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Effects of Fertilization, Variety and Season on Fall Armyworm Attack on Bio-fortified Maize Production in the Kisangani Eco-region (Democratic Republic of the Congo)

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Abstract: *Faced with soil impoverishment and irregular rainfall caused by climate change, a study has been initiated on the cultivation of bio-fortified maize in Kisangani in the Northeast of the Democratic Republic of the Congo. The study aimed at evaluating fertilization effects, new bio-fortified maize varieties and the season (Zea mays L) on production in the face of armyworm infestation. The split-plot experimental set-up was used, the first factor has been the variety and the second the fertilizers. The results have highlighted that the application of fertilizers at the sowing time does not significantly influence any production parameter. However, experimented maize varieties have differently behaved depending on seasons when the armyworm infestation.*
Keywords: *fertilization; season; maize; attack; Spodoptera frugiperda*

I. Introduction

Maize is the main cereal crop produced in the Democratic Republic of the Congo (DRC). It is cultivated in all the provinces of the country where it is present in almost all the fields in pure culture or in association with the majority of the food and market garden crops. In DR. Congo, maize plays a major role in food security and is an important source of income for small farmers. Among other things, this crop is also widely used in the manufacture of traditional drinks. The annual national maize production estimated at more than two million tons for a total of about 1.5 million hectares of maize plantings (FAO, 2017). Under normal growing conditions, maize contributed an average of at least $319 to income per farm household. In October 2016, unprecedented attacks on the maize crop by larvae of a moth (Spodoptera frugiperda, known as the fall armyworm, abbreviated CLA) were reported for the first time in some provinces of the country (FAO, 2017).

Joint MINAGRI-FAO-INERA-UNIKIN-UNILU missions were dispatched to the areas where the alert was made, notably in the Libenge Territory in South Ubangi Province and in the Kambove and Kilwa Territories in Haut-Katanga Province. As result of these missions, the armyworm has ravaged at least 400 ha of maize in the Libenge territory in South Ubangi and 600 ha in the Kambove territory in Haut-Katanga. The losses caused by these attacks are estimated at $480,000 and $720,000 respectively (FAO, 2017). Low yields are observed, generally below 1000 kg per hectare (Nyembo et al., 2015). These low yields are due in part to low use of improved varieties and agricultural inputs, extensive damage from various pests, and poor agricultural practices (Nyembo et al., 2014).

According to Useni et al. (2013), inadequate plant nutrition management and low soil fertility are the main factors responsible for lower yields. However, it is known that the soil in the Kisangani region is sandy-clay and are poor in plant-available elements. The humus-bearing horizons are poorly developed as a result of heavy rains that cause leaching. The soil is acid with a pH of 5-5.8. Consequently, these soils are increasingly unproductive and agricultural activity is low.

The objective of the present study was to evaluate how the new bio-fortified maize varieties introduced in the Kisangani region respond to the combined application of tertiary and organic fertilizers in the face of armyworm attack, depending on the cropping season. Specifically, the aim was to determine the optimal dose of fertilizer to apply to each variety that would allow it to increase production and resist armyworm attack.

II. Research Methods

2.1 Experimental Environment

The trial was conducted in the village of Malimba in the Territory of Banalia in the Province of Tshopo in the North East of the DRC. The GPS coordinates of the site are: 00° 42' 47,3" North latitude, 025° 15'43,8 East longitude, Altitude 381m (Figure 1).

