**Planting of Deli *dura* x AVROS *pisifera* and Deli *dura* x La Me *pisifera* Oil Palms at High Densities for Increased Bunch Yields in Liberia**

**Abstract**

Like other African oil palm growing countries Liberia is confronted with a severe deficit of palm oil. Development of industrial plantations and smallholders’ programmes that benefit from industrial plantations’ provisions of improved *tenera* planting materials and technical assistance is an ultimate way towards raising and maintaining the country’s palm oil production. In the prevailing context of preservation of rainforests, oil palm development in Liberia looks for high production per unit area rather than high area per unit production. Therefore, Mano Palm Oil Plantation Liberia Inc. planted Malaysian Deli *dura* x AVROS *pisifera* and African Deli *dura* x La Me *pisifera*, each at 3 different high densities in view of selecting the high bunch yielder for its future expansions for an early return of investments and experience-sharing with the neighbouring smallholders’ sector. At the prime age of 8-10 years after planting, Deli *dura* x La Me *pisifera* established at 180 palms ha-1 recorded the highest annual bunch yield (18,46 t ha-1) of all the two types of materials and various planting densities put together. Deli *dura* x AVROS *pisifera* planted at 178 palms ha-1, the highest density for the type of planting material, ranked first (14.12 t ha-1). Deli *dura* x AVROS *pisifera* behaved like its African counterpart in producing a high number of small bunches under the severe dry season and soil management conditions of Mano Palm Oil Plantation. Planting at 178 palms ha-1 for Deli *dura* x AVROS *pisifera* and at 180 palms ha-1 for Deli *dura* x La Me *pisifera* should be adopted with the proviso recommending a thinning for the first 10 years after planting to 138 or 143 palms ha-1 and a thinning to 143 or 160 palms ha-1 for the second 11-12 years after planting, after which periods bunch yields started to decline. Irrigation and good agricultural practices are prerequisites for improving yields of drought-sensitive Deli *dura* and AVROS *pisifera* in particular and in the African oil palm belt in general

**Keywords:** Oil palm,planting density,bunch number, average bunch weight, water stress, etiolation, thinning, Lofa estate

1. **Background**

The oil palm is of great importance to many countries in Africa. It is a considerable source of edible palm oil and palm kernel palm oil and of income as well. The aim of oil palm growers is to maximise the cumulative palm oil (and kernel) yield and securing an early return on investment. The latter assumes high productions in the first 10 to 12 years after planting. The commercial high oil yield hybrid, named t*enera* is produced by crossing *dura* with thick shelled fruits and *pisifera* with shell-less fruits from different origins (Bakoumé and Louise, 2007) namely Deli, AVROS, La Me, Yangambi, Lobe, to name but a few. To this date, popular oil planting materialsare Deli *dura* x AVROS *pisifera* in south-east Asia and Deli *dura* x La Me *pisifera* in Africa. The first are known for lower bunch number of higher mean bunch weight and the second for their higher bunch number of lower mean bunch weight.

Liberia is an expansion of the African oil palm (*Elaeis guineensis* Jacq.) belt (Bakoumé et al., 2017). Palm oil has been produced from natural oil palm groves, improved *tenera* smallholdings, and improved *tenera* industrial plantations since the 1960s with interruptions due to civil unrest. In 2023, oil palm orchards were estimated to cover 124,053 ha, including 44,053 ha (36%) of four industrial plantations including Mano Palm Oil Plantation Liberia Inc. (10,254 ha) and 80,000 ha (64%) of smallholdings (Vasudevan o/c Darmalingam, 2024. Mano Palm Oil Plantation, personal communication). The country’s population was 5,418,377 inhabitants on July 13, 2024 at 8:05 a.m. when the African population reached 1,496,248,781 inhabitants (Worldometers, 2024). Liberia’s basic demands for oils and fats were estimated at 130,000 tonnes on the basis of the world average individual consumption of oils and fats estimated at 24 kg year-1. Country production of palm oil, almost the unique locally produced vegetable oil, was 22,500 tonnes in 2019. According to Oil World (2022) the country imported 36,600 tonnes of palm oil in 2019, then 28,000 tonnes in October 2020-September 2021 and 30,000 tonnes in October 2021-September 2022. Liberia counts on industrial plantations to meet its growing demand for palm oil for food and nonfood uses. The government of Liberia has prioritised palm oil production as one of the most important industries for the future, and there is interest from global companies (Proforest, 2023). However, it is strongly believed that agriculture, including that of oil palm, brings widespread income and improves livelihood and sustainability of rural areas (Chenoweth, 2012).

