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Initial growth of coffee plants associated with the use of kaolinite and adjuvant

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ABSTRACT

Abiotic stresses cause significant damage to coffee plants' development. Seeking solutions to mitigate them, studies about antiperspirant action have been intensified, for instance, kaolinite, which produces a film of particles with reflexive properties. In this context, this experiment aims to evaluate the effects of applying kaolinite doses in different colors with or without the addition of adjuvant on biometric variables during coffee plants' initial growth. The randomized block design was used with three repetitions in an incomplete factorial scheme with an additional treatment, resulting in 11 treatments and 33 plots. The first factor comprised three kaolinite doses (20, 40, and 60 g); the second factor had two kaolinite colors (white and cream), and the third factor was the absence or presence of an adjuvant, also including an additional treatment (control). The plot consisted of four seedlings of the cultivar IPR 100. It was observed that the plant height (PH), number of plagiotropic branches (NPB), leaf area index (LAI), leaf dry matter (LDM), shoot dry matter (SHDM), root dry matter (RDM), and total dry matter (TDM) presented significant differences. Regarding PH, the dose of 40 g of cream kaolinite increased 7.07 cm more than the control. For LAI, the dose of 40 g with adjuvant had a 97.65 increase. For LDM and TDM, the dose of 40 g of white kaolinite with adjuvant presented respective increases of 5.2 and 12.78 g. The application of white kaolinite with adjuvant increased SHDM by 4.52 g. For RDM, the dose of 40 g of white kaolinite with adjuvant increased 6.51 g more than the control. The dose of 40 g of white kaolinite with adjuvant had a higher effect on the biometric variables.

Key words: Antiperspirant; biomass; *Coffea arabica* L.; thermal stress; particles' film.

1 INTRODUCTION

Brazil, the largest coffee beans producer, predicted for the 2020/2021 harvest the production of 46,878.7 thousand bags of coffee beans, a reduction of about 25.7% compared with the previous harvest (Companhia Nacional de Abastecimento - CONAB, 2021). Such decrease is associated with the physiological effects of the negative biennial and the adverse climatic conditions of drought, high temperatures, and frost in the productive regions.

Due to climatic factors, such as temperature, air and soil humidity, coffee crops for commercial production are practically confined to the intertropical region, ranging between the latitude 20-25º N and the latitude 24º S (Bicho et al., 2011). The Arabian coffee, the main species of economic interest of the genus *Coffea*, presents a narrow optimal thermal range between 18 and 22 ºC (Matiello et al., 2010), limiting its productive area in a tropical country like Brazil.

The adverse environmental conditions oblige many coffee producers to use the *recepa* pruning (stumping) to protect the plantation and permit a higher production in the next crop. Such adversities impose on researchers and farmers the necessity of studying management techniques that mitigate the effect of higher than ideal temperatures, such as shading (Ribeiro et al., 2019), space reduction (Ronchi et al., 2015), selection of high-temperature tolerant cultivars (Brito et al., 2019), and more recently the application of kaolinite has been used (Santos et al., 2021).

In the last years, studies about products with antiperspirant action have increased. Three types of products are known: particles' film, reflector materials, and stomata closing promoters (Glenn, 2012; Ahmed et al., 2013; Conde et al., 2018; Ribeiro et al., 2019). The antiperspirants that stand out are the pellicle forming such as kaolinite and the reflectors because they are not toxic and have a longer efficient period compared with those of metabolic effect that stimulate stomatal closure (Ahmed et al., 2013).

Kaolinite is mentioned by Glenn and Puterka (2005) as an antiperspirant that forms a particles' film, being described as a modified clay, multifunctional, of white color, not porous, non-pollutant, and low abrasiveness. It is sold as a powder (Glenn et al., 2010), diluted in water, and applied through a spray. When dry, it covers the leaf surface with a white pellicle, forming a particles film with reflexive properties (Dinis et al., 2016).

The literature cites the use of kaolinite with beneficial effects on many crops, such as papaya (Campostrini; Reis; Souza, 2010), grape (Glenn et al., 2010; Dinis et al., 2016; Conde et al., 2018), apple (Glenn, 2009), eucalypt (Santos et al., 2021), cotton (Silva; Silva, 2015), and coffee (Steiman; Bittenbender, 2007; Cobra et al., 2020).

