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Leaf architecture and estimates of leaf area and leaf dry weight in young compact oil palms clones

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Introduction

The oil palm industry is based on the use of the species *Elaeis guineensis* Jacq., which originated in West and Central Africa. Most commercial oil palm plantations originate from planting D x P seeds obtained from crosses of Deli *dura* mother plants and *'pisifieras'* as pollen sources. The American oil palm, *E. oleifera*, has not been used yet commercially due to its low oil content, however, its hybrids with *E. guineensis* are a promising option since they have a better oil content, and present a varied degree of tolerance/resistance to some diseases/disorders; in particular spear rots in Tropical America (Chinchilla 2007).

Stem growth with age in traditional DxP crosses imposes a limit for commercial exploitation when palms become too tall for harvesting. Besides this, leaf length, if too long, will also limit plant density. These limitations are particularly evident in the most popular variety, named Deli x AVROS, which could suffer severe etiolation if planted too close together in an environment with sunshine limitations (Corley and Tinker 2003). A new option is the use of compact seed varieties (Escobar et al. 2007). These palms originated as variants from a wild cross between the American oil palm and the African oil palm. The slow stem growth and short leaves of these genotypes would allow them to be planted at much higher densities than traditional DxP varieties, increasing yields per unit of area and prolonging the commercial life of the plantation.

Oil palm, although monoic, is crossed pollinated, which causes a large variation between individual palms (originated from seeds) in terms of growth and yield potential. The use of clones is an alternative for getting a more uniform plantation in terms of vegetative growth and yield. Nevertheless, the use of clones obtained from normal DxP crosses does not eliminate the limitations of large trunks and long leaf length. The situation changes with compact palms, which can be cloned and overcome these limitations (Alvarado et al. 2006). ASD of Costa Rica started its cloning program in 1982, and by the year 2000 had built a modern laboratory to start producing compact oil palm clones at a semi-commercial scale.

The commercial value of the compact clones resides mostly in the possibility of increasing productivity by augmenting planting density. This is the reason why the study of morphological and physiological characteristics associated with productivity in these materials is of primary importance. For traditional seed varieties, such Deli x AVROS, there is a known protocol for

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estimating vegetative growth and yield potential. These procedures can be destructive, but there are non-destructive alternatives for estimating vegetative growth. A good summary of these methods was done by Breure and Verdooren (1995). These procedures have to be validated for compact seeds varieties and clones.

The objective of this work was to validate (or adapt) for three compact clones, the procedures and equations previously developed for use with traditional oil palm seed varieties to estimate leaf area and leaf dry weight. Foliar architecture of the compact clones was also studied in terms of their light interception ability.

Methodology

The study was conducted during the last part of year 2005 in commercial clone plots located in the coastal South Pacific of Costa Rica (8 masl., 22-32 °C averages minimum and maximum temperatures, 4,903 mm average rainfall in recent years).

Vegetative growth was measured using both destructive and non destructive methodologies. Other data took included information on plant architecture and light interception by the canopy. Data came from 15 plants of each genotype: three compact clones (Sergio, Prince and Savegre) and a tester (a standard Deli x AVROS cross). Information on leaf and petiole cross section area was taken from leaf 17 of the phyllotaxy. Standard measures such as rachis and petiole length, trunk diameter and leaf area were taken following Corley and Tinker (2003) and Breure and Verdooren (1995). The diameter of the crown was measured as illustrated in figure one.

Non destructive methods to estimate leaf area and leaf dry weight

Leaf area was estimated using the Hardon et al. (1969) equation:

$Area\ (m^2) = c\ (n * l * w)$

Where:

c = correction factor;

n = number of leaflets per leaf;

l and w = length and width of leaflets.

The estimated values found through the Hardon equation (using a correction factor of 0.55) were compared with real values of leaf area, and new correction factors were developed to get more realistic estimates of this parameter for each one of the clones.

Petiole cross section (*PxS*) and leaf dry weight were estimated using the methodology described by Corley et al. (1971):

$W = 0.102\ PxS + 0.206$

Where:

W = leaf dry weight (kg)

PxS is petiole cross section.

The true leaf dry weight (determined on an electronic scale) was compared with the estimated value, in order to modify the original equation and obtain more realistic estimates.

