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Growth comparison of 22 genotypes of conilon coffee after regular pruning cycle

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A regular pruning cycle (RPC) reduces costs when implementing crop treatments and facilitates semi-mechanized harvesting. However, there is information on plant development under this system. Thus, this study aimed to assess the new branch growth of 22 genotypes of *Coffea canephora* (conilon) after a regular pruning cycle. The assay was conducted at Cachoeiro de Itapemirim, Southern Espírito Santo State, Brazil. Measurements of 12 morphoagronomic traits were performed, and their relationships with temperature and rainfall were studied. The branch vegetative growth rates varied seasonally throughout the assessment period, with higher growth rates and higher temperatures, even not extreme, during rainy periods and lower growth rates and milder temperatures during the dry season. The logistic model with best fit to describe pattern of cumulative growth by genotypes following RPC was sigmoid for all the studied traits.

Key words: *Coffea canephora*, growth curve, seasonality, temperature.

INTRODUCTION

Coffee stands out as a worldwide product of great importance and is cultivated in more than 80 countries, with approximately 143.4 million of 60-kg bags production in 2015. Approximately, 35% of total production was *Coffea canephora* (conilon or robusta) (ICO, 2016). Brazil is the largest coffee producer and exporter, having harvested 43.24 million bags in 2015 on 1.99 thousand hectares with the planted species *C. arabica* (Arabica) and *C. canephora*. Conilon coffee accounts for approximately 26% of coffee produced in country and has been used for many years in mixtures with Arabica coffee to enhance flavour of drink and to prepare soluble coffee (CONAB, 2016).

The conilon coffee tree is characterized by

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reproduction through allogamy (cross- fertilization). Therefore, use of asexual propagation becomes necessary to obtain productive varieties with a defined maturation cycle (Bragança et al., 2001). Furthermore, productivity of plants propagated by cutting is higher than that of plants propagated by grafting (Partelli et al., 2014). Conilon coffee varieties are usually polyclonal, formed by sets of genotypes (Barbosa et al., 2014; Leroy et al., 2014; Dalcolmo et al., 2015), usually grouped according to their maturation cycle, which varies from early to late (Fonseca et al., 2004).

A coffee plantation should have a canopy architecture that promotes optimal gas exchanges to be effective (DaMatta et al., 2007). Coffee plant growth may be affected by environmental stresses common in agricultural systems (Batista-Santos et al., 2011; Partelli et al., 2014; Ramalho et al., 2014; Rodrigues et al., 2016). There are numerous biotic and abiotic factors responsible for growth changes, which may act directly or indirectly and usually act jointly. Therefore, it is difficult to identify primary factor influencing a given growth pattern (Ivoglo et al., 2008). Furthermore, various genotypes and several parts of same plant may have different responses, growing at different rates and in different seasons (Pereira et al., 2007).

The vegetative growth of *C. arabica* coffee tree branches is noticeably seasonal in latitudes where Brazilian coffee production is concentrated, with maximum growth coinciding with rainy seasons with hot and long days, and reduced growth coinciding with dry seasons with cold days and short photoperiods (Barros et al., 1997; Silva et al., 2004; Amaral et al., 2006; Ferreira et al., 2013). Growth seasonality would be associated with fluctuations in minimum air temperature, lower than 14°C (Amaral et al., 2006).

Seasonality is a variable phenomenon affecting species and variety of *C. canephora.* Growth-rate reductions begin when field temperatures are lower than 17°C (Partelli et al., 2010) for most genotypes (Partelli et al., 2013). This pattern is explained by conilon coffee evolution, which occurred under ecological conditions of African lowlands (Davis et al., 2011). Low temperature affects several components of conilon coffee photosynthetic mechanism, reducing stomatal conductance, net photosynthesis, photochemical efficiency of photosystem II, thylakoid electron transport and enzymatic activity, lipid classes and fatty acids, even changing composition and structure of complexes of photosynthetic pigments (Partelli et al., 2009; 2011; Batista-Santos et al., 2011; Scotti-Campos et al., 2014).

