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Seasonal Vegetative Growth in Genotypes of *Coffea canephora*, as Related to Climatic Factors

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Abstract

Knowledge about the seasonality of different genotypes of *Coffea canephora* is an important tool for this crop management, particularly with regard to irrigation and fertilisation issues. This study was conducted in Espírito Santo, Brazil and aimed at to evaluate the seasonal vegetative growth in genotypes of *C. canephora*, as related to climatic factors, based on the growth of groups of orthotropic and plagiotropic branches with different ages. Three groups of plagiotropic branches and one group of orthotropic branches of 14 genotypes (Ipiranga and 13 that belonged to the variety Vitória) were selected and marked to followed along the one-year experiment. Three-year-old plants were cultivated under full-sun conditions, with a spacing of 3 m between rows and 1 m between plants. The growth rates of the orthotropic and plagiotropic branches differed among the genotypes and underwent seasonal variation during the entire year, with high correlations to the air temperature. Under the natural experimental conditions, the growth rate of the branches decreased when the minimum air temperatures were below 17.2ºC for most of the genotypes studied. The plagiotropic branches presented lower vegetative growth, mainly for the coffee berries, compared to the younger branches. Presumably, the genotypes of *C. canephora* demanded more nutrients for growth between mid-September and the second week of May.

Keywords: Robusta coffee, different genotypes, temperature, plagiotropic branches

1. Introduction

The genus *Coffea* has more than 124 species, among which *C. arabica* L. and *C. canephora* Pierre ex A. Froehner (Davis et al., 2011) are responsible for the yield of about 99% of traded coffee bean. In recent years, the global production of coffee surpassed 144 million bags (Ico, 2013). Brazil is the largest coffee producer and exporter worldwide. In the 2012 the production of *C. arabica* (Arabica coffee type) and *C. canephora* (Robusta coffee type) reached approximately 38.4 and 12.5 million bags (each bag of 60 kg), respectively, occupying an area of 2.27 million hectares (Conab, 2013), being exported a total of about 32 million bags in 2011 (Ico, 2013). Although *C. arabica* is the most cultivated species, *C. canephora* is increasing its importance, worldwide. The same is occurring in Brazil, which has most of its *C. canephora* production in the State of Espírito Santo, which in the 2012 was responsible for 8.49 million bags (Conab, 2013).

In *C. canephora*, inflorescences (glomeruli) are formed from ovules (one glomerulus for each ovule) randomly located in the side-leaf axils formed during the growing season of the current year. Therefore, flowering closely depends on the growth of plagiotropic branches. In coffee, reproductive development begins with gemmation, or flowering, followed by the formation of fruitlets and berry expansion until reaching their normal size. The berry formation and ripening stages are then observed (A. P. Camargo & M. B. P. Camargo, 2001; Pezzopane et al., 2003; Moraes et al., 2008; Petek et al., 2009).

The growth pattern of Arabica coffee is modified by increasing the photoperiod to 14 hours. Fruit removal does not prevent decreased growth rates of branches and leaves, though these organs are larger in coffee trees without fruits. Furthermore, fluctuations in the potential photosynthetic rates do not explain growth variations, and decreases in these rates may be related to biochemical resistance in the chloroplasts. Increased stomatal resistance in the afternoon coincides with drastic reductions in the growth of branches and leaf area. Moreover, the growth of leaves and orthotropic and plagiotropic branches follows the curves of minimum, average, and maximum temperatures (Silva et al., 2004; Amaral et al., 2006).

In coffee, low temperatures (below the range of 13-17 ºC, depending on the authors and genotypes) and pronounced water deficit (-3 MPa) affect various components of the photosynthetic process, as it reduces the stomatal conductance, net photosynthesis, photochemical efficiency of photosystem II, thylakoid electron transport, enzyme activity and carbon metabolism as a whole. Low temperatures also affect the composition and structure of photosynthetic pigment complexes and of the lipid matrix of cell membranes, particularly in the chloroplast, although to different extent among genotype and species (Campos et al., 2003; Ramalho et al., 2003; Silva et al., 2004, Praxedes et al., 2006; Partelli et al., 2009, 2011; Batista-Santos et al., 2011). Such changes may reflect impairments or damages, but in some cases are responses towards plant cold acclimation. Such acclimation ability on coffee genotypes seems to greatly rely on the control of antioxidative conditions, frequently linked to a lower photochemical use of energy through photosynthesis, as observed to happen under low temperatures (Ramalho et al., 2003; Fortunato et al., 2010), water deficit (Ramalho et al., 1998; Lima et al., 2002) and high irradiance and N-deficiency (Ramalho et al., 1998) stresses. Therefore, these changes would configure distinct morphological and physiological acclimation traits in *Coffea* spp.