The main effects described are leaf thermal regulation reducing the impact of high temperatures; efficient use of water resources by the plant, enhancing water deficit response; carbon assimilation because the stomata remain open for more extended periods; protection against scalds (Boari et al., 2015) and pests and diseases (Nateghi; Paknejad; Moarefi, 2013; Silva; Silva, 2015).

From the above, the hypothesis of this work is that the application of different colors and doses of kaolin associated or not with the presence of adjuvant will promote the vegetative growth of the coffee tree in its initial development. Therefore, this study aims to evaluate the effects of applying kaolinite doses in different colors with or without the addition of adjuvant on biometric variables during coffee plants' initial growth.

2 MATERIAL AND METHODS

The experiment was conducted in the Experimental Station of Horticulture and Biological Control Professor Mário César Lopes (latitude 24º46' S, longitude 54º22' W, and altitude about 420 m), pertaining to the Western Paraná State University (Universidade Estadual do Oeste do Paraná-UNIOESTE), Campus of Marechal Cândido Rondon - PR. It was conducted under field conditions between November 2, 2020, and May 8, 2021. The meteorological data about the experimental period was obtained in the Meteorological Station of Automatic Surface Observation of Marechal Cândido Rondon (Figure 1).

According to the Köppen classification, the region's climate is of the type Cfa, mesothermal, and humid subtropical (Alvares et al., 2014). The mean air temperature annual average was between 22 and 23 ºC, and the relative air humidity was between 70 and 75%. The total yearly rain precipitation varied between 1600 and 1800 mm, with reference evapotranspiration between 1000 and 1100 mm per year (Nitsche et al., 2019).

The substrate soil is Latossolo Vermelho distroférrico of a very clayish texture (695 g kg^{-1} clay, 212 g kg^{-1} silt, and 93 g kg^{-1} sand) (Santos et al., 2018). The portion of soil collected for the experiments was sieved (mesh 4 mm). Then, samples were randomly collected and sent for soil chemical attributes characterization (Teixeira et al., 2017).

The soil chemical analysis results before the experiment were: pH in $CaCl_2$ = 5.55; organic matter = 34.25 g kg^{-1}; P (available) = 21.58 mg dm^{-3}; Ca^{2+} = 2.09 $cmol_c$ dm^{-3}; Mg^{2+} = 1.57 $cmol_c$ dm^{-3}; K^+ = 1.31 $cmol_c$ dm^{-3}; Al^{3+} = 0.12 $cmol_c$ dm^{-3}; H+Al = 4.29 $cmol_c$ dm^{-3}, SB = 4.97 $cmol_c$ dm^{-3}; CTC = 9.26 $cmol_c$ dm^{-3}; V = 53.7%.

The randomized block design was used with three repetitions in an incomplete factorial scheme with an additional treatment (3 x 2 x 2 - 1) + 1, resulting in 11 treatments and 33 plots. The first factor comprised three kaolinite doses (20, 40, and 60 g); the second factor had two kaolinite colors (white and cream), and the third factor was the absence or presence of adjuvant (mineral oil in the proportion of 0.05% used to act as a spreader and adhesive), also including an additional treatment (absolute control), receiving water in the same volume of syrup that the other kaolin-based treatments received. The factorial scheme was incomplete by the absence of the dose 60 g (white and cream color) with adjuvant due to the technical impossibility of applying it without obstructing the spray nozzle. The plot had four seedlings, each seedling deposited in a pot with 12 dm^3 of soil.

