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Research Paper

Diagnosis of the causes of low yields of cocoa trees (*Theobroma cacao L.*) in Wamba and Rungu territories in Haut-Uele Province, DR Congo

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Summary
Our research aimed to determine the causes behind the low yield of cocoa cultivation in the Territories of Rungu and Wamba in the Province of Haut-Uélé. The results obtained showed that three variables, namely: production, area and number of plants attacked, have a significant influence on the yield of all varieties (Forastero, Criollo and Trinitario) combined. In contrast, the other variables (age, number of diseased plants and total number of plants) did not show a statistically significant effect on performance (p-value > 0.05). The areas of the plantations vary between 1 and 30 hectares, with an average of 6.27 hectares. The cocoa farmers surveyed have plantations of very variable dimensions, from the smallest to the largest, depending on the case. As far as production is concerned, it varies from 40 to 8700 kg, with an average of 1275.40 kg. This is in line with the area of the plantation. As for the yield, it varies from 18 to 500 kg/ha, with an average of 153.30 kg/ha.
Keywords*: Cocoa tree, Areas; Production; Efficiency; Attack Rate*

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I. INTRODUCTION

Cocoa cultivation experienced a global boom from the end of the 19th century, when the cocoa tree was introduced to the African continent from the islands of the Gulf of Guinea. In the 1950s, bean production on the African continent already represented 2/3 of world production, then estimated at 700,000 tons. Cocoa production in Africa is estimated at 2.6 million tons, for a world production of about 3.7 million tons. With 183,000 tonnes of marketable cocoa for the 2007/2008 season, Cameroon ranks 5th in the world among producing countries, after Côte d'Ivoire, Ghana, Indonesia and Nigeria and ahead of Brazil (Anon, 2008).

In Cameroon, the cocoa orchard covers an area of about 400,000 ha. The cocoa tree is cultivated by about 260,000 smallholders and is estimated to support more than one million inhabitants of the forest area (Anon, 2001). The average yield of Cameroonian plantations is low, at around 300 kg/ha, whereas it can reach or even exceed 3,000 kg/ha when cocoa is grown in optimal conditions (Toxopeus, 1985). These poor yields are due to several factors, including the aging of the orchard, the low use of improved varieties and agricultural inputs, and the resulting high pest pressure.

In the Democratic Republic of Congo and more precisely in the province of Haut-Uélé, the cocoa yield is low and even derisory, estimated at around 20 to less than 500 kg of dried beans per hectare. So we wanted to look for what would be at the root of this low yield. Cocoa is now at the top compared to coffee and other products at the mercurial level on the world market. This is why it is necessary to revive its cultivation and promote this sector.

Vanden Put (1981) and Janssens (2001) point out that cocoa beans quickly lose their germinative power once they emerge from the pod and that farmers do not control the mechanisms techniques and processes for the production of seedlings of quality and quantity.

In the Democratic Republic of Congo, cocoa cultivation continues to grow in the former large provinces of Kivu, Equateur and Orientale. Unfortunately, it is faced with so many problems that would be at the root of the low production in general.

The present research has focused on the diagnostic study of the causes of these low cocoa yields in the territories of Wamba and Rungu in the Haut-Uélé Province of DR Congo.

II. MATERIALS AND METHODS

Study environment

This work was carried out in the territories of Wamba and Rungu located in the Haut-Uele province in northern DR Congo.

The Wamba Territory (fig.1a) is located between 2° 08' 48.78" N latitude and 27° 59' 00.29 E longitude. Its average altitude is 773 m (https://w.w.w.africamuseum.be) while Rungu (fig.1b) is located between 1° 50' and 3° 15' N latitude, and 26° 50' and 28° 30' E longitude. Its altitude varies between 500 and 800 m.

