INTERNATIONAL JOURNAL OF PEST MANAGEMENT, 1995, 41(2) 114–121

Borer infestation and damage in relation to maize stand density and water stress in the Ivory Coast

(*Keywords:* maize borers, *Busseola fusca*, *Eldana saccharina*, *Mussidia nigrivenella*, yield loss)

P. MOYAL

ORSTOM, Departement MAA, 213, rue La Fayette, 75480 Paris cedex 10, France

Abstract. Borer infestations of maize crops grown at various planting densities were studied in the Ivory Coast. The number of larvae per stem for both stem borers, i.e. *Busseola fusca* (Fuller) (Lepidoptera, Noctuidae) and *Eldana saccharina* Walker (Lepidoptera, Pyralidae), was similar at different densities of planting in rainy conditions but was higher in low density crops in water stress conditions. The number of larvae of the cob borer *Mussidia nigrivenella* Ragonot (Lepidoptera, Pyralidae) per plant did not vary with crop density. Crop losses caused by borers decreased when the stand density was reduced and increased when the crop was suffering from water stress. The interactions between the various yield components and the compensation mechanisms that occurred, which were depending on the attack patterns, were studied.

1. Introduction

Borers are the main insect pests of maize in the Ivory Coast (Moyal, 1988a). Seven species, all Lepidoptera, have been reported in this country (Pollet *et al.*, 1978; Dabiré 1980; Moyal and Tran, 1991a, 1992). Of these, three are predominant: (i) *Busseola fusca* (Fuller) (Noctuidae) is a stem borer, attack by which occurs mainly in the forest area (Figure 1) during the first part of the cultural cycle (oviposition usually occurs between 15 and 40 days after seedling emergence); (ii) *Eldana saccharina* Walker (Pyralidae) is a stem borer which attacks maize throughout the Ivory Coast, generally during the second part of the cultural cycle (oviposition usually occurs from 60 days after seedling emergence); (iii) *Mussidia nigrivenella* Ragonot (Pyralidae) is a cob borer which has been recorded throughout the country.

Maize crops grown at the present time by peasants of the Ivory Coast are low input cropping systems. Plant density is low, for instance between 10 000 and 15 000 plants per hectare in the region of Gagnoa (Figure 1) (SATMACI, 1986). Fertilizers are little used: for instance, only 17·3% of the maize area supervised by the organization in charge of the development of agriculture in the savannah area receive N-P-K fertilizers (CIDT, 1988). Maize crops are generally not irrigated and may then suffer from water stress, especially in the central region during the first growing season (planting in February–March) (Gigou, 1987).

High-yielding varieties, which require high inputs, have been created by agronomic research workers, who are encouraging the move from low input peasant agriculture (target 1, according to Rouanet, 1987) to a more intensive one (target 2). In this study, the borer infestation and effect on yield components in high intensity cropping systems (target 2) are compared with those observed in target 2 crops suffering from water stress and with those observed in low input cropping systems (target 1).

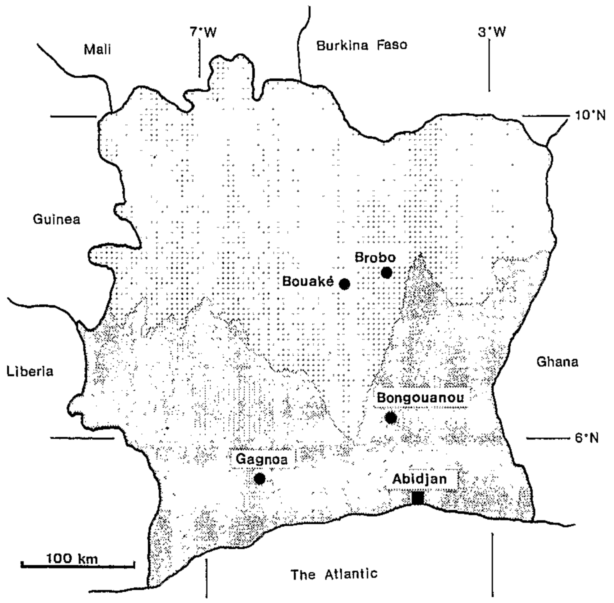


Figure 1. Map of the Ivory Coast showing the study localities (●), the forest region ▩ and the savannah region ▤.

2. Materials and methods

2.1. Borer infestation

Borer infestation in relation to growing modalities was studied in four localities: Gagnoa and Bongouanou in the forest region, and Bouaké and Brobo in the savannah region (figure 1). The maize variety used was *'Composite Jaune de Bouake'* (*CJB*), which is the most widely distributed variety in the Ivory Coast (CIDT, 1984). It has a 100-day growth cycle and a maximum yield of 6200 kg per hectare (IDESSA, 1982). Experimental designs, dates of sowing and planting densities are shown in Table 1. Three planting densities were tested: the high input crop was consistent with the agronomic research recommendations, while planting densities and fertilizer inputs in the other two crops were a half and a quarter the high level. In the case of insecticide trials, only samples from plots receiving no insecticide treatments were considered. The experimental units were plots 25m long and 4m wide with five maize rows (0·80m between rows). Between 25 and 50 plants

