Morphometric and Productive Characterization of Nineteen Genotypes from the Colombian *Coffea* Collection

Caracterización Morfométrica y Productiva de Diecinueve Genotipos de la Colección Colombiana del Género *Coffea*

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Abstract. *Nineteen genotypes of the Colombian Coffee (**Coffea arabica** L.) Collection were characterized through features related to productivity, crown architecture and light interception. The results revealed significant differences among genotypes. Branches and leaves were found to be dominantly plagiophyl. Leaf area (LA) and Leaf area index (LAI) made accession CU1812 (which corresponds to variety Castillo®) stand out for its photosynthetically active radiation (PAR) interception and coffee bean production. Likewise, a PAR based cluster analysis allowed dividing the genotypes in three groups. Because of their higher yield, the most outstanding genotypes were Caturra, CU-1812 and Harrar R2. This factor showed correlation with PAR absorption. The current results are useful for future works in coffee breeding programs.*

Key words: Germplasm, productivity, crop breeding, quantitative characters.

Resumen. *Se caracterizaron 19 genotipos de la Colección Colombiana de Café (Coffea arabica L.); para ello se estudiaron aspectos relacionados con la arquitectura del dosel, la interceptación de la radiación y la producción. Los resultados mostraron diferencias significativas entre los genotipos, predominando en las ramas la distribución plagiofila; una disposición similar se observó en las hojas. El área foliar (AF) y el índice de área foliar (IAF), contribuyeron a que la introducción CU1812, componente de la variedad Castillo®, se destacara por presentar los mayores valores de interceptación de radiación fotosintéticamente activa (RFA) y producción de café cereza. Así mismo, el análisis de agrupamiento con base en la RFA, permitió ordenar los genotipos en tres grupos, destacándose Caturra, CU-1812 y Harrar R2 por su mayor rendimiento, factor que mostró correlación con la RFA captada por el dosel. Los resultados obtenidos en esta investigación son de utilidad en futuros trabajos de mejoramiento genético en café.*

Palabras clave: Germoplasma, productividad, fitomejoramiento, caracteres cuantitativos.

Morphological, physiological, agronomic and economic differences among coffee (*Coffea arabica* L.) genotypes have been an important object of study in breeding programs intended for the selection of promissory materials. In this respect, coffee research in Colombia has been enriched by works such as those of Castillo and Quiceno (1968), who measured productivity in six Colombian coffee varieties; Orozco and Marín (1972), who classified 42 Ethiopian material selections according to biometric measures, whereas Castillo (1975 and 1977) featured 38 *C. arabica* accessions through yearly harvest distribution, grain attributes and productivity; Cadavid (1997) determined photosynthetic rates in 12 coffee genotypes; Orozco and Jaramillo (1978) observed the behaviour of 25 *Coffea* genotypes subjected to hydric deficit; Puerta (2000) examined the cup quality of a series of varieties; Moreno (2002) investigated variety Tabi for its ressistance to rust; Cortina (2000) evaluated several accessions in search for genetic ressistance to the coffee berry borer (*Hypothenemus hampei)*; Ramírez (2004) characterized the activity of the enzyme Ribulose - 1,5 - bisphosphate carboxylase/oxygenase (Rubisco) in 23 *Coffea* genotypes; and progress is being made in the species' genome structure, which is likely to be very useful in the development of new varieties (Algrano, 2011).

The Photosynthetic Efficiency of a crop largely determines its yield potential, which results from light interception. In turn, the latter is a function of crown architecture, which is considerably heterogeneous. For this reason, the evaluation of coffee genotypes recognizes the importance of leaf architecture when it comes to understanding the processes of absorption, transmission and reflection of radiant energy and their bearing on productivity (Fageria *et al*., 2006). Opposing

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views have regarded the effect of architecture on photosynthesis and crop biomass production. For Shibles (1987), both attributes could increase substantially with a more erectophil arrangement of the crown, which allows greater penetration and more uniform distribution of radiation. Contrastingly, in studying the morphological characteristics of coffee production, Salazar (1988) found that under the same cropping conditions, plagiotropic branching plants (planophil), were more productive than orthotropic (erectophil) ones. This concept is shared with Arcila (2007), who claims that coffee plants with planophil architecture outweigh the productivity of erectophil ones. However, the orientation of branches and leaves is considered to be a major structural aspect. Radiation interception by the canopy is noticeably influenced by the angle between the normal leaf and the direct light beam. This angle determines the projected area of the foliage elements on the horizontal plane, which represents their light interception ability (Sinoquet and Andrieu, 1993, cited by Montoya *et al*., 2009).

Based on the above, the current research aimed to classify some introductions of the Colombian Coffee Collection through their architecture and contribution to productivity under similar environmental conditions.

