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Impacts of climate variability on the production of Dwarf x Tall and Tall x Tall coconut (*Cocos nucifera* L.) palm hybrids planted on the coast in Côte d'Ivoire

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ABSTRACT

The Ivorian coast is the main coconut production area where agriculture is mainly rainfed. However, in this area, climate variability poses a great threat to the growth and sustainable development of agriculture. This study aimed at highlighting the impacts of climate variability on the production of the most popular Dwarf x Tall and Tall x Tall coconut palm hybrids in the world. It is based on the evaluation of the production of the hybrids from statistical tests (ANOVA, STUDENT's T-test at 5%) and the results of the standardized precipitation and evapotranspiration indices (SPEI) during the period of 2009 to 2018 of the study area. The results obtained revealed that the NJM×GOA+ hybrid was significantly differentiated by its good production potential of bunches (10 bunches), fruits (151 nuts) and copra (3.69 t). The maximum fruit production per year was observed in the Dwarf × Tall hybrids (101 nuts). The highest mass productions of copra per tree and copra per hectare were recorded in the Tall × Tall hybrids. The maximum productions of the ten hybrids were observed in 2012, 2015 and 2018 and the lowest in 2014 and 2017. Productions gradually increase or remain stable for consecutive wet years (2009 to 2011) prior to harvest. The onset of drought in one year (2012, 2013, 2015, 2016) and pronounced for two consecutive dry years (2012 to 2013 and 2015 to 2016) prior to harvest significantly decrease the level of production. These cumulative effects of drought are most pronounced in NRC×GRL+, NRM×GTN, NJM×GD001, NJM×GD002, and NJM×GD003 hybrids. NJM×GOA+, GVT×GTN, GSL×GTN, NRM×GVT, and NVS×GVT hybrids are developing abilities to express themselves better under this climate variability. They could be taken into account in the crop improvement program and proposed to growers to improve the yield of coconut trees under rainfed conditions.

Keywords: Côte d'Ivoire, coast, climate variability, coconut palm hybrids.

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INTRODUCTION

Climate variability is a major global issue, which is increasingly significant on the international scene. It is harmful for the entire planet and particularly harsh for vulnerable regions of Africa (IPCC, 2014). Indeed, the economy of most countries in Africa depends on agriculture, which is dependent on the climate (Deschênes et al., 2007; Lobell et al., 2010). In these countries, the effect of climate variability on the agricultural sector is felt directly on the economy, given that, on average, agriculture contributes 20 to 30% of the Gross Domestic Product (GDP) and represents 55% of total export value (FAO, 2016). One of the most recurrent phenomena of climate variability is drought, which has negative impacts on agricultural production and the socio-economic development of a country (Begueria et al., 2010). Also, drought causes severe economic losses in the field of agriculture due to the drastic drop in agricultural production (Nath et al., 2017). In view of these findings, it seems relevant to focus on the relationship between agricultural production and climate variability in order to develop adaptation strategies indicated to improve the resilience of communities living in Africa (Makougoum, 2018).

In Côte d'Ivoire, the coconut palm is the main perennial crop in the coastal zone. It ensures the subsistence of coastal families where other speculations such as rubber, oil palm, cocoa and coffee cannot develop (Assa et al., 2006). However, the sustainability of coconut cultivation is threatened. Indeed, the Côte d'Ivoire, the main coconut production area, practices agriculture that depends on the rains, making this area largely dependent on climatic conditions (Konan et al., 2006). Unimproved coconut palms of the Grand Ouest Africain (GOA) ecotype are the most common in these village plantations. GOA trees take 7 to 8 years before flowering and are not very productive with a production of about 10 000 nuts per hectare per year (Konan, 1997). Added to this are several constraints acting on the development of the nut and contributing to the low yields of the coconut palms. These constraints include the poor quality of the plant material planted, the low drought tolerance of the plant material, the occurrence of dry sequences, seasonal irregularities accentuated by water stress due to the pronounced effects of climatic variability of year to year (Oropeza et al., 2005; Van Der Vossen and Chipungahelo, 2007; Agoh et al., 2021). In addition, the long duration (approximately 44 to 48 months) from floral initiation to nut maturity on adult coconut trees makes it difficult to attempt to ascertain the cumulative effects of climatic variables on coconut production species. This is why the creation of improved plant material adapted to Climate Change (CC) continues to be one of the main objectives of the coconut program in Côte d'Ivoire hosted by the National Center for Agronomic Research (CNRA). The work initiated by the CNRA in terms of varietal selection has enabled the creation of a varied range of hybrids, Dwarf x Tall and Tall x Tall, by judiciously involving in the crosses the Tall and Dwarf ecotypes making up the International Coconut Collection for Africa and the ocean it hosts. To date, information on the relationship between climatic parameters and production levels of these hybrids is less provided. This study aimed at highlighting the impacts of climate variability on the production of the most popular Dwarf x Tall and Tall x Tall coconut palm hybrids in the world with a view to identifying the hybrids most adapted to Climate Change and make the most of coconut cultivation.

MATERIALS AND METHODS

Study site

The work was carried out on the experimental plot numbered 050 housing the Multilocal test coded PBGC 45 of the International Coconut Collection for Africa and the Indian Ocean located at the Marc

Delorme research station of the National Center for Agronomic Research (CNRA) in Ivory Coast. The Marc Delorme station is located in the South-East of Côte d'Ivoire between 5°14' and 5°15' North latitude and 3°54' and 3°55' West longitude (CCT, 2006, Koffi et al., 2017) (Figure 1).

The soil of the Marc Delorme station is essentially made up of soil with sesquioxides of the ferralitic type leached in bases and contains significant contents of fine sands with a little clay at depth with low organic matter contents. It is composed of 5.2 g.kg-1 of carbon (C), 0.5 g.kg-1 of nitrogen (N), 4.2 Cmol (+) kg-1 of soil with a capacity of cation exchange (CEC), 0.25 Cmol (+) kg-1 of soil with the sum of exchangeable bases and 0.04 g.kg-1 of assimilable phosphorus (P) with a water pH equal to 5.7 (N'Goran, 2005). The climate belongs to the equatorial transitional regime (Attiean climate) whose rhythm of the seasons is regulated by the displacement of the Intertropical Front (ITF). The Attiéan climate is characterized by 4 seasons including 2 rainy seasons (April to July and October to November) and 2 dry seasons (December to March and August to September) (Eldin, 1971; Goula et al., 2006). From the planting of the coconut trees to the collection of agronomic data (2002 to 2018), the rainfall and the average annual temperature were 1383.4 to 1770.68 mm and 25.9 to 26.9°C respectively.

Plant material

Ten coconut palm hybrids, resulting from Dwarf×Tall crosses with 8 hybrids and from Tall ×Tall crosses with 2 hybrids, were studied. The parental accessions involved in the crosses that made it possible to obtain these hybrids come from African countries (Côte d'Ivoire, Benin, Tanzania, Mozambique), Latin America and the Caribbean (Mexico, Jamaica, Brazil) were used. (Table 1). The coconut palm hybrids Port-Bouët 121 improved (PB121+) and Port-Bouët 113 improved (PB113+) resulting from the crossings Malaysia Yellow Dwarf (MYD) x Grand Ouest Africain improved (GOA+) Cameroun Red Dwarf (CRD) x Tall Rennell improved (GRL+) respectively are used as controls and remain the most popular in Côte d'Ivoire for their high early production (Bourdeix et al., 2005).

The coconut trees were planted in 2002 according to a completely randomized Fisher block design with 5 repetitions at a density of 143 trees per hectare. Each of the elementary plots has 16 trees of each hybrid planted in 4 rows. Observations were made on a population of 6 asymptomatic trees (sanitary status assessed visually) randomly selected from each elementary plot. That is a total of 30 trees per hybrid. The total area of the trial is 6.5 hectares.

Methods

Collection of climate data

The climatic data relating to rainfall and temperature from 1961 to 2018 are taken from the previous results of the work of Agoh et al. (2021). Climate data were used to characterize and identify years of drought and humidity from the Standardized Precipitation and Evapotranspiration Indices (SPEI) from 1961 to 2018 (Agoh et al., 2021) (Table 2).

Collection of production data

The production data collected from 2009 to 2018 concerned the number of bunches per tree per year (NbR/tree/year), the number of fruits per tree per year (NbFr/tree/year), the copra mass per tree per year (Cop/tree/year) and copra mass per hectare per year (Cop/hectare/year). The number of bunches and the number of fruits on the trees were evaluated following the guidelines of Wuidart and Rognon (1978). The copra content of the nuts was quantified every 2 months from the nuts harvested from the trees in the field. Thus, every two months, bunches bearing mature nuts are harvested from each tree from a sickle attached to a Chinese bamboo at least 10 m high. Using a marker, the nuts were identified by indicating the number of the parcel and the tree then conveyed to the Laboratory to determine the copra composition (kernel dried at 6% humidity) according to the protocol of Wuidart and Rognon (1978). The different characters evaluated are compared not only with each other, but also with the control PB121+ and PB113+. To do this, they were grouped according to the type of crossing of the "Dwarf × Tall" hybrids and "Tall × Tall" to highlight the type of crossing adapted to the ecological conditions of the area.