Fig. 1. *Measuring crown diameter. Right. A detail of the leveling devise*

Destructive methods for determining leaf area and leaf dry weight

After taking the information for non destructive methods, each leaf was cut off the plant and the rachis was then divided into four sections of the same length with the leaflets detached from each section. Each part was put in individual paper bags and taken to a place where true leaf areas and dry weights were determined.

To define true leaf dry weight, all tissues were dried in ovens with forced hot air (70 ºC). The time to obtain a constant weight varied between the different tissues: rachis and petioles required about 96 hours, and leaflets 48 hours. Dry weight was determined with an electronic scale and true leaf area was obtained by using an electronic leaf area meter (LI-COR model 3100).

Leaf architecture and light interception

Leaflet arrangement along the rachis: every leaflet along the rachis was ranked according to its orientation (angle) with respect to the plane of the rachis. Leaflets were catalogued as erect (angle between 60-90º), semi-erect (angle between 30-59º), or flat (angle between 0 - 29º)

Leaf profile (rachis curvature): the change in the angle with respect to the horizontal along the rachis was determined in order to define its curvature. This angle was determined with a special device (Fig. 2) on the middle of each one of the four sections into which the rachis was divided. Data were fit to a second degree polynomial equation to obtain the curvature of the leaf (from a concatenation).

Light interception was measured with a spot radiometer, model SKP215 (Skye Instruments Campbell Scientific Ltd), which was placed approximately 50 cm and 20 cm below and above the mid part of the four different sections of the divided rachis. These measurements were complemented with data from open skies (I_0), away from the shade of leaves. The values obtained were used to estimate the mean (for the four rachis sections) photosynthetically-active radiation intercepted (PARin) (Fig. 2)

Fig. 2. *Instruments used to determine rachis curvature. Right. Measuring PARin not intercepted with a radiometer*

Results and Discussion

Vegetative growth in compact clones

The Sergio clone was the most compact of the three studied: it had a smaller crown diameter and shorter leaves, but a higher value for the petiole cross section (*PxS*). Growth was intermediate for the Prince clone and the Savegre clone was a rather vigorous plant (Table 1), and somewhat similar to the Deli x AVROS seed variety.

Table 1. Vegetative growth[1] in three oil palm compact clones

Variable	*Sergio*	*Prince*	*Savegre*
Number of leaves	37.0	37.5	35.9
Total of leaflets	208.5	203.2	232.0
Leaflet length(cm)	64.4	68.1	68.8
Leaflet width (cm)	3.7	3.5	3.6
Stem diameter (cm)	40.7	37.9	42.0
Canopy diameter (cm)	489.5	541.9	660.1
Palm height (cm)	355.3	351.0	457.4
Petiole length (cm)	47.2	67.6	76.5
Rachis length(cm)	216.5	216.9	270.4
Petiole width (cm)	4.4	2.9	4.0
Petiole height (cm)	2.5	3.2	2.2

Petiole cross section (*PxS*)	5.5	4.5	4.1

[1] Leaf in position 17 of the phylotaxy for 15 palms. Plants 29 months old.

The general appearance of the whole plant also varied between clones: Sergio and Prince clones had 'open' crowns', and the Prince clone in particular, had an umbrella-like appearance. The Savegre clone, on the other hand, resembled more the *'guineensis'* type (more upright crown and less umbrella type.

Leaf area estimates

Estimates of leaf area using Hardon's equation (Hardon et al. 1969) overestimated the real leaf area, determined by using a LI-COR leaf area meter. For Deli x AVROS, this overestimate was 33% (Table 2). This was unexpected, since Hardon's formula was developed using a *'guineensis'* variety.

Table 2. Estimates of leaf area (m^2) for a seed variety (Deli x AVROS) and three compact clones

Material	'True' leaf area[1]	Estimated leaf area[2]	Overestimation (%)
Deli x AVROS	2.82	3.73	32.27
Prince	1.69	2.77	63.90
Savegre	2.31	3.23	39.83
Sergio	1.76	2.66	51.14

[1] 'True' leaf area values were obtained with a leaf area meter LI-COR, model 3100

[2] Estimated from Hardon's equation (Hardon et al. 1969): [$m^2 = c\,(n * l * w)$]

Prior studies had found discrepancies between 'true' leaf areas and those estimated using Hardon's equation, but differences were not considered large. Bulgarelli et al. (1998) found that in the Deli x AVROS variety such differences were only 3.2 %, using a particular methodology to measure true leaf area (not an electronic device).