MATERIALS AND METHODS

Location. The research was conducted at CENICAFÉ's (National Center for Coffee Research) *Paragüaicito* Experimental Sub-station, located in the Colombian municipality of Buenavista, department of Quindío (1250 masl; 4° 23' N, 75° 44' W; annual average temperature of 21.6 °C; annual rainfall of 2,118 mm and cummulative annual sunshine of 1,796 h). The area corresponds to a very wet premontane forest (Holdridge, 1947).

Plant material. The experiment evaluated trees of 19 *Coffea* genotypes from CENICAFÉ's genebank, selected for their diversity of origin, genetic features and potential value for the development of new varieties. Table 1 describes some characteristics of the studied materials. The trees were established at a distance of 2.0 x 1.5 m. Field data collection started between 22 and 28 months after planting in the permanent growing site.

Experimental design. A completely randomized block model with three replications and ten plants per experimental plot was applied. The experimental unit was the tree. Two of these units were selected per genotype, repetition and plot.

Evaluated variables

With the exception of leaf area, which was assessed only once, the other variables were measured four times, once every two months.

Number of branch pairs per tree (No). Counting from the first main planophil branch.

Crown diameter (cm). Measured at the broadest part of the tree, in the north-south (NS) and east-west (EW) directions.

Crown projection area (m²). Estimated by the following equation:

$$AC = \pi\left(N - S/2\right)\left(E - W/2\right)$$

Where:
π = 3.14116
N = Northwards branch length
S = Southwards branch length
E = Eastwards branch length
W = Westwards branch length

Total tree height (cm). Measured from the base of the stem to the apex.

Crown insertion height (cm). Measured from the base of the stem to the first main branch.

Branch length (cm). Measured from the point of insertion on the stem to the apex. It was taken on three branches from the middle third of the tree.

Branch inclination angle (°). Measured in three branches per stratum (the latter defined by dividing the total number of main stem nodes into three equal parts), this parameter's determination followed a modification of the method of Norman and Campbell (1989).

Inclination angle of the leaves (°). Measured on 20 leaves from each tree stratum.

Leaf area (m²). Measured on the last sampling date by removing 25% of the leaves from one tree per genotype

Table 1. Identification, origins and attributes of 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ's *Paragüaicito* Experimental Sub-station, located in Buenavista, Quindío - Colombia.

Genotype	Origin	Attribute
AR-56	Ethiopia	Wild material collected in Orstom's[4] prospection.
BA-36	India	Variety containing gene SH_3, which confers ressistance to coffee rust[4].
Blue Montain	Jamaica	Típica selection appreciated for its quality[4].
Borbón Rojo	Reunion Island	Variety of *C. arabica* from Reunion Island (formerly Bourbon Island) featured by its elevated production per tree. In contrast with the Típica variety, whose new shoots are bronze, Borbón's shoots are green (Orozco, 1986).
Caturra	Brazil	Mutant of variety Borbón found in Brazil: low plant with short internodes (Orozco, 1986).
CU-1812	Colombia	One of the components of variety Colombia, now variety Castillo® and Castillo Regionals[4].
Dilla Alghe	Ethiopia	Selection that was launched as variety in some countries[4].
Harrar R2	Ethiopia	Material valued for its organoleptic quality[4].
E-87	Ethiopia	Wild material collected in the FAO's prospection[4].
E-167	Ethiopia	Wild material collected in the FAO's prospection[4].
ET-544	Ethiopia	Wild material collected in Orstom's prospection.
F-502	Tanzania	Selection taken from Borbón and Kent populations[4].
K-7	Kenya	Variety grown in Kenya, considered resistant to the coffee berry disease (CBD)[4].
KF-03	Ethiopia	Variety grown in Kaffa, commercially planted by some farmers[4].
Laurina	Reunion Island	Mutant of *C. arabica*, seeds sharpened at one end. It has shown resistance to prolonged droughts in Brazil (Orozco, 1986).
Mundo Novo	Brazil	Variety of *C. arabica* widely grown in Brazil, probably the result of crossing varieties Típica and Borbón. It is also the progenitor of the variety Catuai (Orozco, 1986).
Rume Sudan	Sudan	Introduction of interest for its resistance to the CBD[4].
SL-28	Kenya	Variety grown in Kenya, appreciated for its organoleptic quality[4].
Típica Rojo	Yemen	The most widespread and well-known variety of *C. arabica*. It is the type of the species described by Linnaeus, and the progenitor of most of the known cup coffee varieties (Orozco, 1986).

[4] Cortina, H. 2013. Breeding program. Cenicafé. Personal communication.