When cultivated at low temperatures (below 17ºC), *C. canephora* presents marked decreases in growth (Libardi et al., 1998; Partelli et al., 2010) and photosynthesis (Ramalho et al., 2003; Batista et al., 2011), with negative impact on yield. The climate parameters for the zoning of *C. canephora* varieties are based on the region of origin. Thus, understanding the seasonal characteristics of the vegetative growth of *C. canephora* in the most important Espírito Santo region is a decisive tool for crop management, mainly irrigation, and the planning of crop fertilisation programmes. Because there are few studies related to *C. canephora* vegetative growth and the effects of climate, the present work aimed to evaluate the vegetative growth rates of the branches of different genotypes and relate this growth pattern to climatic factors. This analysis was based on the seasonal growth of groups of orthotropic and plagiotropic branches of different ages, in Nova Venezia, northern Espírito Santo.

2. Material and Methods

The experiment was conducted in the municipality of Nova Venezia, northern Espírito Santo, Brazil, located approximately at 18°43'46"South, 40°23'10"North, with an average elevation of 100 m. According to the Köppen classification, the climate is Aw, tropical with a dry season. During the experiment, the average values of temperature, relative air humidity, and rainfall were collected by the automatic weather station located at 3.8 km from the study area, at 154 m of elevation.

The evaluated *C. canephora* plants were three years old and grown under full sun, with a spacing of 3 m between rows and 1 m between plants within the row. The soil is classified as cohesive Red-Yellow Latosol, with dystrophic saturation, low CTC, clayey, and undulated relief (Embrapa, 2006). The following values for soil properties were obtained: pH (water) of 5.41; 6.1 mg dm^{-3} P; 66 mg dm^{-3} K; 1.35 $cmol_c$ dm^{-3} Ca; 0.78 $cmol_c$ dm^{-3} Mg; 7.0 mg dm^{-3} $S\text{-}SO_4$; 0.2 mg dm^{-3}B; 0.4 mg dm^{-3} Cu; 36,8 mg dm^{-3} Fe; 21.0 mg dm^{-3} Mn; and 3.2 mg dm^{-3} Zn in the 0.00-0.20-m layer. The plants were properly managed and irrigated during the experiment.

The experiment consisted of 14 genotypes: plants belonging to the variety Vitória 'Incaper-8142' of *C. canephora* (1V, 2V, 3V, 4V, 5V, 6V, 7V, 8V, 9V, 10V, 11V, 12V, and 13V) (Fonseca et al., 2004) and the super-late cultivar (Ipiranga-501). Each plot consisted of five randomly marked plants, with their branches marked on 09/10/2010. Four groups of branches were used: orthotropic (Ortho), old plagiotropic with berries (PlagVCC), old plagiotropic without berries (PlagVSC), and new plagiotropic (PlagN). The PlagVCC branch was randomly marked by observing the age and number of productive buds. The PlagVSC branch was marked as the last plagiotropic branch grown in the orthotropic branch. The orthotropic branch was marked from the base of the PlagVSC branch. On 29/01/2011, one plagiotropic branch was selected and marked on each plant. Measurements were obtained at an average interval of 15 days for one year (until 08/10/2011).

From those measurements, the daily rate of vegetative growth of the different treatments and groups of plagiotropic and orthotropic branches was calculated. The data for vegetative growth were subjected to an analysis of variance ($P<0.05$) in a completely randomised design. The association between vegetative growth and low temperature was also assessed. The increases are discussed and related to the climatic data and crop irrigation.

3. Results and Discussion

Within the experimental period, the minimum and average temperatures (Figure 1A) presented the lowest average values from May 16 to September 24 (autumn-winter), which characterised a period of conditions adverse to the growth of orthotropic and plagiotropic branches (Libardi et al., 1998; Partelli et al., 2010). In fact, our data agree with those results, as lower growth was observed during this period in almost all of the genotypes studied (Figure 2), confirming that *C. canephora* shows reduced growth during winter (Libardi et al., 1998; Partelli et al., 2010).