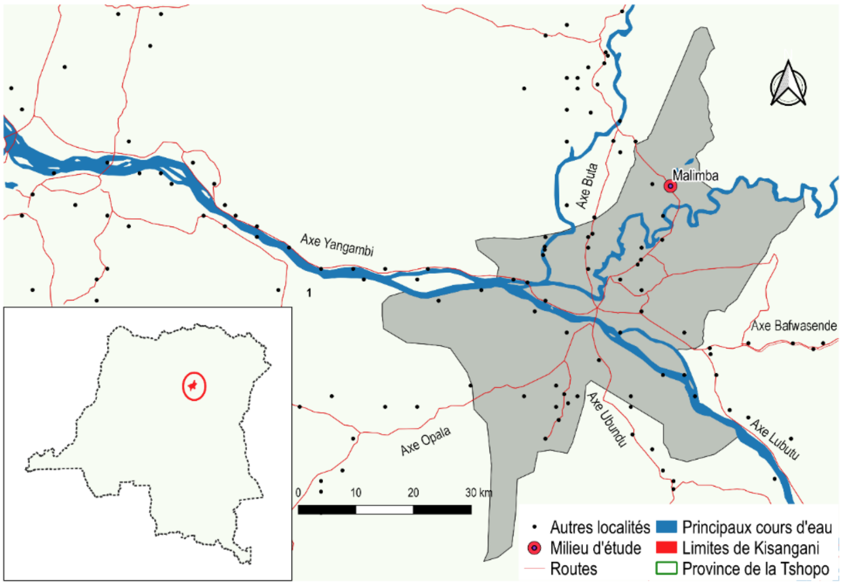

Figure 1. *Map of the Study Area*

The trial was conducted during two cropping seasons, namely B2018 and A2019. The eco-climatic data of the site as well as its proximity to the city of Kisangani give it an equatorial climate of the Af type of the Koppen classification (FAO, 2005). The trial was conducted on sandy soil covered with grassy vegetation composed mainly of Chromolaena odorata and Tithonia diversifolia. The climatic conditions that prevailed during the trial are given in Table 1 below.

Table 1. Climatic Data for the Experimental Period from the Rain Gauge Installed at the Test Site in Malimba

Period / Climatic parameters		Test 1 in season B2018			Test 2 in season A2019		
		November	December	January	February	March	April
Précipitation (mm)	Quantity (mm)	150	145	146	268,8	556,6	393,4
	Number of rainy days	10	7	2	5	8	11
Temperature (°C)	Max	28	22	32	34	32	32
	Average	26	18	20,5	20	26	26
	Min	24	18	20,1	19	21	21

(Source: Mini-station installed at the experimental site)

The high amount of rainfall was recorded in the month of March 2019. The month of April recorded 11 days of rain with more than two dry weeks. On the other hand, the maximum temperature was recorded in the month of February 2019.

2.2 Material

The plant material consisted of three biofortified maize varieties and one local maize variety. These are Composite-Synthetic varieties with orange-yellow grains enriched in provitamin A, Zinc and Iron distributed by CIAT-HarvestPlus Bukavu. These maize varieties have a cycle of about 150 days in the high-altitude region (HarvestPlus, 2019). They have an average real-world yield of 3.5 to 5 tons/ha.

2.3 Local Variety: Yellow Plata

This is a local variety with yellow, horny grains, sweet taste, easy to grind, rich in amino acids. Its cultural cycle is 3 months and it bears 1 to 2 ears per plant. It is the most cultivated variety in the Kisangani region with a yield of 800 to 1000 kg/ha (SENASEM, 2008).

Table 2. Description of Bio-fortified Corn Varieties Used in the Study

Variety / **Caractères**	**SAM4 VITA- A**	**SAM4 VITA-B**	**PVA SYN-18F2**
Origin and Year of Diffusion in DR. Congo as Biofortified Variety	CIMMYT Zimbabwe/ZARI– 2014	CIMMYT Zimbabwe/ZARI– 2014	IITA Nigeria 2015
Breeder	HarvestPlus/UNILU	HarvestPlus/UNILU	HarvestPlus/INERA Mulungu
Number of days to male flowering	60	60	53
Number of days to female flowering	68	68	60
Number of days to maturity	150	150	140
Height insertion of the ears	79 cm	79 cm	88 cm
Color of grains	Orange/Yellow	Orange/Yellow	Orange/Yellow
Type variétal	Composite-Synthetic	Composite-Synthetic	Composite-Synthetic