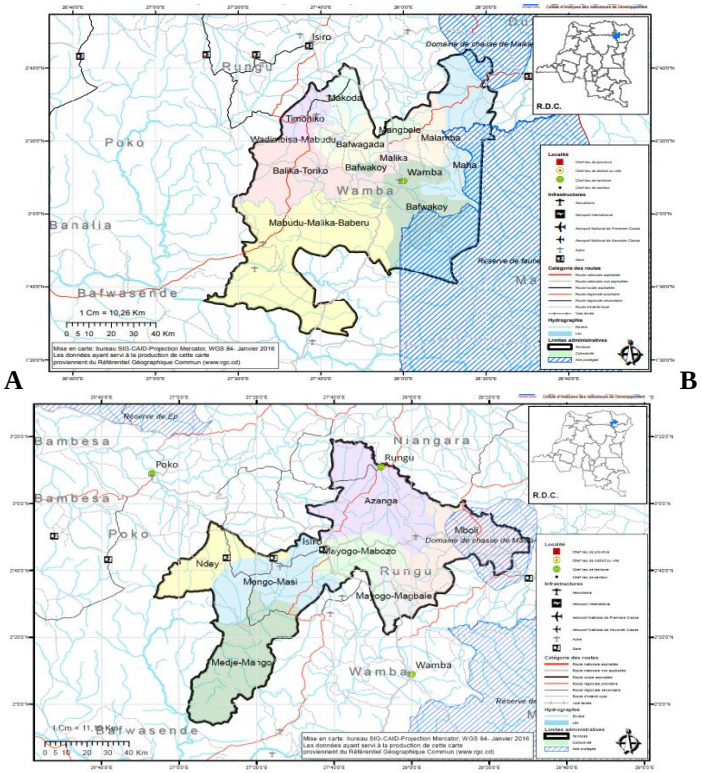

Figure 1. Administrative Maps of the Wamba and Rungu Territories (htts://caid.cd)

Survey in the peasant fields

The survey was carried out in the period from August to November 2023 in the province of Haut-Uélé, precisely in the territories of Wamba and Rungu. A questionnaire was administered to each farmer in order to collect information on their profile and on the plantations visited. The information sought focused on Diagnosis of low yield of cocoa cultivation in the territories of Wamba and Rungu.

In addition, the area, production, yield and attack rate were the agronomic parameters considered. Farmers were interviewed individually in their cocoa plantations to confirm the information provided in the field. A translator was called upon if necessary to facilitate communication. This interview was the main method used in data collection. Each interviewee had to have a cocoa plantation of at least one hectare in one of the two territories selected for this study and be willing to answer the questions asked in order to be selected. As for the plantation, it had to be at least one hectare in size, have entered production and be located in the study area.

Data collection

For the data collection method, we proceeded by:

For production and yields with a scale we weighed the dry cocoa beans, because for the areas we measured with a tape, for the attack rates we proceeded by counting diseased plants in each plantation surveyed.

Statistical analysis of the data

The results of the statistical analysis of the data on the diagnosis of cocoa crop yield in the Wamba and Rungu territories were obtained through the use of several analytical methods and statistical tests, including descriptive statistics, correlation analysis, multiple linear regression (MLR) and the Kruskal-Wallis test and these analyses were carried out using the Tanagra software (version 1.4.50). These methods have made it possible to highlight the relationships between certain quantitative variables and to identify the factor having a significant impact on the yield of the cocoa crop.

III. RESULTS AND DISCUSSION

3.1 Area, production and yield of cocoa trees

Table 01 presents data on the area, production and yield of cocoa trees in the study area. This data collected during a survey is essential to assess the performance and production potential of cocoa cultivation in our study environment.

ITEM	Surfaces/ha	Production 2023 (Kg)	Rdt (kg/ha)
1	5,00	1758,00	351,60
2	15,00	5300,00	353,33
3	2,00	40,00	20,00
4	10,00	180,00	18,00
5	4,00	100,00	25,00
6	30,00	8700,00	290,00
7	1,00	60,00	60,00
8	1,00	370,00	370,00
9	2,00	116,00	58,00
10	2,00	1000,00	500,00
11	2,00	150,00	75,00
12	2,00	57,00	28,50
13	1,00	40,00	40,00
14	2,00	60,00	30,00
15	15,00	1200,00	80,00
Are	94,00	19131,00	2299,43
Averages	6,27	1275,40	153,30
Standard deviation	8,15	2466,05	167,04
CV (%)	129,98	193,36	108,96

The results of Table 01 show that the areas, production and yields are very scattered with very high coefficients of variation. These high values indicate a heterogeneous distribution for plantation area, production and yield of cocoa in the study area.

