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Research Article

Minimum distance from the soybean sowing line in intercropping with coffee trees in formation

Distância mínima da linha de semeadura da soja em consórcio com o cafeeiro em formação

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ABSTRACT

The definition of the minimum distance between the soybean sowing line and the orthotropic branch in intercropping with the coffee tree in formation guided the objectives of this research. The experiment was conducted in the demonstration area of the Federal University of Uberlândia, Monte Carmelo Campus, Minas Gerais. The coffee trees were planted in March 2021, with a spacing of 3.5 m between rows and 0.6 m between plants, using the IPR 100 cultivar. Soybeans were planted between coffee tree rows in November 2021, cultivar LG 60162IPRO, with a spacing of 0.4 m between rows and 14 seeds per linear meter. Only the coffee trees were irrigated using a drip system, with spacing between drippers of 0.6 m and a flow rate of 2.1 L h^{-1}. The intercropping configured five management methods with soybean planting rows and distance from the last row to the orthotropic stem: T1: control without soybeans, T2: 2 rows - 1.55 m, T3: 4 rows - 1.15 m, T4: 6 rows - 0.75 m, and T5: 8 rows - 0.35 m from the coffee tree. Each plot consisted of five coffee plants. The following were evaluated in the coffee trees of the three central plants: length, width, and thickness of two leaves per plant, chlorophyll index (SPAD 502), leaf temperature, stomatal count, length of a pair of plagiotropic branches located in the middle third of the coffee tree, number and distance of internodes, and number of primary plagiotropic branches. Soybeans planted between coffee trees did not alter the development pattern of the leaves and branches of *Coffea arabica* L. when kept at distances greater than 0.75 m from the coffee tree stem. It is suggested that this is the minimum critical tolerance distance for coffee trees without them developing mechanisms to avoid shading and altering their growth pattern.
KEYWORDS: *Coffea arabica* L. Development Intercropping

RESUMO

A definição da distância mínima da linha de semeadura da soja com o ramo ortotrópico em consórcio com o cafeeiro em formação norteou os objetivos dessa pesquisa. O experimento foi realizado na área demonstrativa da Universidade Federal de Uberlândia, Campus Monte Carmelo, Minas Gerais. O plantio do cafeeiro ocorreu em março de 2021, no espaçamento de 3,5 m entre linhas e 0,6 m entre plantas, utilizando-se a cultivar IPR 100. Executou-se o plantio da soja na entrelinha do cafeeiro em novembro de 2021, cultivar LG 60162IPRO, no espaçamento de 0,4 m entre linhas e 14 sementes por metro linear. Somente o cafeeiro foi irrigado por sistema de gotejamento, com espaçamento entre os gotejadores de 0,6 m e vazão de 2,1 L h^{-1}. O consórcio configurou cinco formas de manejo com linhas de plantio de soja e distância da última linha em relação ao caule ortotrópico: T1: controle sem soja, T2: 2 linhas - 1,55 m, T3: 4 linhas - 1,15 m, T4: 6 linhas - 0,75 m e T5: 8 linhas - 0,35 m do cafeeiro. Cada parcela foi composta por cinco plantas de cafeeiro. Foram avaliados nos cafeeiros das três plantas centrais: comprimento, largura e espessura de duas folhas por planta, índice de clorofila (SPAD 502), temperatura da folha, contagem de estômatos, comprimento de um par de ramos plagiotrópicos localizado no terço médio do cafeeiro, número e distância de entrenós e número de ramos plagiotrópicos primários. A soja na entrelinha do cafeeiro não alterou o padrão de desenvolvimento das folhas e ramos de *Coffea arabica* L. quando mantidas distâncias

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superiores a 0,75 m do caule do cafeeiro. Sugere-se que esta seja a distância mínima crítica de tolerância do cafeeiro sem que ela desenvolva mecanismos de evitar sombreamento e alteração do padrão de crescimento.

PALAVRAS-CHAVE: *Coffea arabica* L. Desenvolvimento. Cultivo consorciado.