(One of every two branches was chosen to harvest one of every four leaves). Leaf area was measured with a Delta-T Area Measurement System (Delta-T Devices Ltd®, Burwell, Cambridge, England). The obtained value was multiplied by four (4) to obtain the tree's leaf area.

Leaf area index (LAI). Obtained by dividing the leaf area of the tree by the projection area of the canopy on the ground, which was calculated on the basis of the average diameter of the NS and EW directions. This value was divided by two to derive the radius (r). The value of the parameter was calculated from the circle's area formula ($A = \pi r^2$).

Solar radiation interception (%). It was calculated as the difference between the incident radiation on the upper part of the tree and the one reaching its base, both measured with a Ceptometer mod. Sunscan SS1-UM-2.0 (Delta-T Devices Ltd®, Burwell, Cambridge, England).

Albedo (%). Expressed as the percentage of radiation reflected by the tree's crown surface relative to the incident radiation, this parameter was obtained from two photosynthetically active radiation (PAR) readings taken from each tree using the indicated Ceptometer. One of them corresponded to incident radiation on the upper part of the tree, and the other one to reflected radiation.

Coffee bean cumulative production (kg). Obtained by summing up the fruit harvested from the 10 trees of each plot during the first 15 months of production.

Statistical Analysis. The data were analyzed through descriptive statistics and linear regression analysis; analysis of variance and means comparison (Duncan's test at 5%); and principal component analysis, all processed in SAS 8.2.

RESULTS AND DISCUSSION

Except for the case of LAI, the analyses of variance showed no significant effect of the blocks on any of the variables considered. This implies that the statistical differences between treatments were due to contrasts between genotypes.

Crown architecture

Branch attributes. The canopy of the studied genotypes showed a continuous branching pattern, characterized by a combination of vertical (trunk) and horizontal (branches) shoots in the same individual (Hallé, 2010), which is typical of tropical trees. The genotypes showed significant differences in the number of branch pairs, values ranging from 21.83 (E-167) to 36.50 (Laurina) (Figure 1A). It should be considered that the number of branch pairs, together with the number of nodes per branch, is part of the components of plant yield. Besides, this attribute depends on the region of the country where the crop is located (CENICAFÉ, 2001, quoted by Arcila, 2007).

The North-South tree crown diameter varied from a minimum of 80.13 cm for Laurina to a maximum of 215.29 cm for BA-36 (Figure 1B). A similar trend was found in the East-West diameter (Figure 1C), the differences being significant in both cases. The results are relevant to the study of canopy growth and the determination of the space occupied by each of the genotypes in a plantation, due to the close relationship between crown size, tree density and photosynthetic capacity (Hemery *et al*., 2005; Nájera and Hernández, 2008).

The genotype Laurina exhibited the smallest crown projection (Figure 1D), which coincides with the results obtained by Orozco and Marín (1972). This parameter proves interesting as it correlates directly to incident radiation efficiency. It is important to note that, when interacting with solar radiation, the tree casts a shadow whose length depends on tree height and solar elevation angle (Peña, 2007), this claim is validated by verifying that genotypes with greater crown projection are also the tallest ones (Figure 1E).

Laurina was found to be the shortest genotype (123.13 cm high), significantly overcome by genotypes Harrar R2, K7, Blue Mountain and BA-36 (Figure 1E). It is worth noting that, among tree quantitative parameters, height is especially important due to its close association with production (Castillo and Moreno, 1987), which influences the decision on the number of crops per renewal cycle, an aspect that is influenced by the environment. These specific conditions favor a higher growth rate that leads to reducing the number of harvesting seasons, thus facilitating harvest itself and improving its quality (Alvarado and Ochoa, 2006).

Crown insertion height ranged from 69.29 cm in genotype Caturra to 97.46 cm in genotype Blue Montain, the difference between them being significant (data not shown). Knowing this morphological component facilitates pruning decision making (Nájera and Hernández, 2008), but it should be noted that this insertion point moves up as the tree grows, which is, in turn, an effect of changes in the amount and quality of incident light (Arias, 2005).

Branch arrangement was consistent in all genotypes, as indicated by Hallé (2010). A significant dissimilarity was found between BA-36, which exhibited the longest branches (109.83 cm), and Laurina, with the shortest ones (50.32 cm) (Figure 1F). This feature is explained by Montoya *et al*. (1961), who emphasize the marked influence of genetic factors on the relation between branch length and number of nodes. However, despite its being an architectural specificity of each material, internode length is also highly dependent on weather conditions during plant growth and development (Niinements, 2007).

