Evaluation of Adaptation and Yield Stability of Cocoa Progenies in Marginal Conditions: Results from an on Farm Cocoa Trial Set up in a Forest–Savannah Transition Area in Cameroon

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Abstract: Cocoa is an important crop in Cameroon, where it is cultivated in different areas, including marginal areas, characterized by a rather low level of annual rainfall and marked dry seasons. In order to release cocoa varieties with a good level of adaptation to these marginal conditions, nine full-sib progenies, already released to farmers in other producing areas of the country, were assessed on twelve on farm cocoa plots, set up in 2006, in Mbam et Inoubou county, which is a forest–savannah transition zone. The traits assessed were mortality rate, yield and yield stability. Mortality rate and yield vary widely among trial plots and among progenies. Four out of the nine assessed progenies present a yield level significantly higher than the five others. The lowest level of yield stability (estimated by the contribution to total ecovalence) was observed in both the highest and the lowest yielding progenies. Recommendation for the large-scale release of these progenies to farmers of the county, and to other cocoa producing forest–savannah transition areas, are made, based on the results obtained from this study.

Keywords: cocoa; yield; yield stability

1. Introduction

The cacao tree (*Theobroma cacao* L.) is a perennial plant of the Malvacea family (Alverson et al. [1], originating from South America [2] (Motamayor et al., 2002), and is cultivated for its beans, used for the confection chocolate. The first indices of use of cocoa beans were discovered in Ecuador, dating back to 3300 years B.C. [3] (Zarrillo et al., 2018). The species is structured in three morpho-geographical groups: Criollo, Forastero and Trinitario, the last one being described as a hybrid group, between Forastero and Criollo. This classification was revised and refined by Motamayor et al. (2008) [4], who established the existence of ten genetic groups, based on a molecular diversity study.

Today, cacao is cultivated in Africa, producing 76% of the worldwide production, in Central and South America (16% of worldwide production) and in Asia-Oceania (8% of worldwide production) (ICCO, 2018) [5]. Cacao was introduced to Cameroon in 1876, probably from Trinidad, but the impact of this first introduction (only 13 plants) on cacao cultivation in the country remains unknown. Later, in 1885, 322 plants were introduced to the south western region of the country, most probably from Sao Tomé and Fernando Po. The 322 plants represented varieties collected in various countries of Latin America and were then supposedly used as sources of seeds for cocoa cultivation in this region (Bartley,

2005) [6]. Today, Cameroon, produces 285,000 tons of cocoa beans (exported after fermentation and drying processes), representing 6% of the worldwide production, and placing this country at the position of fifth highest producing country of the world (ICCO, 2018) [5]. In Cameroon, cocoa breeding started at the beginning of the 1950s, based on the identification of promising trees in the cocoa farms, in the south of the country. The seeds, obtained from these cocoa trees, were sown in a research station of the IRCC (Institute of Research of Cacao and Coffee), in Nkoemvone, and 489 trees, issued from these seeds, were selected for their level of yield. These trees were used for vegetative multiplication and included in the local cocoa gene bank, with a SNK code (Selection of Nkoemvone). Among these SNK clones, 35 were released to local cocoa farmers, as plants issued from rooted cuttings, from 1957. This program was abandoned in 1968, because of the poor performances of the clones released to farmers (Paulin and Eskes, 1995) [7], probably due to the poor rooting system of the plants, released to farmers as rooted plagiotropic cuttings. In 1959, a new cocoa breeding program was initiated, based on the creation and selection of full-sib progenies, issued from 350 crosses between local SNK clones and imported clones, issued from selection performed in Trinidad and from collecting expedition in Peru (Paulin and Eskes, 1995) [7]. The parents of the 22 highest-yielding full-sib progenies were planted in bi-clonal seed-gardens, between 1971 and 2002, in the southern, central and south western parts of the country (Efombagn, 2012) [8], for the diffusion of the progenies resulting from recombination of the parents. These progenies contribute to the genetic background found in most of the plantations in Cameroon (Efombagn et al., 2006) [9]. Then, Cameroon took part to an international project of cocoa participatory breeding from 2004 until 2010 (Eskes, 2011) [10], aiming to select progenies combining high yield and low level of susceptibility to black pod disease, caused by Phytophthora megakarya (Nyassé et al., 2007) [11]. One of the activities of this project has consisted of the assessment of nine progenies issued from seed-gardens in on farm cocoa trials set up in the Mbam and Inoubou county, a forest–savannah transition zone in the central region of Cameroon, characterized by a rather low annual rainfall level and by two marked dry seasons. The present paper analyzes the results obtained on the level of survival and yield of these nine progenies, after their assessment during seven years, in twelve cocoa plots, set up in two villages of this county, and their consequences for their release to cocoa farmers of this county and of other areas, with similar climatic conditions.