Statistical analysis

Evaluation of the production of coconut hybrids

To test the variability within the distribution of the values of production traits (number of bunches per tree, number of fruits per tree, mass of copra per tree, mass of copra per hectare) of the hybrids recorded over the decade from 2009 to 2018, a variance homogeneity test was performed.

An analysis of variances (ANOVA) was carried out for all the characters studied for the ten hybrids. When a significant difference was observed between the different variables ($p < 0.05$), the comparison of the means was made using the NEWMAN and KEULS test at the 5% threshold. For the comparative study of the production data of the "Dwarf × Tall" and "Tall × Tall" hybrids, a comparison of the mean using the STUDENT T test at a 5% level of significance was carried out.

Evaluation of the effects of dry and wet periods on the production of coconut hybrids

The dry and wet years determined when calculating the standardized precipitation and evapotranspiration indices (SPEI) according to the method mentioned in the study by Vicente-Serrano et al. (2010) during the period 2009 to 2018 in the study area (Agoh et al., 2021) were related to the production in number of bunches, nuts and copra of the hybrids. The rates of trait reductions related to the production of Dwarf x Tall and Tall x Tall Coconut type hybrids were calculated according to the following formulas:

$$T_r(\%) = \frac{Prs_1 - Pfh}{Pfh} \times 100 \quad (1)$$

$$T_r(\%) = \frac{Prs_2 - Pfh}{Pfh} \times 100 \quad 2)$$

$$T_f(\%) = \frac{Pfs_1 - Pfh}{Pfh} \times 100 \quad (3)$$

$$T_f(\%) = \frac{Pfs_2 - Pfh}{Pfh} \times 100 \quad (4)$$

$$T_c(\%) = \frac{Pcs_1 - Pfh}{Pfh} \times 100 \quad (5)$$

$$T_c(\%) = \frac{Pcs_2 - Pfh}{Pfh} \times 100 \quad (6)$$

Prs_1: Production of bunches preceded by the occurrence of a drought year**;** **Prs_2**: Production of bunches preceded by the appearance of two consecutive dry years; **Pfs_1**: Fruit production preceded by the occurrence of a drought year; **Pfs_2**: Fruit production preceded by the onset of two consecutive dry years; **Pcs_1**: Copra production preceded by the manifestation of a year of drought; **Pcs_2**: Copra production preceded by the onset of two consecutive dry years; **Pfh**: Maximum fruit production preceded by wet years; **T_r** : Bunches Reduction Rate (%); **T_f** : Fruit reduction rate (%); **T_c** : Copra reduction rate (%)

The aforementioned statistical analyzes were performed using SPSS 22.0, STATISTICA 7.1 and CDM 3.0 software.

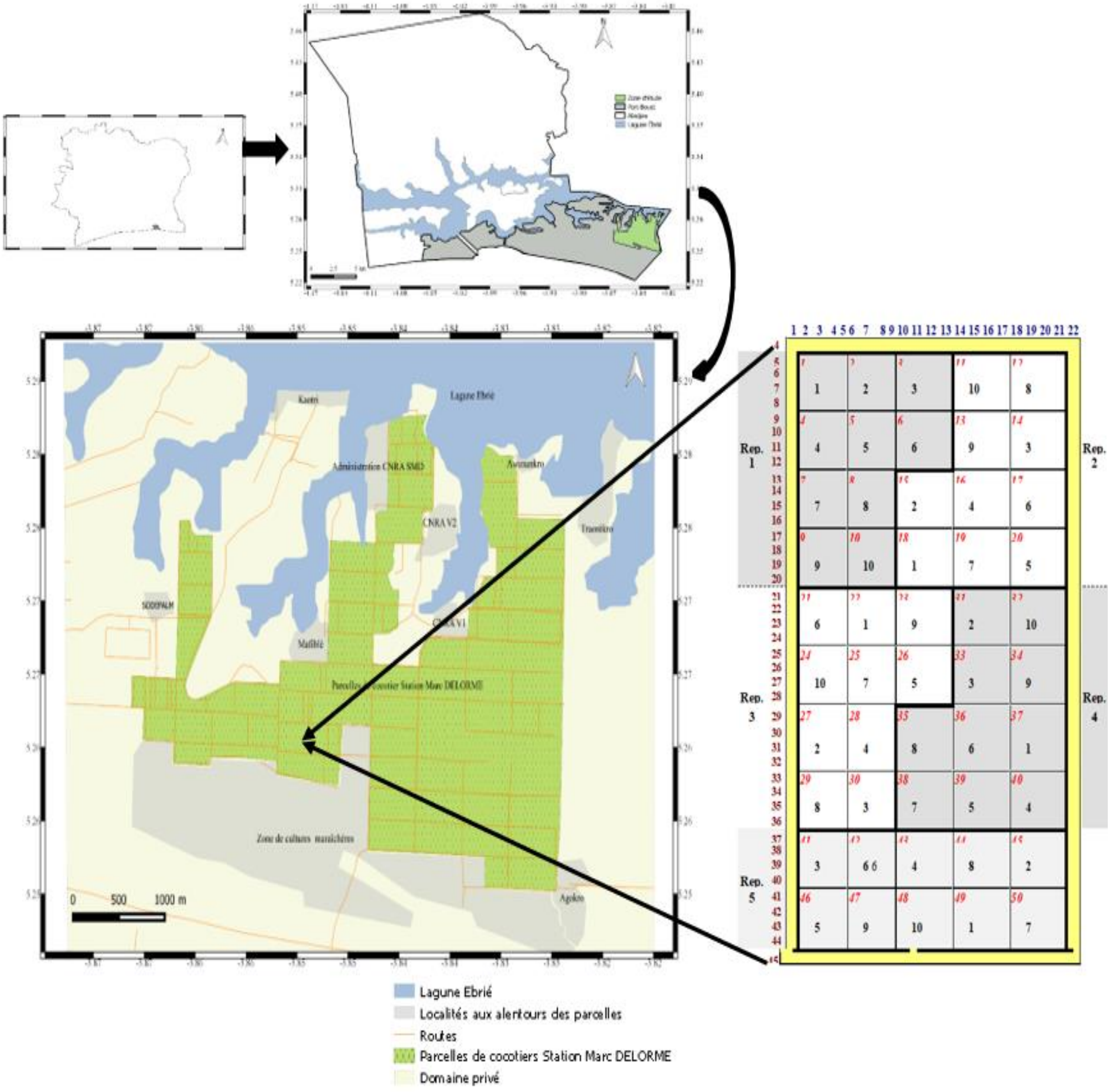


Figure 1: Geographical map of the study site (Marc Delorme Station) showing the experimental plot numbered 050. On the right the numbers 1 to 10 in black bold, on plot 050, represent the 10 hybrids evaluated.

Table 1: Some characteristics of the 10 Dwarf x Tall and Tall x Tall coconut palm hybrids studied.

Cultivar Number	Crossings	International code	French code	Number of trees analyzed
Hybrids Dwarf x Tall (number = 8)				
1	Nain Jaune Malaisie x Grand Ouest Africain amélioré	MYD x WAT+	NJM x GOA⁺/PB121⁺	30
2	Nain Rouge Cameroun x Grand Rennell amélioré	CRD x RIT+	NRC x GRL⁺/PB113⁺	30
5	Nain Rouge Malaisie x Grand Vanuatu	MRD x VIT	NRM x GVT	30
6	Nain Rouge Malaisie x Grand Tagnaman	MRD x TAGT	NRM x GTN	30
7	Nain Jaune Malaisie x Grand Takome	MYD x TKT	NJM x GDO01	30
8	Nain Jaune Malaisie x Grand Tenga	MYD x TGT	NJM x GDO02	30
9	Nain Jaune Malaisie x Grand Palu	MYD x PUT	NJM x GD003	30
10	Nain Vert Sri Lanka x Grand Vanuatu	PGD x VIT	NVS x GVT	30
Hybrids Tall x Tall (number = 2)				
3	Grand Vanuatu x Grand Tagnaman	VIT x TAGT	GVT x GTN	30
4	Grand Sri Lanka x Grand Tagnaman	SLT x TAGT	GSL x GTN	30
Total				300

Table 2: Number of wet and dry periods from 1961 to 2018 in the study area.

Classes	SPEI (years)	Total SPEI
Extremely wet (**SPEI**>2,00)	1963	1
Very wet (1,50<**SPEI**<1,99)	1969 ;1975 ;1976 ;1982 ;**2010**	5
Moderately wet (1,00<**SPEI**<1,49)	1961 ;1965 ;1968 ;1973 ; 1974 ; **2009 ;2011 ;2014 ; 2017**	9
Normal (0,00<**SPEI**<0,99)	1962 ; 1964 ;1967 ;1971 ; 1972 ; 1978 ;1979 ;1981 ; 1992 ;1993 ; 1996 ;2001 ; 2008	13
Near normal (-0,99<**SPEI**<0,00)	1966 ;1970 ;1977 ;1980 ;1984 ; 1986 ;1987 ;1991 ;1994 ;1995 ; 1997 ;1999 ;2000 ;2002 ;2005 ; 2006 ;2007 ;**2015**	18
Moderately dry (-1,49<**SPEI**<-1,00)	1983 ;1985 ;1988 ;1990 ;2003 ; 2004 ;**2012 ; 2018**	8
Very dry (-1,99<**SPEI**<-1,50)	1989 ;1998 ;**2013 ;2016**	4
Extremely dry (**SPEI**<-2,00)	0	0

Nb: values in bold indicate the SPEIs included over the production data collection period (2009 to 2018). Source: Agoh et al., 2021.