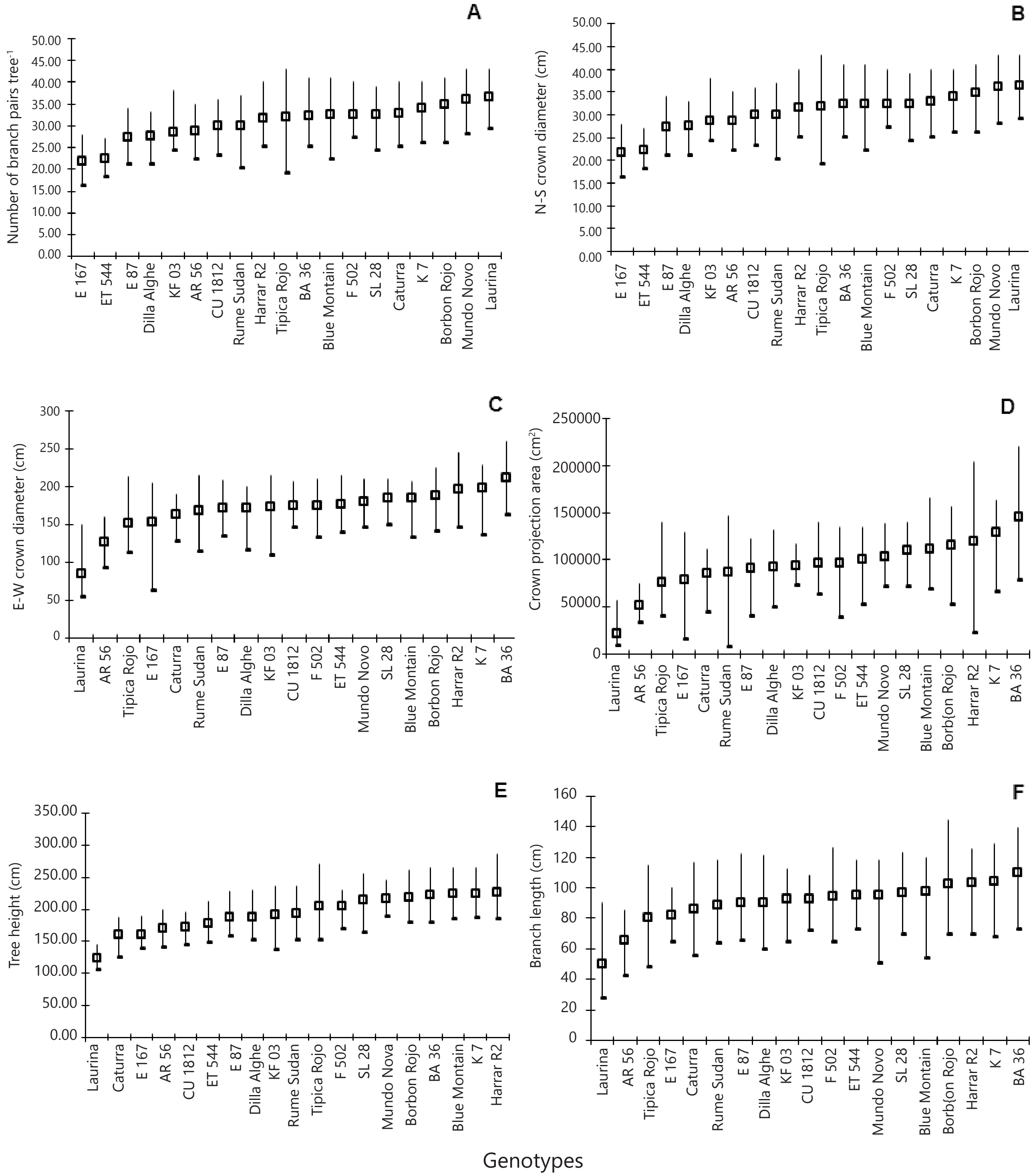

Figure 1. Crown structure components of 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío - Colombia). Number of branch pairs•tree^{-1} (A); N-S crown diameter (B); E-W crown diameter (C); crown projection area (D); tree height (E) and branch length (F). Bars indicate the standard error.

Two basic branch arrangements can be observed in coffee, namely planophil, which is predominantly plagiotropic, and erectophil, which is mainly orthotropic (Arcila, 1990). In the current study, all genotypes displayed a plagiophil branch insertion angle (<45 °), progressively becoming planophil from the tree apex to its base (Table 2). Plants with planophil architecture are apparently more productive than erectophil ones (Arcila, 2007; Salazar, 1988). However, in genotypes between 22 and 28 months old (when the plants are in transition to the productive phase), the erectophil arrangement might change to a more planophil disposition when the plant reaches full maturity. At that point, the weight of the harvest, coupled to the development status of the tree, may overwhelm the branches (Arcila, 1990). Consequently, two types of orientation can be present in the same plant: the original unmodified one on top, and a modified planophil arrangement dominating the lower strata, thus facilitating light penetration into the crown. Furthermore, branch insertion angle, which is genotype specific, influences foliage and radiation distribution inside the crown, two factors that have a marked effect on crop quantity and quality (Alvarado and Ochoa, 2006; Piña and Arboleda, 2010).

