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Effect of Controlled Fertilization on Crop Resistance to Stem Borers: Case of Sugarcane at the Borotou-Koro Integrated Agricultural Unit (North-West Côte d'ivoire)

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Abstract: The stem borer *Eldana saccharina* Walker (*Lepidoptera: Pyralidae*) is a major limiting factor in sugarcane production in Côte d'Ivoire, while yield is also reduced by poor soil quality. Borer management options include multiple approaches, including the proper application of chemical inputs. In such a context, it was interesting to study the effect of reasoned fertilization on the defence responses of sugarcane to *Eldana saccharina*. 3 plots divided into several microplots were used for experimentation. Each plot was subdivided into 3 blocks and each block received a dose based on soil analyses and the objective set. A significant reduction in damage caused by stem borers was observed on the T_1 microplots due to the low rate of fertilizer applied, with average attack rates ≤ 10% overall. It should also be noted that the treatments that received urea alone had attack rates in the order of 6 to 7% unlike the treatments where urea was combined with other types of fertilizer. In fact, nitrogen is not only a factor in sugarcane yield but also a key element in the development of stalk borer larvae if it is not applied in an appropriate manner. While agro-ecological pest management, unlike conventional pest management, does not provide a faster response, it can provide sustainable protection of crops against stem borers while preserving the environment. In this respect, applications of silicon-based fertilizers, the installation of light traps and the application of essential oil against stem borers should be a feature of the next agricultural seasons in Borotou-Koro.

Keywords: Reasoned Fertilization, Stalk Borers, Sugarcane, Côte d'Ivoire

1. Introduction

Sugar cane (*Saccharum sp.*), the most important sugar and energy crop originating from tropical areas, is a herbaceous and perennial crop, with high biomass, due to its high capacity to accumulate sucrose in the stalks and its high biomass yield. It is widely cultived in more than 100 countries in tropical and subtropical regions, with a total area of around 27 million hectares [1]. Annual world production is around 1.95 billion tonnes of fresh sugarcane, which provides almost 80% of sugar, 60% of bioethanol and a total economic value of 75 billion US dollars [2]. It is the main source of gross domestic product (GDP) in many developing countries [3]. In most of these countries, stalk borers are economically important pests, because they significantly reduce the yields yields of many crops such as sugarcane [4].

Several Lepidoptera species causing such damage belong to the genera *Chilo, Sesamia, Diatraea* and *Eldana.* The African stalk borer *E. saccharina* Walker (*Lepidoptara: Pyralidae*) is known as the main insect pest of sugarcane, whose larvae bore galleries into sugarcane stalks [5, 6], especially in their lower parts [7]. This damage to the stem tissue, which is then infected by fungal species (*Fusarium spp.*), is characterized by a dark red discoloration of the tissues surrounding the galleries [8]. This results in a loss of gross cane weight and a reduction in cane juice quality. Losses associated with plant diseases represent a high economic burden, with an estimated annual loss of $220 billion [9].

Effective management of Lepidoptera as part of area-wide pest control programs is multi-strategic and requires several ecologically sound control methods [10]. An environmentally-friendly method is biological control by releasing parasitic hymenoptera to control lepidoptera (borers) [11]. Another is the use of essential oils. Resistance-enhancing strategies have been developed to limit the damage caused by stem borers: cultural control, which includes optimal management practices helping to prevent infestations (e.g. rotation); physical control, which includes techniques whose primary mode of action involves no biological, biochemical or toxicological processes (e.g. manual removal of infested plants); and genetic control, which enables the selection of naturally resistant varieties. However, in most cases, the use of plant protection products proves to be the most effective solution. This is known as chemical control. But this control strategy is increasingly challenged by its negative impact on the environment and human health. Indeed, the direct impact lies in the destruction of living organisms, whether or not they are targeted by these products.

A range of plant protection methods based on natural mechanisms is currently being developed. Biocontrol is based on managing the equilibrium of plant pathogen populations, rather than eradicating them. Through the use of antagonistic microorganisms, biological control makes it possible to combat pathogens, but its efficacy is more proven against pests, and remains inferior to that of pesticides in the case of microorganisms [12].

Another proposed strategy for controlling sugarcane stem borers is the application of silicon to the soil. It confers resistance by improving crop health [13-15]. Soil enrichment with soluble silicon is a crop management technique that promotes plant growth and improves resistance to arthropod pests [15].

The adverse consequences of intensive farming have led to the development of sustainable agriculture, which aims to ensure that agricultural production is economically viable, socially equitable and does not harm the environment or human health. Among the applications implemented for sustainable agriculture, the European Nitrate Directive, created in the 90s, aims to reduce water pollution by nitrates of agricultural origin. On the other hand, limiting the use of pesticides on crops is part of the challenge of sustainable agriculture, which authorizes the use of phytosanitary products, but in a reasonable manner, only if they are really necessary, and gives priority to biological treatments.

In the context of low-input agriculture, it was of interest to study the effect of reducing the application of chemical inputs on sugarcane resistance to stalk borers. Experiments were carried out in open fields, on industrial plots.