Coffee plants grown under low positive temperatures, superimposed to severe water deficiency, suffer several types of impairments and damages with regard to the photosynthetic process, leading to reductions, stomatal conductance, net photosynthesis, photochemical efficiency of photosystem II, thylakoid electron transport, enzymatic activity, and carbon metabolism and, ultimately, in vegetative growth, although with different sensitivities amongst genotypes and species (Ramalho et al., 2003, Silva et al., 2004, Partelli et al., 2009, 2011, Batista-Santos et al., 2011), with *C. canephora* being more sensitive than *C. arabica*.

Reduced growth (Figure 2) was notable when the average minimum temperature was below *ca* 19 ºC (V4, V5, V6, V7, V8, V9, V10, V12, Ipiranga), by the end of March, but decreased growth in some of the branches were found already at *ca*. 21 ºC (V1, V2, V3, V11, V13). Therefore in some cases, growth decreases may begin by in the end of February (Figure 1A), at least for some of the kind of studied branches. A marked decline in growth was observed in most genotypes (V1, V2, V3, V4, V5, V9, V10, V13, Ipiranga) (Figure 2), whereas, although with significant growth reductions, were able to maintain continuous growth (V6, V7, V11, V12). An exception was observed for genotype V8, which maintained high growth rates for most branch groups, especially after the middle of June.

The maintenance of growth in some *C. canephora* genotypes may be associated with mechanisms of tolerance to low temperatures and drought, including the postponement of dehydration to maintain whole-tree photosynthesis, xanthophyll cycle efficiency, increased antioxidant enzyme activity (Fortunato et al., 2010; Silva et al., 2013), and altered leaf lipid and sugar class composition, which might differ among these *C. canephora* genotypes, as found in *Coffea* spp. (Campos et al., 2003; Partelli et al., 2009, 2011). However, to these differences could have contributed the differences in the maturation cycle, as the varieties studied here included those with early, average, late, and super-late maturation cycles (Fonseca et al., 2004).

In general, the highest vegetative growth rates was observed from October 2010 (the start of the measurements) until May 2011 and, subsequently, from mid-September 2011 when most genotypes resumed growth (Figure 2). Thus, most *C. canephora* genotypes may require more nutrients for growth from mid-September to the second week of May due to their higher growth rates.

A slight decrease in the growth rate was observed in summer/autumn (Figure 1), which cannot be attributed to conditions of low minimum air temperature. These punctuated decreases in the growth rate of some genotypes may be associated with a severe attack of *Hemileia vastatrix* that occurred in some clones, high maximum air temperatures (above 34ºC, with some days exceeding 38°C), and the water deficit observed in January and February (Figure 1AB). It must be noted that decreases in the growth rate values varied according to the genotype studied, as *C. canephora* responds differently to soil water deficit (DaMatta et al., 2003; Praxedes et al., 2006).

Considering the several branch groups, the younger plagiotropic branches without berries (PlagN), followed by the old plagiotropic branches without berries (PlagVSC), generally showed higher growth than the orthotropic branches (Ortho) and old plagiotropic branches with berries (PlagVCC), which showed almost no growth before the harvest (Figure 2), what agrees with previous data of our group (Partelli et al., 2010). It is possible that the lowest growth of the old branches may be associated with the genetics of coffee plants and the high demand of carbohydrates and nutrients required to produce the fruits. In addition to the large quantities of carbohydrates required during the expansion phase, the fruits of coffee trees also require substantial amounts of both potassium and nitrogen, which are reallocated from leaves and trunks to the fruit (Partelli & Marré, 2012). Indeed, decreases in the nitrogen content may impair photosynthesis, thereby contributing to the creation of excess energy in the photosynthetic apparatus (DaMatta et al., 2002), which may ultimately lead to oxidative stress and cell damage (Fortunato et al., 2010). Therefore, more than one group of plagiotropic branches should be marked for the estimation of seasonal coffee growth.

The regression analyses between the growth of branches and all the environmental parameters were not significant when the entire experimental period was considered (data not shown). However, a more detailed analysis considering only the period of decreasing temperature allow to find significant correlations with the minimum air temperature (Figure 3). The best adjustment was obtained using the average minimum temperatures observed from 26/03/2011 to 10/09/2011, with R^2 = 0.87 for the orthotropic branches, R^2 = 0.91 for the old plagiotropic branches without berries, and R^2 = 0.92 for the new plagiotropic branches (Figure 3). These results confirm that low air temperature is an important variable reducing the growth of *C. canephora* in the autumn/winter season.