Table 2. Branch insertion angle (°) of 19 Coffea genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío – Colombia).

Genotype	**Stratum**			
	Upper	**Medium**	**Lower**	$\overline{X}$
AR-56	24	31	34	**30**
BA-36	29	36	38	**34**
Blue Montain	37	43	49	**43**
Borbón Rojo	30	37	39	**35**
Caturra	28	36	40	**35**
CU-1812	19	26	36	**27**
Dilla Alghe	33	37	43	**38**
Harrar R2	32	37	40	**36**
E-87	43	44	47	**45**
E-167	43	47	47	**46**
ET-544	41	46	48	**45**
F-502	36	38	39	**37**
K-7	28	32	34	**31**
KF-03	37	41	43	**40**
Laurina	40	43	43	**42**
Mundo Novo	28	30	33	**30**
Rume Sudan	34	36	37	**36**
SL-28	35	41	45	**40**
Típica Rojo	21	25	28	**25**
$\overline{X}$	**33**	**37**	**40**	**37**

Foliage attributes. Leaf insertion angles showed differences across genotypes. Laurina exhibited the highest percentage of leaves in the 0° - 30° range, which is characteristic of planophil distributions; while BA-36, Blue Mountain, Caturra, Cu-1812, Dilla Alghe, E-87, Harrar R2, KF-03, Mundo Novo, SL-28 and Típica Rojo had their highest number of leaves in the 31°- 60° range, which features plagiophil plants. In turn, AR-56, Borbón Rojo, E-167, K-7 and Rume Sudan were dominated by the 61° - 90° range, which is exclusive of erectophil distribution plants (Table 3).

Most of the studied genotypes showed plagiophil distribution, contrasting with reports by Castillo *et al*. (1996), Castillo *et al*. (1997), Alvarado *et al*. (2006) and Montoya *et al*. (2009) on the crown structure of varieties Colombia and Castillo®, in which the planophil distribution was found to be dominant. However, it should be noted that in all the mentioned cases the field establishment age of the trees exceeded 36 months, when the weight of the harvest varies the angle of leaf insertion.

The position of the leaves on the branches has a strong influence on the photosynthetic activity of the whole plant (Sánchez *et al*., 2008). In this sense, if yield is associated to a better distribution of the leaves in the canopy through their leaf insertion angle, AR-56, Borbón Rojo, E-167, K-7 and Rume Sudan are probably more efficient in achieving maximum photosynthesis due to their erectophil arrangement, which allows greater penetration and more even distribution of light, always provided that they have an elevated LAI, as is the case of AR-56, K-7 and Rume Sudan. In contrast, Borbón Rojo and E-167, despite their erectophil foliage arrangement, may have a lower interception of incident radiation because of their low LAI. Laurina differs in this aspect because of its planophil leaf insertion angle, which causes radiation to be intercepted at the upper strata, thus attenuating light and temperature within the crown and limiting photosynthesis (and therefore, biomass production) in the lower strata (Castillo *et al*., 1997).

Table 3. Leaf insertion angle classification of 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío – Colombia).

Genotype	Months			
	22	24	26	28
AR-56	Erectophil	Erectophil	Erectophil	Erectophil
BA-36	Erectophil	Erectophil	Plagiophil	Plagiophil
Blue Montain	Erectophil	Plagiophil	Plagiophil	Plagiophil
Borbón Rojo	Erectophil	Erectophil	Plagiophil	Plagiophil
Caturra	Plagiophil	Plagiophil	Plagiophil	Plagiophil
CU-1812	Plagiophil	Plagiophil	Plagiophil	Erectophil
Dilla Alghe	Plagiophil	Erectophil	Plagiophil	Plagiophil
Harrar R2	Erectophil	Plagiophil	Plagiophil	Plagiophil
E-87	Plagiophil	Plagiophil	Plagiophil	Plagiophil
E-167	Erectophil	Erectophil	Erectophil	Erectophil
ET-544	Erectophil	Erectophil	Plagiophil	Erectophil
F-502	Erectophil	Erectophil	Plagiophil	Plagiophil
K-7	Erectophil	Erectophil	Erectophil	Erectophil
KF-03	Erectophil	Plagiophil	Plagiophil	Plagiophil
Laurina	Planophil	Planophil	Planophil	Planophil
Mundo Novo	Plagiophil	Erectophil	Plagiophil	Plagiophil
Rume Sudan	Erectophil	Erectophil	Erectophil	Erectophil
SL-28	Erectophil	Erectophil	Plagiophil	Plagiophil
Típica Rojo	Erectophil	Plagiophil	Plagiophil	Plagiophil

These considerations emphasize the importance of understanding the heterogeneity of genotype, specific leaf architecture patterns when it comes analyzing the process of absorption, transmission and reflection of radiant energy. In turn, this allows the generation of hypotheses on ecophysiological processes related to carbon capture and photoassimilate distribution as affected by the environment (Fageria *et al*., 2006).