2. Materials and Methods

2.1. Presentation of Study Area

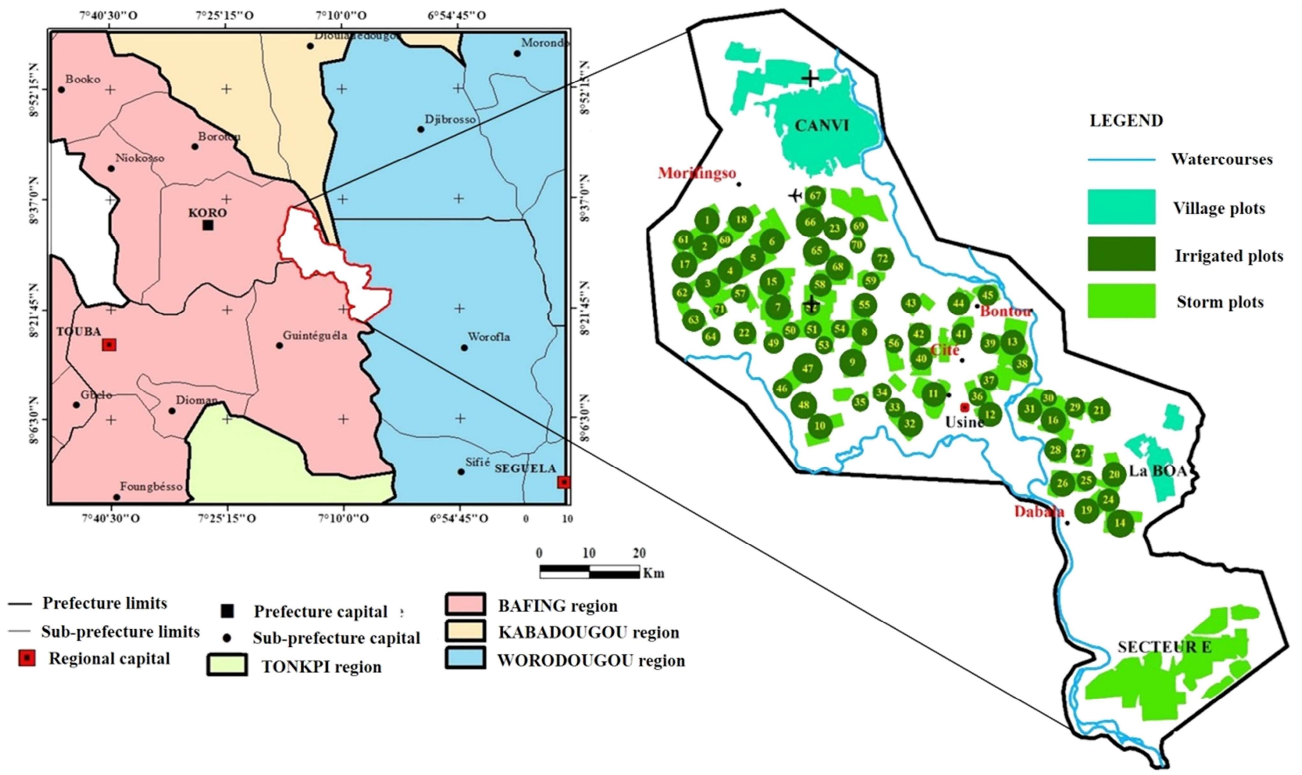


Figure 1. Location of study area.

Integrated Agricultural Unit of Borotou-Koro is located in the northwest of Côte d'Ivoire, in West Africa, and is one of the main sugarcane production areas. Formerly the Borotou-Koro sugar complex, Integrated Agricultural Unit of Borotou-Koro is located 842 km from Abidjan. It is geographically located between coordinates 8°36'11" and 8°21'33" latitude North, and 7°17'41" and 7°5'49" longitude West (Figure 1). The climate is Sudano-Guinean, tropical humid, with two seasons: the rainy season, the longest, from April to October, and the dry season, from November to March. The dominant vegetation in Borotou-Koro is shrub and herb savannah, separated by patches of forest and gallery forest along the watercourses [16]. The fauna is highly diverse. Indeed, this wild fauna includes many species harmful to sugarcane. These include duikers and rodents. Borotou-Koro is characterized by a relief generally made up of flat plateaus, 200 to 400 m high. The relief is fairly flat and monotonous, with large plains [16]. From a hydrological point of view, Borotou-Koro is drained by two rivers, the Bagbe and the Boa, which join the Sassandra River, of which they are two tributaries. Sugar cane is grown here by Sucrivoire, cooperatives and small growers.

2.2. Plant Material

The sugarcane varieties used in our experiments are SP711406 and R570. SP711406, a variety of Brazilian origin, is a cross between SP83/5073 and NA56/79. Popularized since 2007/2008 in Borotou-Koro, it is a variety adapted to the pedoclimatic conditions of the study site; it has a very good germination rate, vigorous growth, with medium to large diameter stems and medium tillering (60,000 to 70,000 stems/ha), good sucrose content (SE%C) [17]. R570 is a sugarcane cultivar developed in 2009 on Réunion Island in the south-western Indian Ocean. As its name suggests, it is the 570th variety developed on this territory. It has very good vegetative vigor (high production per hectare in virgin and especially in regrowth), good sugar content and high purity, sufficient resistance to certain diseases such as smut... These two varieties are expanding rapidly in Borotou-Koro, occupying more than half the area under cane, with a rate of 51.5% (R570 34.5% and SP711406 17%).

2.3. Chemical Fertilizers

Chemical fertilizers, in the form of NPK (18 - 9 - 24 + 2.5S + 2MgO), potassium chloride 60% urea 46% Diammonium Phosphate (DAP 18/46) and kieserite (magnesium sulfate monohydrate), were the primary factors in the experiment. They were applied to the furrows before planting in year N and after cutting in year N+1.

2.4. Processing and Experimental Set-up

2.4.1. Experimental Setup

Experiments were conducted using a complete block design (Figure 2), with 30 * 30 m elementary plots, i.e. 900 m^2 per microplot.