0967–0874/95 $10·00

Table 1. Trials used in the study of borer infestation

Locality	Date of plant emergence	Experimental design	Planting densities (plants/ha)
Gagnoa	20 June 1988	Split-plot (4 blocks) 1st factor: planting density (2 levels) 2nd factor: insecticide treatment (5 levels)	62500 and 15625
	21 September 1988	Randomized blocks (8 replications) factor: plant density (3 levels)	62500 31250 and 15625
	26 June 1989	Split-plot (4 blocks) 1st factor: planting density (2 levels) 2nd factor: insecticide treatment (2 levels)	62500 and 31250
Bongouanou	2 May 1988	Randomized blocks (8 replications) factor: plant density (2 levels)	62500 and 15625
Brobo	11 July 1989	Split-plot (4 blocks) 1st factor: planting density (2 levels) 2nd factor: insecticide treatment (5 levels)	62500 and 31250
Bouaké	12 July 1990	Randomized blocks (4 replications) factor: plant density (2 levels)	62500 and 31250

were sampled for each level of planting density in each trial at each date. Dates of sampling were 40 and 60 days after seedling emergence (d.a.e.) to estimate populations of *B. fusca* and 100 d.a.e. to estimate populations of *E. saccharina* and *M. nigrivenella.* In Bongouanou, only the sampling at 60 d.a.e. was considered because low borer numbers per stem at the other dates made samples unreliable. The standard errors of ratios were estimated according to Buonaccorsi and Liebhold (1988).

2.2. *Borer effect on yield*

The borer effect on yield components and yield was studied from the results of the trial carried out in Gagnoa during the main growing season of 1988 (plant emergence on 20 June 1988). In this trial variable levels of attack were observed following use of insecticide (Table 2), and water stress was severe (see below). The borer effect observed in the trial was compared with the effect predicted by a statistical model developed for a high intensity cropping system suffering no water stress (Moyal, 1993). This model was established from six trials carried out in various regions of the Ivory Coast over a period of several years. It was validated through the results of three other trials, one of them carried out in Gagnoa. The percentage reductions in yield and yield components with respect to pest-free values were therefore plotted versus the same values estimated from the model. The pest-free values in the trial were estimated from the average of data from plots suffering no or very low attacks. Regression analyses were performed and, when significant, the fit slopes (b) were compared with $b=1$ (Tomassone *et al.*, 1983): if the borer

Table 2. Design of the split-plot experiment carried out in Gagnoa (plant emergence on 20 June 1988; four replications)

Factor	Levels
First factor: plant density	1: 62500 plants/ha 2: 15625 plants/ha
Second factor: insecticide treatment	1: no treatment (control) 2: treatment every 10 days with deltamethrin (12 g a.i./ha) 3: one treatment at 35 days after emergence with deltamethrin (15 g a.i./ha) 4: two treaments at 20 and 40 days after emergence with deltamethrin (15 g a.i./ha) 5: two treatments at 40 and 60 days after emergence with deltamethrin (15 g a.i./ha)

damage in the trial was the same as that in high intensity cropping systems suffering no water stress, then the slope should not depart from $b=1$. The analysis of high intensity cropping systems suffering no water stress (Moyal, 1993) showed that stem borer attacks had no direct effect on the grain number per cob-carrying plant. This yield component was therefore not studied here. The yield components studied were: the percentage of harvested plants (number of plants at harvest × 100/number of plants at seedling emergence), the percentage of cob-carrying plants at harvest and the average weight of grain.

2.3. *Water stress*

The crop water balance was estimated by the soil water reserve. The differences 'Rainfall minus Potential Evapotranspiration' (R − PET) permitted an estimate of the soil water reserve to be made from an available reserve of 100 mm in 1 m depth. PET was calculated using the Turc formula (Monteny and Lhomme, 1980). The soil water reserve estimation was initiated 10 days before planting. A crop begins to suffer from water stress when the easily available soil water reserve is depleted: this reserve is about half the available reserve (Bonhomme and Valancogne, 1986). Thus, the evolution of the available reserve for high density crops presented in Figure 2 shows that the trial of the main cycle of 1988 in Gagnoa (plant emergence on 20 June 1988) suffered greatly from water stress twice in the growing season (between 35 and 60 d.a.e., and then from 70 to 80 d.a.e.) while the trial of 1989 (plant emergence on 26 June 1989) did not suffer so much and only between 50 and 60 d.a.e. The remaining trials did not suffer at all from water stress. This estimation of the available reserve from PET is however correct only for high density crops, which cover the ground and have a real evapotranspiration near to PET. When crop density is reduced, the real evapotranspiration has to be calculated by interpolation between the evaporation of an uncovered ground and PET (R. Bonhomme, INRA bioclimatologist, personal communication). Table 3 shows the results for the cycle planted in June 1988 in Gagnoa: while the high density crop suffered greatly from water stress, the low density crop did not suffer at all. In Bongouanou, only the rainfall was known but it was regular and high enough to conclude that no water stress occurred: as a matter of fact, according to Chabalier (1985), 300 mm are needed between 25 and 85 d.a.e. to ensure effective availability of fertilizer in this region at the period of growing, while rainfall during this period was 307 mm.