At a density of 3,333 trees ha^{-1}, LA $plant^{-1}$ ranged from 4.35 m^2 in Laurina to 26.22 m^2 in BA-36 (Table 4), these differences being significant. In researching 3.5 year old trees of variety Colombia, Castillo *et al*. (1997) found 4.94 m^2 LA records at a 12,500 trees ha^{-1} planting density; and 10.17 m^2 at 10,000 trees ha^{-1}. As an adaptive advantage, LA is important for the calibration, adjustment and implementation of agri-environmental simulation models. Hence, measuring it is important in the study of physiological characteristics related to plant growth, the processes of photosynthesis and transpiration, the evaluation of the damage caused by pests and diseases on the leaves and the effect of treatments and cultural practices. It is also known that LA defines the ability of the canopy to intercept PAR, which is the energy source used by plants for tissue production and the synthesis of nutritious compounds (Warnock, 2006; Filho *et al*. 2010). In this sense BA-36, K-7, Mundo Novo, Rume Sudan, Dilla Alghe and SL-28 probably have the highest photosynthetic activity among the studied materials, which is a desirable feature if we consider that photoassimilates are employed by the plant to meet the energy costs of plant maintenance and vegetative and reproductive growth, which ultimately affect yield (Laviola *et al*., 2007).

The analysis of variance established significant LAI differences between the studied genotypes (Table 4) and between blocks. LAI is a dimensionless variable defined by Watson (1947) as the total area of one of the surfaces of a photosynthetic tissue per unit of land. It is considered to be the main biophysical parameter for modeling plant processes such as photosynthesis and evapotranspiration, for evaluating and describing absorbed PAR, and for characterizing plant microclimate (Velazco *et al*., 2010).

Table 4. Leaf area and leaf area index of 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío – Colombia).

Genotype	Leaf Area (m^2)	Leaf Area Index
AR-56	9.68 efg *	1.86 abc
BA-36	26.22 a	1.79 abcd
Blue Montain	12.05 cdefg	1.07 def
Borbón Rojo	16.60 bcde	1.49 bcdef
Caturra	16.95 bcdd	1.99 ab
CU-1812	16.32 cde	1.76 abcd
Dilla Alghe	18.80 abcd	1.97 abc
Harrar R2	15.00 cdef	1.33 bcdef
E-87	11.43 defg	1.20 cdef
E-167	6.94 fg	0.84 f
ET-544	9.11 efg	0.99 ef
F-502	15.40 cde	1.54 bcdef
K-7	24.69 ab	1.66 abcdef
KF-03	15.08 cdef	1.54 bcdef
Laurina	4.35 g	1.94 abc
Mundo Novo	20.52 abc	1.99 ab
Rume Sudan	20.29 abc	2.40 a
SL-28	18.22 abcd	1.66 abcdef
Típica Rojo	11.25 defg	1.46 bcdef

* Means within a column followed by the same letter are not significant according to Duncan's test ($P \leq 0.05$).

The LAI results of the present research set a contrast with those of Valencia (1973), who states that the production of variety Caturra is maximized at LAI = 7.97. This value is obtained at the age of three years in an unshaded population of 10,000 trees ha^{-1}, and at the age of four in a population of 5,000 trees ha^{-1}. In this sense, it must be remembered that in the present case the age of the genotypes under study did not exceed 28 months. Still, the lowest LAI values, which corresponded to E-167, ET-544 and Blue Mountain, probably make them the least efficient materials in terms of dry weight gain. This is a reasonable assumption, provided that LAI, together with temperature, water availability, fertility and radiation intensity, determines photosynthesis intensity (Hernández *et al*., 2012). For its part, Rume Sudan, which exhibited the highest LAI record, had probably reached the optimum value for this index, which is defined, in turn, as the one that supports the maximum dry matter production increase. This condition is reached when the lowest leaf layers are able to maintain a positive average carbon balance, *i.e*., when the crop intercepts virtually all incident PAR (Montemayor *et al*., 2006).

