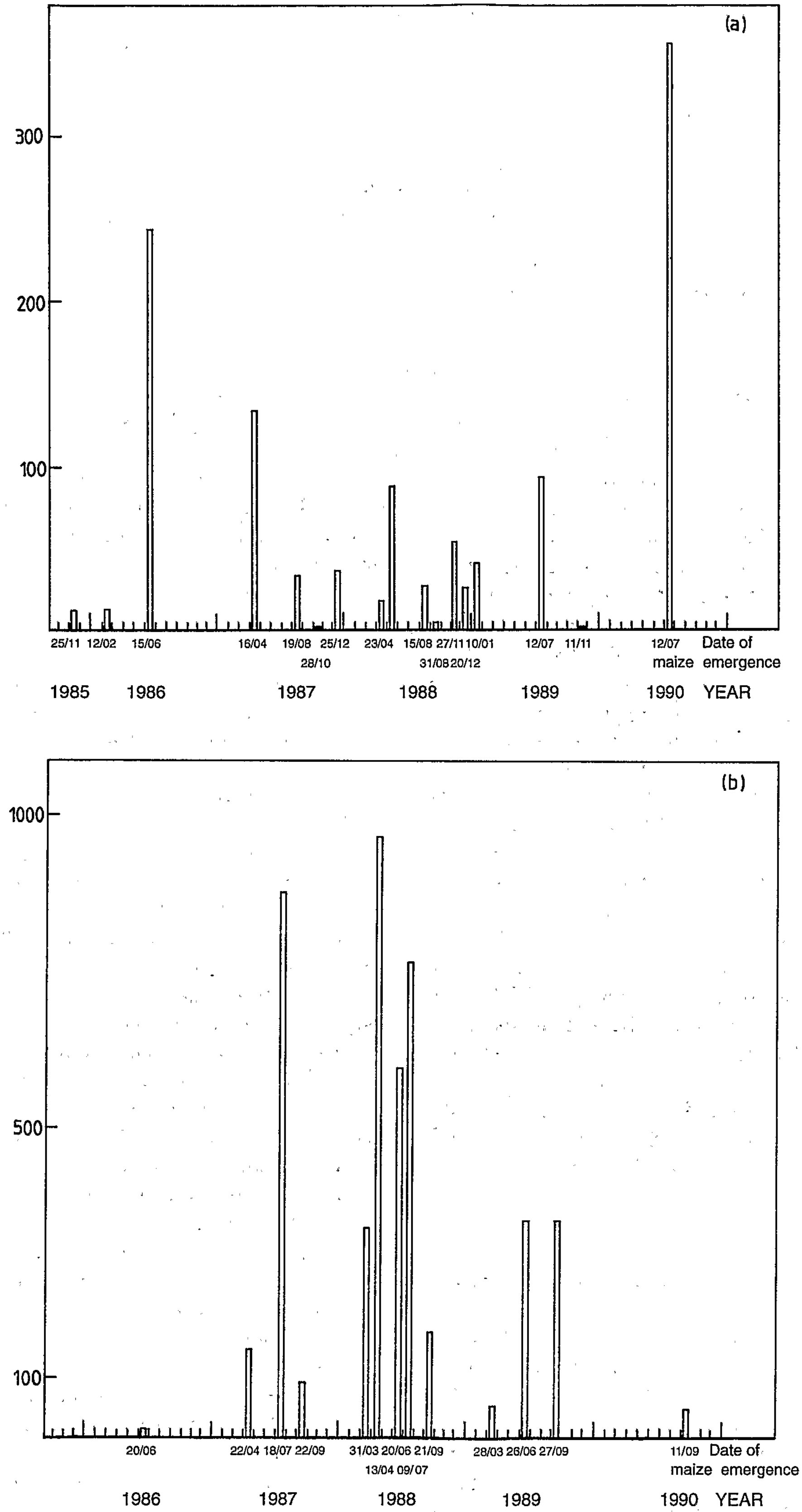

Fig. 3. *Mussidia nigrivenella* population fluctuations over the various maize cycles in Bouaké (a) and Gagnoa (b)