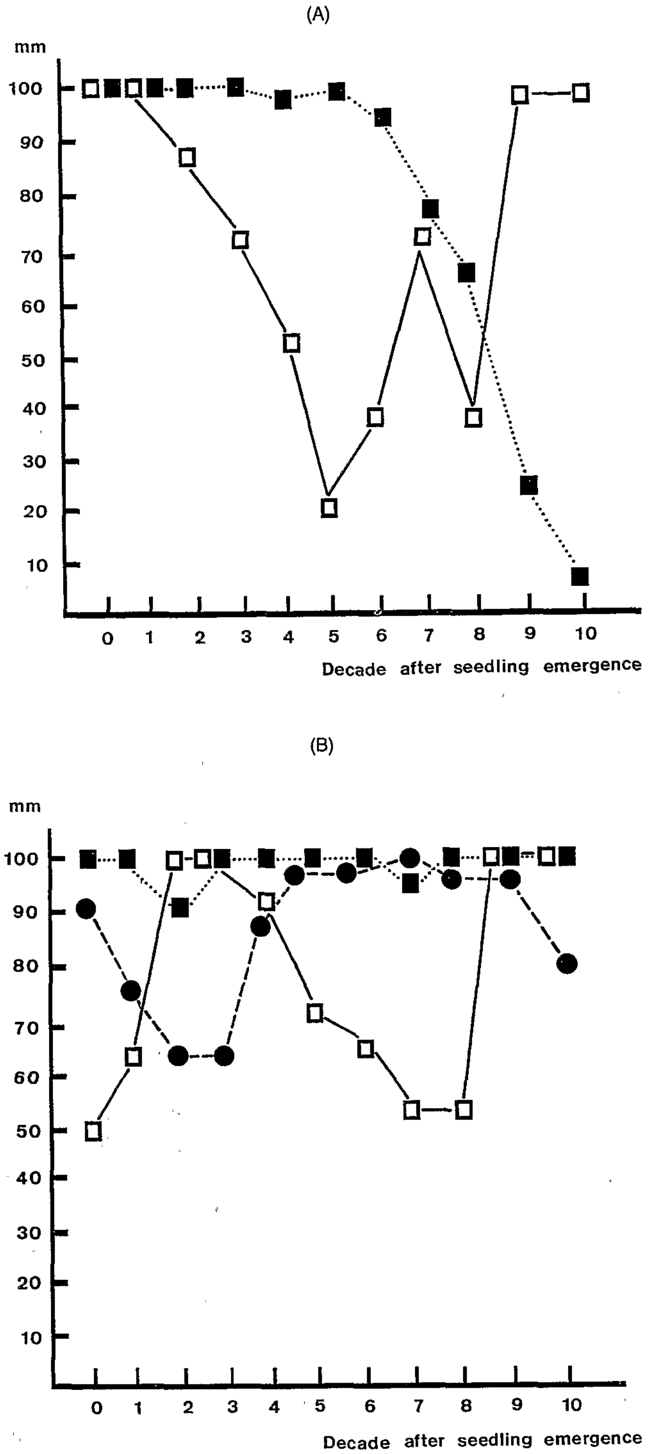


Figure 2. Water reserve available for high density crops (decade 0: 9 days before emergence till emergence day; decade 1: 1 till 10 days after emergence...). A: Gagnoa, emergence on 20 June 1988 (□) and on 21 September 1988 (■). B: Gagnoa, emergence on 26 June 1989 (□); Brobo, emergence on 11 July 1989 (■); Bouaké, emergence on 12 July 1990 (●).

Table 3. Available water reserves for high and low density crops in the experiment of Gagnoa (plant emergence on 20 June 1988)

Days after emergence	Available reserve for the high density crop	Available reserve for the low density crop
−9 to 10	97·6	100
1 to 10	100	100
11 to 20	87·1	100
21 to 30	74·5	100
31 to 41	45·7	87·0
42 to 51	22·5	77·2
52 to 61	40·3	100
62 to 72	70·8	100
73 to 82	38·1	85·8
83 to 92	100	100
93 to 102	100	100

The analyses were performed using S-Plus software (release 3·0) (Becker *et al.* 1988; Chambers and Hastie, 1992).

3. Results

3.1. Borer infestation

The infestation rates in relation to the planting density levels are presented in Figure 3. The ratio of the borer number per stem is plotted against plant growth index ratio. This index is characteristic of the combined effect of water stress and density differences on plant growth. It was calculated as follows: area of the stem base × stem height/3.

The trials which suffered from water stress before the sampling date were distinguished from those where no stress occurred. In figure 3A, the sampling at 40 d.a.e. in Gagnoa (maize emergence on 20 June 1988) was characterized as being without water stress since stress occurred at about 35 d.a.e. and the insects sampled were derived from eggs laid before this date; the crop grown in 1989 in Gagnoa was also characterized as being without water stress since stress occurred after the attack period by *B. fusca*. Likewise, in the trials planted on 21 September in Gagnoa, stress began at about 90 d.a.e. and had little influence on the level of the population sampled 10 days later (Figure 3(B and C)).

Figure 3 shows that the ratio of insect numbers per stem was close to one for the three borer species when no stress occurred. In contrast, when crops suffered from water stress, the more vigorous plants (i.e. the low intensity cropping system) were more heavily attacked by *B. fusca* and *E. saccharina*. Infestations by the cob borer *M. nigrivenella* were independent of the plant growth index whatever water stress occurrence.