INTRODUCTION

Coffee is one of Brazil's most important *commodities*, contributing significantly to the country's gross domestic product. The *Coffea arabica* L. species stands out in the global economy, accounting for 56.7% of production (MAPA 2024). In Brazil, this species represents the largest cultivated area and geographical diversification (CONAB 2023). Coffee tree productivity is expressed in response to the soil and climate conditions experienced in the growing location and can be enhanced by the management established at the time of planting and during the crop's development phases (PINHO et al. 2021). The establishment of coffee plantations requires planning and the use of management techniques that improve land use and maximize available natural resources to enable the best plant responses to nutrition and climate.

In coffee farming, a well-established practice that creates a microclimate favorable to coffee tree development and productivity is the use of cover crops between rows to produce green mass and incorporate organic matter into the soil. In addition, with the mulch formed by the decomposition of cover crops, it is possible to reduce the establishment of invasive plants in coffee cultivation (PEREIRA et al. 2020).

This intercropping, which can be structured with a single species or combination of species, helps build soil fertility, conserve water resources, control weeds, control pests biologically, and improve water availability, contributing to the improvement of the physical, chemical, and biological conditions of the soil (SILVA et al. 2021).

Cover crops, in addition to benefiting the microenvironment, can also contribute to the producer's income when intercropped with another economically important crop, particularly grasses and legumes. Among legumes, soybeans (*Glycine max* (L.) Merr.) represent an option, since they are Brazil's main *commodity* and the main crop grown in the Cerrado, generating revenue mainly in the first two years of cultivation, which are challenging in terms of costs and lack of revenue (PELLEGRINA 2022). Soybean crop residues can contribute organic matter and additional nitrogen to the soil, as well as improve water infiltration through the galleries created by the roots remaining after harvest (CHERUBIN et al. 2022).

The negative aspects of intercropping involving coffee cultivation still lack reliable information for use as an alternative source of income during the planting or pruning phases. This fact has prompted research into the use of cover crops for different purposes, including generating income with species of added economic value. In a study conducted with *C. canephora* in Espírito Santo, it was found that the green manure that stood out in the intercropping with coffee was Mexican sunflower (*Tithonia diversifolia*), which presented higher net income in economic activity compared to pigeon peas, black velvet bean, cowpea, and single-crop coffee (ZACARIAS et al. 2020).

In this study, the species *G. max* was used as an alternative for intercropping coffee trees with a species of potential economic value as a cover crop between rows. The choice of species was based on the legume's ability to form symbiosis with atmospheric nitrogen-fixing bacteria and the possibility of increasing nitrogen availability in the soil and high productivity in the short term, which would guarantee direct and indirect income (BRAVIN et al. 2020). The rapid vegetative development of legumes can also protect newly planted coffee trees from strong winds (SILVA et al. 2015).

The challenge in managing the soybean intercropping system lies in finding the plant population between rows that best utilizes the available area, generates income, benefits the crop, and preserves the morphological development pattern and growth potential measured by the development of the coffee tree's branches and leaves.

Given this context, the objective was to define the minimum distance between the soybean (*G. max* (L.) Merr.) sowing line and the orthotropic branch of the coffee tree in formation, without, however, compromising the morphological and biometric parameters of *C. arabica* L.

MATERIALS AND METHODS

The experiment was conducted in the experimental area of the Federal University of Uberlândia – Monte Carmelo Campus, Minas Gerais. The geographical coordinates of the experimental area are 18° 43' 36'' S and 47° 31’ 23'' W, located at an altitude of 898 m (Figure 1). The soil in the experimental area is classified as Red Latosol, with a clayey texture (SANTOS et al. 2018).

The coffee trees, cultivar IPR 100, were planted in March 2021, with a spacing of 3.5 m between rows and 0.6 m between plants. Planting fertilization consisted of 50 g of P_2O_5 per hole, using simple superphosphate (18% P_2O_5) as the source. Thirty days after the seedlings were planted, top dressing was applied with 20 g of K_2O per plant, divided into three applications per year, and 5 g of N per plant, with this dose being repeated in the following three months using the 22-00-22 formulation (N - P_2O_5 - K_2O).

