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COMPARISON OF EVAPOTRANSPIRATION OF OIL PALM HYBRID OxG AND *Elaeis guineensis* Jacq. AT THE NURSERY STAGE

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ABSTRACT

This study compared the water requirements, evapotranspiration (ETc), crop coefficient (Kc) and water use efficiency (WUE) of Elaeis guineensis *Jacq. and the interspecific hybrid OxG during the nursery stage under varying irrigation levels. Using a randomised block design, four irrigation treatments were applied [0.3, 0.6, 0.9 and 1.2 times evaporation (EV)]. Results showed that the OxG hybrid outperformed* E. guineensis *in terms of vegetative growth, biomass production and WUE, especially under the 0.9 and 1.2 EV treatments. ETc values for the OxG hybrid ranged from 4.7-6.1 mm day^{-1}, while* E. guineensis *showed values from 5.2-6.6 mm day^{-1}. The Kc values ranged from 0.30-1.47 for* E. guineensis *Jacq. and from 0.90-1.39 for the interspecific hybrid OxG. Additionally, the OxG hybrid exhibited 44% higher WUE (0.26 g mm^{-1}) compared to* E. guineensis *(0.18 g mm^{-1}), demonstrating its greater efficiency in water use. The novelty of this study lies in the detailed comparison of the two cultivars' water use characteristics, providing insights into more water-efficient cultivars and supporting the development of precise irrigation strategies. These findings contribute to a more sustainable oil palm cultivation by optimising irrigation management and conserving water resources, particularly in regions facing water scarcity.*

Keywords: irrigation water efficiency, water use efficiency, weighing lysimeters.

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INTRODUCTION

Colombia ranks as the fourth-largest producer of palm oil globally in 2022, contributing 2.2% of the world's palm oil produced from 576,799 ha [National Federation of Oil Palm Growers (FEDEPALMA), 2022]. In Colombia, the palm oil industry plays a crucial role in the national economy, contributing significantly to agricultural production and providing livelihoods for numerous communities. However, this industry faces substantial challenges, particularly due to the widespread occurrence of bud rot (BR), a devastating disease caused by the pathogen *Phytophthora palmivora.* This disease has had a severe impact on *Elaeis guineensis* Jacq., the most widely cultivated oil palm species in Colombia. BR has been observed primarily in regions with high rainfall and prolonged periods of relative humidity, which are common in several of Colombia's palm-growing areas (Torres *et al*., 2015). Over the past few decades, BR outbreaks have caused significant losses. The first major incident resulted in the destruction of 2,400 ha in the North Zone (Urabá Region). Subsequent outbreaks between 2006 and 2012 affected over 75,000 ha in the Central Zone (Puerto Wilches, Santander) and Southwestern Region (Tumaco, Nariño). Most recently, by 2022, BR had forced the removal of more than 14,000 ha of palm plantations in the Northern Zone (Magdalena) (Romero, 2023).

In response to the devastating effects of BR, the Colombian oil palm industry has increasingly turned to the cultivation of interspecific hybrid

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palms, specifically OxG hybrids, which are crosses between *E. oleifera* and *E. guineensis* Jacq. These hybrids have demonstrated partial resistance to BR, making them a promising alternative to traditional *E. guineensis* cultivars in regions where the disease is prevalent (Ávila-Diazgranados *et al.*, 2016; Ayala-Díaz *et al.*, 2023). Since 2007, the adoption of the interspecific hybrid OxG in Colombia has expanded rapidly. In 2006, OxG hybrids represented less than 1% of the total oil palm area in the country, but by 2022, they covered approximately 14% of the cultivated area, equating to 90,000 ha (Romero *et al.*, 2021). This shift underscores the potential of OxG hybrids to sustain palm oil production in the face of BR and other challenges.

OxG hybrids offer several advantages over traditional *E. guineensis* cultivars, including greater genetic diversity, which influences their physiology, productive behaviour, oil quality and resistance to BR. The most planted OxG crosses in Colombia include Coari x La Mé, Brasil x Djongo, Cereté x Deli and Manaus x Compacta (Ayala-Díaz *et al.*, 2023). These hybrids are known for their low stipe growth rate, which could potentially extend their economic lifespan. Moreover, OxG hybrids exhibit high yield potential, with production levels ranging between 30 and 45 t of fresh fruit bunches (FFB) ha^{-1} yr^{-1}, depending on the geographical region (Romero *et al.*, 2021). The oil produced by OxG hybrids is also of high quality, characterised by a high oleic acid content and a lower proportion of saturated fats, which is increasingly preferred in global markets (Romero *et al.*, 2021).

Despite these advantages, the cultivation of OxG hybrids presents unique challenges. One of the most significant issues is their limited natural pollination due to sexual incompatibility between the parent species, resulting in low pollen viability and germination rates. Additionally, the presence of peduncular bracts on female inflorescences hinders pollination by wind-borne insects (Rincón *et al.*, 2013; Romero *et al.*, 2021). To overcome this challenge, Colombian palm oil producers have had to adopt assisted pollination practices. These include the application of *E. guineensis* pollen to female inflorescences during anthesis or the use of artificial pollination techniques involving naphthaleneacetic acid (NAA) to promote the development of parthenocarpic fruits (Daza *et al.*, 2016; Romero *et al.*, 2021; Ruiz-Alvarez *et al.*, 2021).

Another critical aspect of OxG hybrid cultivation is the management of nutritional requirements. Study indicates that OxG hybrids are highly efficient in the uptake of essential nutrients such as nitrogen and phosphorus. However, foliar analyses often reveal lower levels of these and other nutrients, such as potassium, magnesium and boron, compared to *E. guineensis* cultivars (Arias *et al.*, 2023). This efficiency necessitates careful monitoring to ensure that nutrient deficiencies do not negatively impact crop performance. Additionally, the lower nut content in OxG FFB, especially when artificial pollination is used, presents challenges for the oil extraction process. The absence or reduced presence of nuts requires adjustments in the pressing stage, which in turn affects energy and water usage during processing (García, 2023; García *et al.*, 2023).

The shift to OxG hybrids in Colombia's oil palm industry represents a significant change in cultivation practices, driven by the need to manage BR and sustain production. However, the introduction of these hybrids also raises several research questions, particularly regarding their water requirements, vegetative and biomass development, and responses to different irrigation regimes (Romero, 2023). Effective irrigation management is crucial for optimising the growth and yield of OxG hybrids, especially in regions with varying climatic conditions.

There are different studies defining the water requirements of oil palms *E. guineensis* planted in black polyethylene bags during the nursery stage (Bautista, 2003; Burgos *et al.*, 1998a, 1998b; Corley & Tinker, 2015; Delgado *et al.*, 2016; Quencez, 1982; Rees & Chapas, 1963; Sigalingging *et al.*, 2018). Despite numerous trials, there is a lack of studies accurately defining the evapotranspiration (ETc) and crop coefficient (Kc) values of different oil palm cultivars planted in Colombia.

The optimum or adequate water supply to maintain the crop in the nursery stage is still poorly defined, largely due to the variability of conditions under which trials have been conducted, poor experimental design and differences in methodology (Carr, 2011; Henson *et al.*, 2007). In some cases, constant ranges (5-8 mm d^{-1} or 150-200 mm month^{-1}) are often used when ETc values are required (Pulver, 2016; Ruíz *et al.*, 2023), leading the crop to be easily subjected to moisture deficit or excess, which will affect plant growth and development. Moreover, there is a lack of specific data on the water requirements of OxG hybrids, which differ from those of *E. guineensis* due to their distinct genetic and physiological characteristics.

Improving irrigation water management requires a deep understanding of crop water use and agronomic responses under water stress conditions. Water-deficit stress is the main limitation of oil palm productivity (Jazayeri *et al.*, 2015). Water-deficit stress is accompanied by restrictions in nutrient intake (Sun *et al.*, 2011). Nutrient intake, together with water, increases dry matter production and crop yield (Corley & Tinker, 2003). Nevertheless, oil palm productivity can be enhanced by optimising growth during the nursery stage.

The nursery stage is a key cultivation stage. Early events in the life of the crop, especially at the nursery and planting stages, can have strong effects on yield in subsequent years (Breure & Menendez, 1990). In nurseries, poor or uneven watering is the most common cause of pests and diseases and uneven seedling growth (Heriansyah & Tan, 2005).

Designing optimal deficit irrigation strategies that maximise water savings and minimise yield losses is crucial for reducing the vulnerability of oil palm plantations to water scarcity (Carr, 2011; Jamshidi *et al.*, 2020). For OxG hybrids, in particular, it is essential to establish Kc and determine ETc accurately under different irrigation treatments. This is a critical step for improving crop water productivity, especially in water-scarce scenarios (Libardi *et al.*, 2019; Pereira *et al.*, 2021).