The estimation of leaf area had not been previously been done on compact clones since these are rather new planting materials. Considering that these clones inherited the compact character from *E. oleifera*, it was not surprising to find that Hardon's equation did not fit the data well. Considering the above, new correction coefficients were calculated for each one of the compact clones (and the Deli x AVROS seed variety) to adapt Hardon's equation to the new data for real leaf area (Table 3).

Table 3. New correction factor ('c' values in Hardon et al. (1969)[1]) used to estimate leaf area in a seed variety and three compact oil palm clones

Material	Correction factor
Deli x AVROS	0.42
Savegre	0.33
Prince	0.39
Sergio	0.36
Mean[2]	0.37

[1] This mean correction factor was calculated from the individual equations for the Deli x AVROS seed variety and the three clones

[2] [Leaf area, m² = $c\ (n * l * w)$]

The differences between 'true' leaf area and estimated leaf area were largely reduced by using the new correction factors in Hardon's equation. For Deli x AVROS, the difference was nearly 2%. Slight underestimates were observed for the three clones (Table 4).

Table 4. Leaf area for a seed variety (Deli x AVROS) and three compact oil palm clones

Material	'True' leaf area[1]	Estimated leaf area[2]	Estimated leaf area[3]
Deli x AVROS	2.82	3.73	2.85
Prince	1.69	2.77	1.66
Savegre	2.31	3.23	2.29
Sergio	1.76	2.66	1.74

[1] True leaf area values obtained with an LI-COR electronic leaf area meter, model 3100

[2] Hardon et al. (1969): (Leaf area, m² = $c\ (n * l * w)$ uncorrected

[3] Hardon et al. (1969) corrected with new correction factors, 'c' calculated with the true leaf areas for each genotype

In an attempt to simplify matters, the new correction factor calculated for Deli x AVROS was used to estimate the leaf area of the clones. However, this factor overestimated the true leaf area by up to 26% for Sergio clone (Table 5).

Table 5. Leaf area estimates (m^2) for a seed variety (Deli x AVROS) and three oil palm compact clones using a correction factor in Hardon's equation initially determined for Deli x AVROS

Material	True leaf area[1]	Estimated leaf area[2]	Estimated leaf area[3]
Deli x AVROS	2.82	3.73	2.85
Savegre	2.31	3.23	2.03
Prince	1.69	2.77	2.46
Sergio	1.76	2.66	2.13

[1] True leaf area values obtained with an LI-COR electronic leaf area meter, model 3100

[2] Estimated from original Hardon's equation (1969): [$m^2 = c\ (n * l * w)$]

[3] Estimated by using a new correction factor for Deli x AVROS

Leaf dry weight estimates

Corley's equation (Corley et al. 1971), herein referred to as the 'standard equation' (normally used in palms older than two years (Corley 2003) estimated the dry weight of leaves in the compact clones reasonably well (Table 6, third column). The equation did not do very well for Deli x AVROS, which was unexpected, since this equation was developed for a *'guineensis'* variety that is normally far more vigorous than a compact clone.

Table 6. 'True' and estimated leaf dry weights (kg) for a seed variety (Deli x AVROS) and three compact oil palm clones, *Elaeis guineensis*

Material	'True' leaf dry weight (kg)	Estimated leaf dry weight (kg)[1]	New estimated leaf dry weight (kg)[2]	S[3]
Deli x AVROS	1.16	0.90	1.16	0.08
Savegre	0.73	0.73	0.73	0.09
Prince	0.62	0.67	0.62	0.04
Sergio	0.81	0.78	0.80	0.04

[1] Standard equation (kg = 0.102 PxS + 0.206

[2] From the corrected equation using new correction factors calculated from true leaf dry weights

[3] 'True' dry weight standard deviation, n=15

The true leaf dry weights (determined on a scale, table 6) were used to calculate new coefficient factors for Corley's equation to estimate leaf dry weights for the seed variety and the compact clones from their *PxS* values (Fig. 3). The corrected equations for each clone and the Deli x AVROS seed variety are shown in table 7. For the seed variety, the corrected standard equation gave reasonably good estimates of leaf dry-weight, but it was inappropriate for the compact clones, since it may overestimate dry weight by up to 25% (Table 8). For these clones, the original (Corley and Tinker, 2003) equation can be used or, even better, the new corrected equations. Figure 3 is an example of data dispersion around the fitted curve for Deli x AVROS.