Resistance/Tolerance to biotic factors	Good for stem borers ; Good to smut; Good to Helminthosporiose and Cercosporiose; Good for Maize Streak Disease; Good to average to armyworm.	Good for stem borers ; Good to smut; Good to Helminthosporiose and Cercosporiose; Good for Maize Streak Disease; Good to average to armyworm..	Good for stem borers ; Good to smut; Good to Helminthosporiose and Cercosporiose; Good for Maize Streak Disease; Good to average to armyworm.
Resistance/tolerance to abiotic factors	Average to drought and heavy rainfall, fairly good to acidic soils	Average to drought and heavy rainfall, fairly good to acidic soils	Average to drought and heavy rainfall, fairly good to acidic soils
Weight of 100 grains	33,5 g	33,5 g	34,5 g
Yield in real environment	3500- 5000 kg/ha	3500- 5000 kg/ha	3750- 4750 kg/ha
Agro-ecological adaptation	Low, medium and high altitude	Low, medium and high altitude	Basse, Moyenne et haute altitude
	Variety tested in season A	Variety tested in season B	

Source: CIAT- Harvest Plus (2019)

2.4 Methods

a. Experimental Design and Treatments Studied

A split plot design with three replicates and two factors were used in this study. The field was plowed and manually harrowed. The dimensions of each elementary plot were 12m². The distance between the replicates was 2m and between the elementary plots was 1.5m. The field size was 206m² (16.5x12.5m). The first factor, the variety, was made up of four levels: M0 local variety of corn with yellow grains used as control and M1, M2 and M3 varieties with orange yellow grains (JO) were sown at the spacing of 0,8mx 0,5m. Each plot had 5 rows and six patches in all 30 patches per plot. The second factor, fertilizer, consisted of four levels, namely T0 that corresponds to the control with no fertilizer application (Control); T1 mineral fertilizer (NPK-17-17); T2 manure (cow dung); T3 mixture (NPK + Manure).