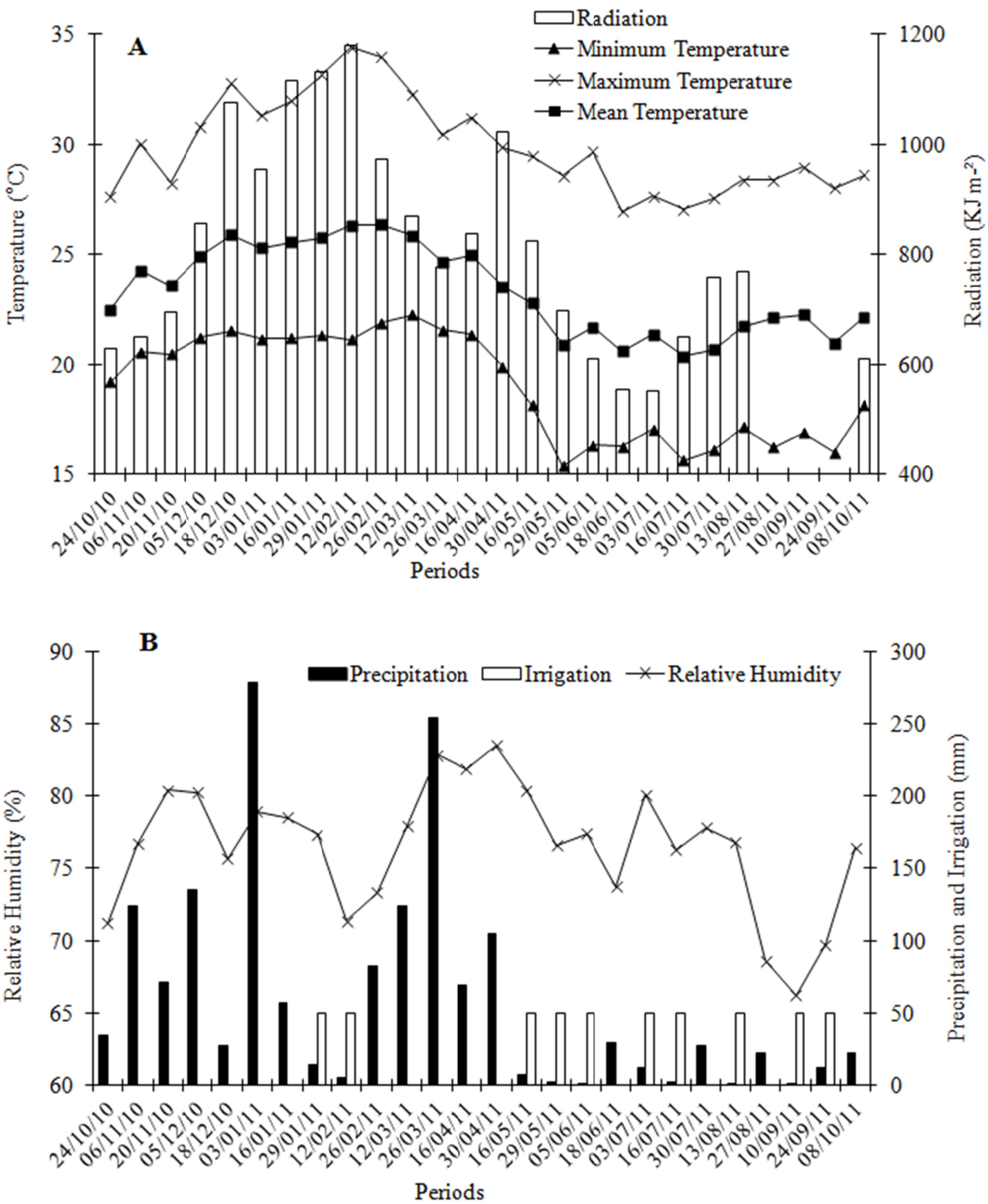