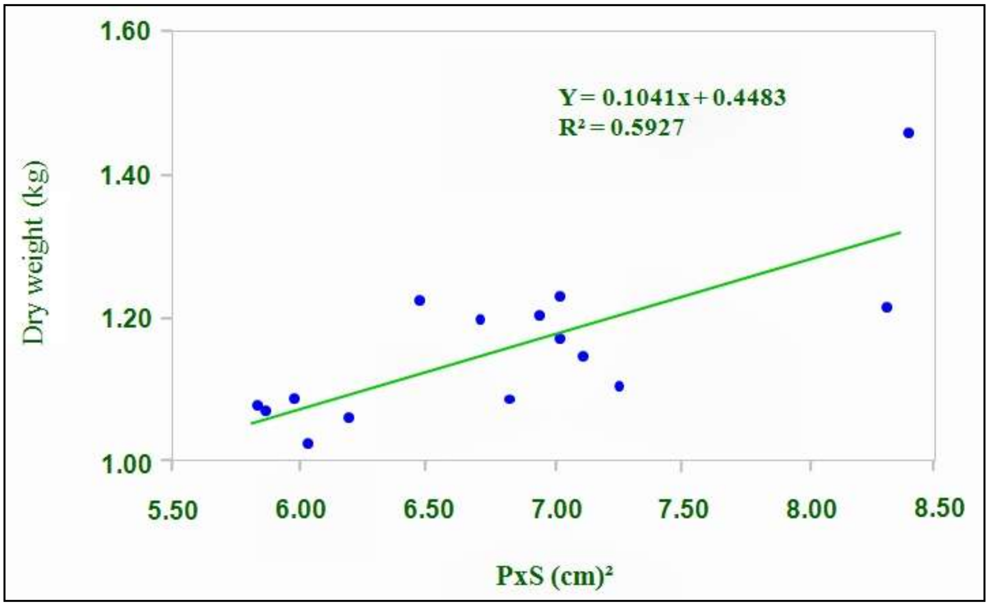

Fig. 3. *Relationship between the PxS (petiole cross section) and 'true' leaf dry weight for Deli x AVROS*

Table 7. Corrected equations for estimating leaf dry weight from petiole cross sections (*PxS*) in a seed variety and three compact oil palm clones, *Elaeis guineensis*

Material	Equation	R^2
Deli x AVROS standard[1]	W = 0.102 PxS + 0.206	
Deli x AVROS new[2]	W = 0.1041 Pxs + 0.4483	0.59
Sergio[2]	W = 0.0784 PxS + 0.2439	0.24
Savegre[2]	W = 0.0831 PxS + 0.3766	0.77
Prince[2]	W = 0.0813 PxS + 0.2489	0.69

[1] Corley and Tinker (2003)
[2] Equations corrected with new coefficients obtained from true leaf weight values

Leaf architecture and light interception ability

Compact clones differed greatly in vegetative characteristics with respect to the seed variety Deli x AVROS which grew faster and more vigorously. Leaf length was notably larger in the seed variety due to longer rachis and petiole lengths (Table 9). The growth habit of these leaves was also more erect than in the compact clones (Fig. 4).

Table 8. Leaf dry weight estimates (kg) for three oil palm compact clones, using an equation developed from the 'true' leaf weight of a seed variety (Deli x AVROS)

Material	'True' dry weight	Estimated dry weight[1]	Estimated dry weight[2]	Difference (%)
Savegre	0.73	0.73	0.92	18
Prince	0.62	0.67	1.03	25
Sergio	0.81	0.78	0.92	25

[1] Estimated fro the standard equation (kg = 0.102 PxS + 0.206)
[2] Estimate from a 'new' equation developed for Deli x AVROS kg = 0.1041 *PxS* + 0.4483

Considering that leaf area is smaller in the compact clones, from a photosynthetic point of view it could be inferred that they have a handicap, which is not necessarily always the case; since their bunch yields can be quite good (Alvarado et al. 2006, Escobar et al. 2007). These findings may indicate that photosynthetic efficiency and bunch index must be better in some compact clones than in Deli x AVROS.