Table 5 shows PAR interception data, including significant differences among treatments. Genotypes CU-1812 (a component of variety Castillo® and Castillo regionals) and BA-36 stand out with records of 98.27% and 96.16%, respectively. These data are very similar to the 96.90% PAR report by Castillo *et al*. (1997) in 3.5 year old plantations of variety Colombia at a density of 10,000 trees ha^{-1}. Yet, variations may occur depending on vegetative stage, plant age, branch and leaf insertion angles, crop management, planting distance, number of branches and fruits, and degree of defoliation, among other factors (Jaramillo, 2005b). On the other hand, the low PAR interception records observed in E-167 are explained by its reduced LA and LAI. In this respect, Jaramillo *et al*. (1993) and Tollenar and Lee (2004) confirm that intercepted PAR is a function of LA, LAI and plant architecture, especially at the critical LAI, which is the one required to intercept 95% of irradiance (Gardner *et al*. 1985; Idinoba *et al*., 2002). Emphasis on PAR interception comes from its central importance as a physical and biochemical precondition of photosynthesis, therefore closely related to dry weight gain and increased productivity (Araus *et al*., 2004; Morais *et al*., 2006).

Defined as the ratio between the radiation reflected by a surface and its total incident radiation (Jaramillo, 2005b), albedo is a very important property in the

Table 5. Interception of radiation and cumulative fruit production of 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío – Colombia).

Genotype	Radiation Interception (%)	Cumulative Production (kg / ten-tree furrow)
AR-56	86.82 d	20.26 egh
BA-36	96.16 abc	19.55 efgh
Blue Montain	95.64 abc	40.50 cde
Borbón Rojo	92.38 abcd	30.54 defg
Caturra	94.51 abcd	64.95 ab
CU-1812	98.27 a	75.68 a
Dilla Alghe	96.83 ab	35.10 defg
Harrar R2	92.34 abcd	62.53 abc
E-87	94-16 abcd	38.65 cdef
E-167	71.32 e	10.92 fgh
ET-544	91.79 abcd	8.07 h
F-502	94.14 abcd	18.82 efgh
K-7	93.70 ab	29.73 defg
KF-03	92.72 abcd	34.13 defg
Laurina	87.57 cd	2.13 h
Mundo Novo	94.09 abcd	49.08 bcd
Rume Sudan	93.59 abcd	14.01 fgh
SL-28	96.32 ab	34.86 defg
Típica Rojo	87.70 bcd	10.64 gh

* Means within a column followed by the same letter are not significant according to Duncan's test ($P \leq 0.05$).

radiation balance of a crop. The current research found no significant differences in this parameter (data not shown), as also reported in previous studies (Cabezas and Corchuelo, 2005). The genotypes in question showed albedo values between 2.57% and 3.59%, which are close to those reported by Jaramillo *et al*. (1993) for 18 month old trees of variety Colombia with an 8.1 m^2 LA. Yet, these values are far from the 16%, 17% and 19% counts found in coffee by Jaramillo (1992) and Ramirez y Jaramillo (2009), and from the 15 to 20% range reported by Jaramillo (2005b) for green crops, in listing the albedo of a series of other surfaces.

Several factors may explain the diversity of the mentioned figures, namely solar elevation, which is inversely correlated with albedo (Jaramillo, 2005b); the way in which the measurement is taken (if assessed on all incident radiation, albedo ranges from 10% to 20% for all crops) (Jaramillo, 2005a); the time of the day at which the measurement is taken (if made at noon, reflection is minimum) (Jaramillo and Marden, 1980); the zenith angle and the spectral composition of radiation (Budyko, 1974).

Coffee berry yield

Yield assessment took into consideration that the expression of this parameter is the consequence of the other evaluated attributes, which are, in turn, related to plant architecture and interception of PAR (Table 6). Genotypes CU-1812, Caturra, Harrar R2, Mundo Novo and Blue Montain stood out for their increased yield, while SL-28 and Dilla Alghae outperformed Borbón Rojo. These results contrast with those of Castillo (1977), found in the climatic conditions of Central Station *Naranjal* (Chinchiná, Caldas, Colombia) and Sub-station *Paragüaicito*. In turn, the lowest yield in the current research corresponded to Laurina (Table 5). Average yield based grouping allowed the formation of three genotype clusters.

The most outstanding genotypes coincide in occupying top positions with regards to number of branches, crown projection area, solar radiation interception and tree height (except for Caturra), as also reported by Arcila (1987) in assessing the components of coffee productivity. The current results correspond with those of Krug *et al*. (1954) and Antunes and Alves (1964), who warn about the low yields of Laurina. Also in the current research, this genotype showed low branch length, crown diameter, crown projection

Table 6. Coffee berry yield based classification of 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío – Colombia).