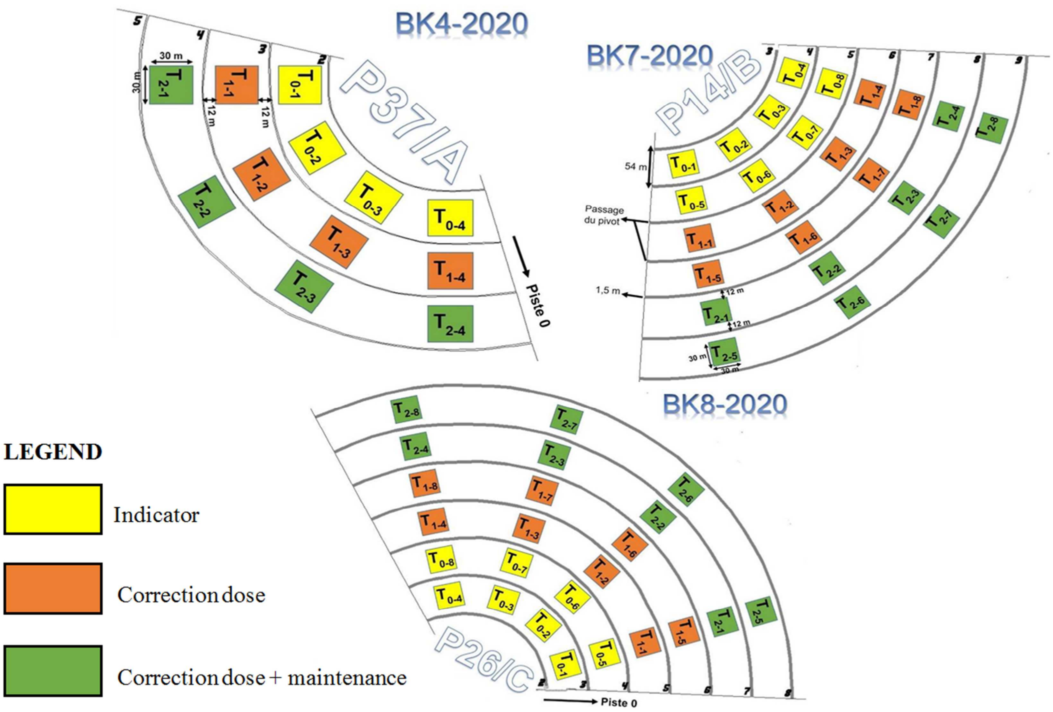


Figure 2. *Diagram of the experimental set-up.*

2.4.2. Treatment

There are three levels of treatment:

1) T_0 = the control, NPK (18.5 - 9 - 24 + 2.5S + 2MgO), commonly used,
2) T_1 = the correction dose,

3) T_2 = the correction dose + maintenance dose to reach 100 tonnes of sugarcane per hectare.

To detect different doses of these treatments, the soils at the experimental sites were characterised using the method of Jahn *et al.* [18]. Before and after the experimental set-up, samples were taken crosswise along two median lines of each experimental plot. Samples from the same plot were mixed to form a composite sample. These composite samples were subjected to laboratory analysis in accordance with AFNOR standards NF X31-107, NF ISO 10694, NF ISO 13878, AFNOR NF X31-130 and NF ISO 11263 [19].

These applications were made during the sugarcane growing cycle: most were applied at the bottom of the furrow before planting, and urea was applied 45 days after planting in year N. However, in year N+1, these applications were made in the field just after cutting.

These different levels are listed in table 1, table 2 and table 3.

Table 1. *Dose of fertilizer applied by BK4 treatment in year N and N+1.*

Plot	Treatment	Mineral fertilizers (Kg. ha^{-1})									
		NPK		Urea		KCl		DAP		Kieserite	
		N	N+1	N	N+1	N	N+1	N	N+1	N	N+1
BK4 (12 ha)	T_0	800	800	-	-	-	-	-	-	-	-
	T_1	-	-	260.87	260.87	258	-	-	-	2	-
	T_2	-	-	255.94	224.05	666.67	566.67	27.36	204.55	194.38	192.31

Table 2. *Dose of fertilizer applied by BK7 treatment in year N and N+1.*

Plot	Treatment	Mineral fertilizers (Kg. ha^{-1})									
		NPK		Urea		KCl		DAP		Kieserite	
		N	N+1	N	N+1	N	N+1	N	N+1	N	N+1
BK7 (25 ha)	T_0	800	800	-	-	-	-	-	-	-	-
	T_1	-	-	260.87	260.87	-	-	66.83	-	-	-
	T_2	-	-	219.57	305.16	105.12	105.12	616.77	464.88	-	-

Table 3. *Dose of fertilizer applied by BK8 treatment in year N and N+1.*

Plot	Treatment	Mineral fertilizers (Kg. ha^{-1})									
		NPK		Urea		KCl		DAP		Kieserite	
		N	N+1	N	N+1	N	N+1	N	N+1	N	N+1
BK8 (27 ha)	T_0	725	725	-	-	-	-	-	-	-	-
	T_1	-	725	256.81	-	90.34	-	22.54	-	-	-
	T_2	-	725	221.60	-	657.01	-	218.19	-	-	-

2.4.3. Calculation of Correction Dose (T_1)

Chemical analysis of plantation soil is used to determine fertilizer requirements. As a preliminary step, soil samples were taken and the dry bulk density (DBD) at each sampling point was determined. The adjustment dose was obtained by calculating, between the soil analysis, the threshold value and the fine soil mass. The calculation formula is as follows:

$$\text{Correction dose} = [((\text{Threshold} - \text{Soil analysis}) * \text{Conversion coefficient}) * \text{Fine earth mass}] \quad (1)$$

Threshold = (CEC * 4) /100 for K; (CEC * 6) /100 for Mg and (CEC * 60) /100 for Ca,

Fine earth mass = soil volume (m^3) * bulk density (t/m^3) * fine soil content (%)

Conversion coefficient = 1meq K^+ = 470 ppm = 470 mg.kg$^{-1;}$ 1meq Mg^{2+} = 200 ppm = 200 mg.kg$^{-1;}$ 1 meq Ca^{2+} = 280 ppm = 280 mg.kg^{-1}.