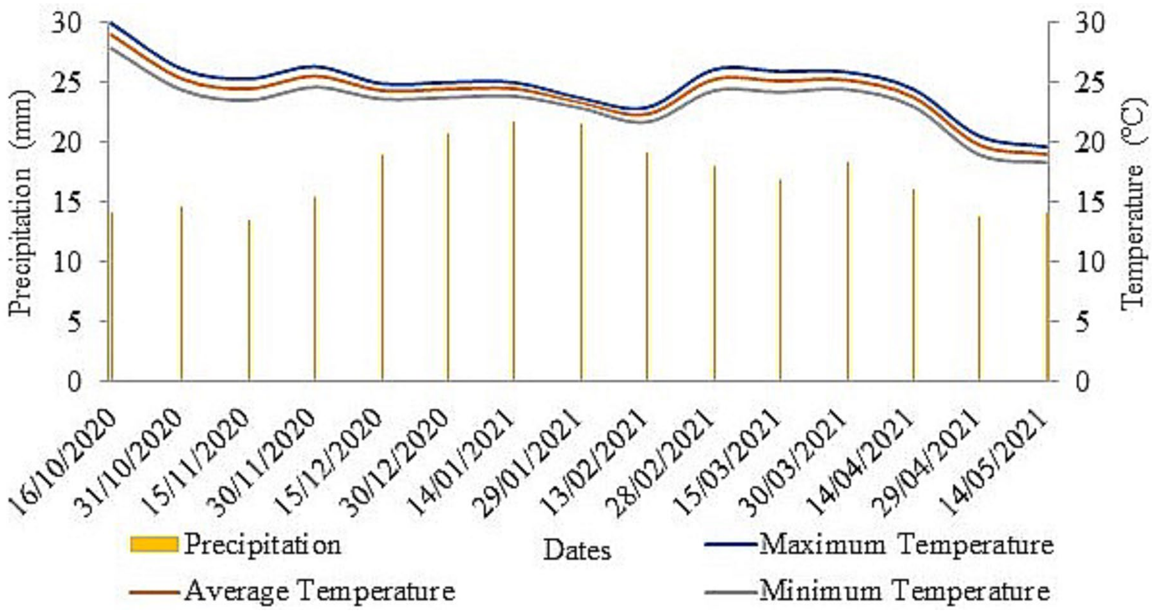

Figure 1: Precipitation, maximum, minimum, and average temperatures between November 2, 2020, and May 8, 2021, Marechal Cândido Rondon-PR.

The cultivar used was IPR 100, which originated from the crossing between a coffee plant from the germplasm Catuaí and the coffee plant "Catuaí" x coffee genotype of the series 'BA-10' with genes of *C. liberica*. IPR 100 is primarily indicated for warm regions with average temperatures above 21.5 ºC (Sera; Sera, 2017).

The substrate fertilizing was conducted based on the Handbook of Fertilizing and Liming for the state of Paraná (Sociedade Brasileira de Ciência do Solo - SBCS, 2017), applying 155 kg ha^{-1} of the commercial formulation of 10-15-15 (N-P_2O_5-K_2O). The coffee seedlings were obtained from a certified nursery and had four leaf pairs and the presence of a "jaguar ear" leaf. They were kept in a semi-protected area for 15 days for acclimation. Seven days before implementing the experiment, the protective fungicide copper oxychloride was applied at the dose of 2 kg ha^{-1} with a spray volume of 200 L.

The kaolinite used was sent for chemical analysis in the Laboratory of Analysis of Minerals and Rocks of the Geology Department of the Federal University of Paraná, that determined the pH of 5.4 and the following chemical composition: SiO_2 (47.56%), Al_2O_3 (36.14%), Fe_2O_3 (1.33%), K_2O (1.20%), TiO_2 (0.40%), CaO (0.03%), MgO (0.11%), Na_2O (0.01%).

The treatments' application started on December 2, 2020, 30 days after transplanting the seedlings. (Cobra et al., 2020). A CO_2 pressurized backpack sprayer was used with a constant pressure of 43.5 Psi, a ceramic triple flat fan spray bar Magnojet, of conical type 100, at a 50 cm height of the plants, and the spray volume of 250 L ha^{-1} (Silva; Ramalho, 2013). At the moment of application, the air temperature and relative humidity were 27 ºC and 54%, respectively, measured using a thermo-hygrometer model HT-700. The wind speed was 4.5 km h^{-1}. The treatments' application occurred in a 30-day interval over six months. The soil humidity was kept close to 0.25 m^3 m^{-3}, field capacity, monitored a soil moisture determiner (model Hidro Farm 1+ FM 2030).

The biometric evaluations conducted were plant height in centimeters (PH), stem diameter in centimeters (SD), number of plagiotropic branches (NPB), leaf area index (LAI), leaf dry matter in grams per plant (LDM), stem dry matter in grams per plant (SDM), root dry matter in grams per plant (RDM), shoot dry matter in grams per plant (SHDM) and total dry matter in grams per plant (TDM). The non-destructive evaluations (PH, SD, and NPB) were conducted monthly after the treatments' applications. The destructive evaluations (LAI, LDM, SDM, SHDM, TDM) were made after the experiment collection on May 8, 2021.

Plant height (PH) was measured with a tape measure from the plant's basis in the soil until the last leaf was established in the main branch (orthotropic). The stem diameter (SD) was measured with a digital caliper at the height of 5 cm of the stem from the soil. The number of plagiotropic branches (NPB) was counted with a pair number table in the experimental area.