Group	Genotype
1	Caturra CU-1812 Harrar R2
2	Blue Montain Borbón Rojo Dilla Alghe E-87 K-7 KF-03 Mundo Novo SL-28
3	AR-56 BA-36 E-167 ET-544 F-502 Laurina Rume Sudan Típica Rojo

area and tree height values. However, it was the only genotype with planophil foliar distribution, while the rest of them showed plagiophil distribution.

The differences found in the present research confirm the genotype specific nature of coffee yield (Arcila, 2007), which is related to leaf arrangement and the way it affects the process of absorption, transmission and reflection of radiant energy (Fageria *et al*., 2006). Along these lines, it must be taken into consideration that both LA and LA distribution, as well as leaf insertion angles, determine how PAR is intercepted, thus influencing photosynthesis and production (Melo *et al*., 2012). In sum, the efficiency of the plant is affected by solar radiation, the ability of the leaves to photosynthesize, LAI, plant architecture and respiration, among other factors. These are both genetic and environmental factors, the latter, in turn, related to agronomic practices (Gardner *et al*., 1985; Santos *et al*., 2010).

In correlating the variables studied in this research, PAR interception showed highly significant association with cherry coffee yield, LA, and crown projection area. Just as well, NS crown diameter and branch length showed significant correlation with production (Table 7). It is important to consider that dry matter production is determined by the amount of incident radiation intercepted by the canopy during the growth period and by its efficiency to turn it into dry matter (Gutiérrez *et al*., 2005). Besides, it is worthwhile noting that, within a single species, the different varieties, races, cultivars or genotypes can exhibit significant variations in their solar radiation trapping ability, which, in turn, depends on LA, leaf spatial arrangement and phenological stage; *i.e*., physiological and morphological changes undergone by the plant during ontogeny (Boote *et al*., 2001, Singh, 1991 and White, 1985, cited by Warnock, 2006).

Table 7. Correlation matrix of morphological variables evaluated in 19 *Coffea* genotypes from the Colombian Coffee Collection, planted at CENICAFÉ´s *Paragüaicito* Experimental Sub-station (Buenavista, Quindío – Colombia).

	LAI	**Leaf area**	**Branch pairs**	**NS crown diam.**	**EW crown diam.**	**Total height**	**Crown projection area**	**Radiation interception**	**Branch length**	**Coffee berry yield**
LAI	1.00	0.52**	0.34*	-0.19ns	-0.17ns	-0.12ns	-0.19ns	0.22ns	-0.28*	0.06ns
Leaf area	-	1.00	0.37**	0.66**	0.60**	0.59**	0.65**	0.53**	0.56**	0.22ns
Branch pairs	-	-	1.00	0.15ns	0.15ns	0.34*	0.22ns	0.40**	0.03NS	0.12ns
NS crown diam.	-	-	-	1.00	0.70**	0.84**	0.55**	0.42**	0.94**	0.28*
EW crown diam.	-	-	-	-	1.00	0.62**	0.98**	0.39**	0.68**	0.22ns
Total height	-	-	-	-	-	1.00	0.70**	0.38**	0.80**	0.17ns
Crown projection area	-	-	-	-	-	-	1.00	0.41**	0.77**	0.20ns
Radiation interception	-	-	-	-	-	-	-	1.00	0.29*	0.37**
Branch length	-	-	-	-	-	-	-	-	1.00	0.27**
Coffee berry yield	-	-	-	-	-	-	-	-	-	1,00

ns= Non significant correlation, *Significant correlation (0.05), **Highly significant correlation (0.01).

CONCLUSIONS

The 19 evaluated *Coffea* genotypes show genetic diversity, which is manifested in their phenotypic differences.

The arrangement of the branches with respect to the stem was plagiophil for most genotypes. This category is featured by insertion angles between 30° and 45°, an orientation that was observed to become gradually planophil towards the base of the tree.

The position of the leaves varied according to the genotype. Laurina was the only one with the highest percentage of its leaves in the 0-30° range, which corresponds to the planophil distribution. The most frequent leaf arrangement was the plagiophil one, featured by angles ranging from 31 to 60°, which was found in genotypes BA-36, Blue Mountain, CU 1812, Dilla Alghe, Harrar R2, E-87, ET-544, KF-03, Mundo Novo, SL-28 and Típica Rojo. On the other hand, in genotypes AR-56, Borbón Rojo, E-167, K-7 and Rume Sudan the angle of insertion was 61 to 90°, which is characteristic of plants with erectophil distribution.

Coffee berry yield allowed separating the genotypes in three groups, among which Caturra, Harrar, CU-1812 and R2 stood out for their higher yield. On the other hand, the highly significant correlations found between PAR interception and cherry coffee production, indicate that yield was tightly determined by incident PAR.

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