The coffee plant was irrigated using a drip system, with spacing between drippers of 0.6 m and a flow rate of 2.1 L h^{-1}. Soybeans were sown between coffee rows in November 2021, using the LG 60162IPRO cultivar, with a spacing of 0.4 m between rows and 14 seeds per linear meter. The soybeans grown between the coffee trees were not irrigated.

In March 2021, before planting the coffee, and in August 2021, before differentiating the treatments, soil samples were collected at a depth of 0-20 cm for chemical analysis and subsequent fertilization recommendations according to crop requirements.

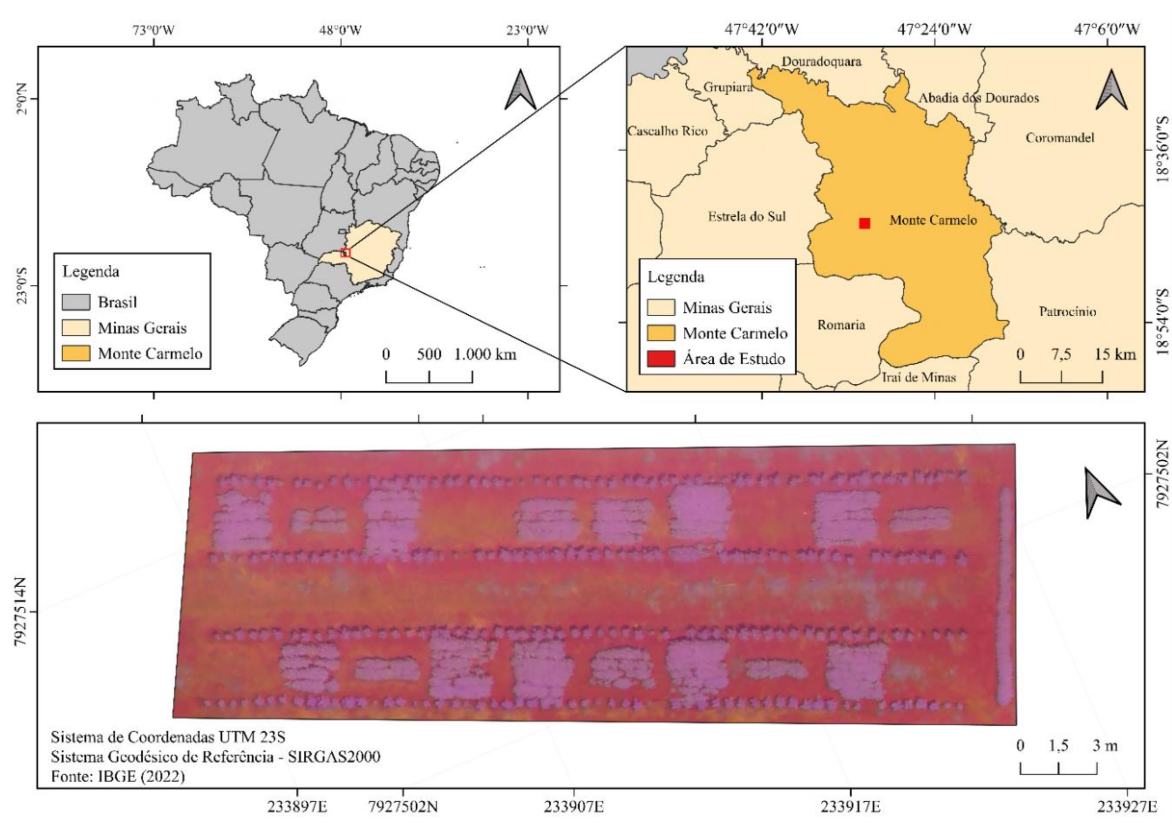

Figure 1. Location map of the study area.

Based on the soil analysis carried out in August 2021 and considering an expected yield of 50 to 60 bags ha^{-1} of soybeans, the standard fertilizer dose according to the recommendation of GUIMARÃES et al. (1999) was 120 kg ha^{-1} $year^{-1}$ of P_2O_5 and 40 kg ha^{-1} $year^{-1}$ of K_2O, with no need to apply mineral N due to inoculation via planting furrows (840 mL ha^{-1} $year^{-1}$) with the bacterium *Bradyrhizobium japonicum*. The mineral fertilizers used were, respectively, simple superphosphate 00-18-00 (N – P_2O_5 – K_2O) and potassium chloride 00-00-60 (N – P_2O_5 – K_2O), applied to the planting furrow in November 2021.