The plants had their structures separated (root, stem, and leaves) in the experiment collection. The leaves passed through the (stand leaf area measurer model LI-3100C Area Meter) to determine the specific leaf area (cm^2 g^{-1}). Then, they were identified and stored in kraft paper bags, dried in a greenhouse with forced-air ventilation at 65 ºC for 72 hours, obtaining the LDM. This methodology was reproduced for the other parts (stem and root), determining SDM and RDM, while SHDM was obtained by adding SDM + RDM, and TDM was obtained by adding RDM + SHDM. After this period, they were weighed with a precision scale of 0.0001 g. LAI was measured by the direct method, using the multiplication of the specific leaf area by the LDM (Lucchesi, 1984).

The data obtained were submitted to Shapiro-Wilk normality tests and Hartley's homogeneity of variances test, verifying the lack of data normality. They were transformed through $\sqrt{x+1}$, and the analysis of variance (ANOVA) was performed. The significant means by the F-test ($p \leq 0.01$ and ≤ 0.05) were compared by the Tukey test. The means exposed in the tables are from the re-transformed data obtained from the inverse operation at $\sqrt{x+1}$. The statistical analyses were made with the program SAS (SAS Analysis System, 2014).

3 RESULTS

The analysis of variance showed significant differences for PH between dose x kaolinite colors; dose x adjuvant; kaolinite colors x adjuvant; and factorial x additional. For NPB and LAI, there was a difference in the interaction between dose and adjuvant. For LDM, there were interactions between dose and kaolinite color, dose and adjuvant, and kaolinite color and adjuvant. For SHDM, there was an interaction between kaolinite colors and adjuvant. For RDM, there was a difference between the additional treatment and the adjuvant. Finally, for TDM, the interactions between kaolinite color x adjuvant and factorial x additional treatment presented differences (Table 1). There were no significant differences regarding the variables SD and SDM, with an average mean of 7.25 cm and 4.17 g, respectively.

In the variable PH, there was an interaction between dose x adjuvant. The dose of 40 g of cream kaolinite without adjuvant differed from that of 40 g of cream kaolinite with adjuvant, presenting a height increase of 5.42 cm (12.92%). For the other combinations, the means did not differ (Table 2). Regarding the dose of 60 g, it could not be analyzed by the lack of treatments with this dose with adjuvant.

Regarding PH, compared with factorial x additional, significant differences were observed in the dose of 40 g of white kaolinite with and without adjuvant, 60 g of white kaolinite, and 40 g of cream kaolinite without adjuvant (Table 2). Comparing the additional (control) treatment with the dose of 40 g of cream kaolinite without adjuvant, a PH growth of 20.27% was perceived for plants that received kaolinite, with an increase of 7.07 cm between the means observed. The doses of 40 and 60 g of white kaolinite without adjuvant and 40 g of white kaolinite with adjuvant had increases of 5.57 cm, 5.24 cm, and 4.62 cm.

Evaluating the NPB in the interaction dose x adjuvant, it is observed that the doses of 20 g and 40 g with and without adjuvant presented no difference (Table 3). The same behavior was observed for the dose of 20 g without adjuvant x 20 g with adjuvant or 40 g with and without adjuvant.

LAI in the interaction dose x adjuvant comparing the doses 20 g x 40 g with or without adjuvant presented no difference between them (Table 4). Within the doses, the dose of 40 g without adjuvant differed from the same dose with adjuvant in the order of 38.53%, with an LAI increase of 97.65, which was not observed for the dose of 20 g.

Regarding LDM within the interaction dose x kaolinite colors, regardless of the doses or color used without adjuvant, the means did not differ between them. However, the results for the dose of 40g between white and cream kaolinite with adjuvant present a difference between the means, with a 55.17% increase for white kaolinite compared with the cream kaolinite, increasing 5.2 g between the treatments (Table 5).

In the interaction kaolinite colors x adjuvant for LDM, the means did not differ between them regardless of the established comparisons. However, in the interaction doses x kaolinite colors, the white kaolinite comparison between the doses 20 x 40 g with adjuvant had a difference between the means of 24.74%, representing an increase of 2.87 g of LDM for the dose of 40 g of white kaolinite with adjuvant. This behavior was not observed for cream kaolinite.

Table 1: Mean square of plant height (PH), stem diameter (SD), number of plagiotropic branches (NPB), leaf area index (LAI), leaf dry matter (LDM), stem dry matter (SDM), root dry matter (RDM), shoot dry matter (SHDM), and total dry matter (TDM).