Oil palm (*Elaeis guineensis* Jacq.) development in Liberia is at a nascent stage and needs to grow fast through an expansion of the planted area. Unfortunately, among the main challenges facing the country’s noble initiative are (i) dry season of 4-5 months, (ii) inadequate planting material, and (ii) control of deforestation by non-governmental organisations. In fact, reduced (not zero) deforestation contributes to the conservation of green rainforests, which is an efficient measure for the preservation of biodiversity and for the control of climate change (Bakoumé, 2018). High-yield oil palm could be harnessed to meet the growing demand for palm oil without destroying more forest (Blamford et al., 2018). One rational way of increasing oil palm yield is not only by using high-yield planting materials but also by increasing planting density, i.e. the number of palms per unit area. The ultimate goal is to produce more with less (Bek-Nelson, 2023). Deli *dura* x AVROS *pisifera* materials are believed to be suitable for the south–east humid tropics. They are commonly planted at 148 palms ha-1 and are yielding up to 35 t ha-1 while Deli *dura* x La Me *pisifera* materials, essential for the humid tropics of Africa, are routinely laid out at 143 palms ha-1. Their maximum yield is estimated at 25 t ha-1. In the first phase of its oil palm project in Bomi County, Mano Palm Oil Plantation (MPOP) planted Deli *dura* x AVROS *pisifera* materials from south-east Asia and African Deli *dura* x La Me *pisifera materials* at various densities above the standard density. In fact, Corley (1976) has noted that different progenies have different optimal densities. Therefore, the company’s initiative aimed at identifying the high performance-linked densities in the first 10 to 12 years of the plantation’s life independently of the type of material for its subsequent plantings. It also envisaged sharing the knowledge with the smallholders’ sector that it is committed to develop.

1. **Materials and methods**
	1. **Materials**

A total of 6 planting densities were used including 3 for Deli *dura* x AVROS *pisifera* oil palms and 3 for Deli *dura* x La Me *pisifera* for the2013’s planting, so the oil palms were 10 years old in 2023. Information on corresponding treatments consisting of combinations of types of materials and planting densities (combinations), the planted fields and their hectares are given in Table 1.

**Table 1**- Details of treatments assessed

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Combination | Type of material | Planting density | Field | Planted area (ha) |
| DLM180 | Deli x La Me | 180 | 2013-F1 | 28.82 |
| DLM178 | Deli x La Me | 178 | 2013-H | 101.97 |
| DLM173 | Deli x La Me | 173 | 2013-B | 99.35 |
| DAV178 | Deli x AVROS | 178 | 2013-F | 83.88 |
| DAV175 | Deli x AVROS | 175 | 2013 G | 74.61 |
| DA171 | Deli x AVROS | 171 | 2013 I | 122.74 |

DLM180 – Deli x La Me material planted at 180 palms ha-1; DAV178 - Deli x AVROS material planted at 178 palms ha-1

The Deli *dura* x AVROS *pisifera* oil palms are more robust than the Deli *dura* x La Me *pisifera* counterparts. Furthermore, they have longer fronds visually. The 6 fields belong to Lofa estate, which was established in Bomi County in Liberia. The estate is located between 6o40'0” and 6o43'0” latitude north and 10o55’0” and 11o1'0” longitude west. Lofa’s soils are acid latosols poor in nutrients, and marked by the presence of surface lateritic gravels, (Bakoume, 2024) (Table 2). Rainfall regime is uni-modal with 7 to 8 consecutive rainy months i.e. from April or May to November and 4 to 5 dry months from December to March or April (Figure 1). Mean annual rainfall for the period of 2021-2023 was 3273 mm received in 144 days. Although the planting at different high densities was not scientifically planned, it was seeking optimum densities for high plantation productivity.