Weighing lysimeters are considered the standard tool for research on crop water requirements, allowing for precise measurements of ETc and the development of accurate Kc values (Anapalli *et al.*, 2018; Libardi *et al.*, 2019). However, while the FAO-56 method (Allen *et al.*, 1998) is widely used for calculating crop ETc and Kc, the values provided by Food and Agriculture Organization of the United Nations (FAO), which are based on global averages and various research studies, may not be appropriate for local climatic conditions (Delgado *et al.*, 2024; Pereira *et al.*, 2021). Therefore, it is necessary to develop Kc values that consider local conditions, as well as specific crop characteristics such as those of the OxG hybrids (Carr, 2011; Kadam *et al.*, 2021). In the context of OxG hybrids in Colombia, no previous studies have adequately addressed these factors, highlighting the need for research tailored to the specific environmental and agronomic conditions of the region.

This study aims to address these knowledge gaps by investigating the water consumption, vegetative growth and biomass development of OxG hybrids under different irrigation levels in Colombia. By developing Kc specific to OxG hybrids and evaluating their responses to various irrigation strategies, this study will contribute to the development of more effective water management practices. The findings will have significant implications for the sustainability and productivity of OxG hybrids in Colombia, providing valuable insights for the broader oil palm industry as it adapts to the challenges of disease management, environmental sustainability and resource efficiency. Understanding the unique water requirements and agronomic characteristics of OxG hybrids will not only help optimise their cultivation but also ensure that the Colombian oil palm industry can continue to thrive in the face of ongoing and emerging challenges.

MATERIALS AND METHODS

This study was conducted in the Eastern oil palm-growing area of Colombia, in the municipality of Cumaral, Meta department, in the Unipalma de Los Llanos S.A. Plantation, with the cultivar *E. guineensis* and the interspecific hybrid OxG. The study was conducted in a double-stage nursery. In the first stage, seedlings were grown until they were two months old. In the second stage, the seedlings were transplanted into large bags with a diameter of 30 cm, following the methods reported by Bautista (2003) and Motta and Beltran (2010).

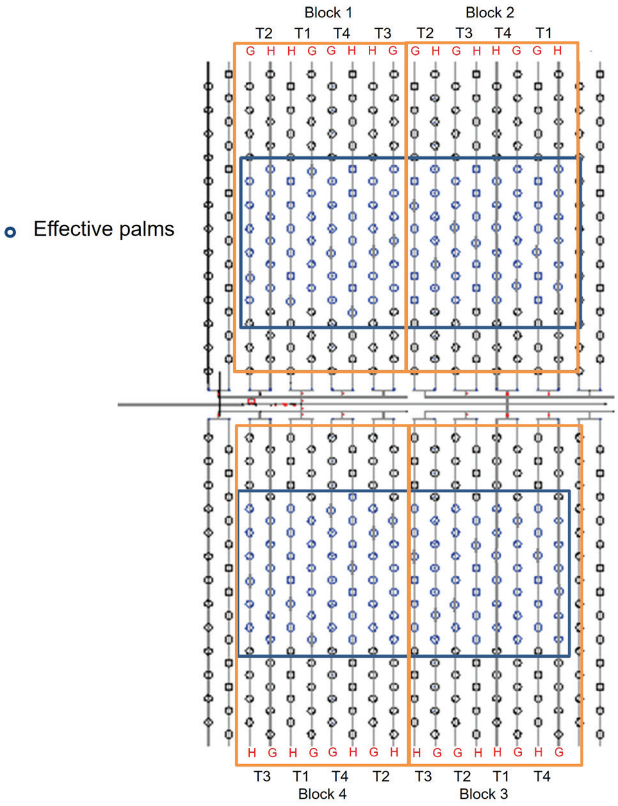
During the nursery stage, a comprehensive fertilisation program was implemented to ensure optimal growth. Fertilisation was carried out every two weeks, applying urea, diammonium phosphate (DAP), potassium chloride (KCL) and kieserite. Pest and disease monitoring was conducted through bi-weekly censuses, where each palm was inspected to determine the incidence of any pests or diseases that might be present at this nursery stage. This monitoring ensured that any issues could be promptly addressed to maintain the health and vigour of the seedlings.

A randomised complete block design with split-plots arrangement was used, with four replications and four treatments. The whole plot corresponded to a set of four water consumption coefficient treatments based on equivalent evaporation (EV) in the Class A Evaporimeter Tank (0.3, 0.6, 0.9 and 1.2 EV) and the split-plots corresponded to two oil palm cultivars (*E. guineensis* and the interspecific hybrid OxG) (*Figure 1*). Each experimental unit consisted of 14 palms, with the central six palms representing the effective plot. In total, there were 448 sample plants, corresponding to four treatments, four repetitions and two cultivars.

Vegetative variables [leaf area (LA), plant height (PH), bulb diameter (BD) and leaf emergence rate] were recorded every two months, and biomass (root, bulb and leaf biomass) was recorded every four months, based on Corley and Breure (1981). In addition, to determine ETc, weighing lysimeters were installed in each treatment to monitor weight variations due to their accuracy, precision and operational conveniences. ETc was calculated using the water balance method with the following Equation (1):

$$\Delta W = P + R - ETc - D \quad (1)$$

where, ΔW (mm) is the change in soil moisture over a specific period estimated from weight variations of the weighing lysimeters, P (mm) is the precipitation or rainfall received during the same period, R (mm) is the applied irrigation



Note: H - hybrid OxG; G - *E. guineensis*; T - treatment.

Figure 1. Schematic diagram of the experimental design. The blue circles represent effective palms, the blue rectangles represent the effective area, and the orange rectangles represent the experimental area.

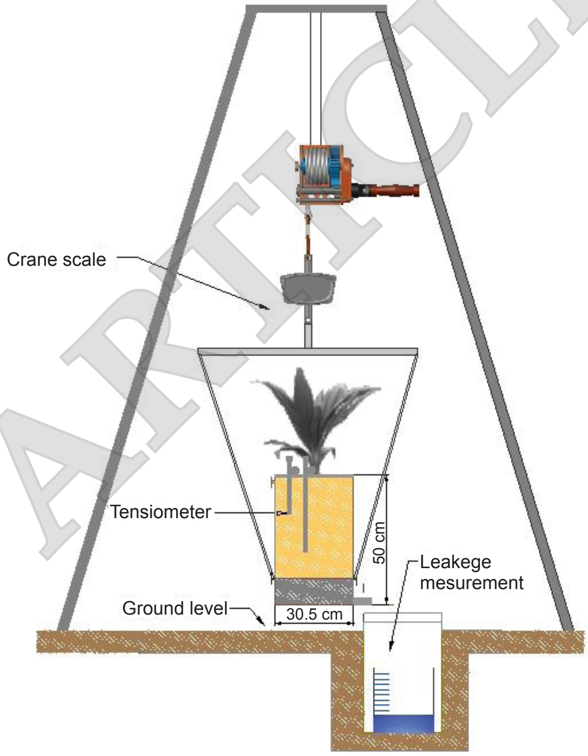


Figure 2. Schematic diagram of the weighing lysimeters.

depth during the specific interval, *ETc* (mm) is the actual evapotranspiration of a reference crop and *D* (mm) is the drainage. Runoff is not considered because this phenomenon is prevented by the walls of the lysimeter (*Figure 2*).

Precipitation and other meteorological variables were measured using a weather station (Model: 2900ET, Watchdog, Spectrum Technologies, USA) throughout the research period, from October 2011 to June 2012. The depth of irrigation was time-controlled in the drip irrigation system designed for the test. The volume of water percolated through the weighing lysimeter system was measured in a lysimeter box (*Figure 2*), whereas weight change was recorded using a 150 kg × 20 g XENIT crane scale. The equivalent evaporation of the Class A tank was estimated using a Cenirrometer tank, and the evaporation measured in the Cenirrometer tank was multiplied by the constant 0.91, as reported by Torres and Cruz (1995). Averages were calculated for 10-day cycles, as recommended by Allen *et al.* (2006).

Reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith method (Allen *et al.*, 2006) based on climatic parameters measured at the weather station [Equation (2)]:

$$ETo = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\dfrac{900}{T + 273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad (2)$$

where, ETo is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m of height (°C), u_2 is the wind speed at 2 m of height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), $e_s - e_a$ is the vapor pressure deficit (kPa), Δ is the slope of the vapour pressure curve (kPa $°C^{-1}$) and γ is the psychometric constant (kPa $°C^{-1}$).

For each treatment, Kc was calculated by dividing ETc by ETo. To analyse the water requirements and to facilitate visualisation, the results were averaged on a decadal time scale (10 days). Composite sampling was performed onsite, and the samples were sent to the leaf and soil analysis laboratory at Colombian Oil Palm Research Center (CENIPALMA). Based on this information, the fertilisation plan was determined for the study period, using the parameters outlined in the nursery methodological guide (Motta & Beltran, 2010). The moisture content at field capacity and permanent wilting point was also determined using the rectangular and biological edge methodology, respectively.