Table 2. Regression analysis results. L1–L2: locality dummy variables

Explanatory variable	Number of damaged grains per cob		Weight loss per cob (grammes)	
	Coefficient	P (>|*t*|)	Coefficient	P (>|*t*|)
Constant	6.2866	0.0064	-0.1162	0.7445
L1	-8.4144	0.0000	-0.3326	0.0050
L2	-4.9982	0.0000	-0.0701	0.2359
Young larvae (< L4)	5.6058	0.0000	0.3326	0.0000
Old larvae	9.4875	0.0000	0.4106	0.0000
(Old larvae)^2	-0.2140	0.0174	–	–
Total number of grains	–	–	0.0022	0.0075
Multiple R^2	0.8564		0.7247	
Residual standard error	10.02		0.8204	

of young larvae. However, a competition effect was observed among old instars; the damage per larva decreased with increasing larva density. This was denoted by the significant negative coefficient of the variable "(number of old larvae) squared". Thus, the difference between the number of damaged grains estimated by this model and that estimated by a model which does not take into account the competition effect is negligibly small up to a density of 10 insects per cob, but increases greatly for higher densities. The number of damaged grains predicted by the first model was reduced by 20 and 44% respectively for densities of 15 and 20 old borers per cob.

The relationship between weight loss and borer densities showed a greater variation ($R^2 = 0.725$, Table 2). The variable "(number of old larvae squared)" was no longer significant whereas the variable "total number of grains per cob" had a significant positive effect. The weight loss for a given borer density was higher for a higher number of grains per cob.

Figures 4A–E and 5A–E show that the model residuals have a constant variance and are distributed according to the normal distribution.

Model validation

The results of the validation studies are shown in Tables 3 and 4. In the case of insecticide trials, the mean value per treatment was computed; where several plots receiving the same treatment were used, the confidence interval of the mean ($P \leq 0.05$) was recorded. When no confidence interval is given, only one plot was used. In 81% of the cases for the number of damaged grains and 73% of the cases for weight loss, either the observed value lay in the prediction interval or the confidence and prediction intervals overlapped. Of the cases that were not accurately predicted, several resulted from very low attacks (the error in the estimated crop loss was then negligible), while others were close to one of the limits of the confidence interval.

DISCUSSION

Population densities

The results of the present investigation show that the density per cob of the borers which are mainly stem borers such as *E. saccharina* or *B. fusca,* usually varied as a function of their density in the stem. The factors involved in the density fluctuations of these pests have been studied by Moyal (1995a and 1995b). Earlier studies on the geographical distribution of *M. nigrivenella* in the northern part of Côte d'Ivoire (Moyal and Tran, 1991b) showed that populations were low in the western and northern regions, and high in the southern and south-eastern regions. The present study confirms previous observations and shows that the mesophil sector of the Guinean zone is the most suitable area for this species. However, low populations were observed in the western part of this sector (Man region). Such a distribution is very similar to that of *E. saccharina.* Moyal (1995b) showed that the low populations of this species in northern and western Côte d'Ivoire are likely to be due to the low winter temperatures coupled with a long and severe dry season. The same factors certainly have a great influence on *M. nigrivenella* populations; the oviposition of this species is reduced during periods of low relative humidity (Moyal, 1988) and insect development is delayed by low temperatures.

The population dynamics of *M. nigrivenella* is similar to that of *E. saccharina* throughout the year. Both show an increase in density up to the second cycle, and a decrease thereafter. The incidence of