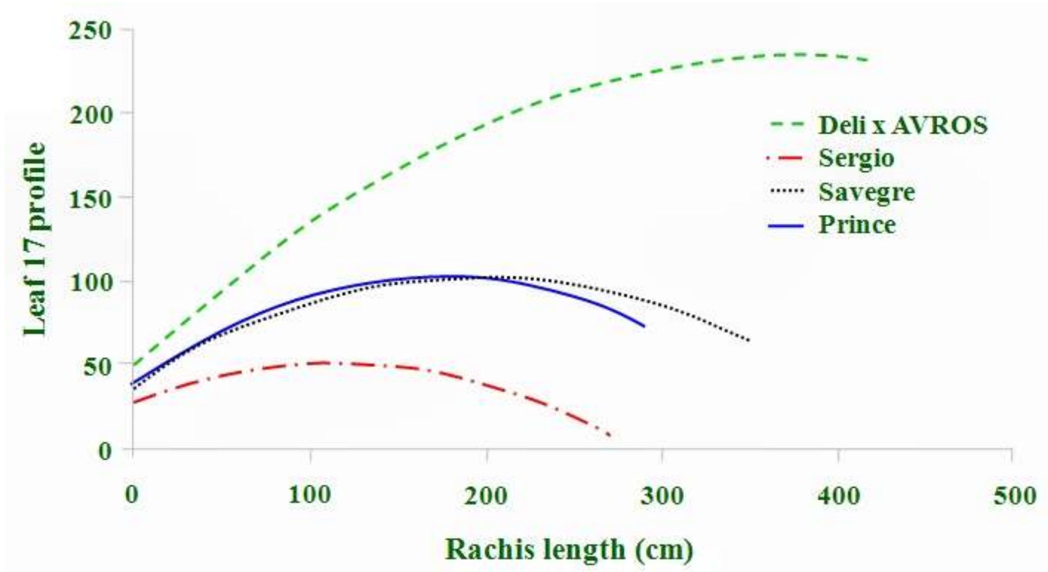

Fig. 4. *Leaf profile and leaf length for Deli x AVROS and three compact oil palm clones (leaf No. 17, n = 15)*

Table 9. Vegetative growth (leaf 17) for the Deli x AVROS seed variety and three oil palm compact clones

Material	Leaf length (m)		Leaf dry-weight (kg)[1]	PxS	Canopy diameter (m)
	Petiole	Rachis			
Deli x AVROS	0.96	3.15	1.16	6.79	7.30
Savegre	0.76	2.70	1.16	4.50	6.60
Prince	0.67	2.17	0.73	4.50	5.40
Sergio	0.48	2.16	0.62	5.60	4.90

[1] 'True' dry weight determine on an electronic scale

Both Sergio and Prince clones have crowns (leaf profile or leaf curvature) that are more open than in the Savegre clone. The insertion angle of the leaves of the latter clone is more acute, and in this it resembles a *'guineensis'* type (Fig. 4).

Light interception (PARin = photosynthetically active radiation) was measured on four sections of leaf 17. Light interception was higher in all three compact clones when compared to the seed variety, Deli x AVROS, except for the portion of the leaf closer to the stem (Fig. 5). For the compact clones, light interception was higher toward the end of leaf 17. However, it would be interesting to determine whether this result is also true for all leaves, which would be associated with a better efficiency in transforming assimilates into bunches (and oil), despite a reduced leaf area with respect to the seed variety, Deli x AVROS.