2.4.4. Calculation of Maintenance Correction Dose (T_2)

According to Cirad, to reach 100 tonnes per hectare, sugar cane needs 120 fertiliser units of nitrogen, 90 of phosphorus, 340 of potassium, 50 of magnesium and 38 of sulphur [20].

First of all, the doses of fertilizing units to be applied were defined on the basis of a soil analysis. To calculate this dose, it was essential to determine the quantity of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) required by the sugar cane available in the soil. All the above-mentioned quantities constituted the correction dose. These quantities are then compared with the nutritional requirements of sugarcane to reach 100 t. ha^{-1} (either in excess or in deficit), enabling the dosage of fertilizing units to be determined. In the case of an excess, if the surplus is less than the latter, the dosage of fertilizing units is equal to the sugarcane's nutrient requirement to reach 100 t. ha^{-1}. Otherwise, it will be zero. On the other hand, when a deficit occurs, a fertilizing unit dosage equal to the correction dosage is added to the sugarcane's nutrient requirements, up to 100 t. ha^{-1}.

Once the fertilizer unit requirements are known, we can find out the fertilizer dosage that represents the commercial product. The quantity of fertilizer required is calculated by dividing the nutrient requirements by the nutrient concentration of the fertilizer. We calculate the quantity of fertilizer to be applied and then calculate the quantity per hectare. The final contribution of the commercial product (kg. ha^{-1}) is calculated as follows:

$$\text{Phosphorus} = (\text{Dose of fertilizer units} * 100) / 44 \quad (2)$$

Nitrogen = (Dose of fertilizer units * 100 / 46) - (final phosphorus contribution * 18 / 100) (3)

Potassium = (Dose of fertilizer units * 100) / 60 (4)

Magnesium = (Dose of fertilizer units * 100) / 27 (5)

2.5. Statistical Analysis

Descriptive statistical analysis enabled us to determine the overall mean and coefficients of variation of these parameters. Analysis of variance was used to test the hypothesis of an influence of fertilizer doses on the parameters studied. The Newman-Keuls test was used to perform multiple comparisons of means at the 5% threshold. These analyses were carried out using XLStat version 2016 software. Parameters were tested for significance and normality using the Shapiro-Wilk and Bartlett tests (P <0.05) with Rstudio software. Data were subjected to analysis of variance (ANOVA), Newman-Keuls test (P <0.05) in quantitative variables. Agricultural and sugar productivity and technological attributes were evaluated according to sugarcane varieties and mineral fertilization. Data were subjected to analysis of variance, and the Newman-Keuls test (P <0.05) was applied to variables in which the main effects and/or interactions were significant.

3. Results

3.1. Effect of Fertilizer Application on Agronomic Parameters

The Newman and Keuls test for comparison of means at the 5% threshold, following the analysis of variance for the year N trials, showed that for trial BK4, only the number of stems per hectare and the rate of internodes attacked showed significant differences. Trial BK7 showed no significant difference. Finally, the third trial, BK8, was significantly different only in height (table 4, table 5 and table 6).

Table 4. *Average values of agronomic parameters in BK4 trials in year N according to treatments.*

Plot	Treatments	Yield (t. ha^{-1})	Stem/ha	Flowering (%)	Height (m)	IA
	T_0	98.33 a	91499 a	7.36 a	333.20 a	24.94 b
BK4	T_1	109.44 a	103499 b	10.80 a	303.55 a	12.28 a
	T_2	88.21 a	94499 ab	12.12 a	283.97 a	17.03 ab
	Pr > F	0.51	0.03	0.35	0.09	0.03
	Significance	No	Yes	No	No	Yes

*IA= internodes attacked (%)

Table 5. *Average values of agronomic parameters in BK7 trials in year N according to treatments.*

Plot	Treatments	Yield (t. ha^{-1})	Stem/ha	Flowering (%)	Height (m)	IA
	T_0	97.81 a	90874 a	5.82 a	317.62 a	11.03 a
BK7	T_1	89.58 a	88749 a	6.86 a	315.77 a	10.35 a
	T_2	88.97 a	91124 a	5.20 a	311.13 a	11.96 a
	Pr > F	0.58	0.82	0.78	0.64	0.77
	Significance	No	No	No	No	No

*IA= internodes attacked (%)

Table 6. *Average values of agronomic parameters in BK8 trials in year N according to treatments.*

Plot	Treatments	Yield (t. ha^{-1})	Stem/ha	Flowering (%)	Height (m)	IA
	T_0	77.72 a	69249 a	1.80 a	286.95 b	11.12 a
BK8	T_1	67.53 a	68249 a	1.28 a	265.83 ab	9.19 a
	T_2	75.18 a	69999 a	0.34 a	250.43 a	9.06 a
	Pr > F	0.99	0.84	0.34	0.035	0.73
	Significance	No	No	No	Yes	No

*IA= internodes attacked (%)

The Newman and Keuls test for comparison of means at the 5% threshold, following the analysis of variance for year N+1 trials, showed that for BK4, only elongation and the rate of attacked internodes showed significant differences. BK7 and BK8 showed no significant differences (table 7, table 8 and table 9).

