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Intercropping of coffee with the palm tree, *macauba,* can mitigate climate change effects

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A R T I C L E I N F O

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A B S T R A C T

Global climate changes can affect coffee production in Brazil, and in other coffee producing countries. We examined the potential for an agroforestry system with the native species, macauba (*Acrocomia aculeata*), to mitigate impacts on coffee production by reducing maximal air temperature and photosynthetic active radiation. The objective of this study was to investigate the influence of an agroforestry system with *macauba* on productivity, microclimatic characteristics and soil physical quality on a coffee plantation in the Atlantic Rainforest biome, in Southern Brazil. We measured soil attributes (moisture, temperature, and physical properties), microclimate conditions (air temperature, photosynthetic active radiation) and coffee production parameters (productivity and yield). Macauba palm trees were planted at different planting densities on the rows and distances from the coffee rows. Planting density of *macauba* and their distance from the coffee rows affected soil thermal-water regime. Compared with the traditional unshaded sole coffee planting, the intercropped cultivation provided more coffee yield on both macauba density planting and distance evaluated. On the other hand, coffee productivity was increased by agroforestry systems just for 4.2 m distance between palm trees and coffee rows. Planting density of *macaubas* did not affect coffee yield and productivity. Best coffee harvest in agroforestry systems with *macauba* was related to higher soil moisture at the depth of 20–40 cm, higher photosynthetic active radiation, and maximum air temperatures lower than 30 °C. Agroforestry with coffee and *macauba* trees can be an adaptation strategy under future climatic variability and change related to high temperatures and low rainfall.

1. Introduction

Climate variability is the main factor responsible for variations in coffee harvest from year-to-year in Brazil (Camargo, 2010). Given the projected global climate change scenarios, there is considerable interest in the potential impact on coffee production in traditional areas of coffee plantation in Brazil.

Among the climatic variables that affect the growth and production of *Coffea arabica*, temperature, light and water availability stand out as the most relevant (Camargo, 2010). According to the Fifth Report of the Intergovernmental Panel on Climate Change (IPCC et al., 2013), coincidentally these variables probably will change in the future, raising the risk for the coffee farmers and the coffee industry of Brazil and other parts of world, as pointed for Nicaragua (Läderach et al., 2017), Nepal (Ranjitkar et al., 2016), Mexico and Vietnam (Eakin et al., 2009) and Ethiopian (De Beenhouwer et al., 2016).

While macroclimate changes are not manageable by coffee producers, there may be agronomic strategies available for reduction the expected consequences of climate change in the medium term by altering in the microclimate. Agroforestry systems are a possible strategy to minimize the effects of climate change on coffee crops (Fazuoli et al., 2007; Lin, 2010; Venturini et al., 2013) by reduction of solar radiation (Pezzopane et al., 2010; Siles et al., 2010) and air temperature (Morais et al., 2006; Pezzopane et al., 2010; Siles et al., 2010; Valentini et al., 2010), leading to the stabilization of microclimate and a decrease in soil carbon dioxide (CO_2) efflux variability (Gomes et al., 2016), as well as a better water use efficiency (Lin, 2010). In addition, agroforestry systems can contribute to the improvement of soil physical quality (Aguiar, 2008) and to provide environmental services and more products to the farms.

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Coffee production under agroforestry systems was common in northern and northeastern regions in Brazil until the 1960s (Jaramillo-Botero et al., 2006). However, these systems used high-density tree planting and often had low coffee productivity (Caramori et al., 2004). Negative effects on production are associated with competition for water, nutrients, and light between tree species and coffee plants. Nevertheless, in the 1970s, through coffee afforestation programmes, agroforestry was re-emphasized because of the benefits of moderate shade to the coffee plants (Caramori et al., 2004). After that, further studies are been required considering different tree species and different spacing aiming to maximize the benefits of agroforestry systems on coffee plantation in diverse regional peculiarities.

Among the tree species suitable for agroforestry, *macauba* (*Acrocomia aculeata*) has gained recent prominence, primarily because it is a palm tree widely distributed throughout Brazil. This palm tree is found in open and relatively dry areas (Mota et al., 2011), has monopodial growth, can reach the height of 20 m, and fruit harvesting concentrates between September and January (Lorenzi, 2006), differently of coffee plants that concentrate production from April to July. A major potential use of *macauba* fruit is for biofuel production since pulp and beans are rich in lipids. In addition, these two fruit components can be used by food industries, and for detergent and cosmetics production (Azevedo-Filho et al., 2012). A National Program for Production and Use of Biodiesel (PNPB), launched in 2004 by the Brazilian Government, has promoted the purchase of those raw materials directly from farmers.

Hence intercropping *macauba* trees with coffee plants could be a profitable venture for farmers. However, there is limited understanding of the interactions between these two species and how they are influenced by tree spacing and planting density, in order to achieve a balance between environmental and economic gains.

Therefore, this study objective to investigate the influence of agroforestry systems with *macauba* on microclimatic characteristics, soil physical quality, and yield of a coffee plantation in the Minas Gerais State, located at Atlantic Rainforest biome in Southern Brazil.