RESULTS

Variability of production-related traits in coconut hybrids

The level of expression of the characters number of bunches per tree per year (NbR/tree/year), number of fruits per tree per year (NbFr/tree/year), mass of copra per tree per year (Cop/tree/year) and mass of copra per hectare per year (cop/hectare/year) of the hybrids studied varied significantly from one year to another ($p < 0.05$) (Table 3). The comparative analyzes of the production levels of the hybrids studied for each of the four characters are illustrated in Figures 2, 3, 4 and 5. At the level of the average annual number of bunches, two groups of hybrids emerge. The NJM x GOA+, NRM x GVT and NVS x GVT hybrids gave a higher number of bunches (9 to 10 bunches/tree/year) (Figure 2). Regarding nut production, NJM×GOA+ expressed a higher average annual fruit production (151 fruits/tree/year). The NJM x GDO01 hybrid with 81 fruits/tree/year provided the lowest fruit production (Figure 3). Relatively to copra production, PB121+ stood out with the highest values, namely 25.81 kg of copra/tree/year and 3.69 t of copra/ha/year (Figures 4 and 5).

The characters number of bunches per tree per year (NbR/tree/year), number of fruits per tree per year (NbFr/tree/year), mass of copra per tree per year (Cop/tree/year) and mass of copra per hectare per year (cop/hectare/year) of Dwarf x Tall and Tall x Tall hybrid types varied significantly across years ($p < 0.05$) (Table 4). The production levels of the Dwarf x Tall and Tall x Tall hybrid types for each of the four traits are shown in Figures 6 and 7. Regarding the average production of the number of bunches according to the Dwarf x Tall hybrid types Tall and Tall x Tall, no significant trend emerges (Figure 6). About the fruit production per year of the "Dwarf × Tall" and "Tall × Tall" hybrids, it varied significantly. Maximum fruit production per year (101 fruits/year) was observed in hybrids resulting from the "Dwarf × Tall" cross. As for the lowest fruit productions per year (94 fruits/year), they were recorded in the "Tall × Tall" hybrids (Figure 6). However, hybrids of the "Tall × Tall" type stand out significantly with higher values of 19.89 kg of copra/tree/year and 2.92 t of copra/ha/year (Figure 7).

The effects of dry and wet periods on hybrid production

The effect of climate variability on the production of the hybrids evaluated is materialized by wet years (2009, 2010, 2011, 2014 and 2017) and dry years (2012, 2013, 2015, 2016 and 2018) (Figures 8 to 11). The highest productions in bunches, fruits and copra in all the hybrids studied were observed during the n +1 dry years (2012, 2015 and 2018) following the wet n years (2011, 2014 and 2017) where the recorded production has dropped significantly. For consecutive wet years, the production of bunches, fruits and copra gradually increases or remains stable (2009 to 2011) while for consecutive years of drought the level of production decreases (2012 to 2013 and 2015 to 2016). The same tendencies are observed in the "Dwarf x Tall" and "Tall x Tall" type hybrids (Figures 9, 10 and 11).

This manifestation of drought affects in variable proportions the level of expression of the characters number of bunches produced per tree per year (NbR/tree/year), number of fruits produced per tree per year (NbFr/tree/year), mass of copra produced per tree per year (Cop/tree/year) and mass of copra produced per hectare per year (cop/hectare/year) of the "Dwarf x Tall" and "Tall x Tall" hybrid types (Tables 5, 6, 7 and 8). However, the yield reduction rates of the ten coconut hybrids after one or two consecutive drought years varied significantly (Tables 5 and 6). Regarding the reduction rates of production after one year of drought, they oscillated from 7.87 to 30.60% and those of production after two consecutive years of drought varied from 16.66 to 52.20%.

The cumulative effect of two consecutive dry years significantly influences the production characteristics of the hybrids evaluated in general and in particular those of the hybrids NRC×GRL+, NRM×GTN, NJM×GD001, NJM×GD002 and NJM×GD003 with rates the highest discounts ranging from 36.53 to 52.20%. As for the NJM×GOA+, GVT×GTN, GSL×GTN, NRM×GVT and NVS×GVT hybrids, they stand out from the others with lower reduction rates between 16.66% and 33.37%.

At the level of the average production of the number of bunches, fruits and copra according to the types of Dwarf x Tall and Tall x Tall hybrids, the reduction rates varied significantly (Table 7 and 8). The yield reduction rates after a drought year in the 'Dwarf x Tall' and 'Tall x Tall' type coconut palm hybrids ranged from 16.97 to 23.03%. Those of production after two consecutive dry years fluctuated from 28.54 to 40.39%. The high rates of reduction in production (40.39%) were recorded after the manifestation of two consecutive years of drought in hybrids "Dwarf × Tall". As for the lowest rates of reduction in production (16.97%), they were recorded in the " Tall x Tall " hybrids (Table 7 and 8).

The level of expression of the characters number of bunches per tree (NbR/tree/year), number of fruits per tree (NbFr/tree/year), mass of copra per tree (Cop/tree/year) and mass of copra per hectare (cop/hectare/year) is strongly influenced by the onset of drought during a year and pronounced for two successively dry years preceding the harvest.

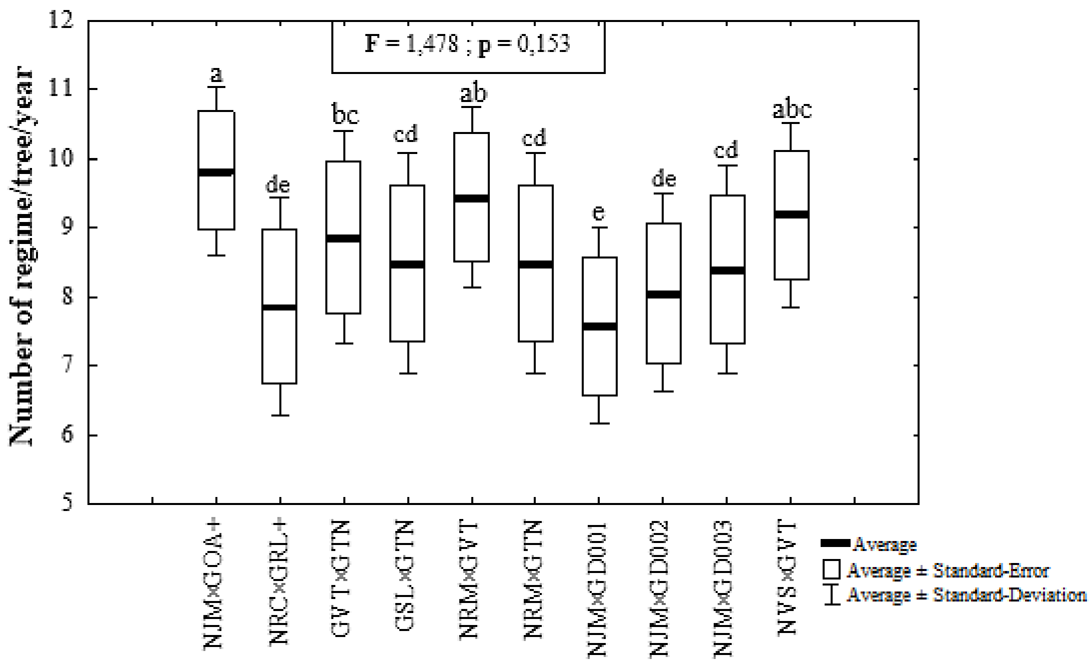


Figure 2: Variability in the number of bunches of the 10 coconut palm hybrids over the period from 2009 to 2018.

Table 3: Variability of variables, number of bunches, number of fruits, mass of copra per tree, mass of copra per hectare in the ten coconut palm hybrids from 2009 to 2018.