For fertilization of coffee trees in the first year after planting, 142.86 kg of N ha^{-1} , 20 kg of P_2O_5 ha^{-1} , and 47.62 kg of K_2O ha^{-1} were applied, using urea (45% N), simple superphosphate, and potassium chloride as sources, respectively.

The experimental design used was randomized blocks, with four blocks and five treatments, namely: (TI) no soybeans, (T2) two rows of soybeans, spaced 1.55 m from the coffee tree trunk, (T3) four rows of soybeans, spaced 1.15 m from the coffee tree trunk, (T4) six rows of soybeans, spaced 0.75 m from the coffee tree trunk, and (T5) eight rows of soybeans, spaced 0.35 m from the coffee tree trunk (Figure 2).

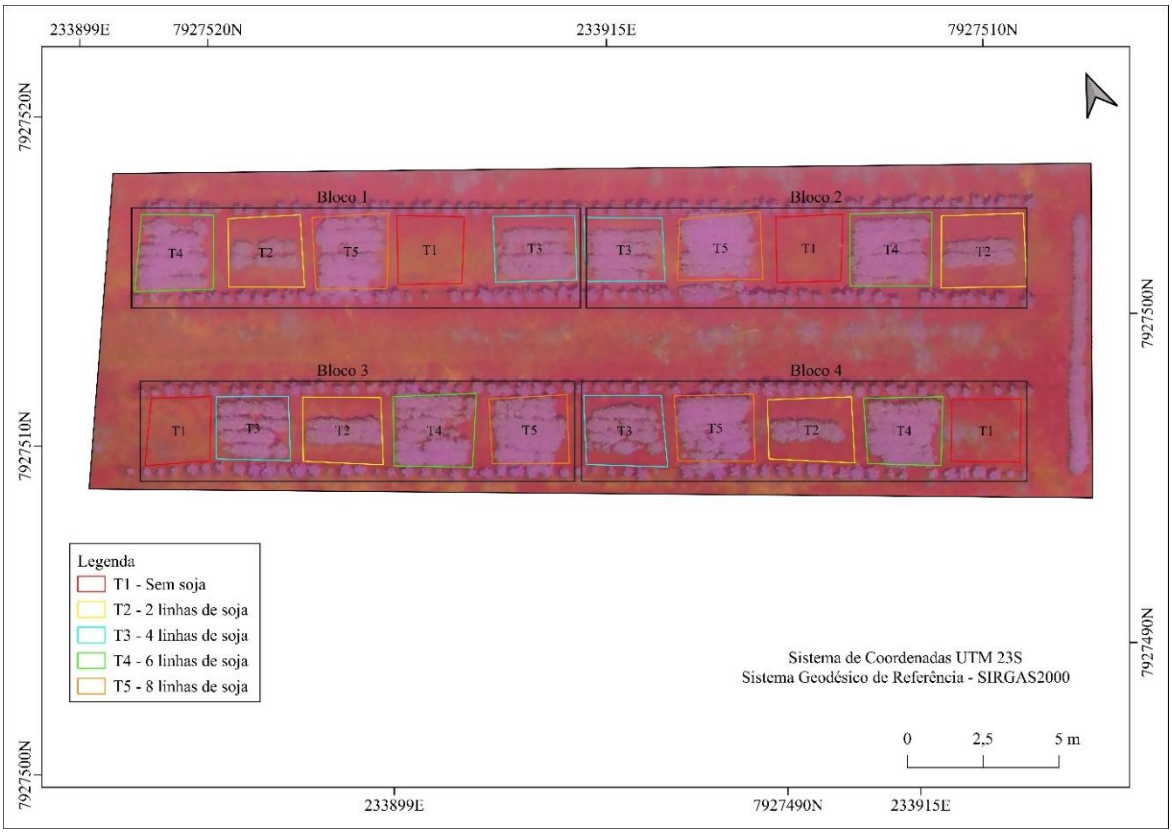

Figure 2. Sketch of the experimental area, with the delimitation of each treatment plot.