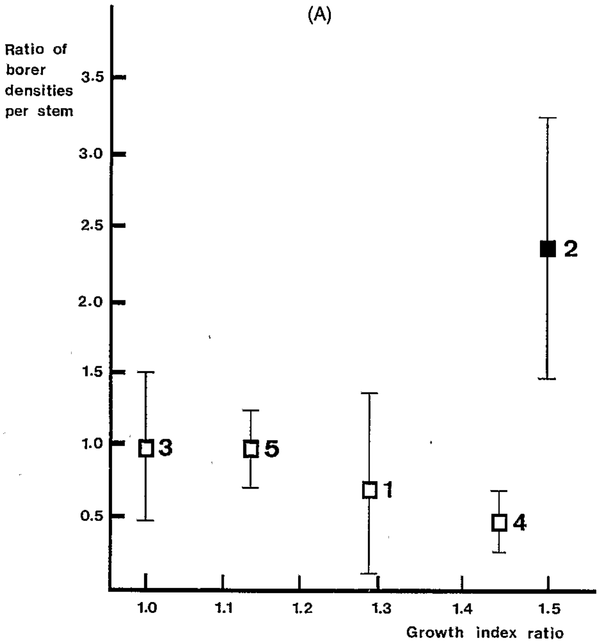
3.2. Borer effect on yield

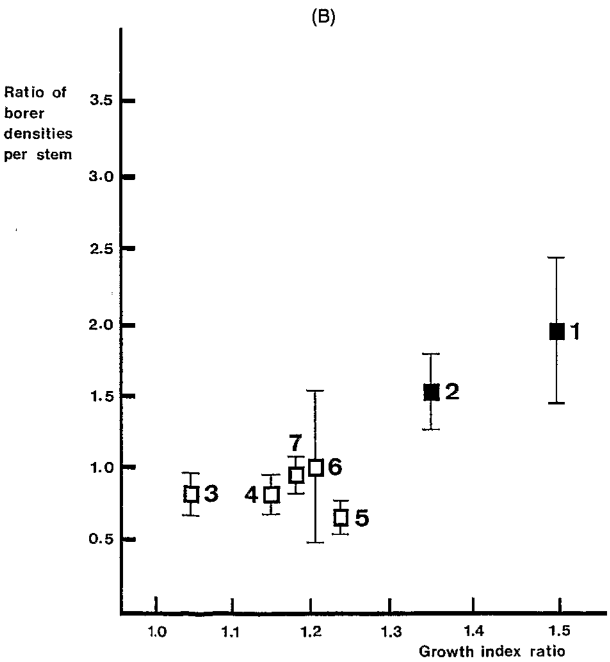
Figure 4 presents the development of stem borer infestation in the trial of the main cycle 1988 in Gagnoa. High infestations by *B. fusca* occurred only 60 d.a.e. Oviposition by *E.*

saccharina occurred mainly between 60 and 70 d.a.e., which is the norm (Dabiré, 1980; Moyal, 1988b).

In the low intensity cropping system (Table 4), the regressions performed for the yield components were not significant: no borer effect was noticeable whereas the borer effect estimated for the high intensity cropping system varied between 0 and 45%. The fit is however significant for yield: the slope ($b = 0{\cdot}3251$) is significantly less than one, which shows that the borer influence was less than in the high intensity cropping system.

In the high intensity system, the crop suffered from water stress (Table 5), but the percentage of harvested plants was not reduced by borer attacks when it would have been reduced by up to 21% in a crop suffering no water stress. In contrast, a heavy borer effect on the percentage of cob-carrying plants was noticed: the regression slope is significantly greater than one, which shows a positive interaction between borer and water stress. No borer effect was observed on the average weight of grain and the estimated loss in crops suffering no water stress varied between 0 and 18%. The borer effect on yield was significantly greater than the effect observed in a crop suffering no water stress. The water stress had a great influence since the constant term shows a pest-free decrease in yield of 30%.





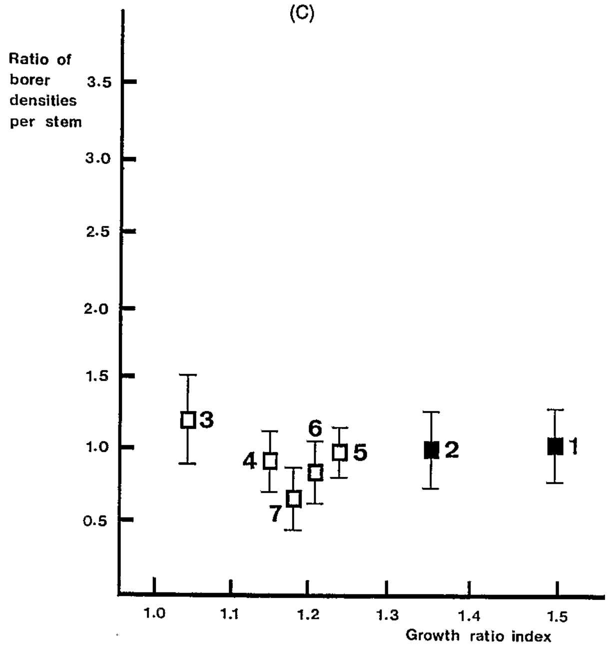


Figure 3. Ratio of borer density per stem (ordinate) versus growth index ratio (abscissa). ■ *High density crop suffering from water stress;* □ *no water stress occurrence. Vertical bars represent standard errors of ratios. A:* B. fusca. *1–2 Gagnoa (maize emergence on 20 June 1988) at 40 and 60 d.a.e., 3–4: Gagnoa (maize emergence on 26 June 1989) at 40 and 60 d.a.e.; 5: Bongouanou at 60 d.a.e. B and C: respectively* E. saccharina *and* M. nigrivenella. *1–2 Gagnoa (maize emergence on 20 June 1988 and 26 June 1989); 3,4,5: Gagnoa (maize emergence on 21 September 1988): respectively 15525 vs 31250 plants/ha, 31250 vs 62500 plants/ha, and 15525 vs 62500 plants/ha; 6: Bouaké; 7: Brobo.*