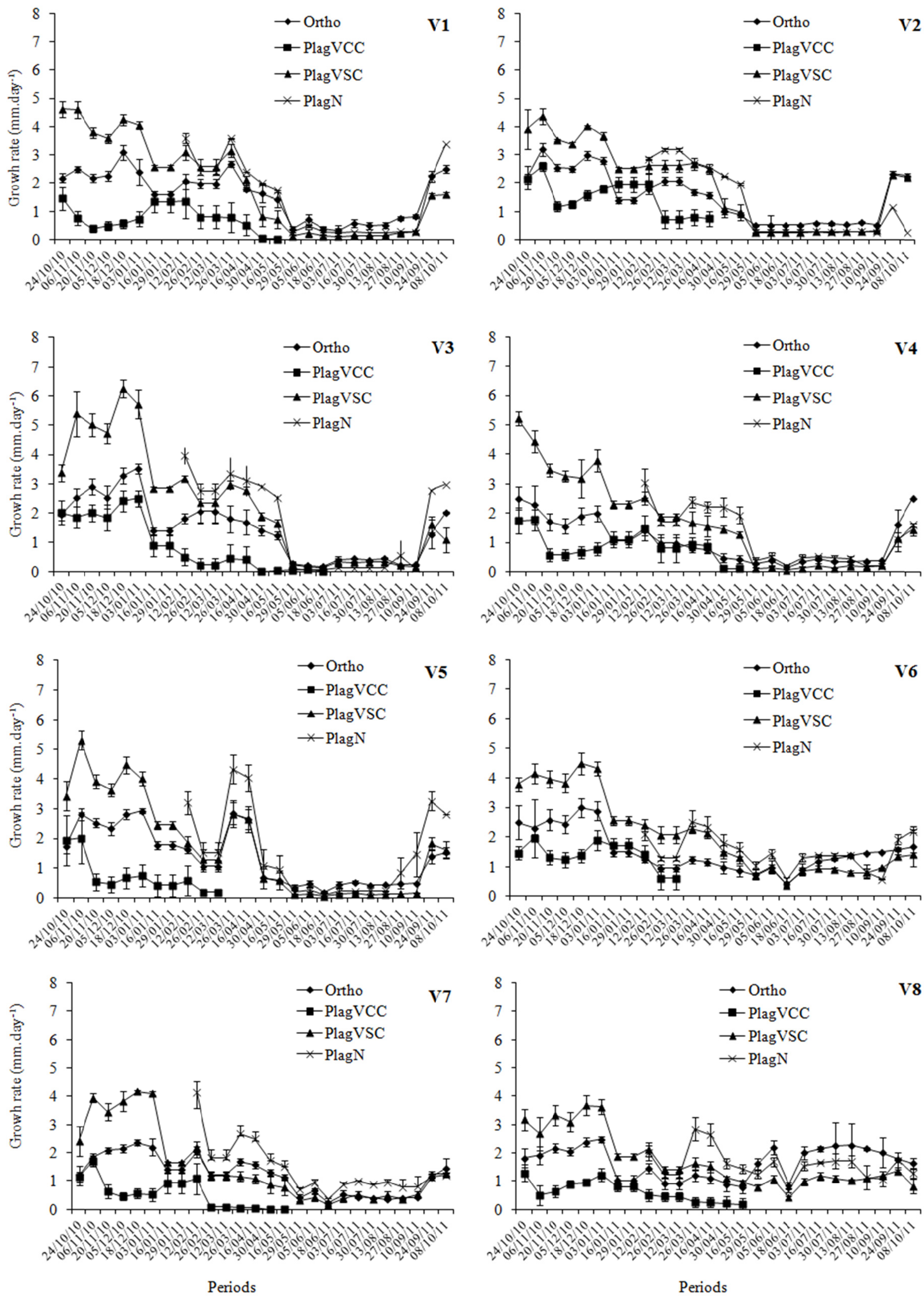