SV	DF	PH	SD	NPB	LAI	LDM	SDM	RDM	SHDM	TDM
		Mean square								
Block	2	13.65	1.28	0.57	9693.07	5.88	1.55	1.99	13.14	22.93
Dose	2	5.47	1.03	0.36	16756.47*	3.81	0.14	12.84	2.53	25.53
Kaolinite	1	2.55	0.52	0.11	37669.51*	12.63*	0.07	4.72	10.79*	1.24
Adj	1	14.11	1.90	0.04	10738.28	13.32*	0.42	66.53*	18.44*	155.01*
Dose*Kaolin	2	18.20*	0.10	0.03	6170.29	2.06	0.01	2.93	1.85	8.56
Dose*Adj	1	4.04	0.27	1.04*	18378.41*	2.45	0.50	3.20	5.17	16.51
Kaolin*Adj	1	1.82	0.61	0.38	53886.22**	32.76*	1.13	1.32	46.06*	62.97*
Dose*Kaolin*Adj	1	15.20*	0.09	0.04	41.55	10.71*	0.51	12.22	6.54	36.65
Additional	1	42.84**	0.41	0.07	297.43	4.20	0.64	18.55*	8.12	51.21*
Error	20	3.17	0.49	0.18	2905.68	1.04	0.71	4.06	2.43	10.18
Total	32					---				
Average		38.61	7.25	2.86	264.56	7.11	4.17	12.02	11.29	23.31
CV (%)		4.62	9.65	14.67	20.37	14.30	14.30	16.75	13.81	13.69

Note. SV – source of variation, DF – degrees of freedom, CV – Coefficient of variation, Adj- Adjuvant, * significant at 5% by the F-test, ** significant at 1% by the F-test.

Table 2: Plant height (PH) of Arabian coffee cultivar IPR 100 submitted to different doses and colors of kaolinite with or without adjuvant.

	PH (cm)									
			Control		34.88	*A*				
Color/ Dose	Without adj						With adj			
	20 g		40 g		60 g		20 g		40 g	
White	38.46	aAα*A*	40.63	aAα*B*	40.12	aA*B*	37.63	aAα*A*	39.50	AAα*B*
Cream	37.93	aAα*A*	41.95	aAα*B*	37.83	aA*A*	39.18	aAα*A*	36.53	AAb*A*

Note: Adj-adjuvant. Lowercase letter comparison in the column between the colors within doses and adjuvants. Uppercase letter comparison in the line between doses within colors and adjuvants. Greek letter comparison in the line between the doses with or without adjuvants within the same color by Tukey's. Uppercase letter in italics compares the treatment x additional by the Tukey test at 5% probability.

Table 3: Number of plagiotropic branches (NPB) of Arabian coffee plants of the cultivar IPR 100 submitted to different doses and colors of kaolinite with or without adjuvant.

			NPB						
			Control		3.00				
Color/Dose			Without adj				With adj		
	20 g		40 g		60 g		20 g		40 g
White	2.50		3.16		2.66		3.33		3.00
Cream	2.66		3.16		2.50		2.83		2.66
	Without adj	20 g	2.58	Aa		With adj	20 g	3.08	Aa
	Without adj	40 g	3.16	Aa		With adj	40 g	2.83	Aa

Note: Adj-adjuvant. Uppercase letter comparison in the column for the factor dose. Lowercase letter comparison in the line between doses within dose and adjuvants by the Tukey test at 5% probability.

Table 4: Leaf area index (LAI) of Arabian coffee plants of the cultivar IPR 100 submitted to different doses, kaolinite colors, with or without adjuvant.

			LAI						
			Control		275.48				
Color/Dose			Without adj				With adj		
	20 g		40 g		60g		20 g		40 g
White	324.35		435.64		212.62		239.99		245.85
Cream	192.48		266.42		153.55		302.92		260.91
	Without adj	20 g	258.41	Aa		With adj	20 g	271.45	Aa
	Without adj	40 g	351.03	Aa		With adj	40 g	253.38	Ab

Note: Adj- adjuvant. Uppercase letter comparison in the column for the factor dose by the Tukey test at a probability of 5%. Lowercase letter comparison in the line between doses within dose and adjuvants by the Tukey test at 5% probability.

Table 5: Leaf dry matter (LDM) of Arabian coffee plants of the cultivar IPR 100 submitted to different doses and colors of kaolinite with or without adjuvant.