4. Discussion

4.1. Borer infestation

4.1.1. *B. fusca.* When no water stress occurred, the ratio of the borer number per stem was close to one, which shows that crop attractivity is correlated positively to stand density. When water stress occurred in the high density crop, the borer number per stem became higher in the low density crop: it seems unlikely that stress reduced the attractivity of the crop in the experiment since it began at the end of the oviposition period (at about 35 d.a.e.) and because it was observed in other trials (Moyal, 1995) that crops suffering from very severe stress were attractive much longer than crops grown in rainy conditions (oviposition occurring up to 60 d.a.e.). Moreover, the percentage of damaged plants was similar in both crops subject to stress and those lacking stress under rainy conditions: 15% in both crops 40 d.a.e. and 52·5% in the high intensity crops versus 55% respectively in the low intensity crops 60 d.a.e. in the trial planted in June 1988 in Gagnoa. This suggests that the difference in population density probably results

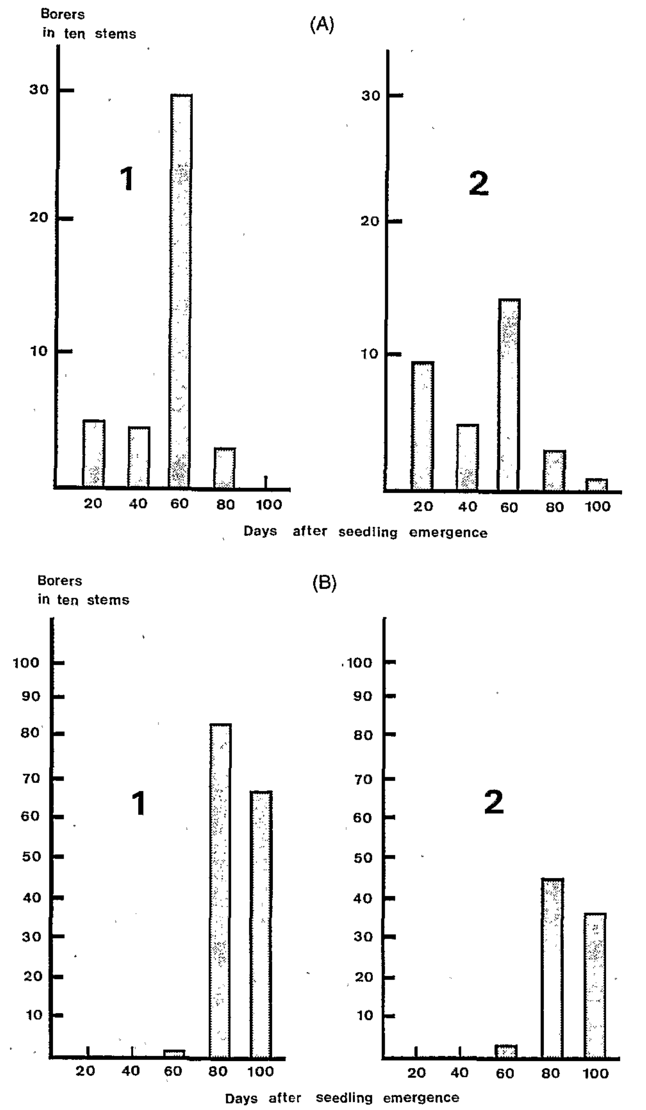


Figure 4. *Borer density in control plots of the trial carried out in Gagnoa (maize emergence on 20 June 1988). A:* B. fusca; B: E. saccharina; *1: low density crop, 2: high density crop.*

Table 4. Low density crop: results of the regression analyses of the percentage reduction of the yield component in the experiment versus the estimated percentage reduction in high density crops suffering no water stress

Yield component	*b* (slope)	$P(>\|t\|)$	R^2	Residual standard error	Test of $b=1$ $P(>\|t\|)$
Percentage of harvested plants	0·0883	0·1102	0·1332	3·275	—
Percentage of cob-carrying plants	−0·0452	0·7264	0·0069	6·438	—
Average weight of grain	0·1252	0·2557	0·0709	5·217	—
Yield	0·3251	0·0175	0·2725	11·602	0·0000

Table 5. High density crop suffering from water stress: results of the regression analyses of the percentage reduction of the yield component in the experiment versus the estimated percentage reduction in high density crops suffering no water stress.

Yield component	*b* (slope)	$P(>\|t\|)$	R^2	Residual standard error	Test of $b=1$ $P(>\|t\|)$
Percentage of harvested plants	−0·0600	0·3913	0·0418	1·713	—
Percentage of cob-carrying plants	2·2764	0·0002	0·5584	9·318	0·0154
Average weight of grain	−0·3739	0·4682	0·0304	10·048	—
Yield	2·3526	0·0008	0·4780	14·996	0·0314

from higher mortality of larvae in plants suffering from water stress. The young larvae of *B. fusca* are feeding on leaves in the whorl, for 10–15 days, before entering the stem. Water stress induces major changes in maize physiology and particularly reduces the protein content of leaves (Robin, 1984). Some morphological changes (greater production of trichomes) have also been observed in wheat (Jones 1992) and may occur in maize. These changes may result in higher mortality of the phyllophagous larvae. The borer number per hectare is, however, still greater in the high stand crops since the borer ratio is about two when the stand density ratio is four. These results seem to be in conflict with those obtained in South Africa by Van Rensburg *et al.* (1989), who compared two hybrids and found that the taller, more thick stemmed hybrids were the more heavily attacked. However, since two different varieties were compared and because the more attractive was also the slower growing, the conditions are not exactly the same as in our experiments. Van Rensburg *et al.* (1988) also experimented with artificial infestations in crops with three different inter-row spacings and showed that the percentage of damaged plants and of larval survival was higher in high density crops. In our experiments, in natural infestation, the percentage of damaged plants did not correlate positively with stand density. In our trials, the low plant density was obtained by increasing the spacing between plants in the row. This suggests that peasant crops should be grown with larger inter-row spacings rather than with reduced plant number within the row.