Figure 1. Averages for minimum, maximum, and mean temperature, radiation (A), precipitation, irrigation, and relative humidity (B) measured during the experiment. Nova Venécia/ES, 2010/2011. Note: It was not possible to obtain radiation data from August 13 to September 24


V1
V2
V3
V4
V5
V6
V7
V8
Ortho
PlagVCC
PlagVSC
PlagN
Growth rate (mm.day-1)
Periods

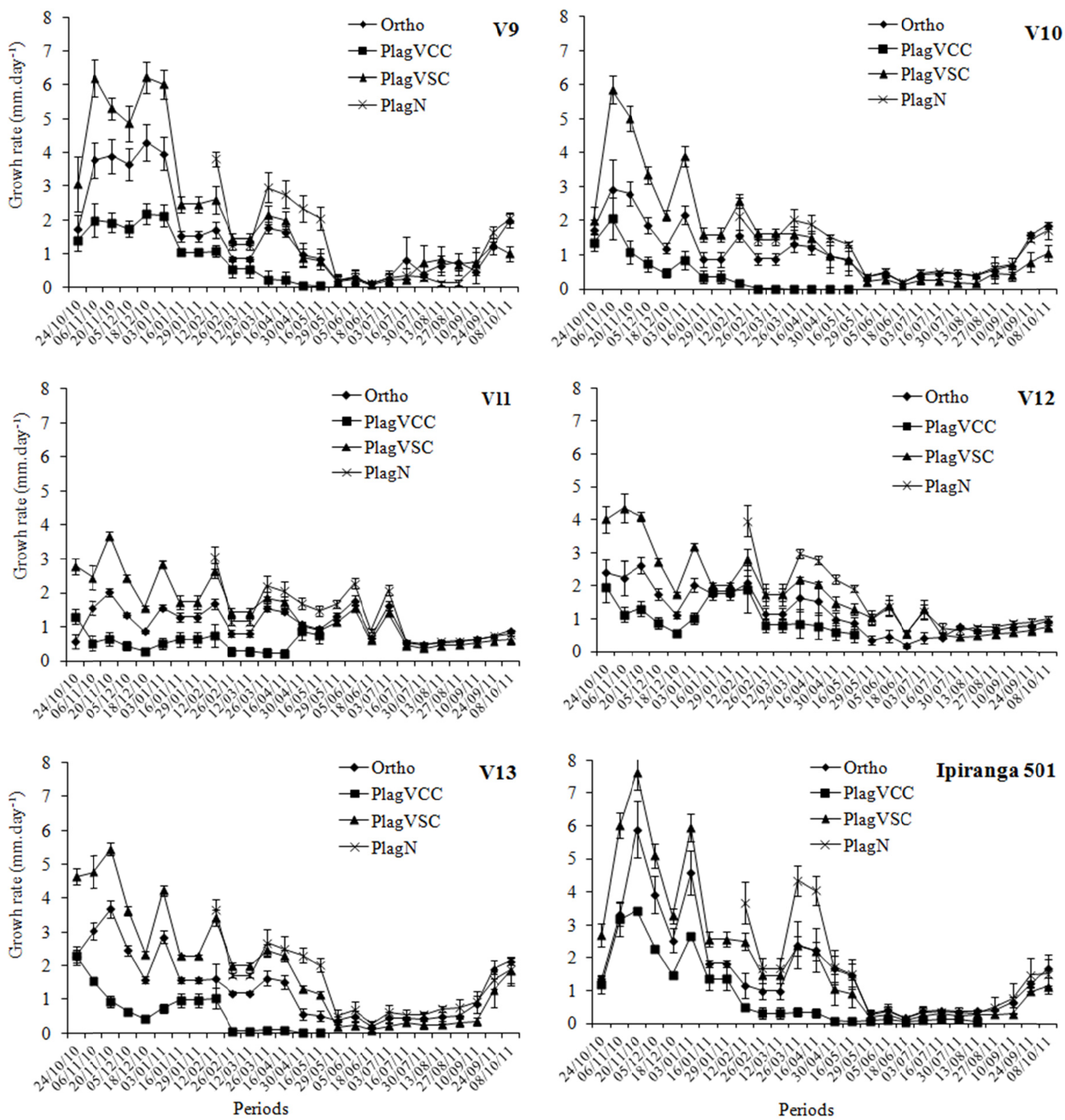


Figure 2. Vegetative growth rate (mm day^{-1}) of groups of orthotropic and plagiotropic branches along one-year experiment in 14 genotypes of *C. canephora*. Each point represents the mean + SE (n = 05)