The substrate used in the study nursery was in good condition, with a loam texture and favourable chemical characteristics for oil palm cultivation (*Table 1* and *2*) (Motta & Beltran, 2010). The moisture content at field capacity was 19%, and the moisture content at permanent wilting point was 9%. These data indicate a usable moisture of 10%. The vegetative variables were assessed at two, four, six and eight months of age in the nursery, while the biomass variables were assessed at four and eight months of age. These measurements were performed in the six central oil palm seedlings of each effective plot.

After the measurements, the water use efficiency (WUE) (g mm^{-1}) of the oil palm nursery plants, based on the cumulative ETc, was calculated according to the following Equation (3) and (4):

$$WUE = \frac{TDW}{ETc} \tag{3}$$

$$IWE = \frac{TDW}{R} \tag{4}$$

where, TDW (g) is the total dry weight oil palm^{-1}, ETc (mm) is the cumulative evapotranspiration, R (mm) is the cumulative irrigation depth and irrigation water efficiency (IWE) (g mm^{-1}). Vegetative variables, biomass and WUE were analysed using the RStudio computer program, and significant differences between treatments were identified according to Tukey's test at $p<0.05$.

RESULTS AND DISCUSSION

Climatic Conditions During the Study Period

The climate of the study area was hot and humid according to the Caldas-Lang model (Moreno *et al.*, 2013). The agrometeorological characteristics assessed during the study period are outlined in *Table 3*. During the evaluation (eight months), an accumulated precipitation of 1,754.8 mm was recorded. During the first two months in the nursery, there was an accumulation of 354.1 mm of precipitation over 31 days. In the two to four months period (the period with the lowest precipitation), the accumulated precipitation was 111.10 mm over 12 days. Between four and six months, there was 288.0 mm of rainfall over 27 days. Finally, in the six to eight months period, the accumulated precipitation reached 1,001.6 mm over 48 days.

TABLE 1. PHYSICAL ANALYSIS OF THE NURSERY SOIL AND RANGES

Parameter	Laboratory analysis result	Nursery soil characteristics
Texture	Loam	Loam
Sand (%)	41.50	-
Silt (%)	32.00	-
Clay (%)	26.50	-
Volumetric soil moisture content at field capacity (%)	19.00	-
Volumetric soil moisture content at permanent wilting point (%)	10.00	-
Bulk density (g cm^{-3})	1.05	-

TABLE 2. CHEMICAL ANALYSIS OF THE NURSERY SOIL AND RANGES

Parameter	Laboratory analysis result	Nursery soil characteristics
OM (%)	2.28	2.00-4.00
P (mg kg^{-1})	37.90	15.00-30.00
K (meq 100 g^{-1})	0.18	0.20-0.40
Mg (meq 100 g^{-1})	0.61	1.50-2.50
K saturation	4.70	3.00-6.00
Ca saturation	68.80	20.00-40.00
Mg saturation	16.00	10.00-20.00
Na saturation	1.00	<15.00
Al saturation	9.40	<15.00

Note: OM - organic matter; P - phosphorus; K - potassium; Mg - magnesium; Ca - calcium; Na - sodium; Al - aluminium.

TABLE 3. AGROMETEOROLOGICAL CHARACTERISTICS OF THE AREA

Parameter	October	November	December	January	February	March	April	May	June
Precipitation (mm)	170.7	183.4	110.3	0.8	49.0	238.5	648.3	348.8	328.4
Solar radiation (W m^{-2})	240.3	217.7	259.0	237.0	274.1	199.5	213.9	217.3	210.9
Minimum temperature (°C)	22.3	22.3	22.0	22.0	21.2	21.9	21.6	22.7	21.8
Maximum temperature (°C)	33.9	32.4	34.0	34.0	35.1	33.1	32.5	32.7	31.5
Average temperature (°C)	26.4	26.3	27.0	27.0	27.3	26.4	26.0	26.1	25.5
Minimum relative humidity (%)	51.7	56.7	39.0	47.0	34.0	45.3	53.8	53.5	55.1
Maximum relative humidity (%)	99.0	99.3	98.0	95.0	92.0	95.8	98.3	98.0	98.3
Average relative humidity (%)	81.5	84.1	79.0	65.0	64.9	76.9	84.0	82.8	83.5
Wind speed (m s^{-1})	0.7	0.5	1.0	1.0	1.4	0.8	0.5	0.6	0.5

Note: Data collected from the weather station installed at the study site.

Vegetative and Biomass Variables

Table 4 summarises significant differences between treatments and cultivars. Associated with irrigation, significant differences ($p<0.05$) in PH and BD were identified from the fourth month of the nursery stage; similarly, significant differences in root dry weight (RDW), bulb dry weight (BDW), leaf dry weight (LDW) and total dry weight (TDW) were assessed from the fourth month. From the second month of the nursery stage, highly significant differences ($p<0.01$) were found between the cultivars.

TABLE 4. SUMMARY OF THE RESULTS FROM THE ANALYSIS OF VARIANCE (ANOVA)

Variable	Irrigation	Cultivar
2-month LER	ns	**
4-month LER	*	**
6-month LER	ns	**
8-month LER	*	**
2-month PH	ns	**
4-month PH	*	**
6-month PH	*	ns
8-month PH	*	**
2-month BD	ns	**
4-month BD	*	**
6-month BD	*	**
8-month BD	*	**
4-month RDW	*	**
8-month RDW	*	**
4-month BDW	*	**
8-month BDW	*	**
4-month LDW	*	**
8-month LDW	*	**
4-month TDW	*	**
8-month TDW	*	**

Note: LER - leaf emergence rate; PH - plant height; BD - bulb diameter; RDW - root dry weight; BDW - bulb dry weight; LDW - leaf dry weight; ns - nonsignificant difference. Significant differences according to the Tukey's test at * - ($p<0.05$) and ** - ($p<0.01$).

Table 5 outlines the results of the vegetative variables (PH and BD) at six and eight months by water treatment. In addition, *Table 6* outlines the biomass (LDW, BDW, RDW and TDW) values at eight months.

Significant differences were found between treatments in both cultivars. The vegetative and biomass variables increased with the volume of applied water. In both cultivars, the treatments with the best results of vegetative and biomass variables were 0.9 and 1.2 EV, which only significantly differed between them in BD at six and eight months of the cultivar *E. guineensis* and in RDW and BDW of the interspecific hybrid OxG. Significant differences in vegetative and biomass variables, except for PH at six months, were also found between cultivars.

As for PH, the most effective treatments for the cultivar *E. guineensis* were 0.9 and 1.2 EV, with a 12% difference between the 0.9 and 0.3 EV treatments. For the interspecific hybrid OxG, this difference was 15%. Significant differences in BD were found in both cultivars, reaching 18% between the 0.3 and 1.2 EV treatments in the cultivar *E. guineensis* and 6% between the 0.3 and 0.9 EV treatments in the interspecific hybrid OxG.

In terms of biomass, the most effective treatments for the cultivar *E. guineensis* were 0.9 and 1.2 EV, without significant differences between them. Nevertheless, these treatments significantly differed from the 0.3 EV treatment by 38% (RDW), 29% (BDW), 22% (LDW) and 28% (TDW). The interspecific hybrid OxG showed significant differences in RDW and BDW between all treatments, reaching 44% and 55% between the 0.3 and 1.2 EV treatments, respectively. The differences in LDW and TDW between the 0.3 and 0.9 EV treatments were 42% and 40%, respectively.

The irrigation treatment that led to the best plant development was 1.2 EV. Under this treatment, at eight months, the cultivar *E. guineensis* showed a higher PH than the interspecific hybrid OxG and was, on average, 11 cm taller, but OxG had higher

TABLE 5. VEGETATIVE VARIABLES OF THE CULTIVARS AT SIX AND EIGHT MONTHS

Cultivar	Treatment (EV)	PH 6 (cm)	CV (%)	PH 8 (cm)	CV (%)	BD 6 (mm)	CV (%)	BD 8 (mm)	CV (%)
E. guineensis	0.3	85.54^{c}	2.38	108.90^{c}	2.38	59.16^{e}	0.71	75.56^{d}	2.00
	0.6	91.19^{bc}	2.11	113.87^{bc}	2.60	63.06^{de}	3.98	77.97^{cd}	1.71
	0.9	100.71^{a}	4.94	124.04^{ab}	3.61	69.23^{bc}	5.18	88.44^{b}	1.26
	1.2	104.67^{a}	4.53	129.43^{a}	2.37	72.93^{ab}	1.38	92.14^{a}	0.66
Interspecific hybrid OxG	0.3	84.44^{c}	6.72	97.55^{d}	7.06	62.42^{de}	2.57	80.53^{c}	1.36
	0.6	91.02^{bc}	3.02	105.25^{c}	4.30	68.33^{bc}	4.32	86.41^{b}	4.77
	0.9	98.21^{ab}	3.91	115.25^{b}	2.40	70.69^{b}	8.66	86.09^{b}	9.62
	1.2	100.50^{a}	7.64	117.89^{b}	5.94	77.35^{a}	8.00	95.86^{a}	6.40

Note: EV - evaporation; PH - plant height; BD - bulb diameter; CV - coefficient of variation. Means with different letters in the same column significantly differ from each other according to Tukey's test (p<0.05). Letter comparisons are valid across both cultivars for each variable.