4.1.2. *E. saccharina* The results are similar to those observed with *B. fusca*: similar borer numbers per stem when no water stress occurs and higher density per stem in the low intensity crop in dry conditions. This development can be compared with observations in sugarcane, a crop severely attacked by *E. saccharina*. Atkinson and Nuss (1989) reported that the borer number per stem was higher in high intensity crops than in peasant-grown crops, and that infestations were higher in crops suffering from water stress. These differences were not caused by higher oviposition but were attributed to an increase in stalk amino acids, which resulted in higher larval survival and shorter development times. In maize crops, infestation ratios are different and water-stressed crops are attacked less. However, nitrogen redistribution from the leaves to the stem and sheaths also occurs in water-stressed maize: senescence of leaves is higher (Barriere and Gay, 1984) and results in an accumulation of amino acids in the stem and the sheaths (Robin 1984). Likewise, the development rate of *E. saccharina* appeared to be quicker in the water-stressed maize plants since 68% of borers had reached at least the last larval instar at 80 d.a.e. versus 44% in the low density crops. Higher infestations should then be observed in water-stressed maize, as in sugarcane, if the oviposition was unchanged in stress conditions. It can then be concluded that, in contrast to *B. fusca* and observations on *E. saccharina* in sugarcane, maize crops suffering from water stress are probably less attractive to adult moths and receive fewer egg batches than crops suffering no stress.

4.1.3. *M. nigrivenella.* The number of *M. nigrivenella* larvae per plant does not seem to be influenced either by the plant growth index or by water stress. This difference from the previous species may be explained by the oviposition behaviour of this cob borer, which is quite different from that of stem borers. *M. nigrivenella* generally lay a few isolated eggs on the cobs (Moyal and Tran, 1989). Its host-plants include various families, not only Graminae or Cyperaceae as is the case in *B. fusca* and *E. saccharina* (Moyal and Tran, 1991b). Moreover, oviposition occurs in this case on fruits, not on leaf sheaths or stems, and can be observed even after the plant has reached full maturity.

4.2. Borer effect on yield

In the low intensity cropping system, the borer effect was significant for yield but not for the yield components studied. This may be explained by the fact that, in this case, the number of grains per plant correlated negatively with the level of attack (Table 6). This yield component was shown to be not directly influenced by borer attacks in high intensity crops (Moyal, 1993). It was even sometimes negatively correlated with yield, i.e. positively correlated with borer attacks. This was because of plant destruction in heavily attacked plots, which resulted in an increase in the grain number in the surviving plants through compensation: this increased to a higher level than in plots protected by insecticide treatments. Here, borer attacks had very little effect either on plant density or on plant sterility. Their action then became clear-cut on the number of grains per plant. In contrast, because of the same compensatory phenomena, the influence of borer attacks on grain filling was not significant. The influence of borers on yield was significantly lower in the low intensity crop than in the high intensity ones. Similar results about yield were achieved by Walker (1960) in eastern Africa, although he used as the independent variable the percentage of maize stalks infested and worked with mixed varieties.

Table 6. Results of the analysis of variance for the number of grains per cob-carrying plant in the low density crop

Treatment	Number of grains	F (4, 12 d.f.) and P-value	Residual standard error	Coefficient of variation
1	425 b			
2	491 a	3·95	27·64	0·06
3	485 a	$P = 0·0287$		
4	451 ab			
5	448 ab			

Figures followed by the same letter are not significantly different with Newman–Keuls test ($p = 0·05$).

Table 7. High density crop suffering from water stress: results of the regression analysis of the percentage of dead-hearts at 60 days after emergence in the experiment versus the estimated percentage reduction of the percentage of harvested plants in high density crops suffering no water stress

b (slope)	$p(>\|t\|)$	R^2	Residual standard error	Test of $b = 1$ $p(>\|t\|)$
0·2439	0·0442	0·2029	2·881	0·0000

In the crop suffering from water stress, borers appeared to have no influence on the percentage of harvested plants. When the percentage of dead-hearts at 60 d.a.e. was observed, which is the cause of the stand density reduction because of borers, a significant regression was achieved (Table 7), with a slope significantly less than $b = 1$. This shows that borers also kill plants in water stress conditions, but less than in rainy conditions. Moreover this result is different from that observed in low density crops since, in this case, the regression for dead-hearts was not significant ($P(>|t|) = 0·259$). The plants with dead-hearts, which would have rotted in rainy conditions, were still present at harvest in water stress conditions, which explains why the percentage of harvested plants was not reduced by borer attacks. These results may be caused by a factor which is not considered in the model and which increases the influence of borers on this yield component in rainy conditions: fungal diseases might be such a factor. Indeed, fungal diseases, which were not thought to be a cause of heavy crop losses in maize since the reduction of American Rust, *Puccinia polysora* Underwood, have recently appeared to cause elevated crop loss in the forest region (Moyal, 1991): fungicide protection increased yield by 30% in the western part, and high incidence of foliar diseases was observed in Bongouanou, in the eastern part. Fungal diseases may therefore be considered as a probable source of the density reduction observed in the forest area during humid periods. Thus, the percentage of harvested plants in pest-free conditions is 99% in the experiment and only 74% in the model. The difference may be caused by fungal damage. The penetration and action of fungi may certainly be encouraged by borer damage and the combined influence of both factors increases plant mortality. Such interactions have been observed between the European corn borer, *Ostrinia nubilalis* Huebner (Lepidoptera, Pyralidae), and various stalk rot pathogens (Keller *et al.*, 1986).