The growth rates of conilon coffee plants decline with age (Bragança et al., 2015). Therefore, pruning and thinning are routine practices among conilon farmers, who use these practices as instruments of rejuvenation and maintenance of crop productivity (Pereira et al., 2007). A regular pruning cycle (RPC), wherein crop shoots are completely renewed every four or five years, is currently an option. Pruning is also aimed to promote and reduce costs of implementing crop treatments and semi-mechanized harvesting.

Understanding vegetative growth is a key tool both for assessing physiological status of plants and in crop-management practices. That’s why this study aimed to examine growth, assessing 12 morphoagronomic traits in 22 genotypes of *C. canephora* and relating these traits to climate conditions temperature and rainfall conditions.

MATERIALS AND METHODS

The study was conducted in Cachoeiro de Itapemirim municipality, Espírito Santo state, Brazil. The experiment was planted in June 2005, in a randomized block design, with 55 treatments (genotypes of *C. canephora* var. Conilon, belonging to breeding programme of Capixaba Institute of Research, Technical Assistance and Rural Extension (Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural, INCAPER – Espírito Santo) and four replicates. Each plot consisted of one row with five plants, spaced 3.0 x 1.2 m, and second, and fourth plants were considered the useful plot. The methods used were same as those recommended by the INCAPER for cash crops, with increased supplemental irrigation.

A total of 51 clonal genotypes resulting from phenotypic selection of mother plants from farms in Castelo region, Espírito Santo state - ES (termed Castelo Assessment [Avaliação Castelo – AC]), three clonal genotypes of cultivar INCAPER 8142 (conilon Vitória) and one clonal genotype of open-pollinated cultivar EMCAPER 8151 (Robusta Tropical), all belonging to breeding programme of INCAPER, ES, were studied. All plants were submitted to a regular pruning cycle (RPC), maintaining two of five orthotropic stems of plants and removing plagiotropic branches that had produced grains in more than 50% of their rosettes, after completing fourth harvest (September 2010).

A total of 22 genotypes were selected from the original experiment to study growth: the 18 most promising clones from the group Avaliação Castelo (AC02, AC03, AC12, AC13, AC22, AC24, AC26, AC27, AC28, AC29, AC30, AC35, AC36, AC37, AC39, AC40, AC43 and AC46), in addition to three genotypes of cultivar conilon Vitória (12V - early, 02V - medium and 13V - late) and cultivar robusta tropical (RT), based on assessments conducted in years 2006, 2007, 2008, 2009 and 2010 (four harvests), regarding productivity criteria, production stability, maturation uniformity, grain size, vigour and rust tolerance. The following traits were assessed in branches grown after RPC during 2010/2011 crop year:

1) Number of new orthotropic branches per plant (OBN), assessed by direct count of new branches with length equal to or higher than 10 cm. Five new branches were kept in each plant to originate new crown, detaching others;
2) Dry matter of removed orthotropic branches (ODM), assessed by weighing following drying in an oven at 65°C for 72 h;
3) Length of new orthotropic branches (OBL), assessed measuring distance between insertions of five new branches with old and their apical meristems (cm);
4) Diameter of new orthotropic branches (OBD), using a standard measurement in central region of second internode of each of five branches (mm);
5) Number of orthotropic nodes (ONN), assessed by direct count in each of five branches;
6) Number of new plagiotropic branches (PBN), assessed by direct count in each of five new orthotropic branches;
7) Length of new plagiotropic branches (PBL), measured in two branches selected per plant, one on each side of crop row and