TABLE 6. OIL PALM BIOMASS OF THE CULTIVARS AT EIGHT MONTHS

Cultivar	Treatment (EV)	RDW 8 (g)	CV (%)	BDW 8 (g)	CV (%)	LDW 8 (g)	CV (%)	TDW 8 (g)	CV (%)
E. guineensis	0.3	44.88^{d}	32.60	60.21^{d}	22.10	121.15^{d}	19.60	226.25^{e}	21.93
	0.6	53.31^{cd}	41.30	67.62^{d}	21.44	130.86^{cd}	14.68	251.78^{de}	20.87
	0.9	72.85^{bc}	17.74	85.11^{c}	19.75	156.05^{bc}	12.45	314.00^{cd}	15.04
	1.2	76.42^{b}	25.47	109.65^{b}	20.62	188.23^{b}	10.87	374.29^{bc}	12.72
Interspecific hybrid OxG	0.3	70.06^{bc}	34.41	62.78^{d}	7.98	119.68^{d}	7.10	252.52^{de}	12.92
	0.6	73.98^{bc}	7.67	83.90^{c}	19.43	151.23^{bc}	13.80	309.11^{cd}	9.97
	0.9	101.29^{a}	26.20	111.31^{b}	20.14	206.05^{ab}	12.13	418.65^{ab}	16.95
	1.2	125.42^{a}	27.36	139.16^{a}	17.49	233.54^{a}	27.09	498.12^{a}	9.62

Note: EV - evaporation; RDW - root dry weight; BDW - bulb dry weight; LDW - leaf dry weight; CV - coefficient of variation. Means with different letters in the same column significantly differ from each other according to Tukey's test (p<0.05). Letter comparisons are valid across both cultivars for each variable.

BD, RDW, BDW, LDW and TDW, with differences averaging 3.7 mm, 49.0, 29.5, 45.3 and 123.8 g, respectively (*Table 5 and 6*).

The results showed that the volume of water affected all growth components of the different oil palm cultivars in the nursery. Water deficit significantly reduces oil palm photosynthesis, transpiration and growth in the nursery stage, which affects the growth of the plants (Rivera-Mendes *et al.*, 2016; Tezara *et al.*, 2021). Silvina *et al.* (2022) found similar results as the amount of water applied in the nursery affected the photosynthetic rate, LA, PH, BD, leaf number, root volume and plant weight.

The reduction in photosynthesis leads to a limited production of photoassimilates and growth regulators, resulting in slow plant growth (Rivera-Mendes *et al.*, 2016). Oil palm seedlings mitigate water loss under stress by reducing their leaf expansion rate and leaf initiation (Najihah *et al.*, 2019). For the hybrid cultivar OxG, soil water potential significantly affects its ecophysiological response. Under optimal moisture conditions, OxG exhibits the highest photosynthetic rate and the lowest respiratory rate. In comparison to *E. guineensis*, under moderate and severe water deficits, OxG maintains a higher photosynthetic rate and lower respiratory rate, directs assimilates primarily towards the roots and uniquely adjusts its water potential through active sugar accumulation (Méndez *et al.*, 2012).

Overall, the findings indicate that irrigation plays a critical role in influencing both vegetative growth and biomass production in both cultivars. The interspecific hybrid OxG demonstrated a higher capacity for biomass accumulation and efficiency under optimal irrigation conditions, making it a potentially more suitable cultivar for regions where water availability is limited but irrigation can be optimised. However, given that no significant differences were observed between the 0.9 and 1.2 EV treatments for most variables, it may be prudent to use the 0.9 EV treatment for practical irrigation management. This conclusion is consistent with previous research, which suggests that over-irrigation can lead to unnecessary water loss through deep percolation and runoff, without significantly improving crop performance (Delgado *et al.*, 2024; Heriansyah & Tan, 2005).

Evapotranspiration (ETc), Reference Evapotranspiration (ETo) and Crop Coefficient (Kc)

Figure 3 shows the ETo, ETc of the cultivar *E. guineensis* and the interspecific hybrid OxG, and the precipitation in each of the treatments by a 10-days [decad (dec)] period.

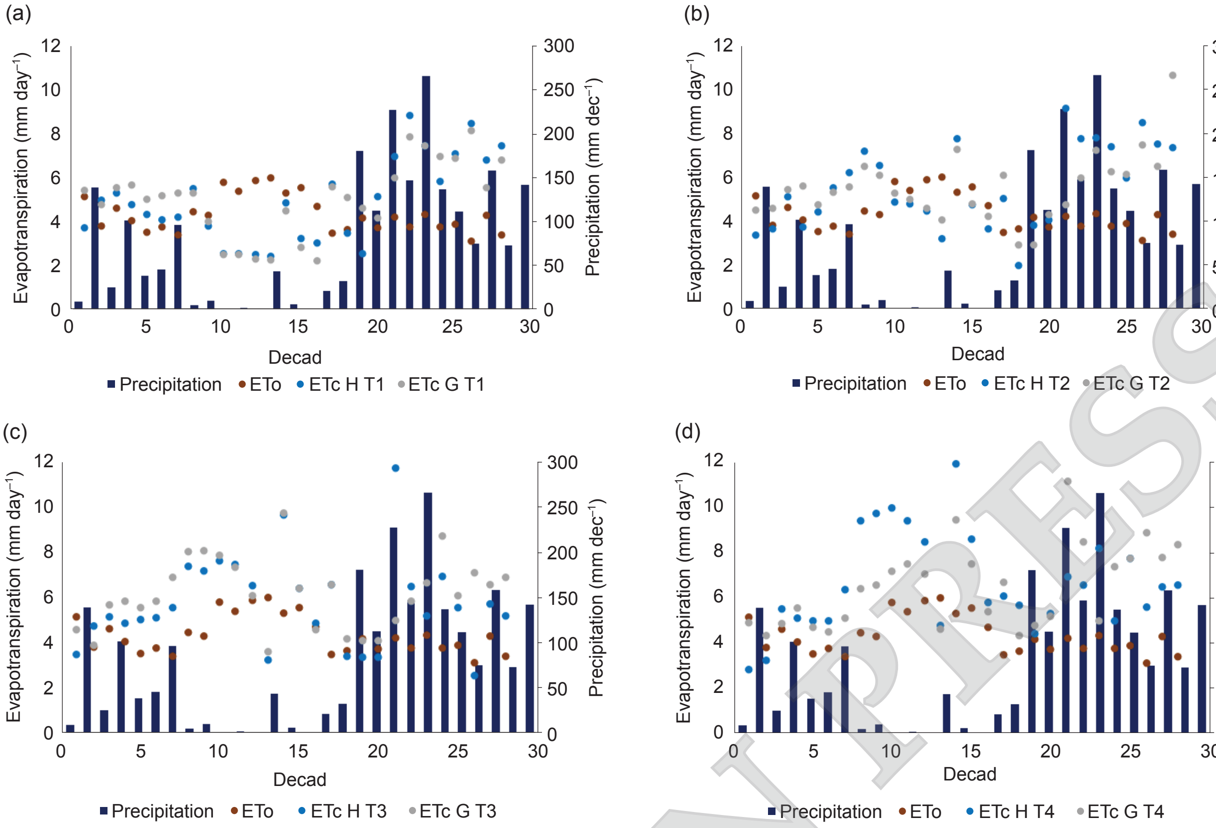


Figure 3. Reference crop evapotranspiration (brown dots) and actual evapotranspiration for the treatments and cultivars under study. Correspond to treatments (a) T1: 0.3 EV, (b) T2: 0.6 EV, (c) T3: 0.9 EV and (d) T4: 1.2 EV, respectively. Blue dots: interspecific hybrid O×G (H); and grey dots: E. guineensis *Jacq. (G).*

The data reveal the variations in ETc between the two oil palm cultivars (*E. guineensis* and the interspecific hybrid OxG) under four different treatments across their distinct growth phases. The ETc values differ not only between the cultivars but also across different growth stages, with a notable increase as the plants transition from the initial to the final phase.

Both ETo and ETc were strongly affected by precipitation. During the dry season (from the 8th to the 17th dec), ETc increased due to the increase in the evaporative power of the atmosphere. From the 18th dec, the ETo values decreased because cloudiness increased, solar radiation decreased and winds slowed down during the rainy season, thereby decreasing the evaporative power. Nevertheless, the mean ETc of the cultivars under study increased due to crop development and increased soil water availability for the ETc process.