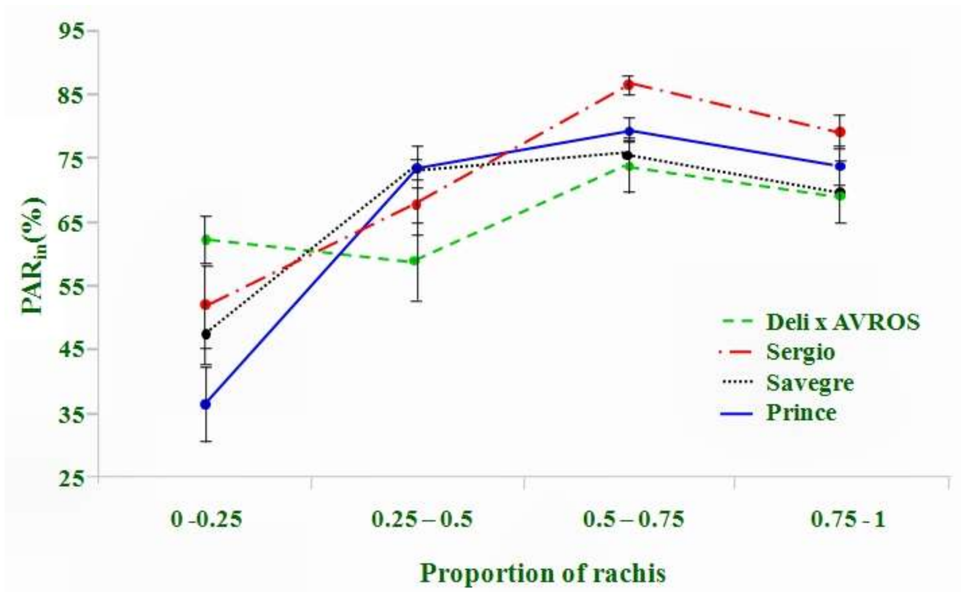

Fig. 5. *Photosynthetically active radiation intercepted (PAR in) measured (spot radiometer) for four sections along the rachis of leaf 17 of the Deli x AVROS variety and three compact clones*.

Among the clones, average PARin for the Sergio clone was higher. This clone showed a higher capture of PARin in all leaf sections, except for the second. Considering an average value for PARin (mean of the four sections of the leaf, fig 6), the Sergio and Prince clones could be considered the most efficient from a photosynthetic point of view.

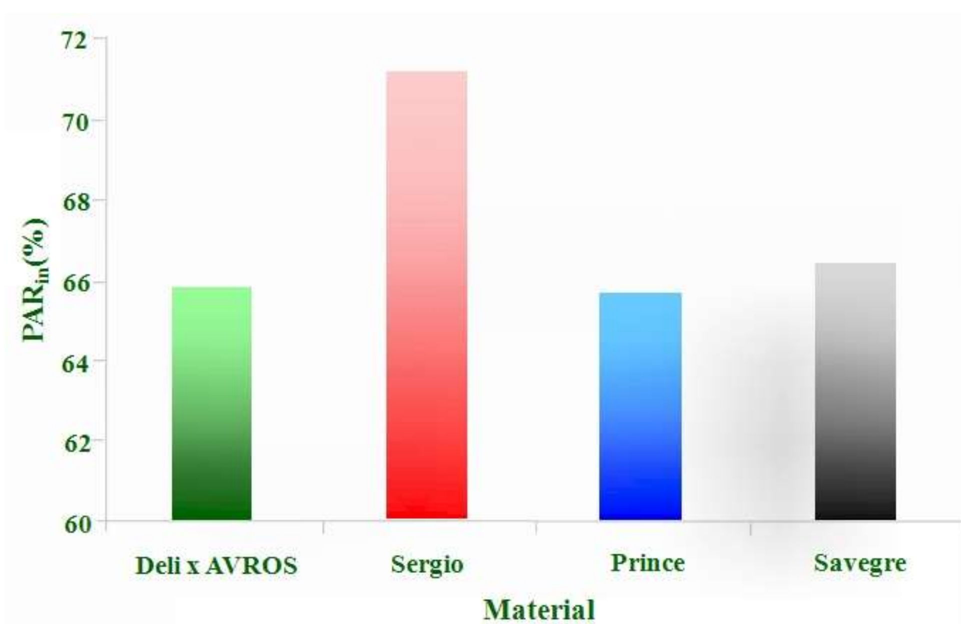

Fig. 6. *Photosynthetically active radiation intercepted (PAR in). Averages of four leaf section along the rachis for the Deli x AVROS seed variety and three oil palm compact clones*

The highest values of PARin were measured toward the middle section of the leaf, which could indicate that there is a limit for the number of plants that can be planted per unit area without negatively affecting yield potential due to light competition, and this would be also true for compact materials.