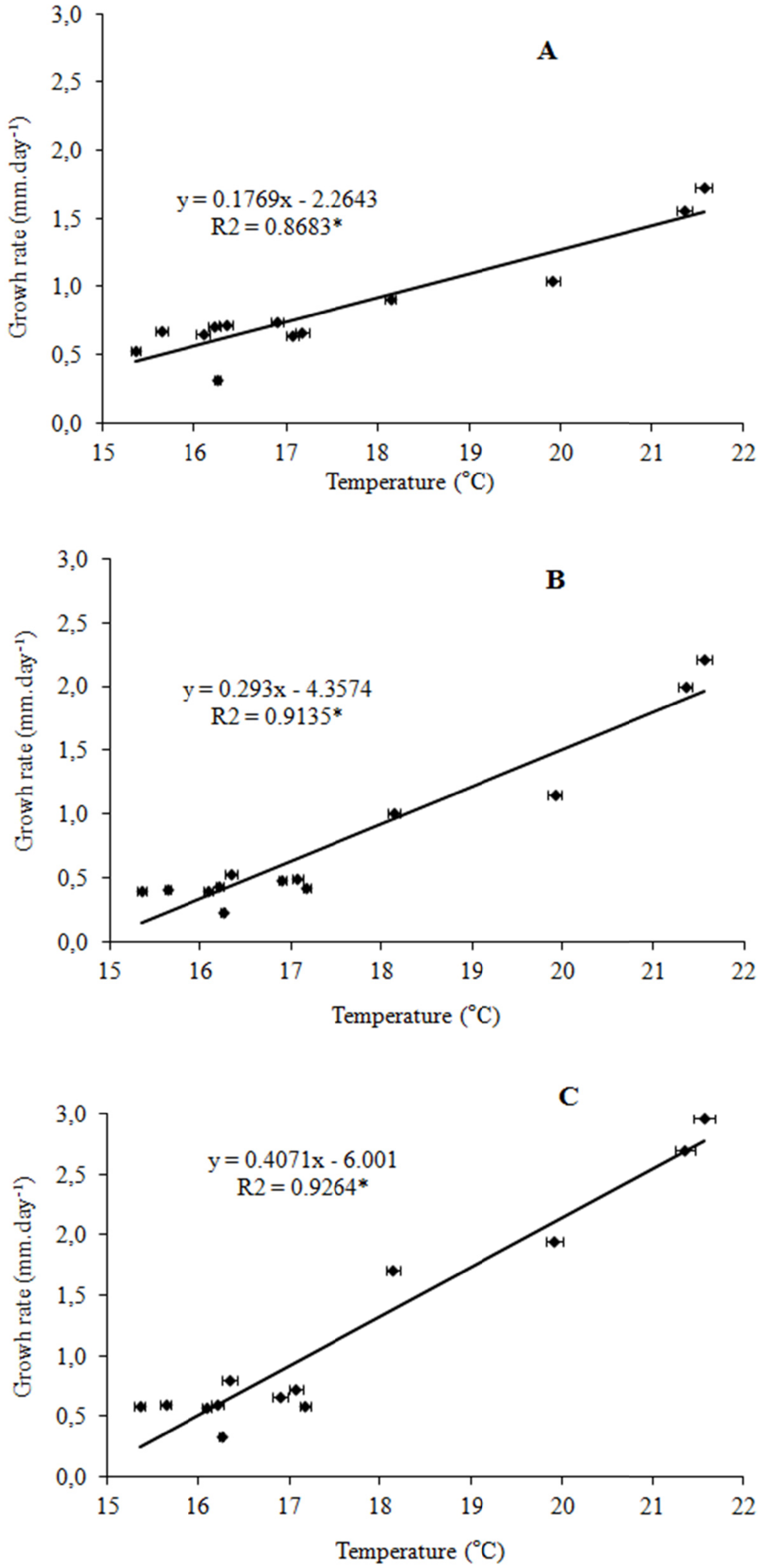


Figure 3. Association between the average minimum temperature (measured between 26/03/2011 and 10/09/2011 - autumn/winter) and the vegetative growth rate of orthotropic branches (A), old plagiotropic branches without berries (B), and new plagiotropic branches (C)

4. Conclusion

Under our experimental conditions, the growth rate of the orthotropic and plagiotropic branches of *C. canephora* differed according to the genotype and underwent seasonal variation throughout the year, which was mainly influenced by changes in the air temperature. Under minimum air temperatures below 17.2°C, the growth rate of *C. canephora* branches was sharply reduced for most of the genotypes studied. Yet, strong differences were found amongst genotypes, with V8 being the one that maintained an appreciable growth rate of most of branch groups along almost the entire year. Over the course of months, plagiotropic branches, mainly those with berries, presented less vegetative growth when compared to the younger branches.

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