**Table 2** - Chemical and nutrient status of the soils of the six treatments

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Combination | Field | pH KCl | N (%) | Avail P(mg kg-1) | CEC(cmol kg-1) | Ca(cmol kg-1) | K(cmol kg-1) | Mg(cmol kg-1) | Na(cmol kg-1) |
| DLM180 | 2013-F1 | 4.15 | 0.105 | 4.90 | 3.520 | 0.369 | 0.043 | 0.089 | 0.024 |
| DLM178 | 2013-H | 4.16 | 0.098 | 2.84 | 3.919 | 0.494 | 0.055 | 0.087 | 0.032 |
| DLM173 | 2013-B | 4.23 | 0.100 | 3.66 | 3.680 | 0.417 | 0.052 | 0.088 | 0.024 |
| DAV178 | 2013-F | 4.15 | 0.105 | 4.90 | 3.520 | 0.369 | 0.043 | 0.089 | 0.024 |
| DAV175 | 2013-G | 4.09 | 0.106 | 20.85 | 5.199 | 0.782 | 0.050 | 0.122 | 0.028 |
| DA171 | 2013-I | 4.07 | 0.104 | 5.49 | 4.719 | 0.414 | 0.048 | 0.078 | 0.024 |

Avail P – available phosphorus; DLM180 – Deli x La Me material planted at 180 palms ha-1; DAV178 - Deli x AVROS material planted at 178 palms ha-1

**Figure 1**: Monthly mean rainfall and rain days recorded in Lofa oil palm estate in 2021-2023

Source: Adapted from Bakoumé (2024)

* 1. **Parameters measured**

Two rounds of harvest were carried out per field per month from 2021 to 2023. At each round, the number of bunches (BN) harvested from each field was recorded at the platform during the loading, together with detached fruits, into the truck. Both detached fruits and fresh fruit bunches were transported to the palm oil mill. The total bunch weight (TBW) was determined at the weighbridge before delivery to the palm oil mill. At the end of the month, the average bunch weight (ABW) was deducted from the TBW and BN. The monthly bunch yield was the monthly TBW divided by the field area.

The fertiliser applications which had been suspended in 2019 following the outbreak of Covid-2019 resumed in 2022. The types and rates of fertilizers applied per palm to the fields in the 6 combinations are given in Table 3.

**Table 3** **-** Fertilizer applications to the six combinations (fields)

|  |  |  |
| --- | --- | --- |
| Type of fertilizer  | Number of applications | Rate (kg palm-1) |
| April 2022 | March 2023 | May 2023 |
| Kieserite (27 % MgO) | 1 | 1.0 | -  |  - |
| NPK (11:07:35+3MgO+0.03B) | 1 | - | 2.0 | - |
| Diammonium phosphate (18 % N+46 % P2O5)  | 1 | - | - | 0.5 |

* 1. **Data analysis**

The 6 combinations were planted at random similarly to a complete randomized design. Each of the 2021, 2022, and 2023 records were assimilated to a replication making a total of 3 replications. The analysis of variance for BN, ABW and bunch yield was performed to search for differences among the 6 combinations. The following linear model was used for bunch yield and its components:

Yij = µ + αi + βj + **ε**ij

Where :
Yij = production of the ith combination in the jth year

µ = overall mean of all combinations

αi = effect of the ith combination

βj = effect of the jth year

**ε**ij = Residual error.

Later, the Duncan’s Multiple Range Test (DMRT) was used to compare mean values of combinations of type of material and planting densities for BN, ABW, and bunch yield. Analyses were performed using SAS software version 9.4. (SAS Institute, 2013)

1. **Results and discussion**

The analysis of variance for BN, ABW, and bunch yield showed statistical differences between combinations of type of materials and planting densities (Table 4). Notably, Deli *dura* x AVROS *pisifera* materials andDeli *dura* x La Me *pisifera* materials share similar *dura* provenances. Early records of the origin of Deli in Southeast Asia indicate that Deli oil palms derived from four seedlings grown from seeds brought from Africa. They were planted in the Buitenzorg (now Bogor) Botanic Gardens in 1848 in Java in Indonesia (Corley and Tinker, 2003). The palms that sprang from these four seedlings were all quite similar and the uniformity of the progeny suggests that all four seedlings may well have originated from a single parent palm (Hartley, 1988).