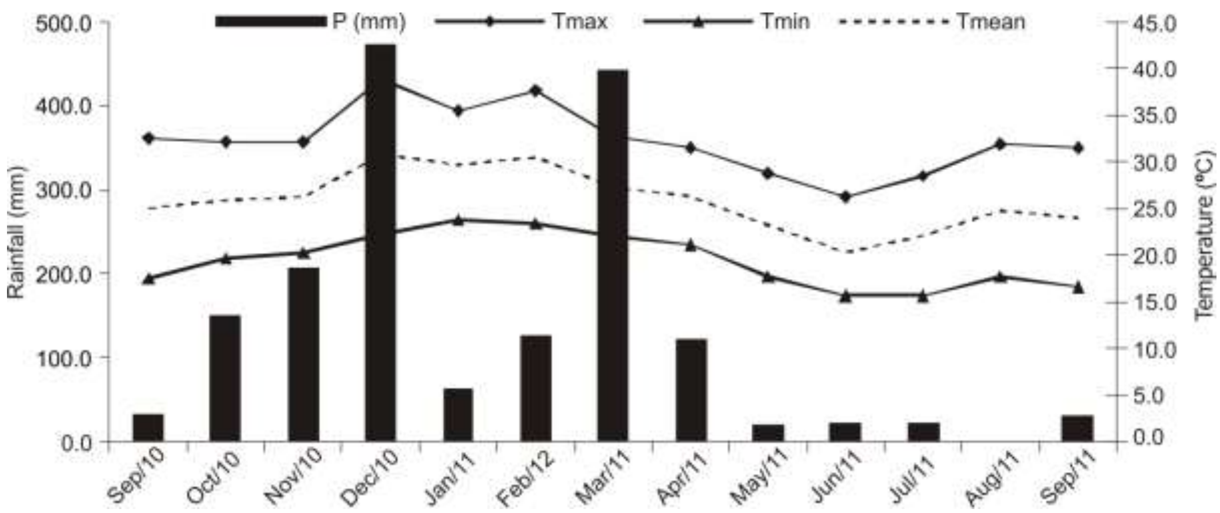

Figure 1. Maximum (Tmax), mean (Tmean) and minimum (Tmin) air temperatures and rainfall (mm) recorded in September 2010 to September 2011 period in the experimental area, Cachoeiro de Itapemirim, Espírito Santo state, Brazil.

calculated measuring to the distance between insertion of those branches in orthotropic branch and their apical meristem (cm);
8) Number of plagiotropic nodes (PNN), assessed by direct count in selected branches;
9) Number of leaves emerged in plagiotropic branches (PLN), directly assessed in the selected branches mentioned in item 7;
10) Maximum crown diameter (MCD), measured in transverse direction to crop row, with ends of longest branches as limits (cm);
11) Orthotropic internode length (OIL), calculated by ratio between monthly growth of each orthotropic branch and number of orthotropic nodes that emerged in a month (ONN; cm);
12) Plagiotropic internode length (PIL), calculated by ratio between monthly growth of plagiotropic branches and number of nodes that emerged in a month (PNN) in both of selected branches (cm).

The monthly growth rates were assessed for all traits evaluated, calculated by the difference between values recorded in current and previous months, divided by number of days between assessments. The cumulative growth was also assessed for traits OBN, ODM, OBL, OBD, ONN, PBN, PBL, PNN, PLN and MCD, calculated by difference between values recorded in the current month and at beginning of the experiment.

Supplemental irrigation was performed through sprinkling, applying one 25-mm rainfall simulation per irrigation, two in year 2010 (09/20 and 10/13) and five in year 2011 (02/08; 06/03; 08/29; 08/30 and 09/06). Rainfall was assessed using a pluviometer installed on experimental area, and temperatures were assessed through readings on a digital thermometer of brand E 7427 (CALARM; Figure 1).

The analysis of variance ($P \geq 0.01$) was performed using free software programming language R (R Foundation for Statistical Computing, 2012) and monthly cumulative growth averages for 10 traits during year. The scheme of plots subdivided in time with genotypes in plot and assessment seasons in subplots was used for this analysis. Regression analyses were subsequently performed per trait for worst- and best-performing genotypes and overall cumulative average (OCA) of 22 genotypes.