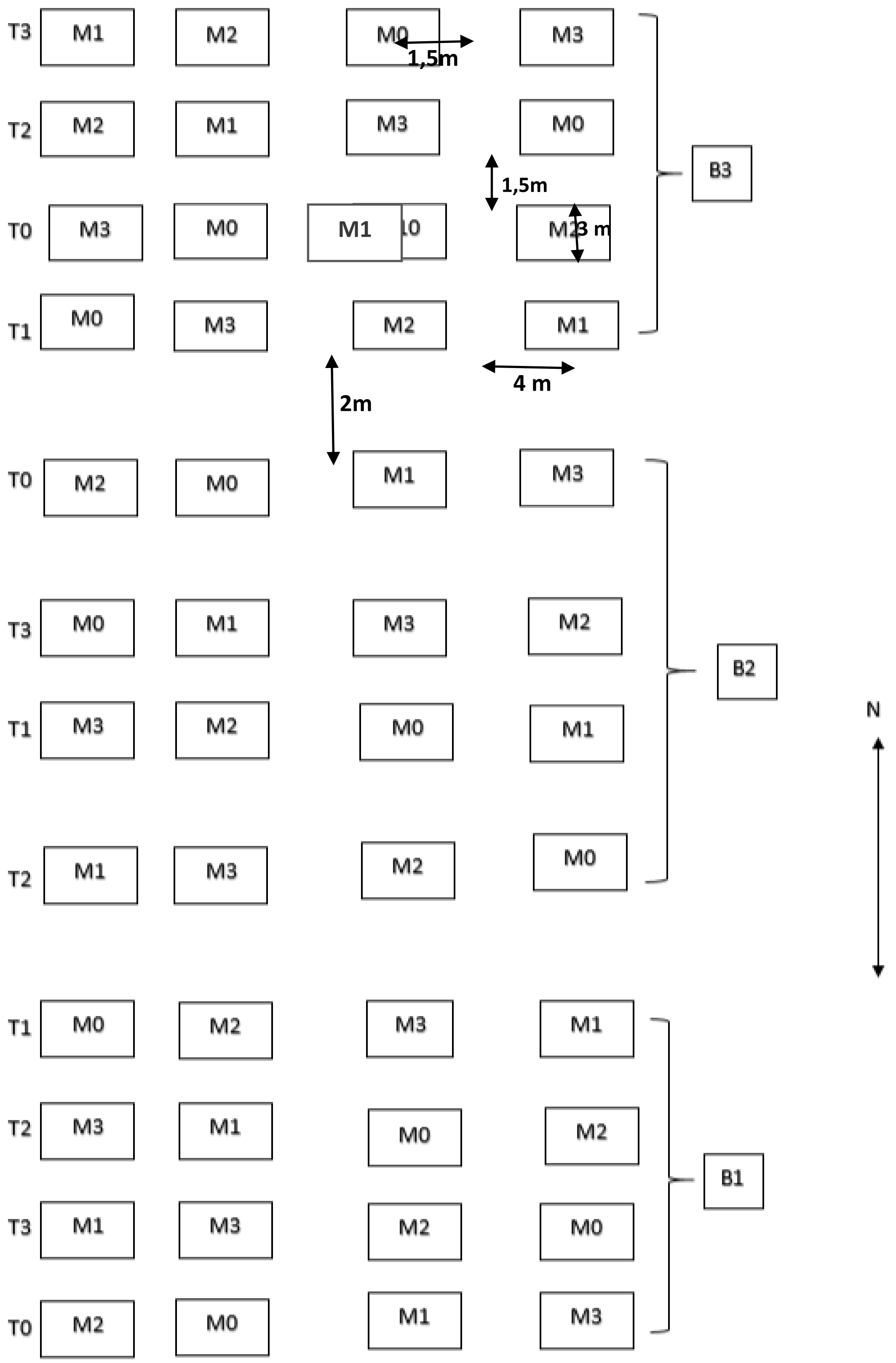

Figure 2. *Split Plot Experimental Setup*

Légende: *T0: control with no fertilizer application; T1: mineral fertilizer (NPK-17-17-17); T2 : manure (cow dung); T3: mixture (NPK + manure); M_0 : local control (yellow plata); M_1: SAM4 VITA- A; M_2 : SAM4 VITA-B; M_3 : PVA SYN-18F2 ; B_1 : Block 1 ; B_2 : Block 2; B_3 : Block 3*

The combination of fertilizers (Sub-block factor) and varieties (Unit plot factor) resulted in sixteen (16) treatments. After clearing the soil, ploughing and harrowing were carried out manually. The quantities of the different fertilizers applied to the plants are followed: for cow dung, a quantity of 9000 g was applied to each large plot before sowing maize, i.e. 9 kg per plot. As for the NPK 17-17-17 mineral fertilizer, it was applied in a furrow about 5 cm deep at a distance of 5cm from the plot, at a rate of 1764g before sowing. The NPK+manure mixture was applied at a rate of 880g of NPK 17-17-17 and the dung at 4500g before seeding. Flat seeding was done at 80cm x 50cm spacing, three grains per stake at 5cm depth. The maintenance consisted of three weedings. The trial was repeated twice, in the B2018 and A2019 seasons.

b. Observed Parameters and Statistical Treatment

Observations were made on vegetative parameters, yield parameters and epidemiological parameters. The observed vegetative parameters refer to the emergence rate which was determined by the ratio of the number of plants that emerged on the number of seeds sown x 100. Leaf area, plant height and crown diameter were measured.

Observations included measuring ear diameter with a caliper, measuring ear length with a tape measure, counting the number of rows per ear, counting the number of kernels per row, and measuring ear weight using an electronic scale with a precision of one thousandth.

The calculation of the percentage of ginning was done by the following formula: total weight of the ear on the weight obtained after ginning multiplied by 100. The weight of 1000 grains and the plot yield were determined by weighing. At harvest, corn cobs were collected from the six feet located in the center of the plots, and the quantities of grain produced per plot were extrapolated in tons per hectare (t/ha).