The areas of the plantations vary between 1 and 30 hectares, with an average of 6.27 hectares and a standard deviation of 8.15. The coefficient of variation (CV) is 129.98%, indicating a relatively high variability in the areas. The cocoa farmers surveyed have plantations of very variable dimensions, from the smallest to the largest, depending on the case.

As for production, it ranges from 40 to 8700 kg, with an average of 1275.40 kg and a standard deviation of 2466.05. The coefficient of variation (CV) reached 193.36%, reflecting a high variability in production. This is in line with the area of the plantation.

As for the yield, it varies from 18 to 500 kg/ha, with an average of 153.30 kg/ha and a standard deviation of 167.04. The coefficient of variation amounts to 108.96%, indicating a relatively high variability in yields. These results can be explained by the variation in the area and production of the various plantations.

3.2 Number of plants per variety.

Table number 2 provides information on the number of plants per hectare for the different plantations and by variety in the study area. It allows us to know the distribution of cocoa plants for each plantation and to

see how they are distributed according to the different varieties. This data is important for assessing the diversity and distribution of cocoa varieties in the study area. The varietieslisted are Forastero, Criollo and Trinitario.

ITEM	NUMBER OF PLANTS PER VARIETY			
	FORASTERO VARIETY	**CRIOLLO VARIETY**	**TRINITARIO VARIETY**	**NUMBER OF FEET**
1	800	200	100	1100
2	900	28	22	950
3	987	113		1100
4	350	70		420
5	1000	100		1100
6	1061	50		1111
7	1000	300		1300
8	900	400		1300
9	1061	50		1111
10	920	32		952
11	1250	50		1300
12	880	20		900
13	1017	47		1064
14	684	30		714
15	800	250		1050
Are	13610,00	1740,00	122,00	15472,00
Averages	907,33	116,00	61,00	1031,47
Ecartype	204,37	116,85	55,15	231,36
CV (%)	22,52	100,73	90,42	22,43

Looking at this table, it can be seen that the number of cocoa plants varied for each variety.
For the Forastero variety, the number of plants varies from 350 to 1,250, with an average of 907.33 vines/ha and a standard deviation of 204.37. The coefficient of variation for this variety is 22.52%, indicating a relatively low variability in the number of plants.
For the Criollo variety, the number of plants ranges from 20 to 400, with an average of 116 feet and a standard deviation of 116.85. The coefficient of variation for this variety is 100.73%, indicating high variability in the number of plants. The cocoa plantations in the study area are not uniform in terms of the number of plants.
As for the Trinitario variety, the number of plants ranges from 22 to 100, with an average of 61 feet and a standard deviation of 55.15. The coefficient of variation for this variety is 90.42%, indicating high variability in the number of plants. The same trend can be observed in other groups of cocoa trees.

3.3. Yield by variety

In this table n°3, we present the yield by variety for each plantation surveyed in our study area. This table allows us to observe the performance of the different varieties of cocoa tree in terms of yield.