Table 7. *Average values of agronomic parameters in BK4 trials in year N+1 according to treatments.*

Plot	Treatments	Yield (t. ha^{-1})	Stem/ha	Flowering (%)	Height (m)	IA
	T_0	119.06 a	77999 a	1.71 a	265.23 a	14.77 ab
BK4	T_1	123.67 a	87499 a	10.17 a	298.40 b	7.87 a
	T_2	137.61 a	91249 a	10.63 a	287.28 b	22.46 b
	Pr > F	0.44	0.13	0.05	0.002	0.013
	Significance	No	No	No	Yes	Yes

*IA= internodes attacked (%)

Table 8. *Average values of agronomic parameters in BK7 trials in year N+1 according to treatments.*

Plot	Treatments	Yield (t. ha^{-1})	Stem/ha	Flowering (%)	Height (m)	IA
	T_0	90.75 a	80249 a	18.23 a	277.34 a	9.41 a
BK7	T_1	90.39 a	76374 a	16.32 a	278.35 a	6.86 a
	T_2	93.89 a	84999 a	12.21 a	263.71 a	9.41 a
	Pr > F	0,93	0.21	0.45	0.71	0.49
	Significance	No	No	No	No	No

*IA= internodes attacked (%)

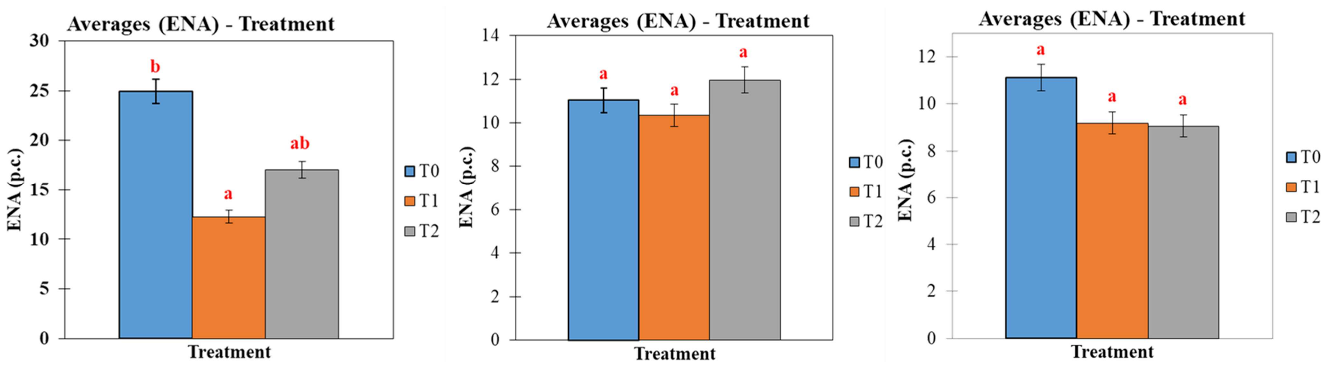
Table 9. *Average values of agronomic parameters in BK8 trials in year N+1 according to treatments.*

Plot	Treatments	Yield (t. ha^{-1})	Stem/ha	Flowering (%)	Height (m)	IA
	T_0	107.22 a	74874 a	12.57 a	267.63 a	11.44 a
BK8	T_1	104.11 a	75499 a	13.78 a	273.21 a	8.03 a
	T_2	97.39 a	73499 a	14.22 a	269.40 a	7.54 a
	Pr > F	0.63	0.94	0.91	0.76	0.32
	Significance	No	No	No	No	No

*IA= internodes attacked (%)

3.2. Average Rate of Internodes Attacked by Stem Borers in Year N

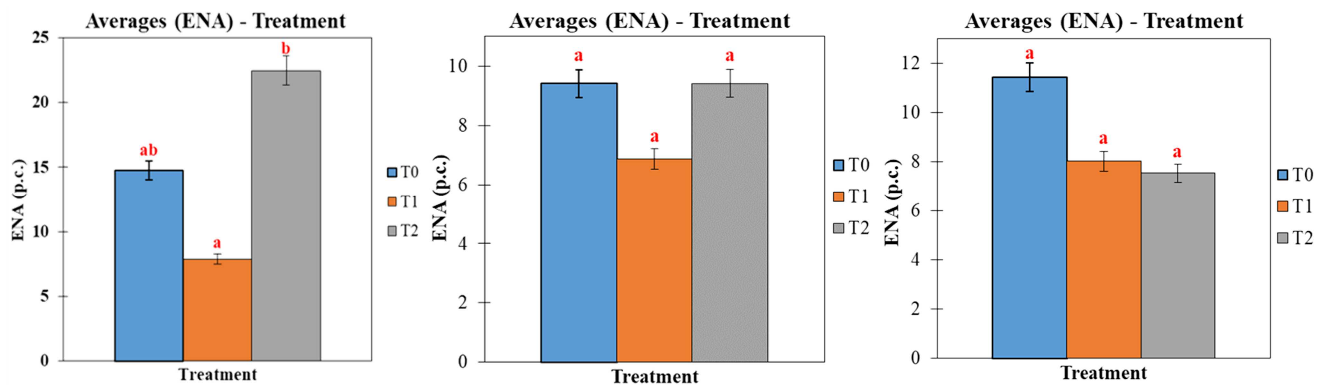
Treatment T_1 in trial BK4 was the least attacked by stem borers, with an attack rate of 12.28%, unlike treatments T_0 and T_2, which had attack rates of 24.94 and 17.03% respectively. Treatment T_1, also from the BK7 trial, was the least attacked, with an attack rate of 10.35%, unlike treatments T_0 and T_2, which had attack rates of 11.03 and 11.96% respectively. Finally, treatment T_2 was the least attacked treatment, with an attack rate of 9.06%, unlike treatments T_0 and T_1, which had attack rates of 11.12 and 9.19% respectively (Figure 3).



a b c

Figure 3. *Average rate of attacked internodes according to treatments in the first year of experimentation (a: BK4; b: BK7; c: BK8.).*