HYBRIDS	**NbR/tree/year**			**NbFr/tree/year**			**Cop/tree/year**			**Cop/hectare/year**		
	Homogeneity test			**Homogeneity test**			**Homogeneity test**			**Homogeneity test**		
	(Mean ± standard deviation)	**F**	**p**	**(Mean ± standard deviation)**	**F**	**p**	**(Mean ± standard deviation)**	**F**	**p**	**(Mean ± standard deviation)**	**F**	**p**
NJM×GOA+	9,82 ± 0,66	2,938	**0,029**	150,74 ± 16,49	1,518	**0,017**	25,81 ± 6,08	1,470	**0,039**	3,69 ± 0,87	2,044	**0,050**
NRC×GRL+	7,86 ± 1,13	1,885	**0,038**	89,64 ± 14,95	2,003	**0,035**	15,92 ± 3,24	2,808	**0,012**	2,28 ± 0,46	3,243	**0,012**
GVT×GTN	8,86 ± 2,53	1,469	0,193	93,94 ± 25,99	2,205	**0,048**	19,41 ± 5,26	1,776	**0,044**	2,78 ± 0,75	2,078	**0,050**
GSL×GTN	8,78 ± 1,59	3,783	**0,002**	95,00 ± 27,72	1,157	**0,050**	20,21 ± 5,02	3,243	**0,005**	2,89 ± 0,71	2,381	**0,041**
NRM×GVT	9,44 ± 1,31	1,113	0,376	113,72 ± 34,05	2,873	**0,025**	17,66 ± 4,51	2,134	**0,036**	2,52 ± 0,68	2,013	**0,046**
NRM×GTN	8,48 ± 1,59	3,783	**0,002**	86,76 ± 27,72	1,157	**0,034**	17,54 ± 5,02	3,243	**0,005**	2,50 ± 0,71	3,543	**0,045**
NJM×GD001	7,58 ± 1,41	0,957	0,489	81,56 ± 24,94	2,594	**0,027**	13,72 ± 3,37	3,304	**0,004**	1,96 ± 0,48	3,704	**0,037**
NJM×GD002	8,06 ± 1,43	0,872	0,557	86,18 ± 21,91	2,030	**0,050**	15,08 ± 3,12	2,104	**0,050**	2,15 ± 0,44	2,178	**0,458**
NJM×GD003	8,4 ± 1,49	0,602	0,788	84,04 ± 21,99	2,304	**0,049**	14,11 ± 3,97	1,540	0,168	2,01 ± 0,45	1,540	0,121
NVS×GVT	9,18 ± 1,09	1,578	0,155	117,64 ± 23,59	2,969	**0,036**	17,67 ± 3,04	1,957	**0,021**	2,52 ± 0,43	2,096	**0,039**

NB: NbR/tree/year = Number of bunches produced per tree per year; **NbFr/tree/year** = Number of fruits produced per tree per year; **Cop/tree/year** = Mass of copra produced per tree per year; **Cop/hectare/year**= Mass of copra produced per hectare per year. In bold, the significant probability values associated with the homogeneity test.

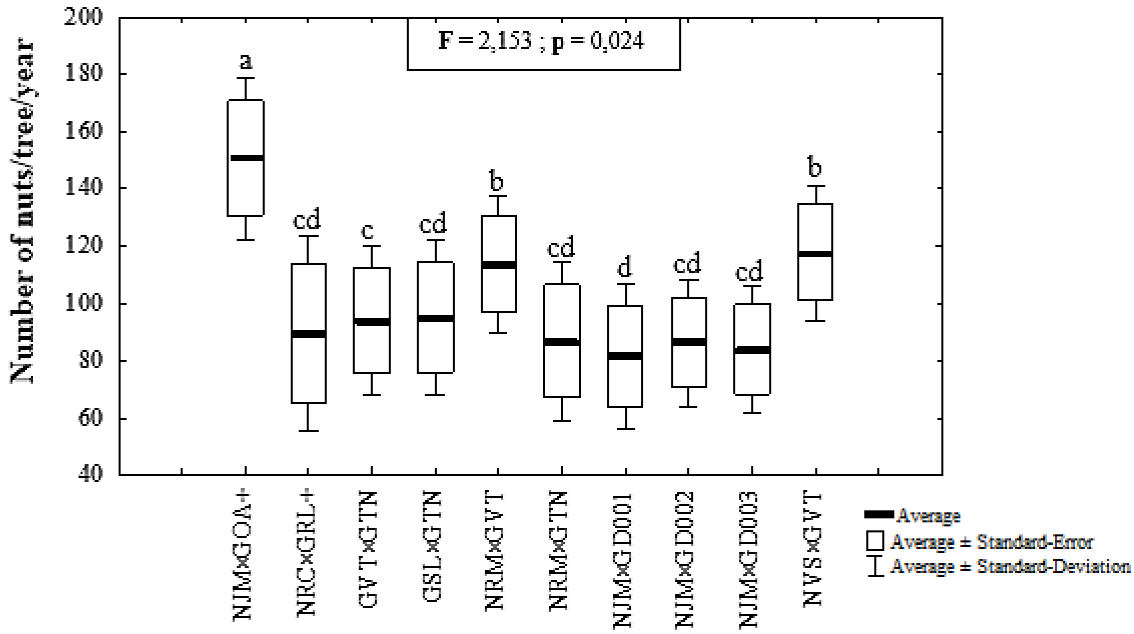


Figure 3: Variability in the number of nuts of the 10 coconut palm hybrids over the period from 2009 to 2018.

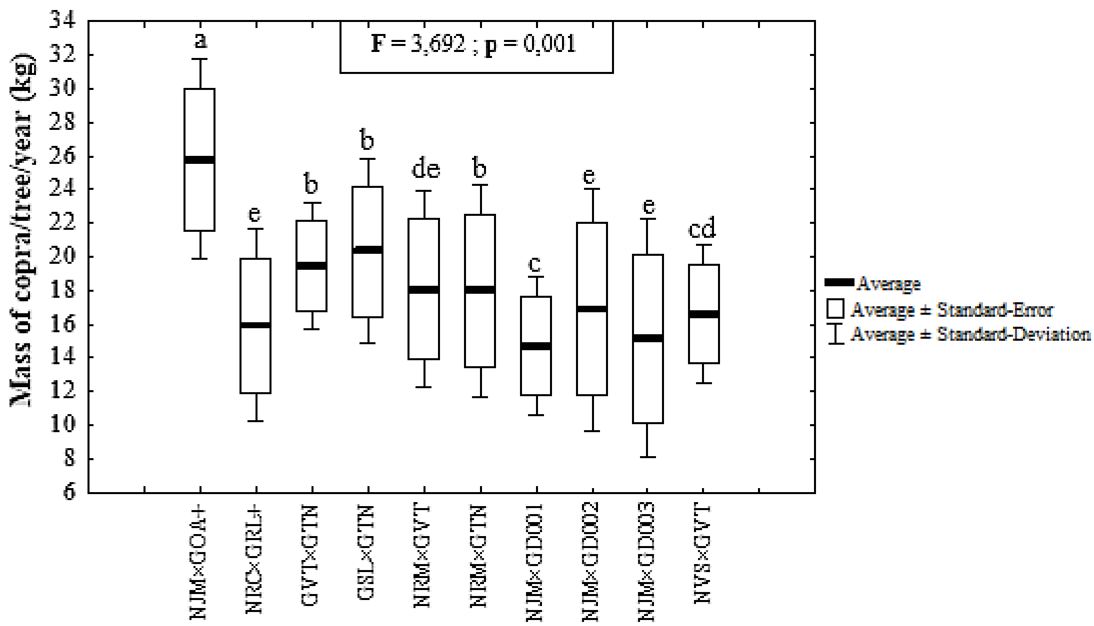


Figure 4: Variability of the copra mass per tree of the 10 coconut palm hybrids over the period from 2009 to 2018.

Table 4: Variability of variables, number of bunches, number of fruits, mass of copra per tree, mass of copra per hectare in two types of Dwarf x Tall and Tall x Tall coconut palm hybrids from 2009 to 2018.

Hybrids	NbR/tree/year			NbFr/tree/year			Cop/tree/year			Cop/hectare/year		
	Homogeneity test			Homogeneity test			Homogeneity test			Homogeneity test		
	(Mean ± standard deviation)	F	p	(Mean ± standard deviation)	F	p	(Mean ± standard deviation)	F	p	(Mean ± standard deviation)	F	p
Dwarf x Tall	8,82 ± 1,59	1,652	0,120	101,29 ± 34,43	2,750	0,008	17,18 ± 6,70	2,805	0,001	2,45 ± 0,96	2,069	0,001
Tall x Tall	8,60 ± 1,57	2,642	0,425	94,47 ± 26,31	1,208	0,037	19,89 ± 4,70	2,409	0,042	2,92 ± 0,73	1,187	0,048

NB: NbR/tree/year = Number of bunches produced per tree per year; **NbFr/tree/year** = Number of fruits produced per tree per year; **Cop/tree/year** = Mass of copra produced per tree per year; **Cop/hectare/year** = Mass of copra produced per hectare per year. In bold, the significant probability values associated with the homogeneity test.

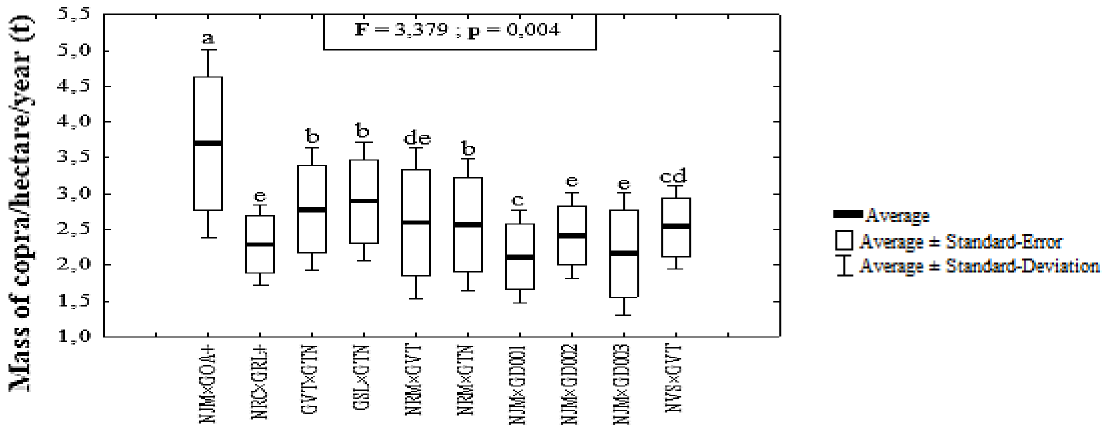


Figure 5: Variability of the mass of copra per hectare of the 10 coconut palm hybrids over the period from 2009 to 2018.
NB: The box plots with the same letters are not significantly different at the 5% threshold (Newman Keuls test).