**Table 4** - Analysis of variance for the components of bunch production and bunch yield (Yield)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source of variation | df | BN |  |  | ABW |  |  | Yield |
| MS | F |  | MS | F |  | MS |  F |
| Combination | 5 | 467321.822 | 15.76\*\*\* |  | 1.470 | 3.97\* |  | 25.228 | 11.15\*\*\* |
| Error | 12 | 29657.056 |  |  | 0.370 |  |  | 2.263 |  |

df; degree of freedom; MS – mean square; F – fisher value; \* - significant difference (p = .05); \*\*\* - very highly significant difference (p = .001)

The difference between Deli *dura* x AVROS *pisifera* materials andDeli *dura* x La Me *pisifera* materials is in the backgrounds of *pisifera*. SP540, one of the ancestors of the AVROS *pisifera*, is expected to represent 75% of the *tenera* genome derived from Yangambi (Democratic Republic of Congo) oil palm breeding programme. In fact, the Yangambi provenance is referred to as a high ABW yielder with good fruit characteristics whilst the La Me (Côte d’Ivoire) provenance is known for its high number of small bunches showing mediocre fruit quality (Adon, 1995). Different densities together with different types of oil palm planting materials created agronomic variation which we studied with the hope of identifying some of them as producing high bunch yields, leading to their adoption for improved oil palm plantation profitability.

The DMRT ranked DLM180 first for bunch yield and formed two overlapping groups with the remaining combinations, meaning that they were comparable for bunch yield (Table 5). At first glance, Deli *dura* x La Me *pisifera* planted at 180 palms ha-1 led to highest improved bunch production per unit area. Bakoumé (2018) proposed that planting density must be a function of the terrain and that the optimum planting density to be adopted should be the highest bunch yielder. DLM180 (18.55 t ha-1) produced 175% of the yield of DLM173, the last among the 3 Deli *dura* x La Me *pisifera-*based combinations.

**Table 5** - Comparison of means of bunch yield (Yield), bunch number (BN), and average bunch weight (ABW) of Deli x La Me and Deli x AVROS materials planted at different densities at 8-10 years after planting

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Combinations | Yield |  |  | BN |  |  |  | ABW |  |  |
| Mean (t ha-1) | Grouping |  | Combinations | Mean(ha-1)  | Grouping |  | Combinations | Mean (kg) | Grouping |
| DLM180 | 18.46 | A |  | DLM180 | 2040 | A |  | DAV175 | 10.85 | A |
| DAV178 | 14.12 | B |  | DAV178 | 1552 | B |  | DAV171 | 10.68 | A |
| DAV175 | 12.03 | BC |  | DLM178 | 1201 | C |  | DLM173 | 10.09 | AB |
| DLM178 | 11.90 | BC |  | DAV175 | 1123 | C |  | DLM178 | 9.71 | AB |
| DAV171 | 11.32 | BC |  | DAV171 | 1043 | C |  | DLM180 | 9.28 |  B |
| DLM173 | 10.55 |  C |  | DLM173 | 1039 | C |  | DAV178 | 9.18 |  B |

DLM180 – Deli x La Me material planted at 180 palms ha-1; DAV178 - Deli x AVROS material planted at 178 palms ha-1; Means followed by the same letter are not statistically significant.

Regarding Deli *dura* x La Me *pisifera* planting materials commonly used in Africa, Corley (1976) recommended planting densities varying from 139 to 200 palms ha-1 for maximal cumulative yield and even over 300 palms ha-1 in the first year of production. A similar trend applied to a small extent to Deli *dura* x AVROS *pisifera* materials where for DAV178 the highest planting density ranked first among the three, in absolute terms. It represented 125% of DAV171 which was classified last (11.32 t ha-1) in the type of material but only 76% of DLM180 (18.46 t ha-1). In fact, Corley (1976) recommended 128 to 165 palms ha-1 for Deli *dura* x AVROS *pisifera* materials in Malaysia where climatic and soil conditions are far better than those prevailing in Liberia. In addition, the author noticed that increasing planting density of Deli *dura* x AVROS *pisifera* by 1 palm ha-1 increases leaf area to a maximum of 0.6% and decreases yield per palm by 0.6% of the yield at 138 palms ha-1. Soil water deficit and etiolation of oil palms were probably factors that affected yields of Deli *dura* x AVROS *pisifera* materials in Lofa estate, in addition to inappropriate fertilizer programmes. Symptoms of water stress observed included (i) the accumulation of 5 to 6 unopened spears rather than the 2 to 3 in normal circumstances, (ii) snapping of green leaves, (iii) drying out of all the leaves at the base of the crown, and (iv) toppling of the upper part of the canopy which comprises the meristem (Figure 2). Reduction of light intensity, increased palm height, and increased leaf length, features reported by Hartley (1988), also characterized etiolating palms. Etiolation was slight to moderate for Deli *dura x* La Me *pisifera* and moderate to severe forDeli *dura* x AVROS *pisifera*. Planting Deli *dura x* AVROS *pisifera* at 178 palms ha-1 made sense.