2. Materials and Methods

Planting material: The assessed progenies are issued from pods obtained from hand-pollination (without isolation of the floral buds), performed in the bi-clonal seed gardens of the station of Nkoemvone of the SODECAO (national entity in charge of the release of the commercial cocoa varieties). The nine full sib progenies assessed are issued from the following crosses (the female parent is indicated in first position): IMC 67 × SNK 109, IMC 67 × SNK 64, SCA 12 × SNK 16, SNK 109 × IMC 67, SNK 109 × T 79/501, T 79/501 × SNK 109, T 79/501 × SNK 13, T 79/501 × SNK 64, UPA 143 × SNK 64. IMC 67, belonging to the Iquitos population (Motamayor et al., 2008) [4] is issued from a seed obtained in a pod collected on a spontaneous tree in Peru (Pound, 1938) [12].

SCA 12, belonging to the Contamana population (Motamayor et al., 2008) [4] is issued from a seed obtained in a pod collected on a spontaneous tree in Peru (Pound,1938) [12]. T 79/501 is issued from a cross performed in Trinidad (IFCC, 1976) [13], between NA 32 (Iquitos population) × PA 7 (Maranon population) (Motamayor, 2008) [4]. UPA 143 is issued from the cross between T 72/1436 and T 72/1433, performed in Ghana (IFCC, 1976) [12]. These two parents of UPA 143 are issued from a cross performed in Trinidad, between NA 32 and IMC 60, both from Iquitos population [4] (Motamayor 2008) [4]. SNK 109, SNK 16, SNK 13 and SNK 64 are issued from trees selected in cocoa farms, in the southern part of Cameroon (Braudeau 1958) [14] and belong to the Trinitario morpho-geographic group.

Experimental design: The study was conducted on twelve cocoa plots, set up by farmers, in 2006, under researchers' supervision, in two neighboring villages in Mbam

and Inoubou county, a transition area between forest and savannah, and characterized by a bimodal rainfall pattern, with a mean annual value of 1300 mm, distributed over 80 days per year. The soils, of sand/silt and sand/clay types are slightly acidic (pH 6–6.7). After cleaning of the plots, cocoa trees were planted at a 3 × 3 m distance, simultaneously with plantain, as well as other perennial species: fruit trees (a mixture of avocado (Persea Americana), citrus and safu (Dacryodes edulis) trees or oil palm (Elaeis guineensis). The spatial design, adopted for the plots where cocoa was intercropped with fruit trees resulted in a density of 960 cocoa trees per hectare (Bourgoing and Todem 2010a) [15], while the plots with cocoa intercropped with oil palm resulted in a density of 700 cocoa trees per hectare (Bourgoing and Todem 2010b) [16]. Each plot allows the assessment of a sub-sample of the progenies. In each plot, each progeny is located on two or three adjacent rows. The details of the numbers of trees of the progenies in each plot are given in Table 1.

Assessed traits and statistical analyzes: Annual l yield estimation: The methodology adopted here is derived from the ones developed by other authors for on farm yield assessment (Tahi et al., 2019 [17], Jagoret et al., 2017 [18]), and allows yield assessment without harvesting, independently from the farmers' harvest calendar. The yield was estimated on each individual tree, using the following formula: $Y_i = N_i \times C_j$, where Y_i = annual yield (g of cocoa) of the tree i, N_i = number of pods produced yearly by the tree i, belonging to the progeny j, estimated by the cumulated number of mature but unripe pods, counted during six annual rounds, at a two months interval, during the period from beginning of 2011 until the end of 2017 (seven years of production), then divided by seven. It was decided to count only unripe pods, to avoid the risk of counting the same pods twice (the counted unripe pods ripen during the two month period after their counting). C_j = weight of cocoa per pod (g) of the progeny j. A sample of at least 50 ripe pods was harvested on at least 20 trees of each progeny. The beans from each pod sample were fermented and dried, separately. The fermented and dried cocoa obtained from each sample of pods was weighted. The weight obtained was then divided by the number of sampled pods.