The overall average of 22 genotypes (AGTx) per trait and season assessed was calculated based on daily growth rates, and values were used to design a graph showing variation in growth rate of each trait regarding assessment season.

RESULTS AND DISCUSSION

The emergence of new branches in plants submitted to an RPC occurred rapidly, which enabled first assessment 30 days after pruning (10/29/2010). September is a season when conilon coffee plant naturally resumes its growth in southern region of Espírito Santo State, according to Amaral et al. (2007) and Libardi et al. (1998), as well as corroborating data from northern regions of States of Rio de Janeiro (Partelli et al., 2010) and Espírito Santo (Partelli et al., 2013). Growth resumption was also found in that period in the present study, given favourable climate conditions (Figure 1). This pattern was further strengthened by breaking apical dominance and changing source-sink relationship through pruning, by increase in minimum air temperature in late September, by supplying supplemental irrigation on 09/20 and by return of rainy season on 09/28, among other contributing factors.

Set of 22 genotypes of conilon coffee for traits OBN, ODM, OBL, OBD, ONN, PBN, PBL, PNN, PLN and MCD are shown in Figure 2. The graphs representing the cumulative monthly growths are the period from 09/20/2010 to 09/20/2011. The logistic models describing a sigmoid pattern were best fitted to represent growth form after RPC for all the traits

The pattern obtained was notably similar to that reported by Bragança et al. (2015), who measured conilon coffee plant growth until sixth year of age. The authors explained that woody plants, such as coffee, should show an initial dry weight accumulation of organs and/or tissues typical of a linear model of growth.