2. Materials and methods

2.1. Site characterization

The experiment was carried out in Viçosa, located in the Atlantic Rainforest Brazilian biome, in Minas Gerais State, Brazil. The agroforestry experiment could not be structured in such a way as to control the heterogeneity of the site and was composed of a single experimental block in a real farm situation. The site was at around 675 m a.s.l. on a Red Yellow Latosol (Hapludox) with clayed texture. It was uniform in terms of soil attributes (Table 1) and slope (northwest, 17%). Additionally, at the start of the experiment, the total area was prepared on the same day, using the same mechanical procedures and received the equal amounts of fertilizes and liming. Since then, all management practices were performed following the same procedures and according to standard techniques used by coffee farmers.

The agroforestry treatments were established in November 2007 with *Coffea arabica* (cv. Oeiras) intercropped or not with macauba: coffee grown 1.4 m (T1) or 4.2 m (T2) away from *macaubas* planted at high row density (318 palm trees ha^{-1}); coffee grown 1.4 m (T3) and 4.2 m (T4) away from *macaubas* planted at low row density (203 palm trees ha^{-1}); and a control treatment, corresponding to the full-sun coffee cultivation (T5) (Fig. 1).

Macauba trees had been planted in two densities: 11.20 m × 2.80 m (high) and 11.20 m × 4.40 m (low). Since distances between rows were the same for both treatments, high and low density refer to narrower and wider spacing of trees within a row, respectively. In both densities, the trees grew to around 6 m height. In all treatments, coffee plants spacing was 2.80 × 0.75, corresponding to 4.762 plants ha^{-1} (Fig. 1).

The experiment was carried out considering four replicates (plots)

Table 1
Soil chemical and physical characterization of the experimental area in Viçosa, MG, Brazil.

Chemical attributes	0–20 cm	Physical attributes	0–20 cm	20–40 cm
pH (H_2O)	5.98			
P (mg dm^{-3})	2.60	Sandy (%)	44	39
K (mg dm^{-3})	103.7	Silt (%)	13	12
OM (dag kg^{-1})	1.91	Clay (%)	43	49
Ca ($cmol_c$ dm^{-3})	1.95			
Mg ($cmol_c$ dm^{-3})	0.66	θFC (m^3/m^3)	0.44	0.44
Al ($cmol_c$ dm^{-3})	0.20	θPWP(m^3/m^3)	0.20	0.22
H + Al ($cmol_c$ dm^{-3})	4.41			
CEC (t) ($cmol_c$ dm^{-3})	3.07			
CEC (T) ($cmol_c$ dm^{-3})	7.28			

Chemical characterization according Embrapa (2011).
θFC: moisture at field capacity.
θPWP: moisture at permanent wilting point.

per treatment, excepting when sensors were used (soil moisture and temperature, and air temperature). Variables recorded by sensors were evaluated considering two replicates, and sensors were installed in the center of two plots. The size of each plot was 8.4 m^2, corresponding to 4 coffee plants. Plots of T2 and T4 are contiguous, but plots of T1 and T3 were divided in two equal parts and management close do macauba plants of two different palm lines.

Since the experiment started, all plots received the same management. Only coffee plants received annual mineral fertilization, corresponding to doses recommended by Guimarães et al., (1999), which is distributed in three applications during the rainy season. In 2013 and 2014, 100 and 150 g of 20-5-20 fertilizer (N – P_2O_5 –K_2O) were used, respectively, per application. The control of weeds was performed periodically in all treatments without pesticides use, just by manual and mechanical weeding, and residues are left on the soil surface.

2.2. Evaluation of soil physical quality and soil moisture and temperature

Soil moisture and temperature were monitored from April to August 2014, coinciding with the dry season in the southeast region of Brazil. Rainfall during 2014 was below average than previous years. While 2014 presented 825 mm the average of 2011–2013 was 1349 ± 75 mm.

Soil moisture and temperature were monitored by sensors (Decagon EM50) placed in the center of two layers, in the top (0–20 cm) and deep (20–40 cm) positions, with two replications per treatment (Fig. 1). Soil layers selected represent the soil portion with the highest concentration of absorbing roots of coffee plants (Rena and Guimarães, 2000). The sensors were coupled to a datalogger (Decagon ECH_2O Logger) which set to take readings at intervals of 60 min. Moisture sensors were calibrated using with gravimetric soil water values.

Rainfall was monitored on the experimental area using two rain gauges. The volume collected was measured daily at around 4:30 pm to get the accumulated rainfall data.

For soil physical quality evaluation, four undisturbed soil cores (5 cm height and diameter) were sampled in the coffee rows at the center of 0–10, 10–20, 20–30 and 30–40 cm depth layers in each treatment (one soil core per plot). These samples were used for the determination of soil bulk density (Bd) and soil microporosity (Mi). Density of particles (Dp), total soil porosity (TP) and macroporosity (Ma) were also evaluated. All soil physical analyzes were conducted according to Embrapa (2011).

2.3. Microclimatic characterization

Maximum and minimum air temperatures were monitored by