Yield analyses: Two factor ANOVA were performed on individual trees' yield values, using the following model: $y_{ijk} = \mu + g_i + p_j + s_{ij} + e_{ijk}$ where y_{ijk} is the yield of tree k of progeny i in plot j, μ is the general mean, g_i is the effect of progeny i, p_j is the effect of plot j, s_{ij} is the interaction between g_i and p_j, and e_{ijk} is the residual effect. In each plot, the number of assessed progenies ranges between 4 and 8. Each progeny is represented in a number of plots ranging between 5 and 12, by a number of trees ranging between 16 and 84. The details are given for each plot and each progeny in Table 1. The design is an incomplete and unbalanced randomized design. The adjusted mean values were estimated for progenies and trial plots (LSMEANS proc GLM) and ranked using the Newman–Keuls method at a 5% threshold.

Annual actual yield: the analyses described above were applied to the values obtained on all planted trees, including the ones which died before the end of the assessment period. This yield methodology considers trees' mortality and truly reflects the agronomical performances of the progenies in farms' conditions.

Annual potential yield: the analyses: The analyses were only applied to the trees that survived the all assessment period. This methodology reflects the potential of the progenies under favorable conditions.

Table 1. Number of trees representing the nine full-sib progenies (named in the first column), in the twelve trial plots.

Plot Identifier Locality Associated Crop	1 Bakoa Oil Palm	2 Bakoa Fruit	3 Bakoa Oil Palm	4 Bakoa Fruit	5 Bakoa Oil Palm	6 Bakoa Fruit	7 Bakoa Fruit	8 Kedia Fruit	9 Kedia Oil Palm	10 Kedia Fruit	11 Kedia Fruit	12 Kedia Fruit
IMC 67 × SNK 109			63		39	66	26	35	48	43	43	37
IMC 67 × SNK 64	54	37	63	58	84	42	43	35	69	44	44	38
SCA 12 × SNK 16	54			58			28	36	69		43	
SNK 109 × IMC 67		40	63				43				43	36
SNK 109 × T 79/501		49		29		42		36		43		35
T 79/501 × SNK 109	54	50	63	58	84	42	29				43	
T 79/501 × SNK 13		36	63	58		42	43				24	
T 79/501 × SNK 64								37	69	43	43	16
UPA 143 × SNK 64	54	34		59	72	42	29	35	30	43	43	35

Yield stability of the progenies was evaluated, calculating their contribution to total ecovalence (Wricke 1962) [19], based on the comparison between observed and expected mean value of each progeny in each plot, as calculated using the following formula: EYjk = Y.. − Yj.. − Y.k, where EYjk is the expected mean yield of progeny j in plot k, Y.. is the observed mean yield value of all progenies in all plots, Yj. is the observed mean yield value of all progeny j in all plots and Y.k is the observed mean value of all the progenies in plot k. These expected values were then used in the formula: $Wj = \sum(Yjk - EYjk)^2$ where Wj is the ecovalence of the progeny j. Because of the unbalanced design, resulting in the presence of the progenies in different numbers of plots. Each Wi value was adjusted (aW), using the following formula: aWj = Wj/pj, with pj = number of plots in which the progeny j is assessed. Total adjusted ecovalence (aWT) was calculated using the following formula: $aWT = \sum aWj$. The contribution to total ecovalence of each progeny (%W) was calculated as follows: %Wj = aWj/aWT × 100.

3. Results

3.1. Results from Analyses

3.1.1. Results from ANOVA

Highly significant effects (p = 0.01) of progeny, plot and interaction are observed on both actual and potential yield values, as shown in Table 2.

Table 2. Results from the two factor ANOVA performed on yield data.