**

**Figure 2**: Water stressed oil palm with toppled crown of leaves

However, Corley (1966) warned that optimal density yield is expected to reach a peak and then decline. He suggested that in order to take advantage of the decrease in optimal density with palm age, to plant initially at high density, and then later to lower the density. Therefore, in Liberia, thinning should be carried out for the robust Deli *dura x* AVROS *pisifera* oil palms to a final planting density of about 138 palms ha-1 on sloping terrain (slope ˃ 5%) and to 148 palms ha-1 on flat terrain (slope < 5%) at10 years after planting to prevent bunch yield decline over time due to etiolation and competition for light between overcrowded oil palms. According to Mohamed Nazeeb *et al.* (2008) , starting densities (of Deli *dura x* AVROS *pisifera*) at 180-200 palms ha-1 at triangular spacing and thinned at around the 12th-14th year after planting by 14-25 per cent, appears viable. Thinning should be done for the less bulky Deli *dura* x La Me *pisifera* oil palms initially planted at 180 palms ha-1 with a view to bringing down the planting density to 143 palms ha-1 on sloping terrain (slope ˃ 5 %) and 160 palms ha-1 on flat terrain (slope < 5 %) at 11-12 years after planting. For Bonneau & Impens (2022) found that a plateau is reached at between 143 and 160 palms per hectare for Pobè C1001F a Deli *dura x* La Me *pisifera* material in the aforementioned pedoclimatic context. Furthermore, the average annual rainfall at the Liberian Plantation site represents 158 per cent of that at the experimental site of the above authors’ work (3273 mm compared with 2069 mm)

The BN was found to be the factor that most explains the yields of the combinations. DLM180 which statistically ranked first for yield, followed by DAV178 in absolute terms were ranked first (2040 bunches ha-1) and second (1552 bunches ha-1) for BN, respectively. DLM178, LM171, DAV175, and DAV171 were grouped together by the DMRT, indicating that the 4 combinations were similar to each other (Table 5). Deli *dura x* La Me *pisifera* materials which are characterized by a high number of small bunches were joined in the instance by Deli *dura* x AVROS *pisifera*-derived combinations renowned for their moderate number of large bunches.

It should be considered that Deli *dura* x AVROS *pisifera*-derived combinations opted for the production of a large number of bunches of smaller size than usual as an adaptation strategy to the marked dry seasons of 4 to 5 months in Liberia. Bunch yield is strongly correlated to the BN: r = 0.74 (Isa et al., 2009) and r = 0.79 (Rosenquist *et al*., 1990). By producing a high number of small bunches under a long drought environment and subsequent water stress, Deli *dura* x AVROS *pisifera*-derived combinations showed that oil palm can be better likened to an r-strategist, or r species, which shows high fecundity or ability to reproduce offspring even with small body size under unstable or unpredictable environments, rather than to a K-strategist, or K species, which produces fewer offspring with large body size when it is subjected to marginal environmental conditions (Piaka, 1970, cited by Bakoume, 2011). Like Deli *dura x* La Me *pisifera*, Deli *dura* x AVROS *pisifera* produced a high number of bunches in the hope that a considerable proportion will attain maturity after abortion of a number of them.

The BN decreased by 15% for Deli *dura x* La Me *pisifera* in 2023 compared to 2021 and by 21% for Deli *dura* x AVROS *pisifera* in the same period. The decrease observed was not only imputed to the fact that BN number diminishes with the age of the oil palm, but also to water stress and to overcrowding leading to etiolation. In fact, maximum abortion is associated with the dry season and limited water supply (Hartley, 1988). Etiolation which is due to high planting density favours the production of male inflorescences at the expense of female inflorescences. The rate of the decrease indicated that Deli *dura* x AVROS *pisifera* oil palms were more affected by etiolation than Deli *dura x* La Me *pisifera* oil palms. Furthermore, the decrease of BN with age is greater at high density, indicating a need to proceed to the above-mentioned thinning of both theDeli *dura* x AVROS *pisifera and* Deli *dura* x La Me *pisifera* oil palms.