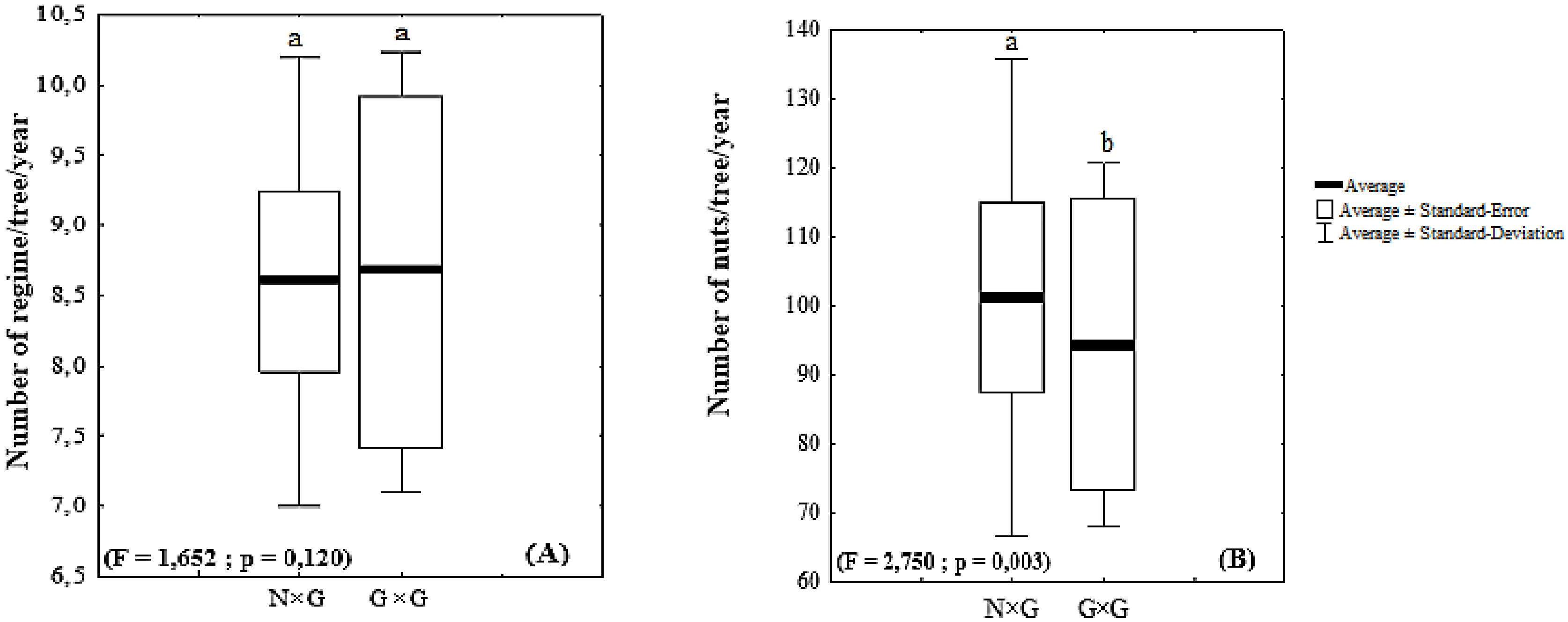


Figure 6: Variability in the number of bunches (A) and nuts (B) of "Dwarf × Tall" and "Tall × Tall" coconut palm hybrids over the period 2009 to 2018.
N× G = Dwarf and Tall hybrid cross, **G× G** = Tall and Tall hybrid cross
For a given variable, the means indexed by the same letter are not significantly different (5% STUDENT T test).

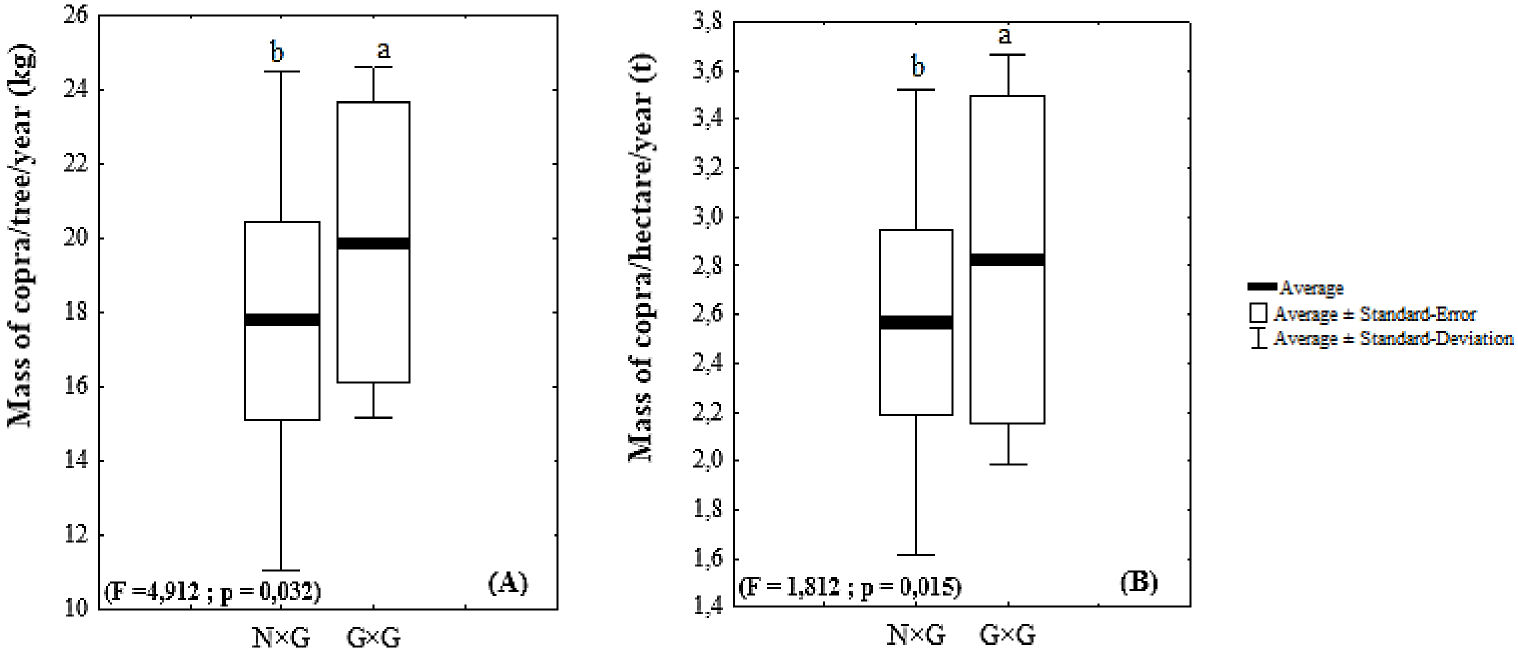
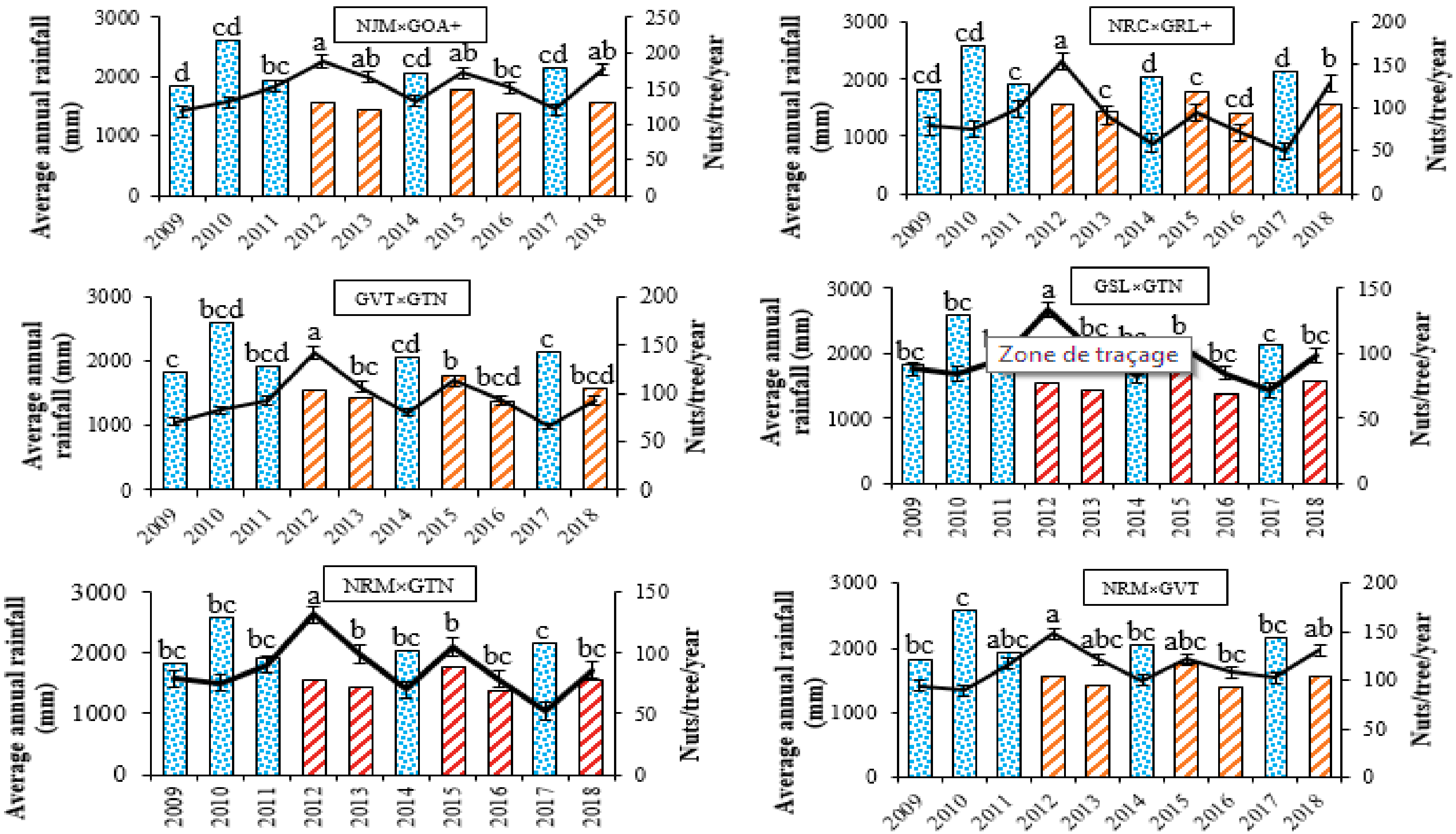