3.3. Average Rate of Internodes Attacked by Stem Borers in Year N+1



a b c

Figure 4. *Average rate of attacked internodes according to treatments in the second year of experimentation (a: BK4; b: BK7; c: BK8).*

In addition, treatment T_1 in the BK4 trial was the least attacked with an attack rate of 7.87% unlike treatments T_0 and T_2, which recorded attack rates of 14.77 and 22.46% respectively. Also, treatment T_1 in the BK7 trial was the least attacked with an attack rate of 6.86% unlike treatments T_0 and T_2, which both recorded attack rates of 9.41% Finally, treatment T_2 in the BK8 trial was the least attacked treatment with an attack rate of 7.87% unlike treatments T_0 and T_2, which both recorded attack rates of 9.41% in contrast to treatments T_0 and T_2 which both recorded attack rates of 9.41% Finally, treatment T_2 in the BK8 trial was the least attacked treatment with an attack rate of 7.54% in contrast to treatments T_0 and T_1 which recorded attack rates of 11.44 and 8.03% respectively (Figure 4).

4. Discussion

The rate of stem borer attack on internodes was highest on microplots receiving NPK. At Borotou-Koro, mineral fertilizers are applied every year at the same dosage and with the same formula, without taking account of soil heterogeneity [16, 17]. Mineral fertilizers with formulas of 18.5 - 9 - 24 + 2MgO were applied to rainfed, single-row irrigated and double-row irrigated plots at rates of 325, 725 and 800 kg. ha^{-1} respectively after each harvest. In total, 800 kg. ha^{-1}, 520.87 kg.ha^{-1} and 1144.35 kg.ha^{-1} were applied to treatments T_0, T_1 and T_2 of BK4 in the first year, respectively. Similarly, treatments T_0, T_1 and T_2 of BK7 were treated with 800 kg. ha-1, 327.7 kg.ha^{-1} and 941.46 kg.ha^{-1} of fertilizer respectively. In the same year, treatments $T_{0,}$ T_1 and T_2 of BK8 were fertilized with 725 kg. ha^{-1}, 369.69 kg.ha^{-1} and 1096.8 kg.ha^{-1} respectively. The same scene was repeated in year N+1. Treatments T_0, T_1 and T_2 of BK4 received 800 kg. ha^{-1}, 260.87 kg.ha^{-1} and 1187.58 kg.ha^{-1} respectively. Treatments T_0, T_1 and T_2 of BK7 received 800 kg. ha^{-1}, 260.87 kg.ha^{-1} and 875.16 kg.ha^{-1} respectively. Finally, treatments T_0, T_1 and T_2 of BK8 each received 725 kg. ha^{-1}. It should be noted that it was only in year N that T_1 received fertilizers other than urea, unlike year N+1 when T_1 only received urea as a fertilizer dose.

Too much fertilizer applied to treatments T_0 and T_2, unlike treatment T_1, damaged the resilience of the cane stalk to pest attack. It has been shown that the annual fertilizer load on the soil has harmful long-term effects. Over time, the nitrogen cycle can be disrupted and associated bacterial populations altered [21]. Excessive use of chemical fertilizers can also damage soil quality and structure. In addition, soil pH is likely to fall over the years, which has a knock-on effect on bacterial diversity, lowering it and making sugar cane more susceptible to disease and pests. In the long term, the current use of fertilizers in Borotou-Koro will cause serious damage to the health of the crop, which may take several years to reverse. Such damage will limit future crop yields. It is therefore important to address fertilizer use and adopt more sustainable practices, including spreading fertilizer when and where it is needed.

A significant reduction in stem borer damage was observed on the microplots with T_1 treatment, due to the low rate of fertilizer applied. These results were corroborated by [22] in Ferke, and particularly in the Ferke 1 plantation. According to him, the lower fertilizer rates applied to the cane soils partly explain the 25 to 30% reduction in *E. saccharina* attacks. According to Péné Bi *et al.,* excessive fertiliser use is the main cause of E. saccharina attacks [22]. Evidence of the relationship between fertilizer and damage caused by *E. saccharina* was demonstrated by in South Africa [23].

In sugarcane, *E. saccharina* infestations can be exacerbated by high nitrogen and water stress [23]. Growers have therefore been encouraged to reduce their fertilizer applications by 10 to 30 kg N. ha^{-1}, depending on the N mineralisation potential of the soil and the likelihood of water stress and borer infestation [24]. There is, however, a yield penalty associated with this practice and it is increasingly recognised that farmers need to return to recommended fertilizer rates that will optimise yields but not run the risk of borer damage [25, 26].

Nitrogen was applied to the treatments 45 days after planting for the first experiment, and at the bottom of the furrow for the second. Damage levels were higher when N was applied early in the sugarcane growth stage, as internodes were more likely to be attacked by stem borers, confirming the results obtained by Goebel *et al.* [27]. Nitrogen is not only a factor in sugarcane yield but also a key element in the development of stalk borer larvae, explains [28]. It is therefore important to control the nitrogen dosage in future fertilizer formulations at Borotou-koro.

Various studies on sugarcane borers have shown their relative sensitivity to local agro-ecological conditions, particularly farming practices. The loss of sugar due to this pest is estimated at 40 to 70% of the rate of internodes attacked by the borer [29]. Damage in South Africa varies from 6 to 10 million euros [30]. In SUCRIVOIRE plantations in Côte d'Ivoire, the fight against this bio-invader is based on prevention. This includes heat treatment and chemical treatment of cuttings intended for primary and secondary planting in nurseries, which will be used for industrial planting. On the other hand, this battle mainly involves selecting sugar cane varieties that are tolerant, or even resistant, to pest attacks. Nevertheless, early harvesting to avoid the build-up of economically damaging infestations, together with other cultural practices, the most important of which is the use of resistant cultivars [31], remain the most widely used tactics for controlling stalk borers.