The DMRT formed two groups of combinations for the ABW overlapping each other, indicating that the 6 combinations including 3 derived from Deli *dura x* La Me *pisifera* and 3 linked to Deli *dura* x AVROS *pisifera* were comparable (Table 5). However, DLM180 and DAV178 ranked second last and last, respectively, in absolute terms. ABW of Deli *dura* x AVROS *pisifera* decreased resulting from an increase of the BN in the suspected process of adaptation to severe dry season of 4-5 months at Lofa estate (Figure 1). Furthermore, the BN and the ABW were negatively correlated, estimated at -0.35 (Isa et al., 2009) and -0.84 (Rosenquist et al., 1988). The BN ranking of the 6 combinations is not reflected in that for the ABW with which it is negatively correlated; implying that factors other than the BN affected the ABW, probably including water stress, etiolation, and non-optimal nutritional status of the palms. In fact, the correlation between the BN and the ABW estimated by various studies do not yet represent equations that would make it possible to predict the value of one of the 2 components as a function of the other. What’s more, studies did not agree on the correlation between bunch yield and the ABW. Isa *et al*. (2009) found this correlation to be moderate (r = 0.33) whereas Rosenquist et al. (1988) found it strong (r = 0.69). In the case of the present study, the high-yielding combinations (DLM180, DAV178) are classified in the group of combinations with low ABW, and, conversely, the combinations with low bunch yields (DAV171, DLM173) performed well for ABW. In Lofa estate, overcrowding derived from high planting density was responsible of palm etiolation, which decreases the ABW (Corley, 1976). According to Hartley (1988), although ABW increases with age at all spacings, it should be noted that the increase at lower density is almost twice that observed at high density. The decrease in ABW was probably more important for Deli *dura* x AVROS *pisifera* oil palmswhere moderate to severe etiolation of oil palms was recorded, irrespective of the planting density, probably due to the long fronds associated to the robust architecture. Furthermore, the increase in the BN did not compensate for the drop in the ABW. Definitely, Deli *dura* x AVROS *pisifera* did not show its superiority compared to Deli *dura x* La Me *pisifera* for bunch yield. One key reason of the poor performance of Deli *dura* x AVROS *pisifera* material is most probably its sensitivity to long lasting water stress resulting to prevailing 3-5 dry months in the African oil palm belt. The material is characterized by a moderate number of large bunches. Water tress provokes abortion of female inflorescences, reduces bunch number and average bunch weight leading to depletion of bunch yields. On the other hand, the Deli *dura* x La Me *pisifera* planting material is relatively less sensitive to long dry seasons. It is characterized by a large number of small bunches. Abortion of female inflorescence is limited. This allows considerable amount of bunches to reach maturity. Hence its higher yields compared to those of Deli *dura* x AVROS *pisifera* material.

1. **Conclusion**

Planting two different types of oil palms by Mano Palm Oil Plantation Liberia Inc., each at different densities aimed to improve production per unit area. It was an important and ambitious initiative for increasing Liberia’s production of palm oil as well as for limiting deforestation. High density-plantings improved bunch yield via increased bunch number. Lofa estate is characterized by 4-5 months of dry season and by a need to improve soil nutritional status and fertilizer applications. The assessment of bunch yield and yield components showed that a maximum density of 178 palms ha-1 should be adopted for Deli *dura* x AVROS *pisifera* while 180 palms ha-1 would be more productive for Deli *dura x* La Me *pisifera.* Given the negative impact of high planting density on bunch yield and BN over time*,* at 10 years after planting thinning should be performed to 138 or 148 palms ha-1 for the Deli *dura* x AVROS *pisifera* and at 11-12 years after planting thinning to 143 or 160 for Deli *dura x* La Me *pisifera*,depending on the terrain, to prevent yield drop. Water stress mitigation measures including irrigation even by gravity would contribute to preserving palm health and further improving bunch yield, mostly for Deli *dura* x AVROS *pisifera* planting materials.. Furthermore, the control of water stress together with appropriate fertilizer applications would add to plantation productivity.

1. **Consent for publication**

Not applicable

1. **Availability of data and materials**

Data and the oil palm fields are properties of the Plantation who can make them available upon motivated request

**COMPETING INTERESTS DISCLAIMER:**

**Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.**

**References**

Adon, B. Evaluation des introductions de palmiers à huile *Elaeis guineensis* Jacq. Utilisation dans le schéma de sélection récurrente réciproque [Evaluation of introductions of oil palm *Elaeis guineensis* Jacq. Use in the reciprocal recurrent selection scheme].. Thèse de doctorat 3e cycle. Faculté des Sciences et Techniques. Côte d’Ivoire, Abidjan, . 1995; 177 p.