				LDM (g plant^{-1})						
				Control	5.99					
Color/Dose			Without adj						With adj	
	20 g		40 g		60 g		20 g		40 g	
White	6.87	aAα	5.80	aAb	6.12	aA	8.73	aAα	11.60	aBα
Cream	6.93	aAα	7.32	aAα	5.99	aA	6.78	aAα	6.40	bAα
	Without adj	white	20.60	*Aa*			With adj	white	26.50	*Ab*
	Without adj	cream	22.81	*Aa*			With adj	cream	23.96	*Aa*

Note: Adj- adjuvant. Lowercase letter comparison in the column between the colors within doses and adjuvants. Uppercase letter comparison in the line between doses within colors and adjuvants. Greek letter comparison in the line between the doses with or without adjuvants within the same color. Uppercase letter in italics comparison in the column for the kaolinite color. Lowercase letter in italics comparison in the line between kaolinite color and adjuvants by Tukey test at 5% probability.

Still, regarding LDM in the interaction dose x adjuvant, the dose of 20 g of white or cream kaolinite with or without adjuvant had no difference. However, 40 g of white kaolinite with or without adjuvant increased LDM by 100% between the doses. This behavior was not observed for cream kaolinite.

For SHDM presented in table 6, there was a difference between the means for the interaction kaolinite colors x adjuvant. It is observed that the means of the treatments with white and cream kaolinite with or without adjuvant did not differ. The same behavior was observed with white and cream kaolinite treatments with adjuvant (Table 6). However, comparing the treatment with white kaolinite with or without adjuvant, a difference of 44.77% is observed, representing an SHDM increase of 4.52 g in the comparison between the treatments. Cream kaolinite with and without adjuvant did not present a difference between the means.

Evaluating the RDM data between factorial and additional, only the dose of 40 g of white kaolinite with adjuvant differed from the Control, presenting an increase of 6.51 g, which is an increase of 67.47% for the treatment with kaolinite (Table 7). Similarly, the factor adjuvant showed a difference between means where the presence of the product influenced RDM accumulation by 30.40%.

Regarding TDM, comparing the factorial and the additional, only the dose of 40 g of white kaolinite with adjuvant differed from the control. Comparing the means, an increase of 12.79 g is perceived, representing an increase of 66.02% for the treatment with kaolinite. It is worth mentioning that the treatment with white kaolinite in the dose of 40 g without adjuvant was 63.19% lower than the treatment with adjuvant, a fact that must be further studied (Table 8).

In TDM, the interaction colors x adjuvant did not differ from treatments without adjuvant (white and cream kaolinite). The same behavior was observed between the treatments with adjuvant (white and cream kaolinite). However, the treatments with white kaolinite, with and without adjuvant, present a difference of 28.63% between them, representing a TDM increase of 5.90 g. The comparison between the treatments of cream kaolinite with and without kaolinite had no difference in the means.

4 DISCUSSION

Among the climatic factors, rain, air temperature, and photoperiod had a higher impact on coffee plants' aerial part growth rate (orthotropic and plagiotropic branches growth, node formation, and leaf expansion) (Ronchi; Damatta, 2007). It is reported in the literature that longer days generate higher plant growth in several regions (Silva et al., 2004). Similarly, Baliza et al. (2012) and Rodríguez-López et al. (2014) demonstrate that seasonal modifications alter plant growth and development, promoting better photosynthetic development with direct implications on yield.

Table 6: Shoot dry matter (SHDM) of Arabian coffee plants of the cultivar IPR 100 submitted to different doses and colors of kaolinite with or without adjuvant.

SHDM (g plant^{-1})									
			Control		9.72				
Color/Dose	Without adj					With adj			
	20 g		40 g		60 g	20 g		40 g	
White	10.71		9.50		10.77	13.26		15.99	
Cream	11.58		11.30		10.512	10.68		10.16	
	Without adj	white	10.10	Ab		With adj	white	14.63	Aa
	Without adj	cream	11.44	Aa		With adj	cream	10.42	Aa

Note: Uppercase letter comparison in the column for the kaolinite color by the Tukey test at 5% probability. Lowercase letter comparison in the line between the kaolinite color and adjuvants by the Tukey test at 5% probability.

Table 7: Root dry matter (RDM) of Arabian coffee plants of the cultivar IPR 100 submitted to different doses and colors of kaolinite with or without adjuvant.