In the 0.3 and 0.6 EV treatments, ETc was lower than ETo during the dry season due to the water deficit because the irrigation failed to meet the water requirement of the crop. In the treatments with the best results in terms of vegetative and biomass variables (0.9 and 1.2 EV), ETc ranged from 2.5-11.9 mm day^{-1} in the cultivar *E. guineensis* and from 3.5-11.1 mm day^{-1} in the interspecific hybrid OxG.

Table 7 summarises the mean ETc values found in each of the development phases of both cultivars grown in a nursery and for the two best treatments in terms of development (0.9 and 1.2 EV). For *E. guineensis*, the ETc under the 0.9 EV treatment increased from 5.2 mm day^{-1} during the initial phase to 6.60 mm day^{-1} in the final phase. Under the 1.2 EV treatment, the ETc values were slightly higher, ranging from 4.80 mm day^{-1} in the initial phase to 8.10 mm day^{-1} in the final phase. For the hybrid OxG, a similar trend was observed, where the ETc under the 0.9 EV treatment ranged from 4.70-6.10 mm day^{-1} and for the 1.2 EV treatment, it ranged from 4.40-6.60 mm day^{-1}. These findings suggest that while both cultivars have similar ETc trends, *E. guineensis* exhibited slightly higher ETc values compared to the OxG hybrid, particularly during the final growth phase. These values are higher than those reported by Ichwan *et al.*, (2019) and Sigalingging *et al.* (2018), who found ETc values ranging from 1.85-4.25 mm day^{-1}. Nevertheless, Burgos *et al.* (1998a) and Delgado *et al.* (2016) reported similar values in the Eastern oil palm-growing area of Colombia, ranging from 3.00-5.60 mm day^{-1}, with a maximum of 8.98 mm day^{-1}.

These results align with existing literature on ETc dynamics in perennial crops, where the ETc typically increases as plants grow and

TABLE 7. SUMMARY OF THE EVAPOTRANSPIRATION (ETc), CROP COEFFICIENT (Kc) AND DURATION OF EACH PHASE OF THE CULTIVARS UNDER STUDY

Cultivar	Phase	Duration (days)	ETc (mm day^{-1})	Kc	ETc (mm day^{-1})	Kc
			0.9 EV		**1.2 EV**	
E. guineensis	Initial	60	5.2	0.30-1.50	4.8	1.0-1.2
	Intermediate	130	6.2	1.25	6.2	1.2
	Final	90	6.6	1.47	8.1	1.8
Interspecific hybrid OxG	Initial	60	4.7	0.90-1.30	4.4	0.6-1.4
	Intermediate	130	5.9	1.16	7.5	1.5
	Final	90	6.1	1.39	6.6	1.5

develop, due to increased leaf area and greater water demand (Carr, 2011; Corley & Tinker, 2015; Romero, 2023). Burgos *et al.* (1998a, 1998b) and Delgado *et al.* (2016) reported a similar pattern in adult *E. guineensis* palms in Colombia, where ETc rates increased as soil moisture content rise. Furthermore, it is essential to highlight that the higher ETc values observed in the 1.2 EV treatment may suggest that, under higher irrigation levels, plants can reach their full ETc potential. However, similar to what was observed in Najihah *et al.* (2019) and Silvina *et al.* (2022), Delgado *et al.* (2024), excessive water supply may not always result in increased water consumption by the plant. Instead, surplus water may be lost through deep percolation or runoff, which suggests that irrigation rates should be carefully managed to avoid water wastage. Gong *et al.* (2020) demonstrated similar findings in tomato crops, showing that while full irrigation facilitates the maximum ETc, any additional water supply beyond the plant's requirements may be inefficient and could lead to water wastage.

The response of the OxG hybrid in terms of ETc was slightly lower compared to *E. guineensis*, particularly in the intermediate and final phases. This might be due to its genetic makeup, which could lead to a lower water uptake efficiency or reduced transpiration rates under the same conditions. However, despite these differences, both cultivars exhibited a steady increase in ETc as the growth stages progressed, highlighting the importance of ensuring adequate water supply throughout the growth period to support optimal physiological functions. This is consistent with Pereira *et al.* (2021), who emphasised that ensuring adequate evapotranspiration rates is critical in managing water resources in the face of climate variability.

Figure 4 shows the Kc estimated for each cultivar in the initial, intermediate, and final phases of the nursery stage for all treatments under study. Broadly speaking, Kc increases in each phase of the development of plants grown in a greenhouse. However, in this study, the Kc was similar in all phases and in both the interspecific hybrid OxG and the cultivar *E. guineensis*, except for the 1.2 EV treatment. Under this treatment, the Kc of the cultivar *E. guineensis* was 20% higher in the final phase.

The summary of the Kc values found in the best treatments based on vegetative and biomass variables (0.9 and 1.2 EV) is presented in *Table 7* by development phase for each cultivar. Kc ranged from 0.30-1.47 (0.9 EV) and from 1.00-1.80 (1.2 EV) in the cultivar *E. guineensis* and from 0.90-1.30 (0.9 EV) and from 0.60-1.50 (1.2 EV) in the interspecific hybrid OxG. Similar results have been found for *E. guineensis*, with Kc values exceeding 1.40 under well-watered conditions in Colombia's Eastern oil palm zone (Burgos *et al.*, 1998a). However, some of these values are higher than those reported by Delgado *et al*. (2016), which may be attributed to differences in climatic conditions. Moreover, the disparities in the findings between Sigalingging *et al.* (2018) and Ichwan *et al.* (2019), which reported Kc values of 0.57 and 0.57, respectively, can be attributed to variations in both climatic conditions and the methodologies employed to estimate ETc.

Tezara *et al.* (2021) noted that OxG hybrids tend to have lower transpiration rates than *E. guineensis*, particularly under water-deficit conditions. The hybrids are sensitive to drought but perform well under optimal irrigation, which is supported by the findings of this study showing slightly lower Kc values for OxG compared to *E. guineensis* in well-irrigated scenarios. These results further highlight the physiological differences between the two cultivars, with *E. guineensis* demonstrating a higher water demand in both treatments (0.9 and 1.2 EV), reflected in its higher Kc values.

Figure 4 and *Table 7* show high Kc values, which might have resulted from differences in plant growth between the weighing lysimeter and the field or surrounding vegetation, which is known as the "clothesline effect". This effect

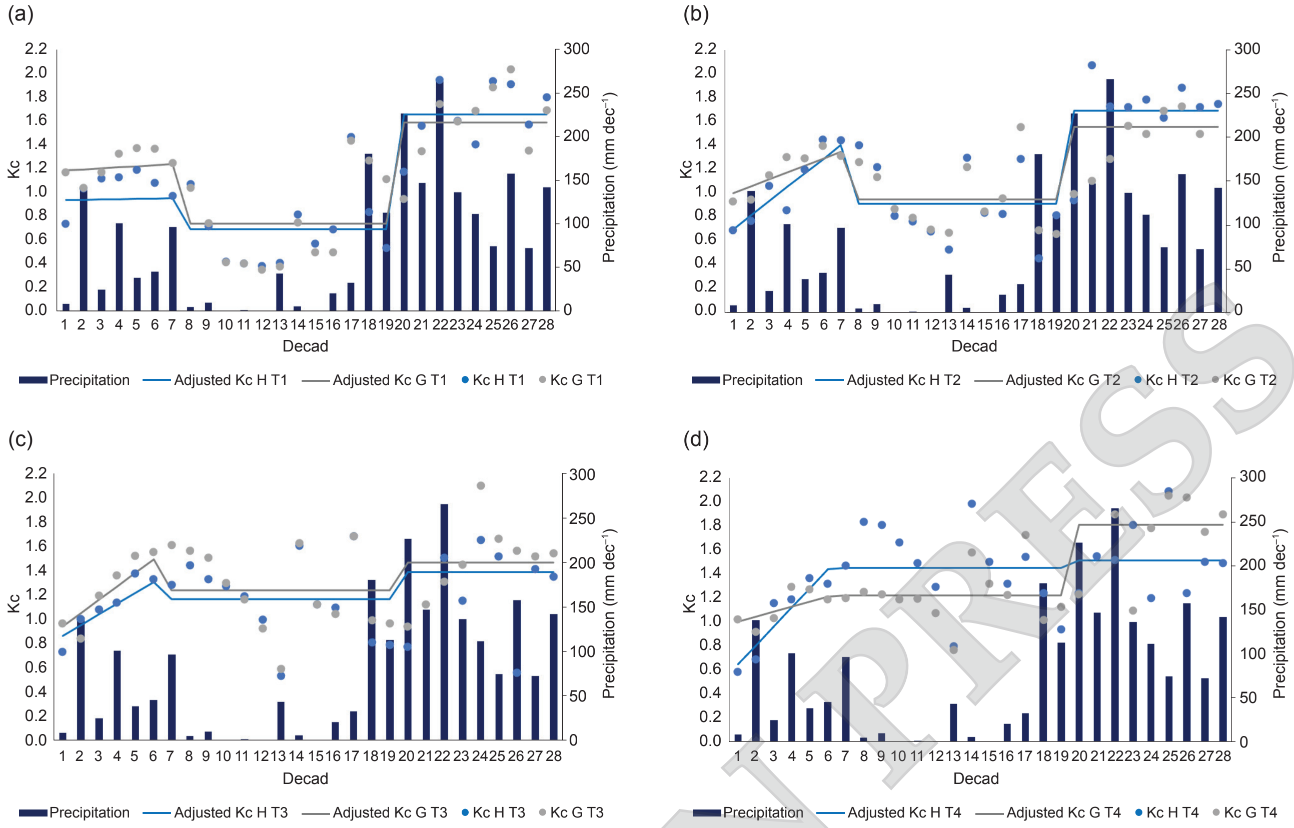


Figure 4. Crop coefficient for the treatments and cultivars under study (blue dots: interspecific hybrid O×G (H); and grey dots: E. guineensis *Jacq. (G)). Correspond to treatments (a) T1: 0.3 EV, (b) T2: 0.6 EV, (c) T3: 0.9 EV and (d) T4: 1.2 EV, respectively. The blue and grey lines represent the adjusted Kc values of the interspecific hybrid O×G (H) and the cultivar* E. guineensis *Jacq. (G) for the different periods.*