The percentage of cob-carrying plants was decreased by about 15% by the observed water stress (72·5% versus 85·9% in pest-free conditions). This reduction was further increased by borer attacks, whereas the average weight of grain, which was also decreased by the water stress that occurred during grain filling (reduction by 13·4% in pest-free conditions), was not influenced by borer attacks.

The number of grains per cob-carrying plant was in this case correlated neither with the average weight of grain nor with the percentage of cob-carrying plants. But the plot of the differences between the estimated and the observed average weight of grain versus the percentage of cob-carrying plants can be fitted to a significant linear regression ($P(>|t|) = 0{\cdot}0123$) with a negative slope. That shows a compensation phenomenon between these two components: the higher the insect attacks, the lower was the percentage of cob-carrying plants in water stress conditions with respect to no stress conditions. The average weight of grain varied in the opposite direction. An explanation of this fact may be given by the results of Prioul *et al.* (1991), who experimented with cob exicisions: these authors observed that excised plants had a photosynthetic activity which decreases much more quickly than that of healthy plants from the 20th day after excision. Moreover, Ruget (1991) showed that grain filling in high density crops is only slightly linked to plant reserves, but is mainly a result of photosynthetic activity: it can then be concluded that, in fields with few cob-carrying plants, the low photosynthetic activity of the sterile plants decreases the competition of nutrients and consequently encourages a better grain filling in the remaining cob-carrying plants.

These results show the complexity of the relationships between the various yield components through compensation phenomena. It seems logical to suppose that borers have an effect similar to water stress at the plant level: this was recently confirmed for *O. nubilalis* by Godfrey *et al.* (1991). But, at crop level, the relationship is far more complex. For instance, water stress during flowering results in a reduction of the grain number per plant (Claassen and Shaw, 1970). According to our results, borer damage does not result in grain number reduction in high density crops since the stand density is first reduced and compensation occurs for grain number: at crop level the effect of borer damage is then different from that of water stress. It is only when the stand density is not reduced, as in low density crops, that the grain number per plant is decreased by borer attacks, resulting in an effect on the crop similar to water stress.

The present investigation showed that high intensity cropping makes maize crops more attractive to borers, leads to more damage for a given attack level, and greater sensitivity to water stress. This work is a first step toward a better understanding of the complex interactions of stress factors and of their influences on yield and its components. Further studies are needed to determine the optimal plant density level for a particular region and growing season and its relationship to the regime of borer control. More work is also needed to determine the interaction between borers and fungal diseases in relation to maize crop loss in the Ivory Coast.

References

ATKINSON, P. R. and NUSS, K. J., 1989. Associations between host-plant nitrogen and infestation of the sugarcane borer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Bulletin of Entomological Research*, **79**, 489–506.

BARRIERE, Y. and GAY, J. P., 1984. Approche physologique de la sénescence du maïs. In A. Gallais (ed) *Physiologie du Maïs* (Paris: INRA), pp. 355–366.

BECKER, R. A., CHAMBERS, J. M. and WILKS, A. R., 1988. *The New S Language. A Programming Environment for Data Analysis and Graphics* (Pacific Grove: Wadsworth and Brooks/Cole), 702 pp.

BONHOMME, R. and VALANCOGNE, C., 1986. Besoins en eau des cultures aux Antilles. Données générales et synthèse de quelques études. *Bulletin Agronomique INRA Antilles-Guyane.* Numéro spécial *'Besoins en eau des cultures et irrigation aux Antilles'*, **4**, 1–16.

BUONACCORSI, J. P. and LIEBHOLD, A. M., 1988. Statistical methods for estimating ratios and products in ecological studies. *Environmental Entomology*, **17**, 572–580.

CHABALIER, P. F., 1985. Bilan de fumures sous cultures de mais dans le centre la Côte d'Ivoire. *L'Agronomie Tropicale*, **40**, 253–259.

CHAMBERS, J. M. and HASTIE, T. J., 1992. *Statistical Models in S* (Pacific Grove: Wadsworth and Brooks/Cole), 608 pp.

CIDT (Compagnie Ivoirienne pour le Développement des fibres Textiles), 1984. *Rapport Annuel d'Activité* (Bouaké: CIDT), 178 pp.

CIDT (Compagnie Ivoirienne pour le Développment des Fibres Textiles), 1988. *Rapport Annuel d'Activité (synthèse). Campagne 1987–88* (Bouaké: CIDT), 92 pp.

CLAASSEN, M. M. and SHAW, R. H., 1970. Water deficit effects on corn. II. Grain components. *Agronomy Journal*, **62**, 652–655.

DABIRE, L., 1980. Biologie et écologie *d'Eldana saccharina* Walker (Lepidoptera, Pyralidae, Galleriinae) foreur du maïs en Côte d'Ivoire et inventaire des autres Lépidoptères foreurs du maïs. Thèse de doctorat de troisième cycle (Paris: Université Pierre et Marie Curie), 196 pp.