RDM (g plant^{-1})										
			Control		9.65	*A*				
Color/ Dose	Without adj						With adj			
	20 g		40 g		60 g		20 g		40 g	
White	10.87	*A*	10.21	*A*	9.54	*A*	12.51	*A*	16.16	*B*
Cream	10.49	*A*	12.25	*A*	12.07	*A*	14.04	*A*	14.42	*A*
	Without adj	10.95	B				With adj	14.29	A	

Note: Adj- adjuvant. Uppercase letter in italics compares the treatments x additional by the Tukey test at 5% probability. Uppercase letter comparison of adjuvant by the Tukey test at 5% probability.

Table 8: Total dry matter (TDM) of Arabian coffee plants of the cultivar IPR 100 submitted to different doses and colors of kaolinite with or without adjuvant.

				TDM (g $plant^{-1}$)				
	Control		19.37	*A*				
Color/Dose	Without adj				With adj			
	20 g		40 g		20 g		40 g	
White	21.50	*A*	19.71	*A*	25.77	*A*	32.16	*B*
Cream	22.07	*A*	23.55	*A*	24.72	*A*	24.58	*A*
	Without adj	white	20.60	Aa	With adj	white	26.50	Ab
	Without adj	cream	22.81	Aa	With adj	cream	23.96	Aa

Note: Adj- adjuvant. Uppercase letter in italics compares the treatments x additional by the Tukey test at 5% probability. Uppercase letter comparison in the column for the factor kaolinite color by the Tukey test at 5% probability. Lowercase letter comparison in the line between the kaolinite color and adjuvants by the Tukey test at 5% probability.

This experiment was conducted in high-temperature conditions, with irregular precipitation and longer days (Figure 1), which favor the aerial development of coffee plants, mainly in the first year of implementation, where it has vigorous vegetative growth since the crop is sensitive to longer photoperiods that influence the growth rate.

The cultivar IPR 100 presents higher tolerance to average-high temperatures. Hence, it is supposed to show satisfactory development at total sun exposure. In this experiment, the average height of the control was 34.88 cm (Table 2), close to the 35 cm obtained by Furtado et al. (2020) when evaluating the cultivars IPR 100 and Tupi in protected cultivation.

For the variable PH, the treatments with higher white kaolinite doses with and without adjuvant had a higher increase than those with cream kaolinite and the control (Table 2). It may indicate that white kaolinite has higher solar radiation reflective capacity without interfering with the plant's photosynthesis capacity. Therefore, plants treated with white kaolinite (doses 40 g and 60 g) probably fixate more CO_2, which leads to higher carbon allocation in the leaves and other growing tissues (Liang et al., 2020).

Besides, the presence of an adjuvant can provide higher permanence of kaolinite particles on coffee leaves, extending the effect of reflectance on this structure. Ramos (2010) highlights that, although many factors influence aerial part height, it is technically accepted by providing an estimated prediction of plant growth and development potential.

This experiment observed that the different treatments did not interfere with the perception of plants regarding the factors listed by Ronchi and Damatta (2007) associated with the growth rate of coffee plants. Significantly, the photoperiod did not show differences between the means of the treatments employed for NPB (Table 3). This fact is positive when it is understood that kaolinite did not reduce the number of plagiotropic branches by the higher solar radiation reflectance.

To understand the importance of this result compared with other types of management, for instance, shading, Rodrigues (2009), while evaluating the growth of young conilon coffee plants growth intercropped with forestry species such as Australian red cedar (*Toona ciliata var. australis* (F. Muell) Bahadur) and *Parkia multijuga* Benth, reported that shading increases reduced the number and the length of plagiotropic branches, which affects coffee plants' vegetative growth and yield.

Colodetti et al. (2018) report that the higher NPB produces a higher number of photosynthesizing leaves, which increases the number of photoassimilates, favoring coffee yield.

While evaluating vegetative performance, Freitas et al. (2007) estimated the variability and genetic correlations in Arabian coffee cultivars of high height and observed that the higher the PH, the higher the NPB. This fact evidences the existence of a compensatory mechanism of vertical growth by a horizontal mechanism. This behavior was not seen in our experiment.

The leaf area is considered a vital yield parameter because the photosynthetic process occurs in the leaf structure (Favarin et al., 2002). C3 photosynthetic metabolism plants, such as coffee generally have a lower luminous saturation point than C4 and CAM metabolism plants (Taiz et al., 2017). Moreover, environmental conditions with higher temperatures increase photorespiration, limiting growth and crop yield (Gerlach et al., 2013) and reducing the longevity of coffee plants.