Epidemiological observations were made on all plants three weeks after emergence, counting the total number of attacked plants, the number of caterpillars per plant, and abundance was obtained by counting all plants on a plot that carried caterpillars.

Raw data on vegetative, epidemiological and yield parameters were analyzed using R Studio version 3.6 software. Analysis of variance (ANOVA) was performed to detect differences between treatments. Comparison of means using Tukey's test was used to detect the best treatment.

III. Discussion

The data for the production parameters are presented in Table 3 below.

Table 3. Influence Of Season on Production Parameters

Parameters	Season	Average	Type of gap
Spike diameter (LSD : 0,15)	A	4,24A [a]	0,22
	B	3,76 [b]	0,48
Length of cobs (LSD : 0,52)	A	16,04 [a]	1,41
	B	14,37 [b]	1,14
No. of grain rows per ear (LSD : 0,38)	A	14,00 [a]	1,07
	B	13,83 [a]	0,75
No. of grains per row (LSD : 1,40)	A	23,35 [b]	3,15
	B	28,08 [a]	3,73
Weight at ginning (LSD : 47,16)	A	1000,54 [a]	123,62
	B	598,44 [b]	107,11
Ginning Pourcentage (LSD : 3,14)	A	84,56 [a]	3,38

	B	83,73 [a]	10,11
Weight of 1000 grains (LSD : 19,03)	A	321,25 [a]	35,15
	B	312,89 [a]	55,14

Legend: LSD (Least significance difference)

Table 3 reveals that maize production parameters are significantly influenced by season. There is a general trend of poor performance in season B.

This could be explained by the fact that the climatic conditions that prevailed during the B season did not allow for the full expression of maize's productive potential despite the non-significant difference detected in this season. Rainfall, number of rainy days and temperatures were low and decreased during the growth of maize in season B compared to season A. This would also account for the fact that the critical flowering-to-setting period did not receive a significant amount of rainfall, which was also irregularly distributed over the crop cycle.

Nevertheless, the results indicate that the ginning percentage and the weight of 1000 grains were not influenced by the season. This behavior can be explained by the fact that these are the varietal traits. The ginning weight was significantly higher in crop season A than in crop season B. This would be due to the availability of nutrients such as nitrogen through fertilizer, which would have increased the yield and its components (Samira et *al.*, 1998; Torbert et *al.*, 2001).

Table 4. Influence of Fertilizer on Production Parameters

Parameters	**Fertilizer**	**Mean**	**SD**
Diamètre d'épis (LSD : 0,21)			
	T_1	4,11 [a]	0,61
	T_2	4,03 [a]	0,29
	T_3	3,95 [a]	0,31
	T_0	3,91 [a]	0,47
Length of cobs (LSD : 0,74)			
	T_1	15,40 [a]	1,56
	T_2	15,29 [a]	1,61
	T_3	15,21 [a]	1,36
	T_0	14,93 [a]	1,62
Number of grain rows per ear (LSD : 0,54)			
	T_1	14,21 [a]	1,26
	T_2	13,92 [a]	0,88
	T_3	13,87 [a]	0,76
	T_0	13,67 [a]	0,65
No. of grains per row (LSD : 1,98)	T_1	31,08 [a]	4,08
	T_2	30,87 [a]	3,76
	T_3	30,79 [a]	3,74
	T_0	30,12 [a]	5,67
Weight at ginning (LSD : 66,69)	T_1	828,96 [a]	267,58
	T_2	799,46 [a]	233,56
	T_3	789,54 [a]	227,49
	T_0	780 [a]	209,95

Percentage of ginning (LSD : 4,44)	T_1	85,74 [a]	7,55
	T_2	84,64 [a]	6,06
	T_3	83,57 [a]	7,4
	T_0	82,62 [a]	8,87
Weight of 1000 grains (LSD : 26,91)	T_1	334 [a]	45,03
	T_2	320,67 [a]	52,43
	T_3	315,25 [a]	36,71
	T_0	298,37 [a]	44,79

Legend: T0: Control with no manure application; T1: mineral fertilizer (NPK-17-17); T2: manure (cow dung); T3: mixture (NPK + manure); LSD (Least significance difference); SD (Standard deviation).