ITEM	Rdt (Kg/ha)	Forastero (kg/ha)	Criollo (kg/ha)	Trinitario (kg/ha)
1	351,60	255,71	63,93	31,96
2	353,33	334,74	10,41	8,18
3	20,00	17,95	2,05	
4	18,00	15,00	3,00	
5	25,00	22,73	2,27	
6	290,00	276,95	13,05	
7	60,00	46,15	13,85	
8	370,00	256,15	113,85	

9	58,00	55,39	2,61	
10	500,00	483,19	16,81	
11	75,00	72,12	2,88	
12	28,50	27,87	0,63	
13	40,00	38,23	1,77	
14	30,00	28,74	1,26	
15	80,00	60,95	19,05	
Are	2299,43	1991,87	267,42	40,15
Averages	153,30	132,79	17,83	20,07
Ecartype	167,04	148,08	30,98	16,82
CV (%)	108,96	111,51	173,76	83,77

From the above, we see that yields vary from strain to strain and within each strain.
For the Forastero variety, the yield varies from 15 to 483.19 kg/ha; with a mean of 132.79 kg/ha and a standard deviation of 148.08. The coefficient of variation for this variety is 111.51%; indicating a high variability in the yields of the different cocoa farmers in the two territories surveyed.
For the Criollo variety, the yield varies from 0.63 to 113.85 kg/ha; with a mean of 17.83 kg/ha and a standard deviation of 30.98 kg/ha. The coefficient of variation for this variety is 173.76%, also indicating a higher variability of yields among growers than for the Forastero group.
For the Trinitario variety, the yield ranges from 2.05 to 31.96 kg/ha, with an average of 20.07 kg/ha and a standard deviation of 16.82 kg/ha. The coefficient of variation (CV) for this variety is 83.77%, indicating high variability in yields. Yields are lower compared to the first two groups, while the hybrid is more productive than the two parents based on hybrid vigour.

3.4 Number of diseased plants

We find data on the number of diseased plants in the fields surveyed. This table allows us to assess the prevalence of diseases among the cocoa plantations surveyed.

ITEM	Total	Stranger	Creole	Trinitarian
1	105,00	93,00	10,00	2,00
2	185,00	175,00	10,00	0,00
3	164,00	150,00	14,00	
4	32,00	32,00	0,00	
5	192,00	174,00	18,00	
6	184,00	180,00	4,00	
7	46,00	38,00	8,00	
8	218,00	198,00	20,00	
9	255,00	253,00	2,00	
10	100,00	100,00	0,00	
11	129,00	127,00	2,00	
12	99,00	98,00	1,00	
13	109,00	103,00	6,00	
14	198,00	193,00	5,00	
15	86,00	72,00	14,00	
Are	2102,00	1986,00	114,00	2,00
Averages	140,13	132,40	7,60	1,00
Ecartype	64,87	63,22	6,54	1,41
CV (%)	46,29	47,75	86,11	141,42

By examining Table 4, we can observe the prevalence of diseases among the different varieties of cocoa in the fields surveyed. The figures vary for each plantation and each variety of cocoa tree for a total of 2,102 diseased plants.

For the Forastero variety, we note a total of 1986 diseased plants, with an average of 132.40 diseased plants and a standard deviation of 63.22. The coefficient of variation for this variety is 47.75%, indicating some variability in the number of diseased plants in the different plantations

Concerning the Criollo variety, we note a total of 114 diseased plants, with an average of 7.60 diseased plants and a standard deviation of 6.54. The coefficient of variation for this variety is 86.11%, indicating a relatively high variability in the number of diseased plants.

Finally, the Trinitario variety has a very low number of diseased plants due to its small number of plants in all the plantations examined, with only two plantations surveyed.

3.5 Disease attack rate per ha (%)

Table 05 provides information on disease attack rates per hectare for different varieties of cocoa tree.

ITEM	Total	Stranger	Creole	Trinitarian
1	9,55	11,63	5,00	2,00
2	19,47	19,44	35,71	0,00
3	14,91	15,20	12,39	
4	7,62	9,14	0,00	
5	17,45	17,40	18,00	
6	16,56	16,97	8,00	
7	3,54	3,80	2,67	
8	16,77	22,00	5,00	
9	22,95	23,85	4,00	
10	10,50	10,87	0,00	
11	9,92	10,16	4,00	
12	11,00	11,14	5,00	
13	10,24	10,13	12,77	
14	27,73	28,22	16,67	
15	8,19	9,00	5,60	
Are	206,42	218,93	134,80	2,00
Averages	13,76	14,60	8,99	1,00
Standard deviation	6,44	6,63	9,23	1,41
CV (%)	46,79	45,42	102,67	141,42

By analyzing this table, we observe variations in the attack rate for each variety and the cocoa tree as a whole, the overall average of which is 13.76%.