Glenn (2012) states that the application of kaolinite contributes to the increase of leaf surface albedo due to the reflectance of the ultraviolet and infrared waves' length. As a form of compensating for the lower amount of light available, the plants invest in the leaf area growth and the chlorophyll concentration in leaves, similar to ombrophilous species (Almeida et al., 2005). It corroborates the results of our experiment in which, regardless of the kaolinite color, the different doses provided differences in LAI. The relationship between the dose of 40 g of kaolinite without adjuvant increased 97.65 compared with the presence of adjuvant (Table 4).

Thus, it can be inferred that kaolinite provided a solar radiation reflectance effect (Dias; Bruggemann, 2010), increasing leaf area albedo, which may have mitigated the impact of high luminous intensity on stomata, contributing to carbon assimilation increase (Otto et al., 2013). In this case, it favors plant development by presenting a higher product concentration. About the higher LAI observed in this experiment without adjuvant; further research is needed to understand this result.

The effect provided by the increase of albedo was already mentioned in the literature for the species: orange, lemon, rubber tree, and common bean (Abou-Khaled; Hagan; Davenport, 1970), coffee (Ricci et al., 2011; Ricci; Cocheto Junior; Almeida, 2013), nuts and almonds (Rosati et al., 2006), and apple (Wünsche et al., 2004).

It is worth mentioning that the increase of leaf albedo generates a more intense growth in coffee plants regarding PH and NPB, which was observed under shading conditions and corresponded to the etiolation effect, a plant mechanism to optimize light capturing, as observed in previous studies (Camargo, 2007; Ricci; Cocheto Junior; Almeida, 2013). However, we cannot affirm that etiolation occurred in this experiment because the stem diameter was not according to the other treatments. Badran and Dwaykat (2018), with the increase of leaf albedo caused by kaolinite application, observed the main results: the reduction of physiological damages caused by thermal stress and solar radiation excess without interfering with the photosynthesis, which favors dry matter accumulation.

According to Charbonnier et al. (2017), dry matter accumulation is positive because it indicates that fixated carbon is used to develop and maintain the vegetal structure based on biomass accumulation. The variation in dry matter accumulation suggests the plant's capacity to capture the available natural resources and use them for its maintenance and development.

In this experiment, the LAI increase might have influenced the higher accumulation of LDM, SHDM, RDM, and TDM. It is worth mentioning that, for LAI, the dose of 20 g without adjuvant had a higher development, indicating a genetic characteristic of the cultivar IPR 100 since it was developed for regions with an average annual temperature above 21.5 ºC (Sera; Sera, 2017). Moreover, low kaolinite doses already reduced the possible thermal stress to which the plant could be submitted, influencing the LAI increase.

For LDM, SHDM, RDM, and TDM, the dose of 40 g of white kaolinite with adjuvant provided a higher dry matter accumulation. This fact indicates that, by the increase of leaf albedo and the higher duration of the product on the plant from the adjuvant, they invested in leaf growth and chlorophyll concentration in leaves (Almeida et al., 2005), contributing to higher carbon assimilation (Otto et al., 2013). Therefore, we can infer that an increase in liquid photosynthesis occurred and that it favored the accumulation of the variables LDM, SHDM, RDM, and TDM.

Santos et al. (2021) observed similar behavior. The authors reported that while comparing the concentration of 3% kaolinite with the control, they increased 54.9% for LDM, 60.9% for SDM, and 57.7% for SHDM. This performance can be explained by Otto et al. (2013), who observed that kaolinite mitigates the effects of high luminous intensity on stomata, favoring carbon dioxide assimilation, resulting in biometric variables increases.

5 CONCLUSION

The dose of 40 g of white kaolinite with adjuvant provided a higher dry matter accumulation for the coffee plant IPR 100 in the biometric variables: leaf dry matter, root dry matter, shoot dry matter, and total dry matter.

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7 AUTHORS' CONTRIBUTION

BPC wrote the manuscript and carried out the experiment. CYT supervised the experiment, co-worked on the manuscript and conducted all statistical analyses. CARMR assisted in the conduct of the experiment and in writing the manuscript and carried out the experiment. BPC wrote the manuscript and carried out the experiment, CYT supervised the experiment, co-worked on the manuscript and conducted all statistical analyses, CARMR assisted in the conduct of the experiment and in writing the manuscript and carried out the experiment.

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