A regional workshop on stem borer control for West and Central Africa, held in Ferké (Côte d'Ivoire) at the end of March, raised the awareness of key players in high-end sugar companies. Implement an integrated approach to achieve their objectives effectively. This includes the use of tolerant varieties resistant to stem borer attacks, good fertilizer application strategies, a multitude of landscapes needed to enhance the biodiversity of flora and fauna, and the use of agricultural products that protect the natural enemies of insect pests. This is the case of mechanised green harvesting of sugar cane with waste cover, which has been practised at Borotou-Koro for 2 years now. Since then, 25% of the sugar cane plantations in Borotou-Koro, i.e. 3,000 hectares, have been subjected to this practice. Although agro-ecological pest control, unlike conventional pest control, does not enable us to react more quickly, it can ensure sustainable protection of crops against stem borers while preserving the environment. In this respect, the application of silicon-based fertilizers, the installation of light traps and the application of essential oil against stem borer at various critical locations on sugarcane plantations should be a feature of the coming agricultural campaigns as far afield as Borotou and Koro.

5. Conclusion

This study was prompted by the extent of damage caused by stalk borers (*E. saccharina*) observed at harvest time in the sugarcane fields of Borotou-Koro over the last five years. The aim was to analyse the level of this damage after good fertilisation and to recommend appropriate control strategies. The result of the present study is that stem borer damage was lower in the T_1 microplots that received less mineral fertilizer, in particular 520.87, 327.70 and 369.69 kg. ha^{-1} of fertilizer in the BK4, BK7 and BK8 trials obtained in the first experiment. Unlike T_0, which received the usual amounts of fertilizer in the 3 trials. Finally, T_2 received the highest doses of fertilizer. These results confirm those obtained in various countries, where the addition of fertilizer based on the bioavailability of mineral elements showed positive interaction effects in reducing the level of stem borer infestation.

In addition, all the factors that can control stem borer populations, such as their natural enemies (parasites, predators), the use of agricultural practices in sugar cane such as mechanical green harvesting, essential oils and the cultivation of utilities close to sugar cane are suggested, which will undeniably strengthen the fight against these attacks in the years to come.

References

[1] Lu G., Wang Z., Xu F., Pan Y. B., Grisham M. P., Xu L. (2021). Sugarcane Mosaic Disease: Characteristics, Identification and Control. Microorganismes 9 (9): 1984. doi: 10.3390/microorganisms9091984. PMID: 34576879; PMCID: PMC8468687. 19 p.

[2] FAO (2019). http://www.fao.org/faostat/zh/#data/, consulté le 4 décembre 2022.

[3] Goebel F. R., Beuzelin J. M., Way M. J. (2018). Progress in understanding and managing insect pests affecting sugarcane. In: Achieving sustainable cultivation of sugarcane. Vol 2: Breeding, pest and diseases. P Rott (eds), University of Florida, Burleigh Dodds series in Agric. Sci.: pp. 363-394.

[4] Kleynhans, Barton M. G., Conlong D. E., Terblanche J. S. (2017). Population dynamics of Eldana saccharina Walker (Lepidoptera: Pyralidae): application of a biophysical model to understand phonological variation in an agricultural pest. Bull. Entomol Res. 108: pp. 283-294.

[5] Potgieter L., Van Vuuren J. H., Conlong D. E. (2016). Simulation modelling as a decision support in developing a sterile insectinherited release strategy for Eldana saccharina (Lepidoptera: Pyralidae). Florida Entomol. 99 (1), pp. 13-22.

[6] VanWeelden M. T., Wilson B. E., Beuzelin J. M., Reagan T. E., Way M. O. (2016). Impact of nitrogen fertilization on Mexican rice borer (Ledoptera: Crambidae) injury and yield in bioenergy sorghum. Crop Protection 84: pp. 37-43.

[7] Juma G., Ahuya P. O., Ong'amo G., Ru B. l., Magoma G., Silvain J. F., Calatayud P. A. (2015). Influence of plant silicon in Busseola fusca (Lepidoptera: Noctuidae) larvae – Poaceae interactions. Bull. Entomol Res. 105: pp. 235-248.

[8] Tomaz A., Coutinho A., Soares B., Peternelli L., Pereira E. et Barbosa M. (2018). Évaluation de la résistance des variétés de canne à sucre au foreur de la canne à sucre Diatraea saccharalis Fab. (Lépidoptères: Crambidae). Bulletin de recherche entomologique, 108 (4), pp. 547-555.

[9] FAO (2019). New standards to curb the global spread of plant pests and diseases. Web page of the Food and Agriculture Organization of the United Nations. Disponible sur: https://www.fao.org/news/story/en/item/1187738/icode/

[10] Guerrero A., Reddy G. V. P. (2023). Communication chimique chez les insectes: nouvelles avancées dans les stratégies de lutte intégrée contre les ravageurs. Insectes.; 14 (10): 799. https://doi.org/10.3390/insects14100799.

[11] Nickpay A. (2016). Improving biological control of stalk borers in sugarcane by applying silicon as a soil amendment. Journal of plant protection research, Vol. 56, No. 4, Doi: 10.1515/jppr-2016-0058, pp. 394-401.

[12] Fenta L., Mekonnen H., Kabtimer N. (2023). L'exploitation d'antagonistes microbiens contre les agents pathogènes des plantes après récolte. Microorganismes. 11 (4): 1044. https://doi.org/10.3390/microorganisms11041044.