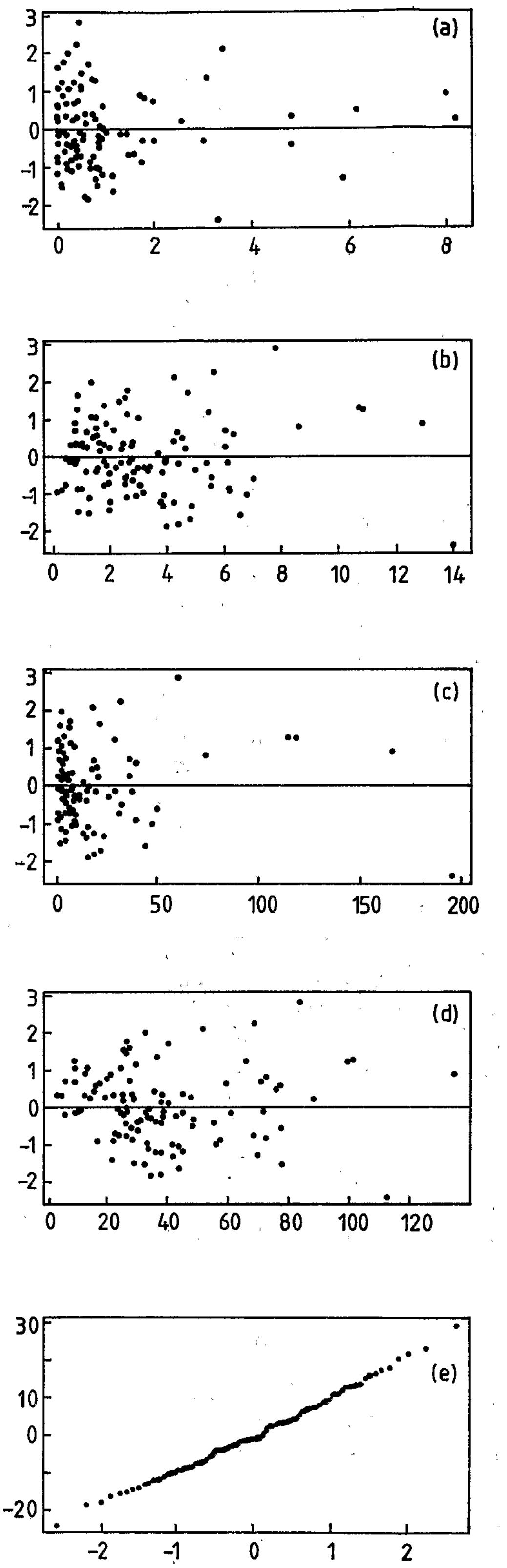

Fig. 4. Residual study for the model of the number of damaged grains. Standardised residuals versus: (a) larvae younger than L4; (b) older larvae; (c) (old larvae) squared; (d) fitted number of damaged grains; (e) residuals versus quantities of Standard Normal

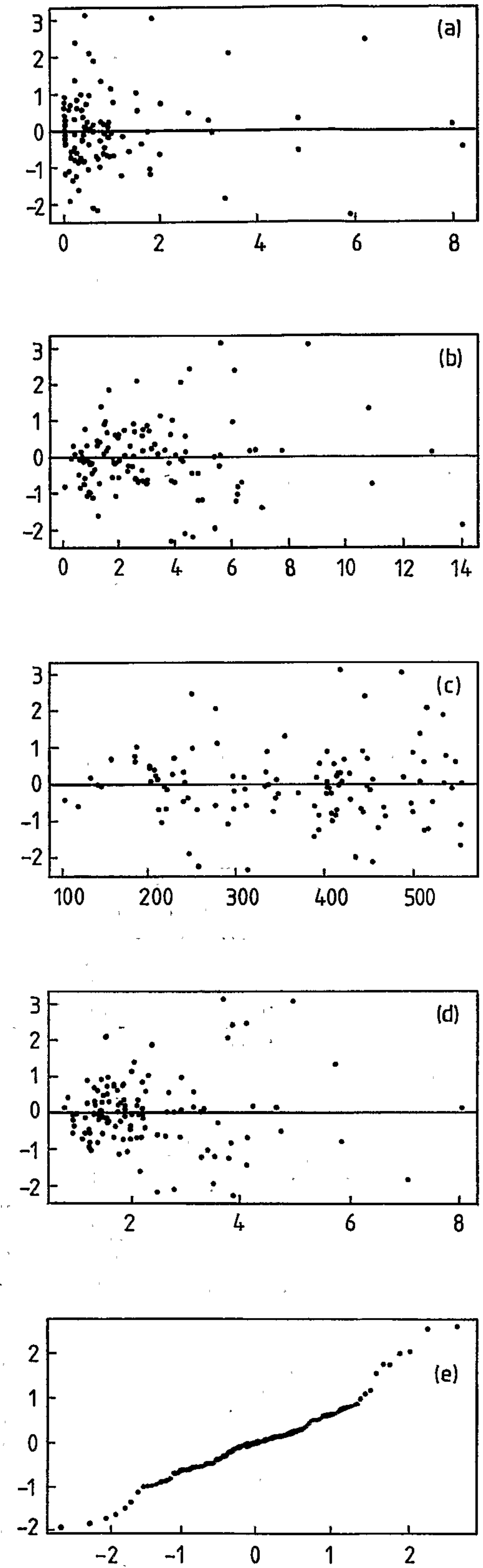

Fig. 5. Residual study for the model of weight loss. Standardised residuals versus: (a) larvae younger than L4; (b) older larvae; (c) total number of grains per cob; (d) fitted weight loss; (e) residuals versus quantities of Standard Normal