occurs when crops are taller than the surrounding vegetation. Consequently, the crops receive a higher amount of radiation, leading to an overestimation of their ETc, which is a common occurrence among greenhouse crops (Allen *et al*., 2011; Martins *et al*., 2019). Values greater than 1.4 have also been observed in sweet corn cultivars under conditions similar to those in oil palm nurseries. These plants were grown in plastic containers without surrounding vegetation, thus exhibiting the clothesline effect (Bayabil *et al*., 2023).

Moreover, the increment of Kc values as the plants progress through different developmental stages has been noted in other crops, such as sugarcane and tomatoes, grown in controlled environments like greenhouses. For example, Libardi *et al.* (2019) observed increased Kc in sugarcane plantlets as they grew, highlighting the importance of accurately determining Kc values to avoid water wastage or deficits. Similarly, Gong *et al.* (2020) found that deficit irrigation leads to lower Kc values in tomatoes due to reduced transpiration under limited soil moisture. These findings are consistent with the results of this study, showing reduced Kc values under the 0.9 EV treatment.

In practical terms, the net volume of evapotranspired water by *E. guineensis* under the 0.9 EV treatment, it increased from 367.1 mL palm^{-1} day^{-1} during the initial phase to 464.9 mL palm^{-1} day^{-1} in the final phase. Under the 1.2 EV treatment, evapotranspired volumes were slightly higher, ranging from 337.8 initially to 570.8 mL palm^{-1} day^{-1} in the final phase. The OxG hybrid exhibited a similar trend; ETc volumes under the 0.9 EV treatment ranged from 331.9-433.7 mL palm^{-1} day^{-1}, while the 1.2 EV treatment ranged from 312.0-466.9 mL palm^{-1} day^{-1}. These values account only for ETc; for irrigation purposes, the gross water requirement should be calculated based on the efficiency of the irrigation system.

Water Use Efficiency (WUE)

Table 8 summarises the biomass production and WUE associated with ETc and with IWE by treatment and cultivar. Some treatments show significant differences, but the 0.9 EV treatment provided the best WUE values for both cultivars. The interspecific hybrid OxG had a 43% higher WUE than the cultivar *E. guineensis.* Concerning the IWE, the interspecific hybrid OxG

TABLE 8. SUMMARY OF THE WATER USE EFFICIENCY (WUE) BY CULTIVAR AND IRRIGATION TREATMENT, OUTLINING THE VALUES OF TOTAL DRY WEIGHT AT EIGHT MONTHS (TDW 8), CROP EVAPOTRANSPIRATION (ETc) AND IRRIGATION WATER EFFICIENCY (IWE)

Cultivar	Treatment (EV)	TDW 8 (g)	ETc (mm)	Irrigation (mm)	WUE (g mm^{-1})	IWE (g mm^{-1})
E. guineensis	0.3	226.3	1,397.6	257.7	0.16^{d}	0.88^{a}
	0.6	251.8	1,534.1	515.4	0.16^{d}	0.40^{cd}
	0.9	314.0	1,708.4	773.1	0.18^{cd}	0.41^{de}
	1.2	374.3	1,807.3	1,030.8	0.21^{bc}	0.36^{e}
Interspecific hybrid OxG	0.3	252.5	1,369.8	257.7	0.18^{cd}	0.98^{a}
	0.6	309.1	1,542.5	515.4	0.20^{bc}	0.60^{b}
	0.9	418.6	1,593.8	773.1	0.26^{a}	0.54^{bc}
	1.2	498.1	1,848.5	1,030.8	0.27^{a}	0.48^{cd}

Note: Means with different letters in the same column significantly differ from each other according to Tukey's test (p<0.05). Letter comparisons are valid across both cultivars for each variable.

outperformed the *E. guineensis* cultivar, exhibiting a more efficient response to water supplied through irrigation.

Similar results were found by Tezara *et al*. (2021), who reported significant differences in WUE and physiological yields of interspecific hybrid OxG and *E. guineensis* plants. They found that the OxG hybrid had a higher WUE compared to *E. guineensis.* Additionally, Bayona-Rodriguez and Romero (2019) reported that certain OxG hybrids exhibited up to 27% higher photosynthetic WUE.

The effects of soil type, irrigation and soil water holding capacity due to soil texture were not considered in this study. To avoid the influence of soil type on WUE and IWE, it is essential to maintain soil water content between field capacity and the readily available water range. This ensures that plants do not experience water deficit stress, thereby providing better values of WUE and IWE. Implementing consistent soil moisture management practices will help isolate the effects of irrigation treatments and improve water use in the crop.

OxG hybrid cultivars offer a promising option for investors in the oil palm industry. These hybrids have demonstrated enhanced WUE during the nursery stage, high yield potential and partial resistance to diseases like BR and lethal wilt (Ávila-Diazgranados *et al*., 2016; Ayala-Díaz *et al*., 2023). Some Colombian plantations have reported yields as high as 45 t of FFB ha^{-1} or 11 t of crude palm oil (CPO) ha^{-1}, demonstrating their productivity under optimal conditions (Romero *et al*., 2021). Furthermore, OxG hybrids are associated with lower production costs and an extended economic lifespan compared to *E. guineensis* (Mosquera-Montoya *et al*., 2024).

Over the past 15 years, technological advancements have further enhanced the economic viability of OxG hybrids. These include the development of parthenocarpy induction techniques (Daza *et al*., 2016; Romero *et al*., 2021; Ruiz-Alvarez *et al*., 2021), precise ripeness criteria for various hybrid cultivars (Mosquera-Montoya *et al*., 2023), and adaptations to the pressing process specifically for hybrids (García *et al*., 2023). Such advancements make OxG hybrids particularly appealing for palm oil production, especially in oil palm regions, where disease outbreaks pose significant challenges. This research not only underscores the potential of OxG hybrids in terms of water requirements in Colombia but also provides insights that could be applied to other oil palm-producing regions to optimise irrigation strategies, yield and manage disease, potentially contributing to global industry sustainability.

CONCLUSION

The nursery stage is a critical period in oil palm cultivation, as early growth conditions significantly influence long-term productivity. This study quantified and compared the ETc, Kc, WUE and vegetative and biomass development of the interspecific hybrid OxG and *E. guineensis* cultivars at different phenological phases and irrigation levels, providing key insights into water management for these cultivars.

Results indicated that both cultivars showed optimal growth under the 0.9 and 1.2 EV treatments, with the OxG hybrid demonstrating superior overall growth. The OxG hybrid exhibited lower ETc values (4.7-6.1 mm day^{-1}) and Kc values (0.90-1.40) compared to *E. guineensis*, which showed ETc values of 5.2-6.6 mm day^{-1} and Kc values from 1.35-1.50. In terms of application, the OxG hybrid's average water consumption ranged from 331.8-433.7 mL $seedling^{-1}$ day^{-1}, while *E. guineensis* consumed between 367.1 and 464.9 mL $seedling^{-1}$ day^{-1}. Additionally, the OxG hybrid achieved a 44% higher WUE (0.26 g mm^{-1}) than *E. guineensis* (0.18 g mm^{-1}), underscoring its efficient water use, which suggests it is a more sustainable option under limited water conditions.

These results contribute to the understanding of water use dynamics in oil palm cultivation. Additionally, this study highlights the importance of considering genetic and physiological differences when designing irrigation strategies, providing valuable guidance for optimising irrigation in oil palm nurseries, especially in water-scarce regions. By optimising irrigation levels to 0.9 or 1.2 EV, growers can enhance plant growth and biomass production while conserving water resources, ultimately leading to more sustainable and productive oil palm cultivation.