[13] Priya, Kumar R., Bhatt R., Kashyap L. & Shera P. S. (2023). Rétention du silicium dans le sol et le cultivar de canne à sucre et son impact sur le foreur des tiges (Chilo auricilius Dudgeon), indices de rendement et de qualité dans le nord-ouest de l'Inde. https://doi.org/10.1007/s12633-023-02508-1.

[14] Verma K. K., Song X. P., Tian D. D., Guo D. J., Chen Z. L., Zhong C. S., Nikpay A., Singh M., Rajput V. D., Singh R. K. (2021). Influence du silicium sur les stratégies de biocontrôle pour gérer le stress biotique pour la protection, les performances et l'amélioration des cultures. Plantes. 10 (10): 2163. https://doi.org/10.3390/plants10102163.

[15] Rahardjo B. T., Achadian E. M. A., Taufiqurrahman A. F., Hidayat M. R. (2020). L'engrais à base de silice (Si) améliore la résistance de la canne à sucre au foreur de la canne à sucre Scirpophaga extraittalis Walker. AGRIVITA, Journal des sciences agricoles, [Sl], v. 43, n. 1, pp. 37-42. ISSN2477-8516.

[16] Yao K. L. (2017). Cartographie au 1/10000ème du potentiel de fertilité des sols du périmètre sucrier de Borotou-Koro (Nord-ouest de la Côte d'Ivoire). Mémoire de Master en sciences de la terre option pédologie, Université Félix Houphouët-Boigny d'Abidjan, Côte d'Ivoire, 87 p.

[17] Yao K. (2018). Effets de la dynamique de l'écume sur le rendement de la canne à sucre (*Saccharum officinarum l.*) dans les complexes sucriers de Borotou-Koro (nord-ouest) et de Zuénoula (centre-ouest), en côte d'ivoire. Thèse de Doctorat de l'Université Felix Houphouët-Boigny Abidjan / Côte d'Ivoire, UFR-STRM. 194 p.

[18] Jahn R., Blume H. P., Asio V. B., Spaargaren O. et Schad P. (2006). Guidelines for soil description. FAO. Fourth edition, ISBN 92-5-105521-1, 109 p.

[19] Buol S. W., Southard R. J., Graham R. C., McDaniel P. A. (2011b). Soil genesis and classification. John Wiley & sons. 13: 9780-8138-0769-0.

[20] Cirad., Gret. et France MAE. (2002). Mémento de l'Agronome. Ministère des affaires étrangères, CIRAD, Montpellier, France, n°50, pp. 77-124.

[21] Pahalvi H., Rafiya L., Rashid S., Nisar B. et Kamili A. (2021). Les engrais chimiques et leur impact sur la santé des sols. Microbiote et Biofertilisants, Vol 2, pp. 1-20.

[22] Péné Bi C., Boua M. B., Coulibaly-Ouattara Y., Goebel F. R. (2018). Stem Borer (Eldana saccharina W) Infestation Outbreak in Sugarcane Plantations of Northern Côte d'Ivoire: Management Strategies Under Implementation. American Journal of Bioscience and Bioengineering, 6 (4): pp. 27-35.

[23] Malekshah S. A. M., Naseri B., Aghdam H. R., Razmjou J., Fathi S. A. A., Ebadollahi A., Changbunjong T. (2022). Physicochemical Properties of Sugarcane Cultivars Affected Life History and Population Growth Parameters of Sesamia nonagrioides (Lefebvre) (Lepidoptera: Noctuidae). Insects. 2022; 13 (10): 901. https://doi.org/10.3390/insects13100901.

[24] Nikpay A., Soleyman-Nejadian E., Goldasteh S., Farazmand H. (2015). Response of sugarcane and sugarcane stalk borers Sesamia spp. (Lepidoptera: Noctuidae) to calcium silicate fertilization. Neotrop. Entomol. 44: 498-503.

[25] Stranack, RA and Miles, N. (2011). Nitrogen nutrition of sugarcane on an alluvial soil on the north coast of Kwazulu-Natal: effects on yield and leaf nutrient concentrations. Proc. S. Afr. sug. Technol. Cul. 84, pp. 198-209.

[26] Rhodes, R., Miles, N. et Keeping, M. G. (2013). Crop nutrition and soil texture effects on eldana damage in sugarcane. Proc. S. Afr. sug. Technol. Cul. 86, pp. 212-136.

[27] Goebel F. R., Way M. J., Gossard B. (2005). The status of Eldana saccharina (Lepidoptera: Pyralidaea) in South African sugar industry based on regular survey data. Proc South Afr Sugarcane Technol. Assoc, 79: pp. 337-346.

[28] Bhatt R., Kumar R., Kashyap L., Alataway A., Dewidar A. Z., Mattar M. A. (2022). Croissance, rendement, qualité et insectes nuisibles de la canne à sucre (Saccharum officinarum) affectés par les régimes différentiels d'irrigation et de potasse dans des conditions de stress. Agronomie. 12 (8): 1942.

[29] Reay-Jones F. P. F. (2005). Integrated pest management of the Mexican rice borer in Louisiana and Texas sugarcane and rice. LSU Doctoral Dissertations. 761. 188 p.

[30] Adeyinka O. S., Tabbassum B., Sharif M. N., Bhatti M. U., Nasir I. A., Husnain T. (2018) Un retard dans l'avancement de la biotechnologie: un contrôle fiable des foreurs de la tige du maïs en Afrique. Journal de recherche sur la protection des plantes. 58 (1): 8-24.

[31] Wang Z., Song Q., Shuai L., Htun R., Malviya M. K., Li Y., Liang Q., Zhang G., Zhang M., Zhou F. (2020). Analyse métabolique et protéomique des mécanismes du métabolisme de l'azote impliqués dans l'interaction canne à sucre-Fusarium verticillioides. J Plante Physiol. 251: 153207.