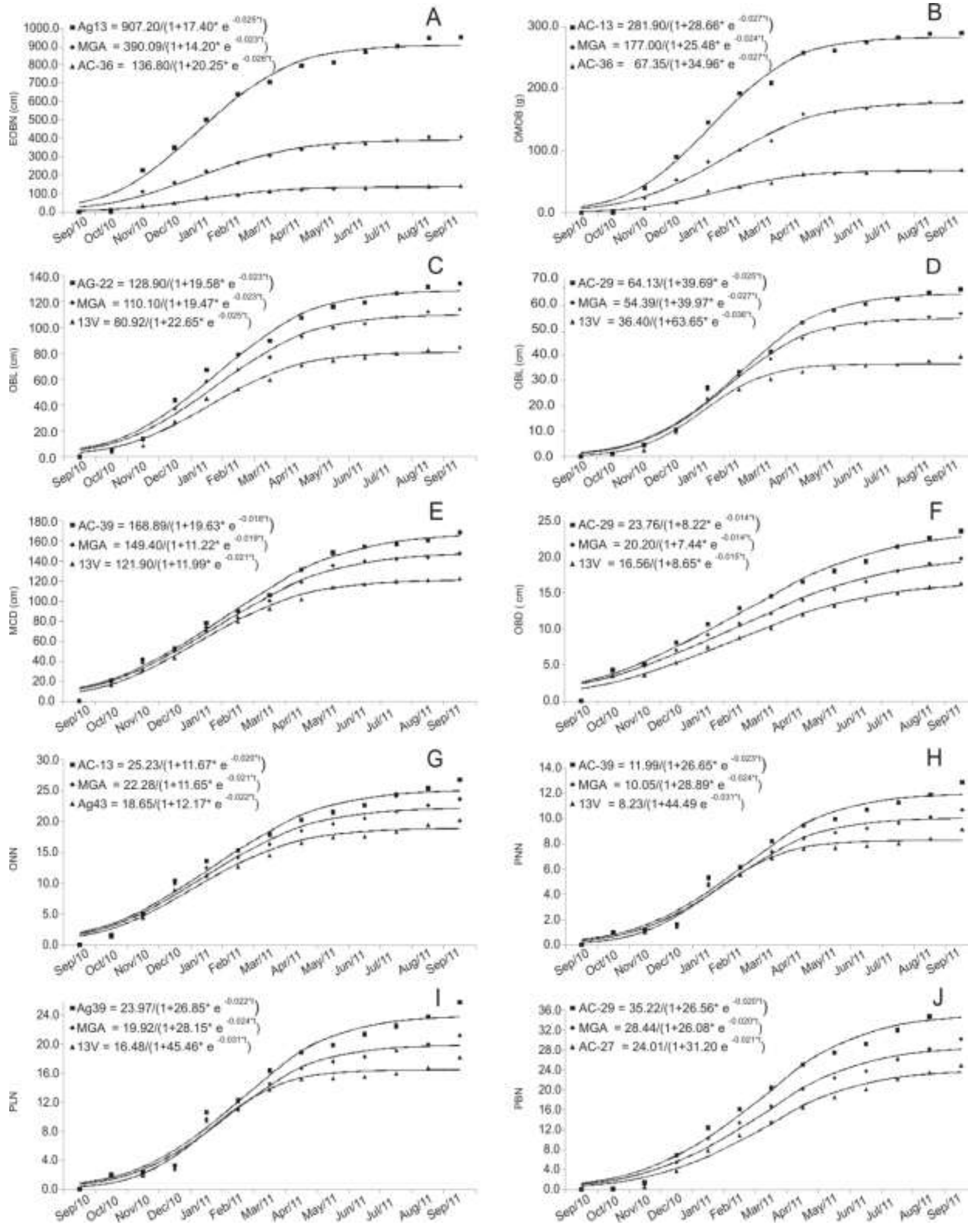

Figure 2. Measured values and regression curves fitted to describe the cumulative growth pattern of the worst- and best-performing genotypes and of the overall cumulative average (OCA) of the 22 genotypes for the following traits: A) emerged orthotropic branch number (OBN); B) dry matter of orthotropic branches (ODM; g); C) orthotropic branch length (OBL; cm); D) plagiotropic branch length (PBL; cm); E) maximum crown diameter (MCD; cm); F) orthotropic branch diameter (OBD; mm); G) orthotropic node number (ONN); H) plagiotropic node number (PNN); I) plagiotropic leaf number (PLN); J) plagiotropic branch number (PBN).

However, internal control mechanisms modify that relationship throughout their growth, and most appropriate way to describe growth becomes a sigmoid curve.

The genotype AC-36 (136.58) grew lowest number of orthotropic branches (OBN) at end of thr period assessed. AC-13 (905.10) was genetic material that grew better (OBN). The average OBN was 389.58 new branches (Figure 2A). Those orthotropic branches weighed on average, 176.19 g after being removed and dried (ODM), ranging from 67.24 (AC-37) to 281.45 g (AC-28; Figure 2B). The five orthotropic branches remaining in plant, intended for new crown formation, had a height of 109.58 cm (OBL). The highest genotype measured 128.26 cm (AC-22), and shortest was 80.71 cm (13V; Figure 2C). The selected plagiotropic branches had an average length of 54.26 cm (PBL), ranging from 36.39 (13V) to 63.84 (AC-29; Figure 2D). The tallest genotype (AC-39) had a maximum crown diameter (MCD) of 165.94 cm, smallest diameter was 121.28 cm (13V), and average crown diameter of all the genotypes was 147.46 cm (Figure 2E). The orthotropic branches of genotype AC-29 (22.78 mm) had largest diameter (OBD), and 13V (16.00 mm) had smallest; average diameter was 19.27 mm (Figure 2F). An average of 22.13 nodes emerged per orthotropic branch (ONN), with one genotype producing 24.98 nodes (AC-13) and another producing only 18.88 nodes (AC-43; Figure 2G).