Figure 7: Variability in copra mass per tree (A) and per hectare (B) per year of the "Dwarf × Tall" and "Tall × Tall" coconut palm hybrids over the period 2009 to 2018.

N× G= Dwarf and Tall hybrid cross, G× G= Tall and Tall hybrid cross

For a given variable, the means indexed by the same letter are not significantly different (5% STUDENT T test).


NJM×GOA+
NRC×GRL+
GVT×GTN
GSL×GTN
Zone de traçage
NRM×GTN
NRM×GVT
Average annual rainfall (mm)
Nuts/tree/year

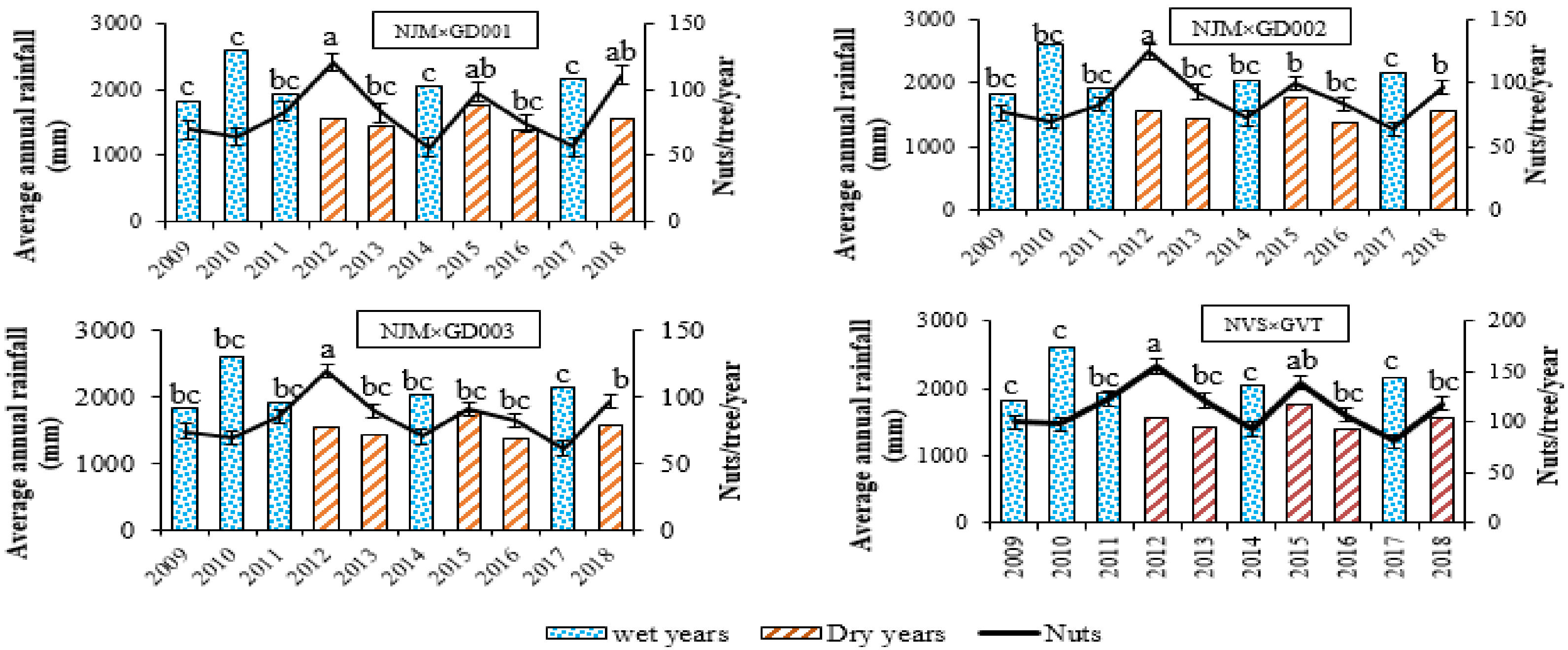


Figure 8: Cumulative effects of wet and dry years on the average annual nut production of the hybrids evaluated over the period from 2009 to 2018.
NB: The histograms with the same letters are not statistically different at the 5% threshold (Newman and Keuls test).

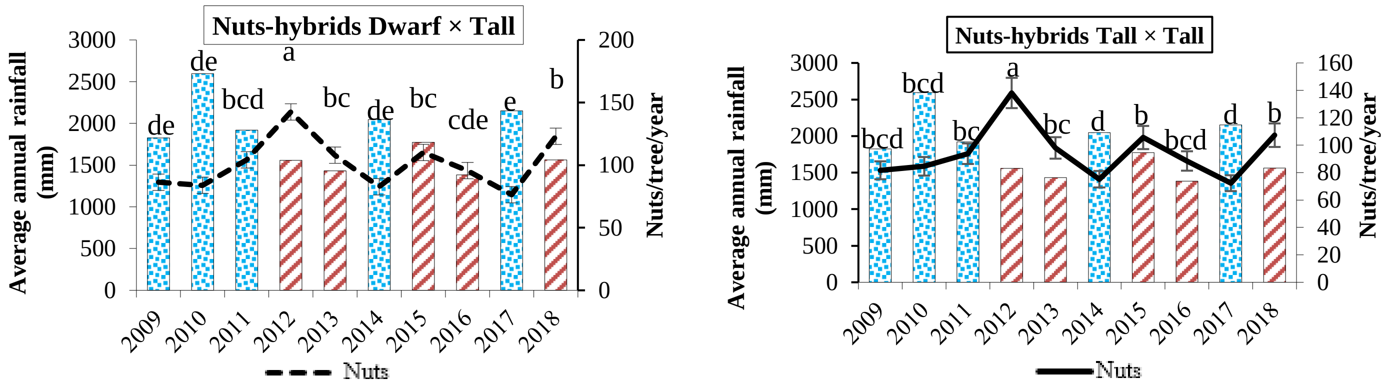


Figure 9: Cumulative effects of wet and dry years on mean annual nut production of 'Dwarf × Tall' and 'Tall × Tall' coconut palm hybrids on the period from 2009 to 2018.