Each plot consisted of five coffee plants, measuring 3 m long and 3.5 m wide. The evaluations were carried out at the three central plants, covering a usable area of 6.3 m^2 (1.8 m long and 3.5 m wide).

Morphological and physiological evaluations of coffee trees were conducted on March 18, 2022, after the soybean harvest, assessing leaf characterization parameters, plagiotropic branches, and environmental data.

In the analysis of the fully expanded leaf of the third node, starting from the apex of the plagiotropic branch, which represented the middle third of the plant, the following characteristics were analyzed:

a) leaf length: determined by measuring the length of the midrib with a ruler, in centimeters;

b) width: determined by measuring the widest part of the limb with a ruler, in centimeters;

c) thickness: determined by measuring the height between the adaxial and abaxial faces of the leaf in the middle portion of the blade, using a caliper, in centimeters;

d) chlorophyll content: taking the average of four measurements taken on the third pair of leaves in the middle third of the plant using the SPAD-502 chlorophyll meter;

e) leaf temperature: assessed using a Minipa infrared thermometer;

f) *in natura* leaf mass and mass after drying in an oven maintained at 65 °C for 24 hours, measured on an electronic scale.

Stomatal density was measured from paraderma impressions of the epidermis of the abaxial surface of the leaves on glass slides using cyanoacrylate instant adhesive. The slides were observed using a Motic Model BA310 trinocular microscope with an AxioCam ERc 5s capture system. The number of stomata was recorded using a 10x objective lens, delimiting an area of 100x100 μm^2. The number of stomata observed in the area was multiplied by 100 to obtain the stomatal density per mm^2.

The plagiotropic branch used to evaluate leaf parameters was simultaneously evaluated for the following parameters: length from the insertion point on the orthotropic branch to the apex, measured with a ruler in centimeters; number of nodes; length of internodes, by measuring the distance from the first internode to the apex of the second internode and from the second to the third internode; and number of leaves on the branch, obtained by counting fully expanded leaves.

Data on air temperature, soil temperature under the canopy, relative humidity, and light intensity were collected using a digital thermo-hygro-anemometer-lux meter (LM 8000).

The data were submitted to analysis of variance using SPEED Stat software (CARVALHO et al. 2020) after meeting the assumptions of normality of residuals, homogeneity of variances, and block additivity. When significant differences were detected, the variables were compared using the *Scott-Knott* test at a 5% probability level.

RESULTS AND DISCUSSION

The morphometric parameters evaluated in the coffee leaf suggest no change in the morphological development pattern of the coffee tree in the intercropping system with lower density of soybean rows between rows. The analyses show that there was no significant difference between treatments at a 5% probability level using the F-test for isolated parameters such as leaf length and thickness and SPAD content, regardless of the sowing density of soybeans between rows. However, the leaf width parameter was altered and differences were detected depending on the number of rows intercropped with *G. max* (p-value = 0.05), with a tendency toward higher values for treatments with a greater number of rows.

The coffee leaves had an average width of 5.52 cm, length of 11.8 cm, and leaf blade thickness of 0.284 mm, with a chlorophyll index of 64.04 SPAD units (Table 1).

The management with six and eight rows of soybean sowing induced an average increase of 0.33 cm in width compared to the management without soybean (Table 1). The altered morphology in the condition of greater proximity of soybean plants to coffee tree branches generated by the increase in the number of planting rows suggests competition for light availability, due to the physiological response mechanism of shade avoidance (LARCHER 2006). The shade cast by soybean crops intercropped with rows planted less than 0.75 cm from the coffee tree trunk was sufficient to disrupt the formation of coffee tree leaves.