GIGOU, J., 1987. L'adaptation des cultures dans le centre de la Côte d'Ivoire. *L'Agronomie Tropicale*, **42**, 1–12,

GODFREY, L. D., HOLTZER, T. O. and NORMAN, J. M., 1991. Effects of European Corn Borer (Lepidoptera: Pyralidae) tunnelling and drought stress on field corn gas exchange parameters. *Journal of Economic Entomology*, **84**, 1370–1380.

IDESSA (Institut des Savanes), 1982. *Variétés de maïs recommandées en Côte d'Ivoire. Note technique* (Bouaké: IDESSA), 11 pp.

JONES, H. G., 1992. *Plants and Microclimate. A Quantitative Approach to Environmental Plant Physiology* (Cambridge: Cambridge University Press), 428 pp.

KELLER, N. P., BERGSTROM, G. C. and CARRUTHERS, R. I., 1986. Potential yield reduction in maize associated with an Anthracnose/European Corn Borer pest complex in New York. *Phytopathology*, **76**, 586–589.

MONTENY, B. A. and LHOMME, J. P., 1980. *Eléments de bioclimatologie. Note Technique* (Adiopodoumé: ORSTOM), 90 pp.

MOYAL, P., 1988a. Crop losses due to insects in the savannah area of Ivory Coast: a review. *Tropical Pest Management*, **34**, 455–459.

MOYAL, P., 1988b. *Les foreurs du maïs en zone des savanes en Côte d'Ivoire. Données morphologiques, biologiques, écologiques. Essais de lutte et relation plante-insecte. Collection Etudes et Thèses (Paris: ORSTOM), 368 pp.*

MOYAL, P., 1991. *Les maladies fongiques foliaires du maïs en Côte d'Ivoire et leur importance en diverses conditions de culture. Note technique* (Bouaké: IDESSA–ORSTOM), 21 pp.

MOYAL, P., 1993. Un modèle statistique des pertes de récolte dues aux foreurs des tiges de maïs en Côte d'Ivoire. In P. Moyal *Modelisation Statistique des Pertes de Récolte Dues aux Foreurs du Maïs en Côte d'Ivoire* (Paris: ORSTOM), pp. 5–26.

MOYAL, P., 1995. *Ecology of* Busseola fusca *(Fuller) (Lepidoptera: Noctuidae) in Côte d'Ivoire. Note technique* (Paris: ORSTOM), 23 pp.

MOYAL, P. and TRAN, M., 1989. Etude morphologique des stades pré-imaginaux des Lépidoptères foreurs du maïs en zone des savanes de Côte d'Ivoire. *Annales de la Société Entomologique de France (N.S.)*, **25**, 461–472.

MOYAL, P. and TRAN, M., 1991a. Cob borer *Mussidia nigrivenella* Ragonot (Lepidoptera, Pyralidae) of maize in Ivory Coast. I—Morphological and biological data. *Insect Science and its Application*, **12**, 208–214.

MOYAL, P. and TRAN, M., 1991b. Cob borer *Mussidia nigrivenella* Ragonot (Lepidoptera, Pyralidae) of maize in Ivory Coast. II—Ecological data. *Insect Science and its Application*, **12**, 215–223.

MOYAL, P. and TRAN, M., 1992. *Chilo aleniellus* (Lepidoptera: Pyralidae), a stem borer of maize in Côte d'Ivoire. *Bulletin of Entomological Research*, **82**, 67–72.

POLLET, A., ROON VAN, N. and MAURITZ, R., 1978, Les ravageurs du maïs en Côte d'Ivoire. Données quantitatives et qualitatives pour la Basse Côte. *Cahiers de l'Office de Recherche Scientifique et Technique Outre-mer, serie Biologie*, **13**, 71–85.

PRIOUL, J. L., REYSS, A. and SCHWEBEL-DUGUE, N., 1991. Métabolisme carboné dans les feuilles sources lors de la phase de remplissage des grains: recherche de critères de remobilisation et de sénescence. In D. Picard (ed) *Physiologie et Production du Maïs* (Paris: INRA), pp. 239–244.

RENSBURG VAN, J. B. J., WALTERS, M. C. and GILIOMEE, J. H., 1988. Plant population and cultivar effects on yield losses caused by the maize stalk borer, *Busseola fusca* (Lepidoptera: Noctuidae). *South African Journal of Plant and Soil*, **5**, 215–218.

RENSBURG VAN, J. B. J., WALTERS, M. C. and GILIOMEE, J. H., 1989. Selective oviposition by the maize stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *Journal of the Entomological Society of South Africa*, **52**, 105–108.

ROBIN, P., 1984. Assimilation du nitrate et remobilisation de l'azote proteique. In A. Gallais (ed) *Physiologie du Maïs* (Paris: INRA), pp. 241–277.

ROUANET, G., 1987. Le maïs en zone tropicale. *Agritrop*, **11**, 63–69.

RUGET, F., 1991. Origine des assimilats pour le remplissage des grains: importance des remobilisations. In D. Picard (ed) *Physiologie et Production du Maïs* (Paris: INRA), pp. 233–238.

SATMACI (Société d'Assistance Technique pour la Modernisation de l'Agriculture de la Côte d'Ivoire), 1986. *Projet agricole centre-ouest. Programme maïs* (Daloa: SATMACI), 22 pp.

TOMASSONE, R., LESQUOY, E. and MILLIER, C., 1983. *La régression. Nouveaux Regards sur une Ancienne Méthode Statistique* (Paris: Masson), 180 pp.

WALKER, P. T., 1960, The relation between infestation by the stalk borer, *Busseola fusca*, and yield of maize in East Africa. *Annals of Applied Biology*, **48**, 780–786.