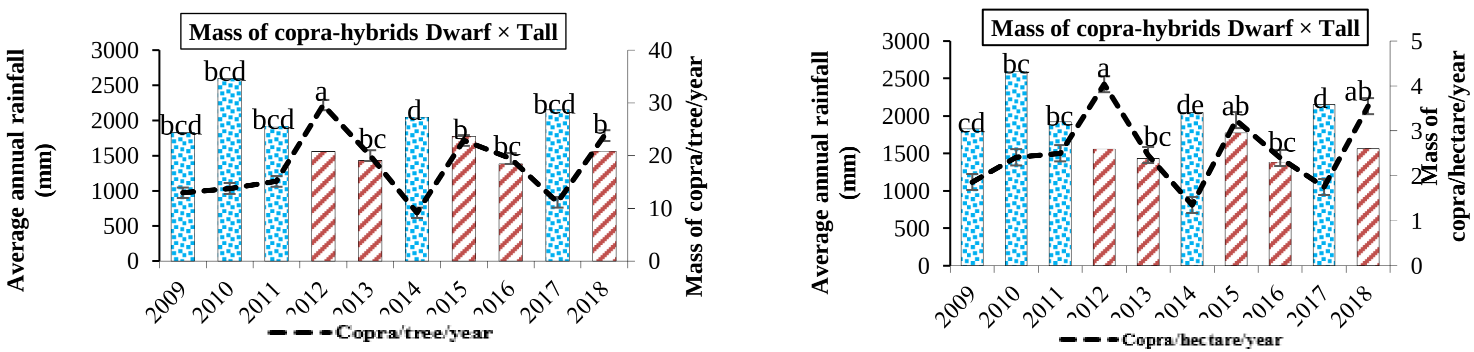


Figure 10: Cumulative effects of wet and dry years on average annual production of copra mass per tree per hectare of "Dwarf × Tall" coconut hybrids over the period 2009 to 2018.

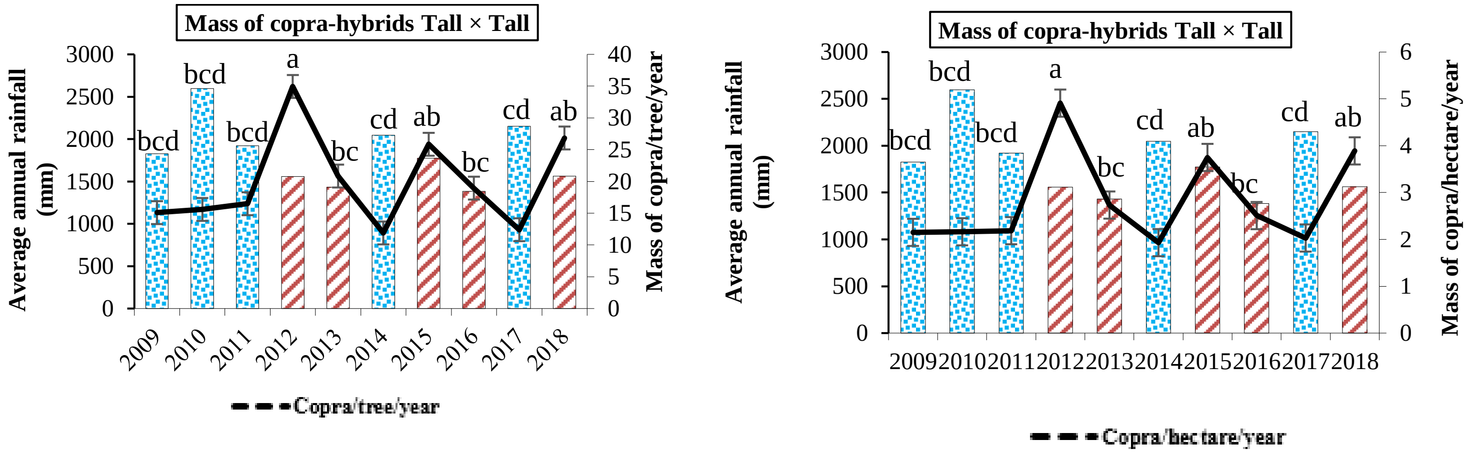


Figure 11: Cumulative effects of wet and dry years on average annual production of copra mass per tree per hectare of “Tall × Tall” coconut hybrids over the period 2009 to 2018.

NB: The histograms with the same letters are not statistically different at the 5% threshold (Newman and Keuls test).

Table 5: Production reduction rate after a year of drought in 10 coconut hybrids.

Hybrids	Rate of production reduction after one drought year (%)			
	NbR/arbre/an	**NbFr/arbre/an**	**Cop/arbre/an**	**Cop/hectare/an**
NJM×GOA^{+}	7,87 ± 3,34 b	12,92 ± 2,92 c	9,00 ± 3,33 d	10,00 ± 2,58 c
NRC×GRL^{+}	23,37± 5,76 a	29,82 ± 10,89 a	25,92 ± 4,78 ab	23,20 ± 6,30 ab
GVT×GTN	16,34 ± 7,24 a	18,81 ± 6,32 bc	17,51 ± 6,51 c	16,73 ± 7,19 bc
GSL×GTN	17,61 ± 5,66 a	18,41 ± 7,43 bc	16,86 ± 6,48 c	17,28 ± 6,09 bc

NRM×GVT	19,65 ± 6,64 a	19,85 ± 5,27 bc	16,08 ± 5,31 c	16,57 ± 5,74 bc
NRM×GTN	20,98 ± 6,68 a	21,86 ± 8,13 abc	20,29 ± 7,37 bc	22,22 ± 8,34 ab
NJM×GD001	24,03 ± 8,23 a	29,29 ± 7,81 ab	24,34 ± 6,97 ab	23,18 ± 6,44 ab
NJM×GD002	21,73 ± 6,41 a	24,93 ± 9,03 ab	21,97 ± 7,12 bc	21,20 ± 6,72 ab
NJM×GD003	21,09 ± 8,79 a	25,82 ± 6,33 ab	30,60 ± 8,78 a	29,33 ± 10,94 a
NVS×GVT	17,54 ± 6,55 a	19,72 ± 4,88 bc	16,53 ± 6,03 c	18,64 ± 6,46 bc
F	1,102	1,065	1,150	2,752
P	0,037	0,010	0,033	0,007

The values in the same column followed by different letters are significantly different according to the Newman-Keuls test at the 5% level. **P**: calculated probability

Table 6: Production reduction rate after two years of drought in 10 coconut hybrids.

Hybrids	**Rate of production reduction after two consecutive drought years (%)**			
	NbR/arbre/an	**NbFr/arbre/an**	**Cop/arbre/an**	**Cop/hectare/an**
NJM×GOA+	16,66 ± 6,74 d	21,46 ± 6,25 c	17,00 ± 6,20 c	19,00 ± 4,05 c
NRC×GRL+	42,96 ± 7,17 ab	49,99 ± 7,07 a	41,89 ± 6,19 a	36,53 ± 4,78 ab
GVT×GTN	28,05 ± 6,61 cd	33,37 ± 6,42 b	29,83 ± 7,97 b	29,24 ± 6,81 b
GSL×GTN	27,42 ± 6,61 cd	32,07 ± 6,50 b	27,22 ± 5,74 b	27,84 ± 8,64 b
NRM×GVT	30,70 ± 12,77 bc	32,34 ± 5,93 b	28,55 ± 9,99 b	28,10 ± 6,43 b
NRM×GTN	36,94 ± 10,34 abc	41,75 ± 16,38 a	39,88 ± 4,45 a	39,16 ± 9,32 a
NJM×GD001	48,96 ± 10,27 a	52,20 ± 10,62 a	46,69 ± 7,37 a	44,98 ± 10,77 a
NJM×GD002	38,32 ± 10,01 abc	42,73 ± 13,30 a	41,81 ± 9,09 a	39,66 ± 6,11 a
NJM×GD003	42,15 ± 16,65 ab	47,83 ± 9,29 a	42,93 ± 10,75 a	43,11 ± 11,57 a
NVS×GVT	28,20 ± 8,17 cd	30,81 ± 9,33 b	28,72 ± 8,50 b	29,17 ± 4,86 b
F	1,780	2,829	1,122	1,287
P	0,050	0,006	0,042	0,029

The values in the same column followed by different letters are significantly different according to the Newman-Keuls test at the 5% level. **P**: calculated probability

Table 7: Rate of yield reduction after a drought year in Dwarf x Tall and Tall x Tall coconut type hybrids.

Hybrids	Rate of production reduction after a drought year (%)			
	NbR/arbre/an	NbFr/arbre/an	Cop/arbre/an	Cop/hectare/an
Dwarf x Tall	19,53 ± 8,03 a	23,03 ± 9,13 a	20,59 ± 8,85 a	20,54 ± 8,58 a
Tall x Tall	16,97 ± 6,36 b	18,61 ± 6,71 b	17,18 ± 6,33 b	17,01 ± 6,49 b
F	1,669	2,411	2,498	2,996
P	0,137	0,044	0,057	0,089

NB: For a given variable, the means indexed by the same letter are not significantly different (STUDENT's T test at 5%). **NbR**= Number of bunches produced per year per tree; **NbFr** = Number of fruits produced per year per tree; **Cop/tree/year** = Mass of copra produced per tree per year; **Cop/hectare/year** = Mass of copra produced per hectare per year.

Table 8: Production reduction rate after two years of drought in Dwarf x Tall and Tall x Tall coconut type hybrids.

Hybrids	Rate of production reduction after two consecutive drought years (%)			
	NbR/arbre/an	NbFr/arbre/an	Cop/arbre/an	Cop/hectare/an
Dwarf x Tall	35,61 ± 13,99 a	39,89 ± 14,03 a	35,93 ± 12,24 a	34,96 ± 11,11 a
Tall x Tall	29,53 ± 7,42 b	32,72 ± 6,30 b	29,53 ± 6,39 b	28,54 ± 7,99 b
F	3,809	2,089	3,241	2,261
P	0,050	0,001	0,002	0,007

NB: For a given variable, the means indexed by the same letter are not significantly different (STUDENT's T test at 5%). **NbR** = Number of bunches produced per year per tree; **NbFr** = Number of fruits produced per year per tree; **Cop/tree/year** = Mass of copra produced per tree per year; **Cop/hectare/year** = Mass of copra produced per hectare per year.