Leaflet arrangement in space with respect to the plane of the rachis was different along different sections of the rachis and for the different genetic materials. However, the largest differences were observed for the Prince clone, where a large proportion of leaflets tended to have a more wide open angle with respect to the plane of the rachis (Figs. 7 and 8).

Leaflet arrangement along the rachis was quite different between the seed variety and two of the compact clones (Prince and Sergio). For the compact clones, leaf arrangement resembled this characteristic in *E. oleifera*. The differences in rachis curvature and leaflet orientation (leaflet arrangement along the rachis) could be important features that determine the ability of the clones to be more efficient from a photosynthetic point of view.

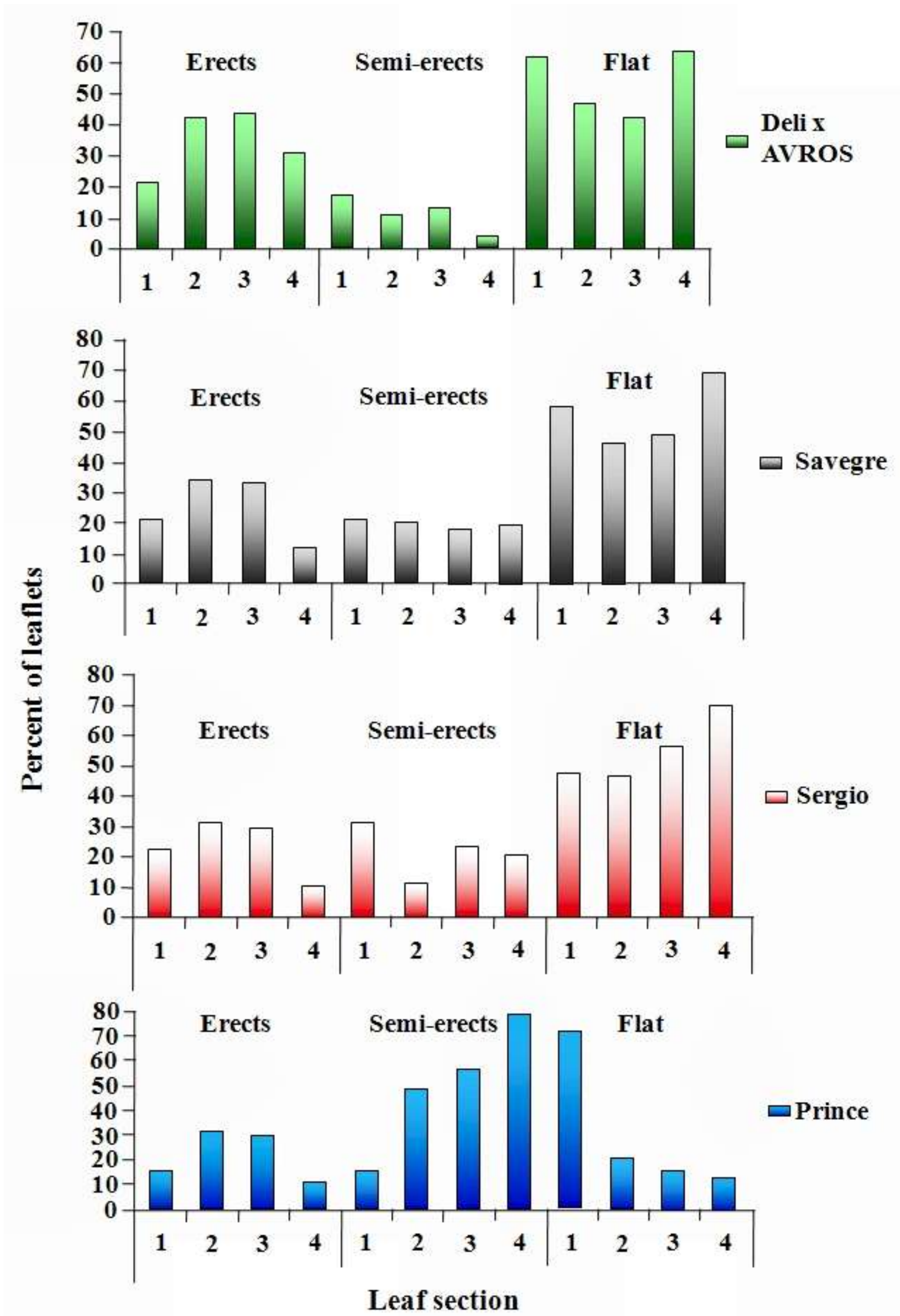

Fig. 7. *Leaflet orientation (angle) with respect to the plane of the rachis along leaf 17 in the seed variety Deli x AVROS and three compact oil palm clones*