Table 1. Width (cm), length (cm), thickness (mm), and average chlorophyll index of coffee leaves (cultivar IPR 100) in intercropping with soybeans (cultivar LG 60162IPRO)

Seeding density in soybean rows	Width (cm)	Length (cm)	Thickness (mm)	Chlorophyll
No soybeans	5.46 b	11.92 a	0.28 a	67.37 a
2 soybean rows	5.33 b	11.52 a	0.28 a	67.98 a
4 soybean rows	5.21 b	11.51 a	0.30 a	60.58 a
6 soybean rows	5.75 a	12.20 a	0.28 a	58.96 a
8 soybean rows	5.83 a	12.03 a	0.28 a	65.35 a

Averages followed by the same letter do not differ significantly from each other according to the *Scott-Knott* test at a 5% significance level.

The leaf shows greater plasticity and adaptation to light availability (CRAVEN et al. 2011) when compared to other plant organs. The greatest leaf width observed was not accompanied by changes in other parameters evaluated. It should be noted that the change in leaf morphology detected did not alter the chlorophyll content, which remained the same across all planting densities. The response suggests that there was no competition between crops for nitrogen nutrients in the intercropping system, regardless of the soybean seeding density. It is believed that the possibility of shading the branches and leaves of the coffee tree is the most negative factor for this intercropping system.

In shaded environments, there is a tendency for total chlorophyll content to increase as a way of enhancing the leaf's capacity to absorb light (LARCHER 2006). However, this was not observed for coffee trees under the management system tested. Corroborating the results, TREVISAN et al. (2012) found no significant differences between the chlorophyll indices of coffee trees grown in full sun and those grown in a system intercropped with papaya trees.

For the variables leaf temperature, fresh mass, dry mass, and number of stomata on the leaf, there was no significant difference between the different treatments evaluated at a 5% probability level using the F-test.

The leaves evaluated had an average temperature of 26.82 °C, fresh mass of 1.15 g, and dry mass of 0.45 g. The average stomatal density observed on a coffee leaf was 907/mm^2, demonstrating that the number of soybean rows used in the intercropping system did not affect these parameters of the coffee plant (Table 2).

Figure 3 shows the paraderma prints of the abaxial surface of the leaves of the different treatments evaluated (T1-T5), highlighting the homogeneity in the number of stomata demonstrated by the statistics. There is also a pattern in the morphology of epidermal cells, both ordinary cells with curved anticlinal walls and the paracytic stomatal apparatus, characteristics that are common to coffee leaves.

Table 2. Leaf temperature (°C), fresh weight (g), dry weight (g), and number of stomata per mm² in coffee leaves as a function of intercropping with soybeans.

Treatments	Leaf temperature (°C)	Fresh mass (g)	Dry mass (g)	Stomatal density mm²
No soybeans	26.65 a	1.19 a	0.47 a	912 a
2 soybean rows	27.05 a	1.13 a	0.44 a	912 a
4 soybean rows	27.91 a	1.03 a	0.40 a	900 a
6 soybean rows	24.99 a	1.19 a	0.47 a	925 a
8 soybean rows	27.50 a	1.24 a	0.49 a	887 a

Averages followed by the same letter do not differ significantly from each other according to the F test at 5% significance.