Examination of Table 4 shows that the production parameters of three tested bio-fortified maize varieties showed all the similar numerical values under the applied treatments. However, when analyzing the LSD, it is noted that the shelling weight and thousand kernel weight are significantly different.

The application of different fertilizers at planting time did not induce effects on production parameters. No fertilizer treatment showed statistically significant differences but these differences are probably numerical. The combined effects analysis shows that no interactions were significant.

Table 5. Influence of Variety on Production Parameters

Variables	Varieties	Mean	SD
Diameter of ears (LSD : 0,21)	M_2	4,09 [a]	0,63
	M_3	4,03 [a]	0,45
	M_1	4,00 [a]	0,32
	M_0	3,87 [a]	0,27
Length of cobs (LSD : 0,74)	M_1	15,64 [a]	1,45
	M_2	15,20 [a]	1,59
	M_3	15,13 [a]	1,54
	M_0	14,85 [a]	1,52
Number of grain rows per ear (LSD : 0,54)	M_2	14,04 [a]	1,01
	M_1	14,00 [a]	0,78
	M_3	13,96 [a]	1,04
	M_0	13,66 [a]	0,85
No. of seeds per row (LSD : 1,98)	M_1	32,04 [a]	3,53
	M_0	30,58 [a]	4,03
	M_2	30,29 [a]	3,54
	M_3	29,96 [a]	5,81
Weight at ginning (LSD : 66,69)	M_1	843,83 [a]	232,27
	M_3	798,63 [a]	227,71
	M_2	783,29 [a]	237,99
	M_0	772,21 [a]	240,52
Percentage of ginning (LSD : 4,44)	M_3	84,86 [a]	7,45
	M_0	84,61 [a]	8,30
	M_2	83,79 [a]	8,44
	M_1	83,30 [a]	5,97

Weight of 1000 grains (LSD : 26,91)	M_3	322,08 [a]	59,57
	M_0	321,42 [a]	40,51
	M_1	312,92 [a]	40,59
	M_2	311,87 [a]	43,38

Légende : M_0 : Témoin local (Plata jaune) ; M_1 : SAM4 VITA- A ; M_2 : SAM4 VITA-B; M_3 : PVA SYN-18F2 ; LSD (Least significance difference); SD (Standard deviation).

The analysis of variance relating to the influence of the variety on the production parameters shows a non-significant difference between the varieties tested.

The comparison of means at the 5% threshold between the different varieties across the production parameters generated a similar result. However, the thousand kernel weight (LSD=26.91) and the ginning weight (LSD=66.69) are numerically different.

Table 6. Seasonal Yields of Different Maize Varieties Tested

Varieties	**Yield (kg/ha)**
M_0	2297,22[a]
M_1	2536,91[a]
M_2	2274,30[a]
M_3	2318,57[a]
Seasons	
B	**2642, 188[b]**
A	**3014,021[a]**

Legend: M0: Local control (yellow plata); M_1: SAM4 VITA- A; M_2: SAM4 VITA-B; M_3: PVA SYN-18F2

The comparison of the yields of three varieties shows non-significant differences. The results in Table 5 show that the varieties tested do not differ significantly in terms of grain yield. Nevertheless, SAM4 Vita A is slightly ahead (2536.91 kg/ha), followed by PVA (2318.57 kg/ha), Plata jaune and SAM Vita B with 2297.22 kg/ha and 2274.30 kg/ha respectively.