DISCUSSION

The results obtained by evaluating the impact of climate variability on the production of number of bunches per tree per year (NbR/tree/year), number of fruits per tree per year (NbFr/tree/year), mass of copra per tree per year (Cop/tree/year) and mass of copra per hectare per year (cop/hectare/year) of the coconut hybrids showed that these characters experienced strong variability overall over the period from 2009 to 2018. These observed variabilities could be explained by the current increasingly unfavorable climatic conditions that have prevailed in the study area for the past few decades. These results corroborate those of Perera et al. (2018) who showed that the main factors that affect the production of coconut palms are genetic and environmental factors. The improved control PB121 presents the best performance in terms of fruit production compared to the other hybrids. On the other hand, the majority of the hybrids studied produced more fruit than the improved control PB113. The behavior of these hybrids is in agreement with the work of Bourdeix et al. (2005) who showed that the better performance of the improved control PB121 in number of fruits per tree is explained by its ability to adapt to environmental conditions and the poor performance of the improved control PB113 is due to its sensitivity to drought. Concerning the other most popularized hybrids studied, they have an unsatisfactory production. This low performance obtained would be due to less favorable ecological conditions (Batugal, 2005). As a result, the appearance of a tree varies and is not always representative of its genetic value. These results indicate that fruit production per tree is not solely dependent on hybrid performance but rather on the cumulative effect of hybrid performance and the environment (Roupsard et al., 2007). However, the performance of the NVS x GVT hybrid should not be neglected in terms of nut production because it is similar to that of the improved control PB121.

The results relating to the variability of the number of bunches per tree per year (NbR/tree/year), number of fruits per tree per year (NbFr/tree/year), mass of copra per tree per year (Cop/tree/year) and copra mass per hectare per year (cop/hectare/yr) of "Dwarf × Tall" and "Tall × Tall" coconut palm hybrids indicated that fruit and copra production varies depending on the type of cross between hybrids. The 'Dwarf × Tall' hybrids performed best in terms of fruit production and those crossed between 'Tall × Tall' achieved maximum copra production per tree per hectare. This better performance in copra production of the "Grand × Grand" hybrids could be explained by the full expression of their genetic potential but also by their ability to adapt to water stress conditions, making them more drought tolerant than the others. (Konan et al., 2006). Also, their voluminous bulb has a very developed root system making water absorption more efficient (Konan, 1997). In addition to this type of grouping of the hybrids mentioned above, to identify the type of cross allowing optimal production of copra, the PB121+ control stands out from the others. These results confirm those of Bourdeix et al. (2005) who showed that the improved control PB121 is very productive in copra thanks to its broad spectrum of adaptability. The average production of 3.69 t of copra from the improved control PB121 per hectare and per year, although higher than the yields of the other hybrids evaluated, is lower than that of the improved PB 121 in the trials reported by Bourdeix et al. (2005) (more than 5.5 t of copra per hectare per year). The drop in yields obtained from the improved PB121 in our trial could be explained by the current ecological conditions which would be marked by a low level of mineral nutrition of the hybrids studied and less favorable climatic conditions. Likewise, this trial was established on old genetic test plots. Consequently, this previous crop has led to a gradual depletion of soil mineral elements with a low density of cover plants such as creeping legumes Pueraria sp. and Centrosema sp. compared to previous plots (N'cho et al., 1993). According to N'goran (2005), the inputs of fertilizing elements in the form of organic or mineral manure in coconut palm farms must be repeated over time to ensure adequate mineral nutrition for the coconut palm. Fertilization and planting a cover legume rebalances mineral nutrition and is a determining factor in operations to renew coconut groves (Pomier and De Taffin, 1982). In addition to these constraints, there have been repeated episodes of drought in recent years, particularly after the 1970s, which made irrigation appear to be the only solution to regularize and stabilize coconut production. As a result, the production of the hybrids evaluated can be maintained at a relatively high level by irrigating the trees during the dry periods coinciding with the different critical stages of development in order to reduce the harmful effects of drought.

The results of the SPEI analysis made it possible to identify the main climatic components of the factors of production. The years of drought and humidity thus determined all occur to varying degrees and at several stages of development of the coconut palms. The average annual fruit and copra production of the “Dwarf × Tall” and “Tall × Tall” hybrids show an identical evolution in the face of favorable water conditions and stress conditions. The maximum average production of hybrids is observed in 2012, followed by 2015 and 2018. The best performance of hybrids in the three years mentioned above could be explained by the wet years preceding the maturity of the nut. The most significant production observed in 2012 is preceded by the wet years 2009, 2010 and 2011 with average annual rainfall of 1826 mm, 2593.3 mm and 1920 mm respectively. Thus, the succession of three wet years before fruit maturity has a significant influence on the production of hybrids. These observations corroborate the work of Babu et al. (1993). The high production in number of nuts and copra in 2015 and 2018 is preceded by the wet year 2014 and the wet year 2017 respectively. There is thus a close link between the number of nuts per bunch and the mass of copra with the climate that prevails the year preceding the maturity of the nut. In this work, Peiris (1993) also observed the significant influence of cumulative rainfall over 1 year before coconut maturity. The average annual fruit and copra production of the hybrids is lower in 2014 and 2017. This drop in production is attributable to the manifestation of drought in the years 2012, 2013 and 2015, 2016. The cumulative effects of two dry years (2012 to 2013) and (2015 to 2016) preceding the year of fruit maturity 2014 and 2017 respectively, significantly lower production. Thus, the manifestation of drought during the successive years preceding the maturity of the fruit causes considerable water stress for the coconut tree, leading to a significant drop in its productivity. The drought of the years 2012 and 2013 has been declared as one of the severe droughts in which several crops were affected (FAO, 2018). Crop production in these years was very mediocre. The years 2015 and 2016 were classified as the warmest years according to the WMO (2019). With 1.2°C warmer than in pre-industrial times, the year 2016, marked by the influence of a powerful El Niño, retains the status of the hottest year. During this year, the decline in food production due to the El Niño phenomenon has contributed significantly to the increase in the number of food insecure people in Southern Africa. In 2015, the deviation of the average temperature from pre-industrial values was 1.1°C. These results are in agreement with the work of Traoré (2016) in the south of Côte d'Ivoire, which underlines a general decrease in precipitation with periods of very marked drought from the 1980s. This climatic trend could explain the drop in precipitation, the production of coconut trees. Despite this downward trend in production at the level of all the hybrids evaluated, the improved control PB121 maintains its production above the average. This result is in agreement with the work of Konan et al. (2006) who points out that the improved hybrid PB121 is the most tolerant to drought and used as suitable plant material with good productivity.

Conclusion

The present work revealed that variations in climate had an impact on the production of bunches, fruits and copra of the hybrids. In terms of the average annual number of bunches of the hybrids studied, the hybrids NJM x GOA+, NRM x GVT and NVS x GVT gave a higher number of bunches. The NJM×GOA+ hybrid expressed a higher average annual fruit production and stood out with the highest values of copra per tree (copra/tree/year) and copra per hectare (copra/ha/year). Comparative analyzes of the production levels of Dwarf x Tall and Tall x Tall hybrid types for each of the characteristics number of bunches (NbR), number of fruits (NbFr), mass of copra per tree (Cop/tree/year) and mass of copra per hectare (cop/hectare/year) revealed that the maximum fruit production per year was observed in the "Dwarf × Tall" hybrids. As for the highest productions of copra per tree (copra/tree/year) and copra per hectare (copra/ha/year) they were recorded in the "Tall × Tall" hybrids. No significant trend emerged in the average production of the number of bunches according to the types of hybrids. Analysis of the effects of climate variability on the production of Dwarf x Tall and Tall x Tall type hybrids shows that the highest bunch, fruit and copra production was observed in 2012, 2015 and 2018. On the other hand, the lowest productions were recorded in 2014 and 2017. Production of bunches, fruits and copra increased gradually or remained stable for consecutive wet years (2009 to 2011) preceding the harvest. However, the onset of drought during one year (2012, 2013, 2015 and 2016) and pronounced drought for two successively dry years (2012 to 2013 and 2015 to 2016) preceding the harvest significantly lower the level of production. These cumulative effects of drought significantly influence the production of NRC×GRL+, NRM×GTN, NJM×GD001, NJM×GD002 and NJM×GD003 hybrids with the highest reduction rates. Overall, the effects of drought are more marked in the "Dwarf × Tall" hybrids than the "Tall × Tall" hybrids. However, the NJM×GOA+, GVT×GTN, GSL×GTN, NRM×GVT and NVS×GVT hybrids develop their ability to express themselves better in this context of climatic variability. Therefore, they could be taken into account in the crop improvement program, subsequently offered to the coastal zone nut farmers with a view to improving yield coconut groves under rainfed conditions.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

All authors contributed to the work and the preparation of the manuscript.

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