Factor	Degrees of Freedom	Potential Yield		Actual Yield	
		F	*p*	**F**	*p*
Plot	11	49.58	<0.0001	33.83	<0.0001
Progeny	8	23.29	<0.0001	27.02	<0.0001
Plot × progeny	48	4.96	<0.0001	5.09	<0.0001

3.1.2. Ranking of the Progenies

A high level of variation is observed between the varieties for mortality (ranging between 14% and 34%), yearly potential yield (ranging between 639 and 1336 g/tree) and yearly actual yield (ranging between 463 and 1180 g/tree), as shown in Table 3. The progeny issued from IMC 67 × SNK 109, with actual and potential yield values of 1180 and 1336 g/tree, is significantly higher yielding then the other ones. On the other hand, the progeny from T 79/501 × SNK 64, with actual and potential yield values of 463 and 639 g/tree, is significantly lower yielding than the others, and presents a high mortality rate (34%). Among the other progenies, the ones from SNK 109 × IMC 67, SNK 109 × T 79/501 and IMC 67 × SNK 64, with actual yield values ranging between 845 and 893 g/tree, and potential yield values ranging between 1015 and 1184 g/tree, are significantly higher yielding than the other progenies issued from T 79/501 × SNK 13, T 79/501 × SNK 109, SCA 12 × SCA 16, UPA 143 × SNK 64 and T 79/501 × SNK 64.

The mean weight of one bean observed on the progenies ranges between 1.1 g (TT 79/501 × SNK 64, T 79/501 × SNK 13 and SCA 12 × SNK 16) and 1.4 g (IMC 67 × SNK 109).

3.1.3. Ranking of the Plots

A high level of variation is observed between the plots for their levels of mortality (ranging between 5 and 44%), and actual yield (ranging between 512 and 1270 g/tree), as shown in Table 4.

3.1.4. Yield Stability

The levels of potential and actual yield observed for each progeny in each plot where it was assessed, as well as the difference between the observed mean yield value and the expected mean yield value (in italics), are shown in Tables 5 and 6, while the contribution of each progeny to total ecovalence is shown in Table 7.

For all progenies, a large level of variability across plots is observed for both potential and actual yield.

The progeny issued from IMC 67 × SNK 109 shows observed mean yield values very different from the expected ones in plots 8, 9 and 12. These high differences result in the high contribution of this progeny to total ecovalence in case of both potential (14.7%) and actual (26.2%) yield. The progeny issued from SNK 109 × IMC 67 shows an observed mean potential yield value much lower than the expected one in plot 12, resulting in a rather high contribution to total ecovalence for this trait (13.9%), while the contribution is low (5.9%) in the case of actual yield. Its level of yield is higher or similar to the mean plot value in all the plots where assessed, except in plot 12. The progeny issued from SNK 109 × T 79/501 shows a mean actual yield value much higher than the expected one in plots 2 and 8 while the opposite situation occurs in plot 4. These high differences result in a higher contribution of this progeny to the total ecovalence in the case of actual yield value (11.5%) than in the case of potential value (4.9%). This progeny shows an actual yield value lower than the mean plot value only in the case of plot 4. The release of this progeny can result in a disappointing level of yield for some of the farmers who will plant it. The progeny issued from IMC 67 × SNK 64 shows observed mean yield values much higher than the expected ones in 4 and 10, while the opposite is found in plots 2 and 5. The contribution to ecovalence in case of both potential and actual yield values is average (9.6% and 10.2%). The mean yield value of this progeny is lower than the mean plot value, in plots 2 and 5. The progeny issued from T 79/501 × SNK 109 shows a mean actual yield value much higher than the expected one in plot 3 while the opposite situation occurs in plot 6. The contribution to ecovalence is higher in case of potential yield values (10.4%) than in case of actual yield (7.6%). This progeny shows a level of actual yield much lower than the mean plot value in three plots (2, 5 and 6). The release of this progeny can result in a disappointing level of yield for some of the farmers who would plant it.

The progeny issued from SCA 12 × SNK 16 show an observed mean yield value much higher than the expected one in plot 7, the opposite situation being observed for actual yield in plot 4. This progeny shows a mean yield value lower the mean plot value in five of the six plots where assessed. The progeny issued from T 79/501 * SNK 13 shows an observed actual yield value much higher than the expected one in plot 4 while the opposite situation occurs in plots 3 and 6. The contribution to total ecovalence is average, in case of both potential and actual yield values (9.2% and 9%) This progeny shows a level of potential and actual yield much lower than the mean value in three of the six plots where assessed (plots 2, 3 and 6). The progeny issued from UPA 143 × SNK 64 shows an observed mean yield value much higher than the expected one in plot 5, but the opposite situation occurs in plot 9. The contribution to total ecovalence is average, in case of both potential and actual yield values (11.7% and 10.9%). This progeny shows a mean actual yield value in five of the eleven plots where assessed (plots 6, 7, 9, 10 and 12). The progeny issued from T 79/501 × SNK 64 shows an observed mean actual yield value much higher than the expected one in plots 8 and 12 and much lower in case of plots 10 and 11. The contribution to ecovalence is very high (22%) in case of potential yield and average (10%) in case of actual yield. This progeny shows a level of actual yield much lower than the mean value of the plot in four of the five plots where assessed (plots 8, 9, 10 and 11).