Table 3. Validation study for the model of the number of damaged grains

Locality	Observed number of damaged grains	Confidence interval (P = 0.05)	Predicted number of damaged grains	Prediction interval (P = 0.05)
Guessabo	102	78.7 – 124.8	94	88.3 – 99.4
	54	39.9 – 68.4	62	58.1 – 66.3
	59	–	61	56.6 – 64.7
	61	46.8 – 74.8	70	65.5 – 74.3
	43	38.1 – 48.7	52	47.7 – 55.3
Man	25	22.3 – 27.9	27	22.1 – 31.0
	10	4.7 – 15.0	24	18.8 – 28.4
	25	20.6 – 29.9	28	22.9 – 32.0
	36	36.1 – 36.6	34	30.1 – 38.1
Bongouanou	24	17.1 – 30.6	25	21.4 – 27.6
	31	–	30	27 – 33.5
	7	–	13	9.1 – 16.5
Daoukro	70	55.8 – 83.8	64	59.5 – 70
	60	59.1 – 59.9	66	60.2 – 71.7
	46	38.9 – 53.9	53	49.2 – 57.1
	84	68.0 – 99.7	82	77.8 – 88.0
Gagnoa	48	–	53	49.0 – 56.9
	59	–	63	58.2 – 66.8
	13	10.6 – 16.3	12	8.1 – 15.9
	87	72.0 – 102.3	72	66.5 – 78.3
	80	57.4 – 103.0	76	69.3 – 83.6
	96	71.3 – 121.4	69	63.8 – 74.7
	131.3	120.8 – 141.8	80	72.4 – 87.8
	6	1.3 – 10.7	2	-2.7 – 7.1
	10	1.0 – 19.5	4	-0.6 – 8.5
	6	1.4 – 11.2	0.3	-4.8 – 5.3

Table 4. Validation study for the model of weight loss

Locality	Observed weight loss	Confidence interval (P = 0.05)	Predicted weight loss	Prediction interval (P = 0.05)
Guessabo	6.42	4.57 – 8.28	5.38	4.92 – 5.83
	2.52	2.30 – 2.74	3.34	3.05 – 3.64
	3.42	–	3.31	3.02 – 3.60
	3.37	1.88 – 4.86	3.74	3.42 – 4.06
	2.42	1.65 – 3.19	2.61	2.29 – 2.94
Man	2.20	1.81 – 2.59	1.67	1.33 – 2.01
	0.76	0.29 – 1.24	1.58	1.23 – 1.93
	1.52	1.03 – 2.01	1.83	1.48 – 2.18
	2.37	2.10 – 2.65	2.14	1.81 – 2.47
Bongouanou	1.24	0.41 – 2.07	1.29	1.01 – 1.56
	1.49	–	1.75	1.48 – 2.01
	0.48	–	0.93	0.64 – 1.21
Daoukro	3.49	3.46 – 3.52	3.36	2.97 – 3.75
	3.90	3.67 – 4.13	3.69	3.26 – 4.12
	2.08	1.48 – 2.68	2.57	2.23 – 2.91
	3.35	2.84 – 3.85	4.46	4.06 – 4.86
Gagnoa	3.23	–	3.77	3.32 – 4.23
	3.27	–	3.78	3.44 – 4.13
	1.43	0.84 – 2.03	1.60	1.21 – 1.98
	5.68	4.84 – 6.53	5.08	4.48 – 5.68
	5.37	4.12 – 6.63	5.64	4.88 – 6.40
	6.23	4.68 – 7.77	5.02	4.36 – 5.68
	8.58	7.76 – 9.40	5.86	5.10 – 6.61
	0.39	0.13 – 0.65	1.26	0.80 – 1.71
	0.74	-0.10 – 1.57	1.22	0.82 – 1.62
	0.60	0.19 – 1.00	1.12	0.69 – 1.55

egg-parasitism (about 100% in October) and the dry season may be the causes of the fluctuations in the population densities of *G. saccharina* . It is likely that the same factors influence *M. nigrivenella* populations. However, this species, in contrast with stem borers, feeds in the fruits of many host-plants from various families (Papilionaceae, Achradaceae, Sterculiaceae, Gramineae, Malvaceae) (Moyal, 1988). Its population densities may thus be influenced by the variations in the fruiting time of these plants.