Future research should further explore the long-term impacts of optimised irrigation on yield and water conservation, as well as refine the Kc estimates under different climatic and environmental conditions. Such research will help ensure the sustainable cultivation of oil palms in the face of increasing water scarcity and climate variability.

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REFERENCES

Allen, R. G., Pereira, L. S., Howell, T. A., & Jensen, M. E. (2011). Evapotranspiration information reporting: I. Factors governing measurement accuracy. *Agricultural Water Management, 98*(6), 899–920. https://doi.org/10.1016/j.agwat.2010.12.015

Allen, R, G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop Evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper No. 56). FAO.

Allen, R, G., Pereira, L. S., Raes, D., & Smith, M. (2006). Evapotranspiración del cultivo: Guías para la determinación de los requerimientos de agua de los cultivos. [Crop evapotranspiration: Guidelines for determining crop water requirements]. FAO.

Anapalli, S. S., Green, T. R., Reddy, K. N., Gowda, P. H., Sui, R., Fisher, D. K., Moorhead, J. E., & Marek, G. W. (2018). Application of an energy balance method for estimating evapotranspiration in cropping systems. *Agricultural Water Management*, *204*, 107–117. https://doi.org/10.1016/j.agwat.2018.04.005

Arias, N., Molina, D., Rincón, A., Pérez, W., & Mesa, E. (2023). Manejo de la nutrición en los cultivares híbridos interespecíficos OxG. [Nutrition management in interspecific hybrid OxG cultivars]. In H. M. Romero (Ed), *Los híbridos interespecíficos OxG de palma de aceite* [Interspecific OxG hybrids of oil palm] (pp. 255-304). CENIPALMA.

Ávila-Diazgranados, R. A., Daza, E. S., Navia, E. A., & Romero, H. M. (2016). Respuesta de diferentes materiales de palma de aceite *(Elaeis guineensis* e híbrido interespecífico *Elaeis oleifera* × *Elaeis guineensis)* a la pudrición de cogollo en la zona suroccidental palmera de Colombia) [Response of various oil palm materials (*Elaeis guineensis* and *Elaeis oleifera* × *Elaeis guineensis* interspecific hybrids) to bud rot disease in the Southwestern oil palmgrowing area of Colombia]. *Agronomía Colombiana, 34*(1), 74–81. https://doi.org/10.15446/agron.colomb.v34n1.53760

Ayala-Díaz, I., Tupaz, A., Daza, E., Avila, R., Montoya, C. & Romero, H. (2023). Mejoramiento genético de los cultivares híbridos interespecíficos OxG [Genetic improvement of interspecific hybrid cultivars OxG] In H. M. Romero (Ed), *Los híbridos interespecíficos OxG de palma de aceite* [Interspecific OxG hybrids of oil palm] (pp. 119-160). CENIPALMA.

Bayabil, H. K., Teshome, F. T., Guzman, S. M., & Schaffer, B. (2023). Evapotranspiration rates of three sweet corn cultivars under different irrigation levels. *HortTechnology*, *33*(1), 16–26. https://doi.org/10.21273/horttech05114-22

Bayona-Rodriguez, C. J. & Romero, H. M. (2019). Physiological and agronomic behavior of commercial cultivars of oil palm (*Elaeis guineensis*) and OxG hybrids (*Elaeis oleifera x Elaeis guineensis*) at rainy and dry seasons. *Australian Journal of Crop Science, 13*(03), 424–432. https://doi.org/10.21475/ajcs.19.13.03.p1354

Breure, C. J., & Menendez, T. (1990). The determination of bunch yield components in the development of inflorescences in oil palm (*Elaeis guineensis*). *Experimental Agriculture*, *26*(1), 99–115. https://doi.org/10.1017/s0014479700015441

Burgos, C., Perdomo, R., Morales, C. T., & Cayón, D. G. (1998a). Efecto de los niveles de agua en el suelo sobre la palma de aceite (*Elaeis guineensis* Jacq.). I. Evapotranspiracion en etapa de vivero [Effect of soil water levels on oil palm (*Elaeis guineensis Jacq*.) I. Evapotranspiration at the nursery stage]. *Palmas*, *19*(1), 17–23.

Burgos, C., Perdomo, R., Morales, C. T., & Cayón, D. G. (1998b). Efecto de los niveles de agua en el suelo sobre la palma de aceite *(Elaeis guineensis* Jacq.*)*. II. Estado hídrico diario de palmas en etapa de vivero [Effect of soil water levels on oil palm (*Elaeis guineensis* Jacq.). *II.* Daily water status of palms at the nursery stage]. *Palmas*, *19*(2), 37–44.

Carr, M. K. V. (2011). The water relations and irrigation requirements of oil palm (*Elaeis guineensis*): A review. *Experimental Agriculture*, *47*(4), 629–652. https://doi.org/10.1017/s0014479711000494

Corley, R. H. V., & Breure, C. J., (1981). *Measurements in oil palm experiments.* Internal report, Unilever Plantation Group.

Corley, R. H. V., & Tinker, P. B. (2003). *The oil palm, 4th edition.* Blackwell Science Ltd.

Corley, R. H. V., & Tinker, P. B. (2015). *The oil palm, 5th edition*. John Wiley & Sons, Ltd.

Daza, E., Pardo, A., Urrego, N., Ayala, I., Ruiz, R., & Romero, H. M. (2016). Evaluación del uso de hormonas sobre la formación de frutos partenocárpicos en el híbrido interespecífico OxG [Evaluation of hormone use on parthenocarpic fruit formation in the interspecific hybrid OxG] [Poster presentation]. *XIII Reunión Técnica Nacional de Palma de Aceite* [XIII National Technical Meeting on Palm Oil]. Bogota, Colombia.

Delgado, T., Torres, J., Jiménez, J., Jurado, J., & Alfonso, O. (2016). *Requerimientos hídricos de la palma en etapa de vivero y palma adulta (10-15 años)* [Water requirements of the nursery palm and adult palm (10-15 years)][Paper presentation]. *XIII Reunión* Técnica Nacional de Palma de *Aceite* [*XIII National Technical Meeting on Palm Oil*]. Bogota, Colombia.

Delgado, T., Ladino, G., & Arias, N. (2024). Evaluation of the effect of soil water conditions on the development and water requirements of adult oil palm (*Elaeis guineensis* Jacq.) in the Northern Region of Colombia. *Agronomy*, *14*(9), 1976. https://doi.org/10.3390/agronomy14091976

Franco bautista, P. N. (2003). *Manejo de viveros de palma de aceite – Manual técnico primera edición* [Oil palm nursery management – Technical manual, 1st edition]. CENIPALMA.

García, J. A. (2023). Avances en el procesamiento del cultivar híbrido OxG [Advances in the processing of the OxG hybrid cultivar]. *Revista Palmas, 44*(4), 192–201.

García, J. A., Kennyher, C. B., Liliana, C. B. I., Liliana, C. A. S., Camilo, B. H. J., Augusto, D. R. C., Eduardo, G. S. A., & Mayerly, S. G. S. (2023). Procesamiento del fruto de los cultivares híbridos interespecíficos OxG [Fruit processing of interspecific OxG hybrid cultivars]. In H. M. Romero (Ed), *Los híbridos interespecíficos OxG de palma de aceite* [Interspecific OxG hybrids of oil palm] (pp. 465-502). CENIPALMA.

Gong, X., Qiu, R., Sun, J., Ge, J., Li, Y., & Wang, S. (2020). Evapotranspiration and crop coefficient of tomato grown in a solar greenhouse under full and deficit irrigation. *Agricultural Water Management, 235*, 106154. https://doi.org/10.1016/j.agwat.2020.106154

Henson, I. E., Yahya, Z., Noor, M. R. M., Harun, M. H., & Mohammed, A. T. (2007). Predicting soil water status, evapotranspiration, growth and yield of young oil palm in a seasonally dry region of Malaysia. *Journal of Oil Palm Research, 19*(2), 398–415.