Table 3. Ranking of the progenies (5% Newman–Keuls) for yield (g of cocoa/tree).

Progeny	Total Number of Cocoa Trees Planted	% of Mortality	Potential Yield (g of Cocoa per Tree)	N.K	Actual Yield (g of Cocoa per Tree)	N.K	Mean Weight of One Cocoa Bean (g)	Mean Weight of Cocoa per Pod (g)
IMC 67 × SNK 109	400	14	1336	a	1180	a	1.4	57.8
SNK 109 × IMC 67	225	28	1140	b	893	b	1.2	42.6
SNK 109 × T 79/501	234	24	1039	b	860	b	1.3	45.9
IMC 67 × SNK 64	611	20	1015	b	845	b	1.3	51.3
T 79/501 × SNK 109	423	34	887	c	668	c	1.2	42
SCA 12 × SNK 16	288	24	833	c	651	c	1.1	40.2
T 79/501 × SNK 13	266	24	803	c	650	c	1.1	35.3
UPA 143 × SNK 64	476	19	791	c	647	c	1.3	44.3
T 79/501 × SNK 64	208	34	639	d	463	d	1.1	38

N.K: Newman–Keuls at a 5% threshold. Different letters indicate significant difference.

Table 4. Ranking of the plots (Newman–Keuls at 5%), according to their level of potential and actual yield (g of cocoa/tree).

Plot id	Village	Intercropping	Number of Planted Trees	% Mortality	Potential Yield (g of Cocoa/Tree)	N.K	Actual Yield (g of Cocoa/Tree)	N.K
7	Bakoa	fruit trees	241	27	1704	a	1270	a
12	Kedia	fruit trees	197	31	1366	b	992	b
9	Kedia	oil palm trees	285	19	1050	c	880	bc
11	Kedia	fruit trees	326	5	1031	c	1000	b
3	Bakoa	oil palm trees	315	31	1013	c	755	cd
6	Bakoa	fruit trees	276	9	913	cd	854	c
4	Bakoa	fruit trees	320	29	836	de	619	ef
10	Kedia	fruit trees	216	37	825	de	571	fg
5	Bakoa	oil palm trees	279	44	803	de	565	g
1	Bakoa	oil palm trees	216	9	783	de	725	de
2	Bakoa	fruit trees	246	29	726	e	600	fg
8	Kedia	fruit trees	214	13	577	f	512	g

N.K: Newman–Keuls at a 5% threshold. Different letters indicate significant difference.

Table 5. Observed and expected potential yield of the progenies.

	1	2	3	4	5	6	7	8	9	10	11	12	Mean
IMC 67 × SNK 109			1225 *−160*		1039 *−136*	1439 *154*	1889 *−186*	540 *−409*	1836 *415*	1098 *−99*	1356 *−47*	1685 *−53*	**1336**
IMC 67 × SNK 64	1041 *207*	555 *−222*	986 *−78*	1138 *251*	575 *−279*	886 *−78*	1889 *134*	568 *−61*	1061 *−40*	985 *109*	1179 *97*	1325 *−92*	**1015**
SCA 12 × SNK 16	570 *−82*			647 *−58*			1841 *269*	458 *12*	817 *−101*		983 *84*		**833**
SNK 109 × IMC 67		824 *−77*	995 *−193*				2066 *186*				1077 *−130*	959 *−582*	**1140**
SNK 109 × T 79/501		1127 *326*		938 *27*		959 *−28*		862 *209*		854 *−46*		1538 *98*	**1039**
T 79/501 × SNK 109	843 *137*	539 *−110*	1346 *410*	767 *8*	789 *63*	491 *−345*	1613 *−14*				1007 *53*		**887**
T 79/501 × SNK 13		488 *−76*	501 *−350*	865 *191*		578 *−174*	1331 *−211*				1088 *218*		**803**
T 79/501 × SNK 64								410 *158*	845 *120*	184 *−317*	532 *−174*	1758 *717*	**639**
UPA 143 × SNK 64	727 *117*	687 *134*		669 *5*	909 *278*	674 *−66*	1353 *−178*	559 *154*	469 *−408*	675 *23*	1019 *160*	1246 *53*	**791**
Mean	**783**	**726**	**1013**	**836**	**803**	**913**	**1704**	**577**	**1050**	**825**	**1031**	**1366**	**964**