The average plagiotropic branch had 10.00 nodes (PNN); one genotype had branches with 11.89 nodes (AC-29), and another had only 8.27 nodes (13V; Figure 2H). A total of 20.54 leaves emerged in each plagiotropic branch (PLN) on average, ranging from 18.14 (AC-35) to 24.93 (AC-39; Figure 2I). An average of 28.21 plagiotropic branches (PBN) emerged in each orthotropic branch, ranging from 23.59 (AC-27) to 34.58 (AC-9; Figure2J).

The following daily rates were assessed when comparing overall cumulative average growth of 22 genotypes (OCA) with time elapsed between first and last assessments (361 days): 1.13 branches (OBN), 0.49 g (ODM), 3.16 mm (OBL), 0.055 mm (OBD), 0.065 nodes (ONN), 0.08 branches (PBN), 1.56 mm (PBL), 0.029 nodes (PNN) and 0.059 leaves (PLN). However, the growth rates of coffee plant shoots (considering the growth of orthotropic and plagiotropic branches, formation of nodes and leaf expansion, among others) are known to vary seasonally, according to climate conditions, particularly rainfall and temperature regimes, although photoperiod also has an effect (Libardi et al., 1998; Amaral et al., 2007; Ronchi and DaMatta et al., 2007; Partelli et al., 2010; 2013), which shows need to analyze coffee plant growth in different seasons.

The daily growth rates showed extremely similar seasonal performances in 12 traits, when comparing monthly growth rates in period of 09/20/2010 to 09/20/2011 (Figure 3) and rainfall and temperature curves for same period (Figure 1). Furthermore, the variation in growth rates was somewhat similar to rainfall and temperature curves in that period. The growth rates were high during rainy periods and periods with higher temperatures, even not extremely so. Conversely, growth rates were lower during the dry season and periods with milder temperatures. That similarity between curves was also reported by several authors (Libardi et al., 1998; Amaral et al., 2007; Ronchi and DaMatta, 2007; Partelli et al., 2010; 2013).

The minimum air temperature began to increase in mid-September 2010, remaining above 17°C until mid-May 2011 (Figure 1). Most of active growth occurred in that period, showing two peaks in growth curves: a first, often larger peak, distributed between months of November to January, and a second peak, less intense, recorded in months of March and April (Figure 3), which was also recorded by Amaral et al. (2007), with small discrepancies in dates of occurrence.

The transient decreases in growth intensity noted between both peaks in February may be explained as a consequence of limitations imposed by maximum air temperatures (Amaral et al., 2007; Libardi et al., 1998; Silva et al., 2004), which remained above 35°C in December, January and February, with a possible association with excessive rainfall (Amaral et al., 2007), which amounted to 328.5 and 328.0 mm in November and December, respectively (Figure 1).

Dardengo et al. (2009) report that decreases in growth rates in this period may also be associated with prolonged drought (43 days of drought occurred between 01/15 and 02/27, a period during which only one 25-mm irrigation could be performed). It is also noteworthy that conilon coffee plants show metabolic losses due to drought and also respond differently to soil water deficit (DaMatta et al., 2003; Pinheiro et al., 2004; Praxedes et al., 2006). The decreased growth rates in that period may also be attributed to fast grain filling because fruits are strongest drains, and therefore, coffee plants grow less in that phase, according to com Amaral et al. (2007). The highest number of orthotropic branches (OBN) emerged in November, with a rate of 3.25 branches day^{-1} (Figure 3A). The emergence of many orthotropic branches is a desirable trait of genotypes, given the need to cut and renew crown. However, such material is undesirable given demand for manual labour required for its removal and energy expenditure to produce dry matter that will be discarded.

The genotypes showed highest growth rates of orthotropic branches (OBL) and maximum production of orthotropic nodes (ONN) in December, with rates of 8.1 mm day^{-1} (Figure 3C) and 0.17 nodes day^{-1} (Figure 3G), respectively. The rate of 8.1 mm day^{-1} was similar to rates found in some genotypes by Partelli et al. (2013) in northern Espírito Santo State in high-yielding crops, albeit well above rates reported by Partelli et al.