Bakoumé, C**.** Lofa estate June 2024-May 2025 agronomic and fertilizer recommendation. Report. Bomi. Mano Palm Oil Plantation. 2024; 14 p.

Bakoumé, C**.** Sustainability of African oil palm agriculture in a changing climatic environment. Food Sci Nutr Tech.2018; 3(5): 000164, Doi: 10.23880/fsnt-16000164.

Bakoumé, C. & Louise, C. (2007) Breeding for oil yield and short oil palms in the second cycle of selection at La Dibamba (Cameroon). *Euphytica*. 2007; 156: 195-202.

Bakoumé, C., Madi Galdima, RAfflegeau, S. & Flori, A. Effects of fires in juvenile oil palm fields on yield, oil palm breeding and plantation*.* J Agric Sci. 2011; 3(3):225-232.

Bakoumé, C., Ndiaye, O., Okoye, M . N., Jannot, C., Konan, E., Ngom, E. J. J., Danso, I. & Danso, F. (2017). Oil palm development in Africa. The Planter. 2017 ; 93(1098) : 623-641.

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., Field, R., Garnsworthy, P., Green, R., Smith, P., Waters, H., Whitmore, A., Broom, D. M., Chara, J., Finch, T., Garnett, E., Gathorne-Hardy, A., Hernandez-Medrano, J., Herrero, M., Hua, F., Latawiec, A., Misselbrook, T., Phalan, B., Simmons, B. I., Takahashi, T., Vause, J., Zu Ermgassen, E. & Eisner, R. The environmental costs and benefits of high-yield farming. Nat Sustain. 2018; 1: 477- 485.

Bek-Nelson, C. Ensuring the resilience of the palm oil industry in the 21st century. Paper presented at the *10th International Planters Conference 2023 (IPC 2023*). Royale Chulan, Kuala Lumpur, 12-14 June 2023.

bonneau, X. & Impens, R. Experimental determination of the optimum oil palm planting density in Western Africa. *OCL*, 2022; 29(30): https://doi.org/10.1051/ocl/2022019

Chenoweth, F. Role of oil palm investments and investors in rural prosperity building and food security in Liberia. Paper presented at *AgriWorld Africa, Palm Oil Africa Conference*. Royal Beach Hotel, Accra, 5-6 September 2012.

Corley, R.H.W. Planting density. In: CORLEY R. H. W., HARDON , J. J. and WOOD, B. J. (eds) Oil palm research. Elsevier Sientific publishing Company. 1976; 273-283.

Corley, R. H. V. & Tinker P. B. *The oil palm*. 4th edition, Oxford: Blackwell Science publication. 2003

Hartley, C. W. S. (1988). *The Oil Palm* (Elaeis guineensis *Jacq.*). New York: Longman Scientific and Technical publication. 1998; 761 p.

Isa, Z. A., Kushairi, A., Rafii, M. Y., Saleh, G. & Rajanaidu, N. Variation in FFB and yield components in Malaysia oil aplm (*Elaeis guineensis* Jacq.) and their correlations with frond production, rachis length, and height. Unedited Proceedings of Agriculture, Biotechnology and Sustainability Conference, PIPOC 2009. Malaysian Palm Oil Board, 9-12 November 2009; 700-736.

Mohamed Nazeeb, A. T., Tang, M. K., Loong, S. G. & Syed Shahar, S. B. K. Variable density plantings for oil palms (*Elaeis guineensis)* in Peninsular Malaysia. J. Oil Palm Res.2008; Special Issue: 61-69.

Oil World. Oil World Annual 2023. ISTA – Mielke, Hamburg.2022

Piaka, E. R. On r and K selection. Am Nat. 1970; 104: 592-597.

PROFOREST. Guidance on Engagement Principles for the National Oil Palm Strategy and Action Plan of Liberia. Africa Regional Office, Accra, 2023; 26 p.

SAS Institute. *Statistical analysis* software. Version 9.4. SAS Institute Inc., Cary, North Carolina. 2013.

Worldometers. World population per country. <http://www.worldometers.info/world-population> (13 July 2024).