The values in the first row are the plot identifiers. The values in normal font are the mean observed annual potential yield value (grams of fermented and dried cocoa produced per tree) of the progenies in each plot. The values in italic show the difference between the observed and expected values. The last column indicates the mean value of each progeny in all plots and the last row the mean value of each plot (in bold).

Table 6. Observed and expected actual yield values of the progenies.

	1	2	3	4	5	6	7	8	9	10	11	12	Mean
IMC 67 × SNK 109			1136 *−18*		906 *−59*	1418 *164*	1462 *−207*	528 *−383*	1807 *527*	779 *−191*	1356 *−44*	989 *−402*	**1180**
IMC 67 X SNK 64	890 *85*	402 *−277*	831 *−3*	930 *231*	438 *−206*	868 *−66*	1405 *55*	502 *−89*	1004 *44*	874 *223*	1194 *115*	1183 *112*	**845**
SCA 12 × SNK 16	549 *−42*			363 *−123*			1578 *442*	336 *−42*	623 *−124*		848 *−19*		**651**
SNK 109 × IMC 67		689 *−23*	758 *−109*				1207 *−176*				1072 *−41*	771 *−334*	**893**
SNK 109 × T 79/501		973 *309*		353 *−332*		947 *28*		862 *285*		632 *−4*		1200 *143*	**860**
T 79/501 × SNK 109	735 *141*	406 *−62*	724 *100*	669 *180*	403 *−31*	404 *−319*	1257 *118*				1006 *137*		**668**
T 79/501 × SNK 13		438 *−32*	327 *−299*	770 *280*		493 *−232*	1106 *−34*				1000 *129*		**650**
T 79/501 × SNK 64								337 *143*	548 *−14*	158 *−96*	495 *−187*	1124 *450*	**463**
UPA 143 × SNK 64	728 *116*	628 *141*		503 *−4*	719 *267*	674 *−67*	951 *−206*	512 *113*	471 *−296*	407 *−51*	1028 *141*	747 *−132*	**647**
Mean	**725**	**600**	**755**	**619**	**565**	**854**	**1270**	**512**	**880**	**571**	**1000**	**992**	**781**

The values in the first row are the plots identifiers. The values in normal font are the mean observed annual potential yield value (grams of fermented and dried cocoa produced per tree) of the progenies in each plot. The values in italic show the difference between the observed and expected values. The last column indicates the mean value of each progeny in all plots and the last row the mean value of each plot (in bold).

Table 7. Contribution of each progeny to total ecovalence (%). This % is indicated by the numbers with a normal font, while the numbers in brackets and italics indicate the mean yield values of the progenies.

Progeny	% Contribution to Total Ecovalence	
	Potential Yield	**Actual Yield**
IMC 67 × SNK 109	14.7 (*1336*)	26.2 (*1180*)
SNK 109 × IMC 67	13.9 (*1140*)	5.9 (*893*)
SNK 109 × T 79/501	5.2 (*1039*)	11.5 (*860*)
IMC 67 × SNK 64	9.6 (*1015*)	10.2 (*845*)
T 79/501 × SNK 109	10.4 (*887*)	7.6 (*668*)
SCA 12 × SNK 16	3.2 (*833*)	8.6 (*650*)
T 79/501 × SNK 13	9.2 (*803*)	9 (*650*)
UPA 143 × SNK 64	11.7 (*791*)	10.9 (*647*)
T 79/501 × SNK 64	22 (*639*)	10 (*463*)