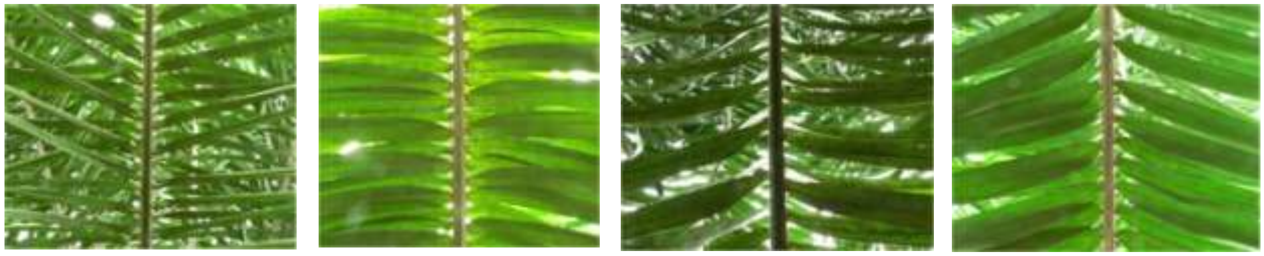

Fig. 8. *Leaflet arrangement along the rachis (middle section of leaf 17) in the seed variety Deli x AVROS (left) and three oil palm compact clones (From left to right: Prince, Savegre and Sergio)*

Conclusions and recommendations

Dry weight and leaf area estimates

It was not possible to get good estimates of leaf area (following the methodology described in this work) by fitting the data to the equation by Hardon et al. (1969). For the Deli x AVROS seed variety, the equation resulted in overestimates of 'real' leaf area values by up to 33 %. For the compact clones, such overestimates were even larger (up to 65%). Considering the above, it was wise to correct the equation with new constants calculated from 'real' leaf area values, as follows:

Deli x AVROS: $m^2 = 0.42\ (n * l * w)$
Sergio: $m^2 = 0.36\ (n * l * w)$
Prince: $m^2 = 0.39\ (n * l * w)$
Savegre: $m^2 = 0.33\ (n * l * w)$

Where:

c = correction factor
n = number of leaflets/leaf
l and w = leaflet length and width

Dry weight estimates using the equation by Corley ($W = 0.102\ PxS + 0.206$; where W is leaf dry weight and PxS is the petiole cross section) gave good estimates for all three clones, but such estimates can be improved by using the new constants resulting from this work's 'real' dry weights, as follows:

Del x AVROS: $W = 0.1041\ PxS + 0.4483$
Sergio: $W = 0.0784\ PxS + 0.2439$
Prince: $W = 0.0813\ PxS + 0.2489$
Savegre: $W = 0.0831\ PxS + 0.3766$

To estimate leaf dry weight for the Deli x AVROS seed variety, the new corrected equation ($W = 0.1041\ PxS + 0.4483$) should be used.

Leaf architecture and light interception

Leaf curvature and leaflet arrangement along the rachis could be useful parameters to consider when selecting promising genotypes. Since this study considered these parameters for leaf 17 only, the entire crown should be studied to corroborate the tendencies found, which may also change with palm age.

Leaves with less curvature (less erect) appeared to intercept more light. This was unexpected, since the opposite has been observed in other plants (Pepper 1977, Hirsch 1978, Duncan 1971, Smith 1991, Liu et al. 2003, Tech 2004). However, it must be considered that measurements were taken on leaf 17 only and not the entire crown; other parameters must also be considered such as leaflet shape, number, and arrangement in space along the rachis, etc.

These results only apply to plants of a certain age, and could change in a population of palms under different density and age arrangements, and have to be verified in commercial lots.

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