For the Forastero variety, the attack rate ranges from 3.80% to 28.22%, with a mean of 14.60% and a standard deviation of 6.63. The coefficient of variation is 45.42% indicating a variability in the attack rate for this variety and the attacks are not evenly distributed in the different plantations.

For the Criollo variety, the attack rate ranges from 0.00% to 35.71%, with a mean of 8.99% and a standard deviation of 9.23. The coefficient of variation is 102.67%; indicating a high variability in the attack rate for this variety.

For the Trinitario variety, the attack rate ranges from 0.00% to 16.67%, with a mean of 1.00% and a standard deviation of 1.41. The coefficient of variation is 141.42%, indicating a high variability in the attack rate for this variety. This situation of heterogeneity can be observed for all varieties.

3.6 Analysis of correlations between the variables studied

In an attempt to explain the links between cocoa yield and other variables, we have established the correlation matrices shown in Appendices 1 to 3. They present the values of the correlation coefficients obtained between the variables studied for all varieties combined.

To better interpret these matrices, we consider it necessary to present the linear regressions of these variables. It should be noted that only two varieties were retained for further analysis given the limited number of data at Trinitario

3.7 Multiple linear regression results between the variables studied

Multiple linear regression (MLR) allowed us to evaluate the linear relationship between the different variables and deduce the most characteristic ones that significantly influence the yield. Statistical significance was considered at risk p-value < 0.05 (*) for a significant relationship and p-value < 0.01 (**) for a highly significant relationship.

Table 6: Multiple linear relationship between total yield and total number of plants, number of diseased plants, number of plants attacked, age, area and production**.**

	Coefficients	*Standard error*	*Test- t*	*P-value*
Constant	244.485	176.637	1.384	0.204
Total Feet	-0.265	0.172	-1.542	0.162
No. of Sick Feet	0.194	0.553	0.350	0.735
No. of Feet Attacked	0.798	0.281	2.839	0.022*
Age (An)	6.472	9.957	0.650	0.534
Surface areas (ha)	-29.559	9.893	-2.988	0.017*
Production 2023 (Kg)	0.119	0.033	3.625	0.007**

The results presented in Table 6 provide information on the impact of each independent variable on performance. Thus, it has been shown that three (03) independent variables, namely production (p-value = 0.007), area (p-value = 0.017) and number of plants attacked, exert a significant influence on the yield of all varieties (Forastero, Criollo and Trinitario) combined. In contrast, the other variables did not show a statistically significant effect on the latter (p-value > 0.05).

This situation can be explained by the fact that the cocoa yield evolves in the same direction as production and vice versa for the area.

Indeed, when production and the area sown increase, the yield should normally increase while it is in the opposite direction for the number of plants attacked.

When the attack rate decreases, the yield must increase, and it decreases when the attack rate increases. Thus, these variables have a direct influence on performance.

Table 7: Multiple linear relationship between Forestero's yield, number of diseased plants and number of plants attacked

	Coefficients	*Standard error*	*Test- t*	*P-Value*
Constant	0.122	190.172	0.001	1.000
Ages (An)	9.248	11.902	0.777	0.455
Total Feet	-0.138	0.221	-0.622	0.548
No. of Sick Feet	0.688	0.698	0.986	0.348
No. of Feet Attacked	0.785	0.370	2.125	0.059

In this table, it can be seen that none of the variables, namely the number of diseased plants and the number of plants attacked, are significantly associated with Forestero's yield (p-value > 0.05).