However, the yield is a parameter dependent on other factors. The comparative analysis of the results showed that the tested varieties behaved differently when grown in different seasons. There was a superiority in production in season A (3014.02 kg/ha), compared to only 2642.188 Kg/ha in season B. The high production in season A is inherent to the regular distribution of rainfall during the vegetation period, which made possible the availability of nutrients. Secondly, the infestation rate of armyworms was low, so that the maize was able to keep almost all its leaves and consequently performed well the photosynthetic activity for its nutrition. Indeed, grain yield is closely dependent on the amount of water available during the period from anthesis to maturity (Richard, 1983). The maintenance of stable yield under water deficit conditions in some maize varieties can be explained by the ability to pump water from deep within the plant. According to Passioura, (2004) the ability of roots to exploit soil water reserves under stress is a particularly effective response for the development of grain production. Le poids d'un grain est d'environ 0,3g, ce qui représente 300g pour 1000grains, en effet le poids moyen de 1000 grains est un paramètre important, indiquant la quantité de semences à utiliser par hectare.

On the other hand, the higher the weight of 1000 grains, greater the amount of seed to be used per hectare. The results show that the use of improved maize varieties (from HarvestPlus or the local variety) significantly increases maize yields, thus showing the importance of breeding new varieties.

Table 7. Variation in the Incidence of *Spodoptera frugiperda* as a Function of Variety and season at the 5% Threshold

Varieties	Incidence (%)	Number of caterpillars per plant	Abundance (plot)
$\mathbf{M_0}$	$14{,}16^a$	10^a	36^a
$\mathbf{M_1}$	$18{,}05^a$	15^a	51^a
$\mathbf{M_2}$	$16{,}44^a$	10^a	35^a
$\mathbf{M_3}$	$14{,}66^a$	8^a	28^a
LSD	10,87	7,30	25,40
Variation between seasons			
Season B	$\mathbf{25{,}54^a}$	$\mathbf{18^a}$	$\mathbf{62^a}$
Season A	$\mathbf{6{,}11^b}$	$\mathbf{3^b}$	$\mathbf{13^a}$
Mean	**15,83**	**10,75**	**37,26**
LSD	**7,69**	**5,20**	**18,00**
Cv(%)	**119,60**	**119,40**	**119,00**

Results showed that the incidence of *S. frugiperda* on the local and bio-fortified maize varieties introduced in the Kisangani region were similar. Statistically, all maize varieties tested against CLA showed similar behavior despite some negligible numerical differences. This indicates that the armyworm attacks all maize types in the same way. In addition, CLA attack was variable across seasons. It was highest in season B (25.54%) and lowest in season A (6.11%).

In fact, in farming areas, with the use of local degenerated varieties, maize yields do not exceed one ton per hectare compared to 6 to 8 tons per hectare found by Nyembo, (2010). In the United States of America, in the 100% increase in maize yield, 40% is due to improved cultural practices and 60% is related to genetic improvement and maize yields have increased from 1 t/ha in the 1930s to 7 t/ha in the 1990s (Troyer, 1990). According to Badu (2006), research to improve yield potential is an important part of breeding programs in sub-Saharan Africa. This corroborates the research results of Nguetta (2006) in Congo Brazzaville, who showed that rainfed rice yields increased from 2 to 4 tons per hectare with the use of improved varieties. The evaluation of varieties cannot be reduced to predicting their performance in different soil and climatic environments. The varieties tested gave similar maize grain yields to those currently used under Kisangani conditions, and have interesting potential for the promotion of maize cultivation in the region. These preliminary results obtained can be used to promote the dissemination of these varieties in the region, since the performance of the genotypes depends strongly on the environmental conditions, they encounter during their crop cycle.

IV. Conclusion

The objective of the present study was to evaluate the effect of fertilization and new biofortified maize varieties from CIAT-HarvestPlus against CLA attack under edaphoclimatic conditions in Kisangani region. The results obtained show that the application of fertilizers at planting time did not significantly influence any production parameter. However, the varieties tested behaved differently when grown at different seasons. The results also showed that the observed varieties showed similar behavior to CLA attack as the local varieties. The attack depends on the cropping season.

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