Heriansyah, & Tan, C. C. (2005). Nursery practices for production of superior oil palm planting materials. *The Planter 81*(948), 159–171. https://doi.org/10.56333/tp.2005.003

Ichwan, N., Fajra, A. M., Marbun, S. M., & Sumono, N. (2019). Crop coefficient and water requirement for oil palm (*Elaeis guineensis* Jacq.) on the nursery based on radiation evaporation method. *IOP Conference Series Earth and Environmental Science, 260*(1), 012041. https://doi.org/10.1088/1755-1315/260/1/012041

Jamshidi, S., Zand-Parsa, S., Kamgar-Haghighi, A. A., Shahsavar, A. R., & Niyogi, D. (2020). Evapotranspiration, crop coefficients, and physiological responses of citrus trees in semi-arid climatic conditions. *Agricultural Water Management*, *227*, 105838. https://doi.org/10.1016/j.agwat.2019.105838

Jazayeri, S. M., Rivera, Y. D., Camperos-Reyes, J. E., & Romero, H. M. (2015). Physiological effects of water deficit on two oil palm (*Elaeis guineensis* Jacq.) genotypes. *Agronomía Colombiana*, *33*(2), 164–173. https://doi.org/10.15446/agron.colomb.v33n2.49846

Kadam, S. A., Gorantiwar, S. D., Mandre, N. P., & Tale, D. P. (2021). Crop coefficient for potato crop evapotranspiration estimation by field water balance method in Semi-Arid Region, Maharashtra, India. *Potato Research*, *64*(3), 421–433. https://doi.org/10.1007/s11540-020-09484-8

Libardi, L. G. P., De Faria, R. T., Dalri, A. B., De Souza Rolim, G., Palaretti, L. F., Coelho, A. P., & Martins, I. P. (2019). Evapotranspiration and crop coefficient (Kc) of pre-sprouted sugarcane plantlets for greenhouse irrigation management. *Agricultural Water Management*, *212*, 306–316. https://doi.org/10.1016/j.agwat.2018.09.003

Martins, I. P., De Faria, R. T., Palaretti, L. F., Santos, M. G. D., & Filho, J. A. F. (2019). Evapotranspiration and crop coefficient of basil determined by weighing lysimeters. *Horticultura Brasileira*, *37*(4), 373–378. https://doi.org/10.1590/s0102-053620190402

Méndez, Y. D. R., Chacón, L. M., Bayona, C. J., & Romero, H. M. (2012). Physiological response of oil palm interspecific hybrids (*Elaeis oleifera* H.B.K. Cortes versus *Elaeis guineensis* Jacq.) to water deficit. *Brazilian Journal of Plant Physiology*, *24*(4), 273–280. https://doi.org/10.1590/s1677-04202012000400006

Moreno, H., Molina, A., & Rincón, V. (2013). *Uso de información meteorológica para el manejo agronómico de la palma de aceite – Guía No 1. Tecnologías para la agroindustria de la palma de aceite: Guía para facilitadore* [Use of meteorological information for the agronomic management of oil palm – Guide no. 1. Technologies for the oil palm agroindustry: Guide for facilitators]. CENIPALMA.

Mosquera-Montoya, M., Camperos, J. E., Ruiz, E., Hernández, D., García, A., Vargas, L. E., Mesa, E., Munévar, D., & Sinisterra, K. (2023). Evidence of sustainable intensification in the production of palm oil from crops planted with *Elaeis oleifera* x *Elaeis guineensis* in Colombia. *Frontiers in Sustainable Food Systems*, *7*, 1217653. https://doi.org/10.3389/fsufs.2023.1217653

Mosquera-Montoya, M., Ruíz-Álvarez, E., Munévar-Martínez, D. E., Ardila, C., Amaya, S. L. C., Aponte, E. B., & Duarte, N. C. (2024). Costos de producción para la palma de aceite en empresas referentes por su adopción tecnológica en Colombia en 2023 [Production costs for palm oil in leading companies for technology adoption in Colombia in 2023]. *Palmas*, *45*(2), 40–53. https://doi.org/10.56866/01212923.14266

Motta, D., & Beltran, J. (2010). *Establecimiento y manejo de viveros de palma de aceite - Tecnologías para la agroindústria de la palma de aceite: Guia para facilitadores* [Establishment and management of oil palm nurseries - Technologies for the oil palm agroindustry: A guide for facilitators]. CENIPALMA.

Najihah, T. S., Ibrahim, M. H., Razak, A. A., Nulit, R., & Wahab, P. E. M. (2019). Effects of water stress on the growth, physiology and biochemical properties of oil palm seedlings. *AIMS Agriculture and Food*, *4*(4), 854–868. https://doi.org/10.3934/agrfood.2019.4.854

National Federation of Oil Palm Growers (FEDEPALMA) (2023). *Anuario Estadístico 2023. Principales cifras de la agroindustria de la palma de aceite en Colombia y en el mundo 2018-2022* [Statistical Yearbook 2023: Key figures for the oil palm agroindustry and the world 2018-2022]. https://publicaciones.fedepalma.org/index.php/anuario/article/view/14129

Pereira, L., Paredes, P., Hunsaker, D., López-Urrea, R., & Shad, Z. M. (2021). Standard single and basal crop coefficients for field crops. Updates and advances to the FAO56 crop water requirements method. *Agricultural Water Management*, *243*, 106466. https://doi.org/10.1016/j.agwat.2020.106466

Pulver, E. (2016). Mitos sobre el agua y la palma de aceite en Colombia [Myths about water and palm oil in Colombia]. *Revista Palmas*, *37(4)*, 109–112.

Quencez, P. (1982). Oil palm nurseries in plastic bags without shading. *Oléagineux*, *37*, 397–407.

Rees, A. R., & Chapas, L. C. (1963). Water availability and consumptive use in oil palm nurseries. *Journal of the West African Institute for Oil Palm Research*, *13*, 52–65.

Rincón, S. M., Hormaza, P. A., Moreno, L. P., Prada, F., Portillo, D. J., García, J. A., & Romero, H. M. (2013). Use of phenological stages of the fruits and physicochemical characteristics of the oil to determine the optimal harvest time of oil palm interspecific OxG hybrid fruits. *Industrial Crops and Products*, *49*, 204–210. https://doi.org/10.1016/j.indcrop.2013.04.035

Rivera-Mendes, Y. D., Cuenca, J. C., & Romero, H. M. (2016). Physiological responses of oil palm (*Elaeis guineensis* Jacq.) seedlings under different water soil conditions. *Agronomía Colombiana*, *34*(2), 163–171. https://doi.org/10.15446/agron.colomb.v34n2.55568

Romero, H. M. (Ed.). (2023). *Los híbridos interespecíficos OxG de palma de aceite* [Interspecific OxG hybrids of oil palm]. CENIPALMA.

Romero, H. M., Daza, E., Ayala-Díaz, I., & Ruiz-Romero, R. (2021). High-oleic palm oil (HOPO) production from parthenocarpic fruits in oil palm interspecific hybrids using naphthalene acetic acid. *Agronomy*, *11*(2), 290. https://doi.org/10.3390/agronomy11020290

Ruiz-Alvarez, E., Daza, E. S., Caballero-Blanco, K., & Mosquera-Montoya, M. (2021). Complementing assisted pollination with artificial pollination in oil palm crops planted with interspecific hybrids OxG (*Elaeis guineensis* x *Elaeis oleifera*): Is it profitable? *OCL*, *28*, 27. https://doi.org/10.1051/ocl/2021014

Ruíz, R., Delgado, T., Zapata, A., & Romero, H. M. (2023). Manejo y uso del agua en cultivares híbridos interespecíficos OxG [Water management and use in interspecific hybrid OxG cultivars]. In H. M. Romero (Ed), *Los híbridos interespecíficos OxG de palma de aceite* [Interspecific OxG hybrids of oil palm]. CENIPALMA.

Sigalingging, R., Sumono, N., & Rahmansyah, N. (2018). Evapotranspiration and crop coefficient of oil palm (*Elaeis guineensis* Jacq.) on the main nursery in a greenhouse. *IOP Conference Series Earth and Environmental Science*, *122*(1), 012099. https://doi.org/10.1088/1755-1315/122/1/012099

Silvina, N. F., Dini, N. I. R., & Zebua, N. F. (2022). The effect of water volume on growth of several oil palm varieties (*Elaeis guineensis* Jacq.) aged of 8-14 months in main nursery. *International Journal of Science and Research Archive*, *7*(1), 292–301. https://doi.org/10.30574/ijsra.2022.7.1.0199

Sun, C., Cao, H., Shao, H., Lei, X., & Xiao, Y. (2011). Growth and physiological responses to water and nutrient stress in oil palm. *African Journal of Biotechnology*, *10*(51), 10465–10471. https://doi.org/10.5897/ajb11.463

Tezara, W., Domínguez, T. S. T., Loyaga, D. W., Ortiz, R. N., Chila, V. H. R., & Ortega, M. J. B. (2021). Photosynthetic activity of oil palm (*Elaeis guineensis*) and interspecific hybrid genotypes (*Elaeis oleifera* x *Elaeis guineensis*), and response of hybrids to water deficit. *Scientia Horticulturae*, *287*, 110263. https://doi.org/10.1016/j.scienta.2021.110263

Torres, J., & Cruz, R. (1995). *El Cenirrómetro* [The cenirrometer]. *Serie Divulgativa, No. 03, Segunda Edicion*, 1-4. https://www.cenicana.org/pdf_privado/serie_divulgativa/sd_03/sd_03.pdf

Torres, G. A., Sarria, G. A., Martinez, G., Varon, F., Drenth, A., & Guest, D. I. (2016). Bud rot caused by *Phytophthora palmivora*: A destructive emerging disease of oil palm. *Phytopathology*, *106*(4), 320–329. https://doi.org/10.1094/phyto-09-15-0243-rvw