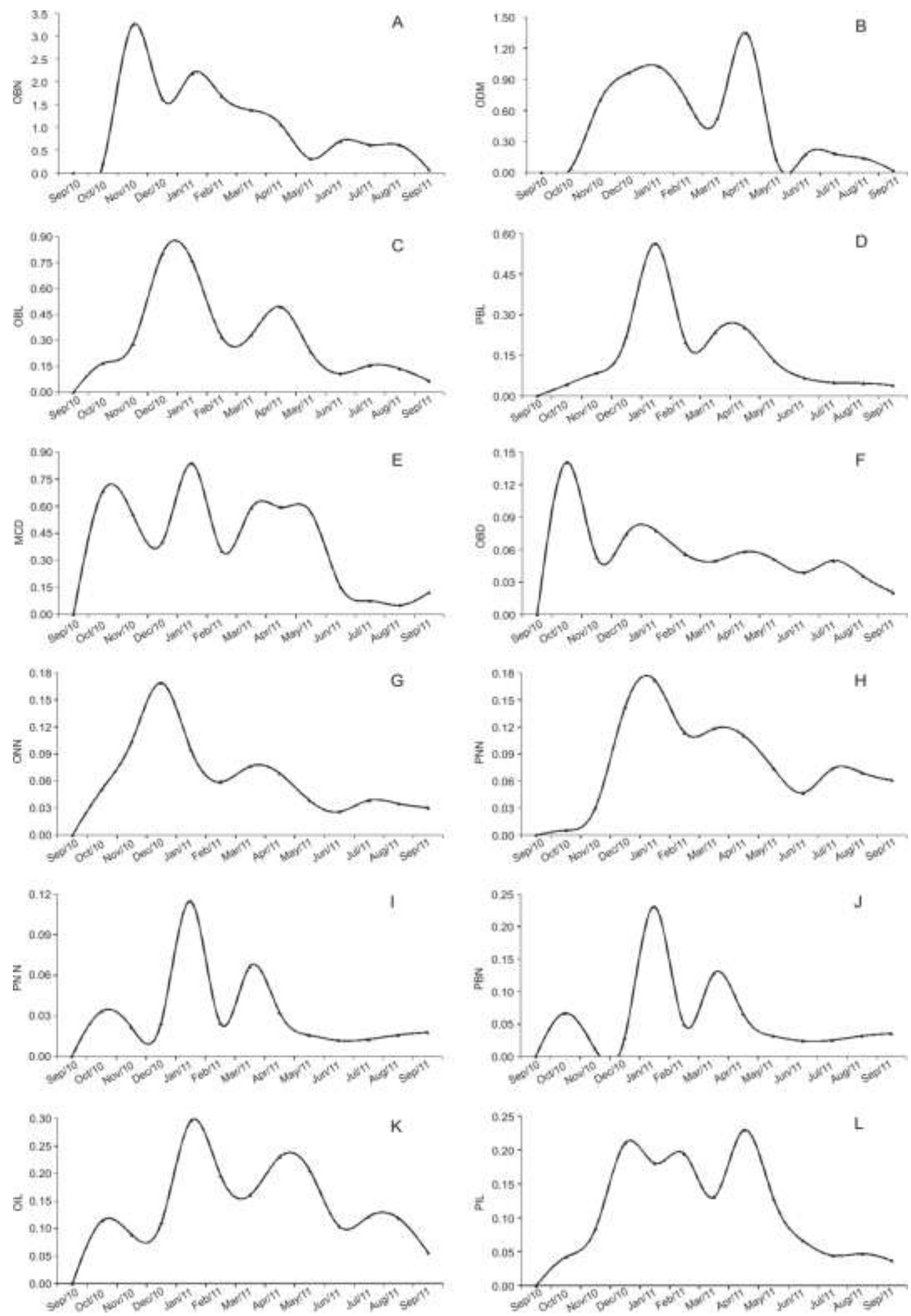

Figure 3. Variation of growth rates among the assessed seasons regarding the following traits: A) emerged orthotropic branch number (OBN; branches day^{-1}); B) dry matter of orthotropic branches (ODM; g day^{-1}); C) orthotropic branch length (OBL; cm day^{-1}); D) plagiotropic branch length (PBL; cm day^{-1}); E) maximum crown diameter (MCD; cm day^{-1}); F) orthotropic branch diameter (OBD; mm day^{-1}); G) orthotropic node number (ONN; nodes day^{-1}); H) plagiotropic node number (PNN; nodes day^{-1}); I) plagiotropic leaf number (PLN; leaves day^{-1}); J) plagiotropic branch number (PBN; branches day^{-1}); K) orthotropic internode length (OIL; cm day^{-1}); L) plagiotropic internode length (PIL; cm day^{-1}).

(2010) in northern region of Rio de Janeiro State in crops with low productive potential. The high growth rate may be explained by age of new branches, which were stimulated by changing source-sink relationship through pruning and good crop management.

The growth peaks of traits of plagiotropic branch length (PBL), maximum crown diameter (MCD), orthotropic branch diameter (OBD), plagiotropic branch number (PBN), plagiotropic node number (PNN), plagiotropic leaf number (PLN) and orthotropic internode length (OIL) occurred in January, with the following rates: 5.6 mm day^{-1} (Figure 3D), 8.4 mm day^{-1} (Figure 3E), 0.08 mm day^{-1} (Figure 3F), 0.17 branches day^{-1} (Figure 3J), 0.11 nodes day^{-1} (Figure 3H), 0.23 leaves day^{-1} (Figure 3I) and 2.9 mm day^{-1} (Figure 3K), respectively.

The highest values of traits dry matter of orthotropic branches (ODM) and plagiotropic internode length (PIL) were recorded in April, with rates of 1.35 g dry matter day^{-1} (Figure 3B) and 2.3 mm day^{-1} (Figure 3L), respectively. The peaks of those two traits occurred late, most likely as a form of compensatory growth (Ronchi and DaMatta, 2007) following return of rainy season in March