Table 8: Multiple linear relationship between Criollo yield, number of diseased plants and number of plants attacked

	Coefficients	*Standard error*	*Test- t*	*P-Value*
Constant	-6.708	14.418	-0.465	0.652
Ages (An)	0.036	2.257	0.016	0.987
Total Feet	0.194	0.083	2.326	0.042*
No. of Sick Feet	0.179	1.596	0.112	0.913
No. of Feet Attacked	0.010	0.110	0.094	0.927

In this table, it can be seen that only the total number of plants exerts a statistically significant influence on the yield of the Criollo variety ((p-value = 0.042). On the other hand, the other variables did not show a significant effect on the return of the latter (p-value > 0.05).

This situation is justified by the fact that the more cocoa plants planted, the more Criollo production increases, and therefore, the more the yield increases. In other words, the density of the plants and therefore the spacing are major factors on the yield of this variety in the territories under examination.

III.DISCUSSION OF THE RESULTS

The data on the area of cocoa plantations obtained during the research ranged from 1 to 30 hectares, i.e. an average of 6.27 hectares. This situation was valid for the two territories surveyed. The highest area of 30 hectares was found in Wamba territory, while the highest in Rungu territory was 15 hectares. The average area value obtained during this research is much lower than an average of 36.4 hectares found by Makelele (2021) during his study on the development of the cocoa sector and its impact on forest land management in the Beni area. The smallest value of the area found on land (1ha) is also lower than the 2 to 5 hectares found by the United Nations REDD+ program (2017), in the research on sustainable cocoa production in Côte d'Ivoire.

In addition, the analysis of variance by the student's t-test indicates significant differences because (P=0.017).

As far as production is concerned, the 2023 production, the values obtained from the planters varied from 40 to 8700kg, i.e. an average of 1275.40kg. The differences in production between farmers are due to the size of the plantations and the cultivation techniques adopted by each cocoa farmer. The average recorded during our research is lower than the production of 1501.63 Kg obtained by **Baka (2019)** during his study on cocoa production in Côte d'Ivoire. As for the total production provided by all planters in Rungu and Wamba territories in 2023 (19131kg or 19,131 tons), it was much less than 120 tons per territory in North Kivu (Makelele, 2021). This reflects the low production of this crop in the study area.

The result of the statistical analysis by the student's t-test reveals a significant difference (P= 0.007).

As for the yields recorded in the course of our research, they vary in the intercourse of the

Valley from 18 to 500 kg, or an average of 153.30 kg/ha. The average found during our study is much lower than the yield of 2519.37Kg/Ha of cocoa per producer obtained by **Youb (2018)** in his study on the evaluation of two varieties of cocoa trees in the central region of Cameroon.

The low yields obtained in our study area and those of the others can be explained by the intensity of this crop in the two territories surveyed.

III. Conclusion

Our study aimed to determine the root causes of the low yield of cocoa cultivation in the Territories of Rungu and Wamba in the Province of Haut-Uélé.

The results obtained showed that three varieties, namely: production, area and number of plants attacked, have a significant influence on the yield of all varieties (Forastero, Criollo and Trinitario) combined. On the other hand, the other variables (age, number of diseased plants and total number of plants) did not show a statistically significant effect on the latter (p-value > 0.05).

The areas of the plantations vary between 1 and 30 hectares, with an average of 6.27 hectares and a standard deviation of 8.15. The coefficient of variation (CV) is 129.98%, indicating a relatively high variability in the areas. The cocoa farmers surveyed have plantations of very variable dimensions, from the smallest to the largest, depending on the case.

As for production, it ranges from 40 to 8700 kg, with an average of 1275.40 kg and a standard deviation of 2466.05. The coefficient of variation (CV) reached 193.36%, reflecting a high variability in production. This is in line with the area of the plantation.

As for the yield, it varies from 18 to 500 kg/ha, with an average of 153.30 kg/ha and a standard deviation of 167.04. The coefficient of variation amounts to 108.96%, indicating a relatively high variability in yields. These results can be explained by the variation in the area and production of the various plantations.

By analyzing this parameter, we observe variations in the attack rate for each variety and the cocoa tree as a whole, the overall average of which is 13.76%.

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