Crop loss models

The validation studies show that the crop loss models fitted give a reliable prediction of the damage due to cob-borers for population densities varying between 0 and 18 borers per cob. However, in all the trials used for developing and validating the models, *M. nigrivenella* was the dominant pest. Moyal (1988) observed that *Mussidia nigrivenella* frequently accounts for up to 90% of cob-borers in a farm. In central Côte d'Ivoire, nevertheless, the main cob-borer in some plots was *E. saccharina*. Estimation of crop loss in this case is then more difficult since the damage may be quite different when the pest infests the cob from the stem at a more or less old instar or when it lays eggs on the husks and enters the cob after hatching. Indeed, the importance of direct infestation of cobs appears to vary greatly, depending on the trial. For instance, in the second maize cycle of 1989, 28% of the larvae of *E. saccharina* infested ears in Brobo as compared to only 8% in Gagnoa for similar densities of populations (Moyal, 1993b).

The locality effect in the models resulted from the more or less important damage that was not due to the insects collected at harvest. The damage was low in central and eastern Côte d'Ivoire, and the difference between both regions was small, although significant. On the contrary, the damage was high in western Côte d'Ivoire. This may have been due to several factors, such as: early attacks by a stem and cob-borer found only in this region, *Chilo aleniellus* (Strand) (Lepidoptera: Pyralidae) (Moyal and Tran, 1992); early infestation by *C. leucotreta,* suggested by the high densities of that species observed at harvest in San-Pédro in 1988, whereas it generally completes its development before harvest; and a higher mortality of borers before harvest. It is recommended that the models fitted for western Côte d'Ivoire be used only for that region, and that the models developed for the other regions be used for most localities of Côte d'Ivoire.

The regression analyses showed that the variable "(number of old larvae) squared" had a significant negative effect on the number of damaged grains, and that the variable "total number of grains" had a significant positive effect on weight loss. Both results indicate the same competition phenomenon. The first result shows that the damage per larva was reduced when borer density increased. This was certainly not due to lack of food, since the number of damaged grains was always much lower than the total number of grains in the observations, and a small proportion of each damaged grain was consumed. This was likely due to the increased contacts between larvae. Indeed, borers enter the cob between the silks and stay mostly at the apical end of the cob where frequent contacts may then occur even at rather low population densities. When population densities increase, larvae disperse towards the other parts of the cob. Where grain numbers are low, the contacts between larvae increase, and then the damage per larva should logically be reduced due to increased competition effect, as observed in the weight loss model. It is then likely that experiments which would include a big range of pest densities combined with various total grain numbers would give more accurate models, showing significant interactions between larva and grain numbers that would give a better description of competition phenomena. In our trials, all the possible combinations between both variables did not occur and the competition phenomena were expressed in different ways in both models. However, the damage predictions were reliable, as shown by the validation studies.

From the findings of this study, it is possible to quantify the damage due to cob-borers and to compare it with that due to stem borers. Thus, the weight loss model shows that the yield loss due to cob-borers is much lower than that due to stem borers (Moyal, 1993a). For instance, cob infestation by five old larvae reduces yield by about 2.5% (for cobs of 130 g and 400 kernels), whereas such an infestation in the stem results in complete destruction of the crop when it occurs during the first part of the cycle; it results in a yield reduction of 37% when it occurs during the second part of the cycle. For the same cob-borer density, the number of damaged grains would average 50, or a reduction of about 12.5% in whole grains. In Côte d'Ivoire, cob-borers are much less injurious to maize crops than stem borers. However, they still can lead to high financial losses for seed producers, particularly in the mesophil sector of the Guinean zone.

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