and compensating for delay that occurred during drought between 01/15 and 02/27 (Figure 1). This pattern may also be associated with end of grain-filling period and the fact that no limitation occurred due to temperature, with maximum and minimum values in that month being 31.5 and 21.1°C, respectively.

The minimum air temperatures were below 17°C from mid-May to September 2011, a period during which lowest growth rates were also recorded. The rates of ONN, PBN, PNN and PLN traits decreased to their lowest values in June, when minimum air temperature was 15.7°C, by approximately 0.3 mm day^{-1}, 0.05 branches day^{-1}, 0.01 nodes day^{-1} and 0.02 leaves day^{-1}, respectively. The lowest rate of MCD was recorded in August, at a minimum temperature of 17.0°C, which only grew at 0.5 mm day^{-1}. The other traits showed lower values of growth rates in September, under a minimum temperature of 16.6°C, with a growth of 0.06 branches day^{-1} (OBN), 0.02 g D.M. day^{-1} (ODM), 0.6 mm day^{-1} (OBL), 0.4 mm day^{-1} (PBL), 0.2 mm day^{-1} (OBD), 0.6 mm day^{-1} (OIL) and 0.4 mm day^{-1} (PIL). Those results are consistent with the current understanding that field temperatures below 17°C are associated with decreased growth rates of conilon coffee plants (Partelli et al., 2010, 2013).

Conclusions

The logistic model describing a sigmoid pattern was best fit for all the studied traits, representing cumulative growth form after a regular pruning cycle. The growth rates varied seasonally throughout the year, with higher rates during rainy periods and higher temperatures, even not extremely so, and lower rates during dry season and milder temperatures. The growth rate of 8.1 mm day^{-1} may be explained by the age of new branches, which were stimulated by changing source-sink relationship through pruning.

Conflict of Interests

The authors have not declared any conflict of interests.

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