4. Discussion

Our experiment was conducted in twelve experimental plots managed by farmers, in two different villages, under two different intercropping systems, and with variable levels of agronomical care, in terms of weeding, fertilization and insecticide treatment. As a result, a high level of variability is observed among the plots. Indeed, seven of our plots show a level of actual yield (between 765 and 1270 g of cocoa per tree) clearly higher than the mean level of yield observed by Jagoret et al. (2017) [18], in traditional cocoa plots (560 g of cocoa/tree, corresponding to an annual yield of 616 kg/ha, at the density of 1100 trees/ha, usually observed in the traditional adult plots in the same area), while the five remaining progenies show a level of actual yield ranging between 512 and 619 g/tree) similar to or slightly lower than this value. This high level of variability should be considered when providing information to farmers about the level of yield to be expected from these progenies. This information should not only consist of the mean value, but also of the range of values that could be observed for each progeny. In addition, our experiment reveals a large difference between potential and actual yield of each progeny, caused by a rather large mortality rate, ranging between 14% and 34%, according to the progeny. The yield values of the progenies communicated to the farmers should be the ones of actual yield, considering mortality rate. The release of such information would result in realistic farmers' expectation from the commercial varieties they cultivate. The results obtained on yield and yield stability of the nine assessed progenies allow us to make recommendation about their future release, to farmers who cultivate cocoa in the county (Mbam et Ibounou) where the trial was set up, and, subsequently, in other areas, where cocoa is cultivated under similar climatic conditions. Indeed, our study allows us to assess the progenies for their level of yield, in climatic conditions which are considered as marginal for cocoa cultivation, because of the rather low rainfall and its marked dry seasons. On the other hand, these climatic conditions also severely limit the incidence of *Phytophthora megakarya*, a disease which severely challenges cocoa production in other producing areas of Cameroon (Despreaux et al., 1989) [20]. Among the assessed progenies, the one issued from IMC 67 × SNK 109 shows a significant higher mean level of actual and potential yield than all the other ones. Despite its low level of yield stability, indicated by its high contribution to total ecovalence, this progeny shows a high level of yield is in seven of the nine plots where assessed, while its yield is similar to the mean plot yield value, in the remaining plots. This indicates that this progeny can be released, with a high probability of ensuring a high or, at least, a satisfying level of yield to farmers of Mbam et Inoubou, who will cultivate it. In addition, this progeny produces cocoa beans with a mean weight (1.4 g) much higher than the value (1 g) considered as the minimal one required by some cocoa exporters and manufacturers. For these reasons, it is recommended to release this progeny in priority. The progenies issued from SNK 109 × IMC 67, SNK 109 × T 79/501 and IMC 67 × SNK 64, show a level of yield significantly higher than the five lowest yielding

progenies. These three progenies show an average contribution to ecovalence, revealing a relative stability of yield, and their release would ensure a good level of yield to most of the farmers of Mbam et Inoubou who would cultivate them. In addition, they produce cocoa beans with a mean weight ranging between 1.2 and 1.3 g, higher than the 1 g considered a s a minimal value by some cocoa exporters and manufacturers. Despite their yield level significantly lower than the one observed on IMC 67 × SNK 109, it is thus suggested to release the progenies from IMC 67 × SNK 64 and SNK 109 × T 79/501, in addition the one from IMC 67 × SNK 109, in order to reduce the inconveniences resulting from the release of a single progeny (low level of genetic diversity, risks of incompatibility between trees).

The significant difference observed between the levels of yield of progenies issued from reciprocal crosses (IMC 67 × SNK 109/SNK 109 × IMC 67 and T 79/501 × SNK 109/SNK 109 × T 79/501) confirm the existence of reciprocal effects for this trait, showed by Despréaux et al. (1989) [20] in a diallel trial experiment conducted in Cameroon, and in a diallel trial experiment conducted in Ghana, by and Ofori and Padi (2020) [21]. Although our assessment, based on seven consecutive years of production, can be considered as reliable enough to make recommendation about the release of the progenies to farmers, it would be interesting to continue the assessment of the progenies in the same trial plots during a longer period, in order to estimate their longevity and their yield stability over time (Tahi et al., 2019) [22]. Finally, our study allows us to recommend the release of the three progenies issued from IMC 67 × SNK 109, IMC 67 × SNK 64 and SNK 109 × T 79/501 to the farmers of the Mbam et Inoubou county, and to introduce these progenies in other forest-savannah transition areas, with similar climatic conditions and where cocoa is currently being cultivated, in both central and eastern regions of the country.

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