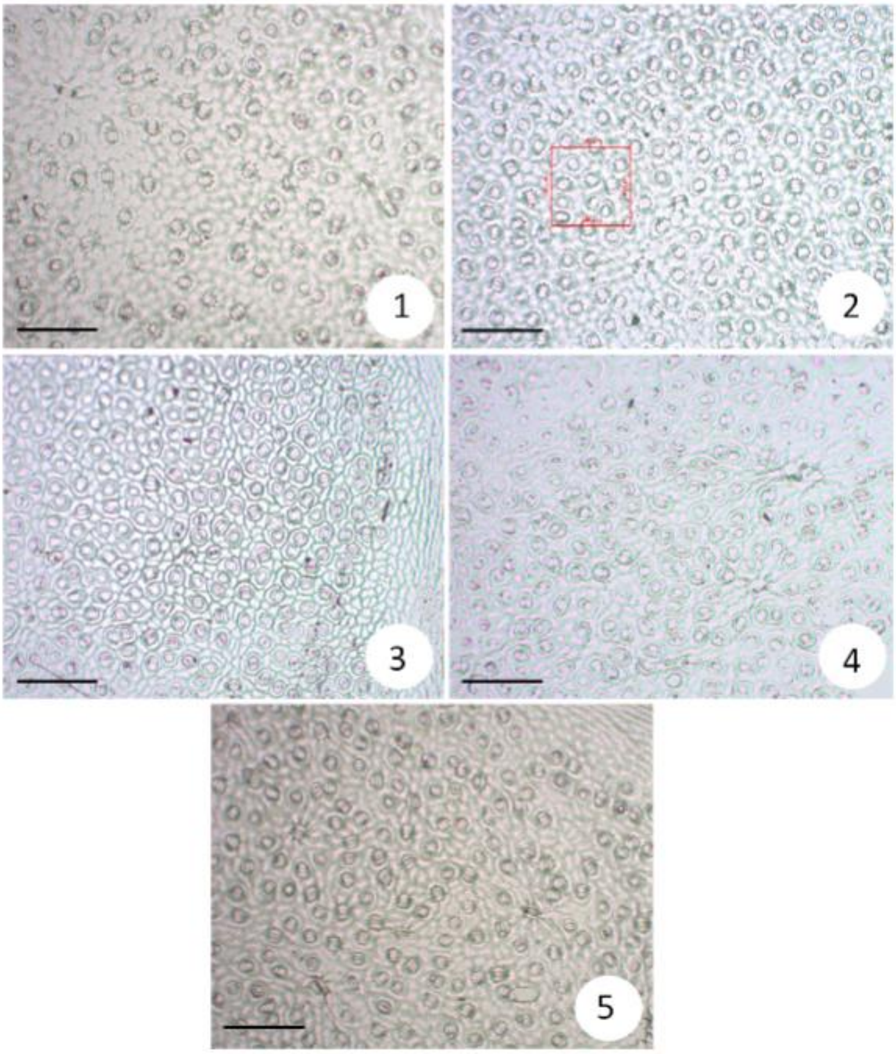

Figure 3. Impressions of *Coffea arabica* leaf blades in each treatment of intercropping soybeans with coffee trees. T1, Control treatment, without soybeans between rows; T2, Two soybean rows; T3, four soybean rows; T4six soybean rows; and T5, eight soybean rows. Useful area of 100 µm x 100 µm used to count stomata. Scale bars: 100 µm.

Opposite results were obtained by GOMES et al. (2008) and NASCIMENTO et al. (2006), who found that coffee trees in monoculture had a greater number of stomata than those grown in intercropping with acacia and rubber trees due to the shade provided by these species. When evaluating stomatal density and leaf temperature characteristics in isolation, it suggests that the shading provided by the greater proximity of soybean plants to coffee branches caused by the density of soybean sowing rows was not sufficient to alter the plant's physiological response pattern, allowing only a change in leaf morphology due to shading caused by soybeans at a distance of 0.75 m from the orthotropic stem (six rows of soybeans).

This assertion gains further support when one observes that the plagiotropic branch analyzed did not change its growth response pattern. In the analysis of internode distance and number of leaves and internodes, no significant differences were detected between treatments at the 5% probability level using the F-test.

The plagiotropic branches evaluated had an average length of 35.85 cm from the stem, 11.42 nodes, and 24 leaves. In these, there is a distance of 2.25 cm between the 1st and 2nd internodes and 3.16 cm between the 2nd and 3rd internodes (Table 3).

Table 3. Length of the plagiotropic branch (cm), internode distance (cm), number of internodes and leaves of the coffee tree as a function of intercropping with soybeans.

Treatments	Branch Length (cm)	Distance from the first internode (cm)	Distance from the second internode (cm)	Number of nodes	Number of leaves
No soybeans	36.36 a	2.18 a	3.52 a	11.27 a	24.08 a
2 soybean rows	35.71 a	2.10 a	2.88 a	11.56 a	25.55 a
4 soybean rows	35.83 a	2.43 a	2.83 a	10.95 a	21.91 a
6 soybean rows	34.53 a	2.28 a	3.37 a	11.40 a	24.33 a
8 soybean rows	36.84 a	2.32 a	3.03 a	11.88 a	25.77 a

Averages followed by the same letter do not differ significantly from each other according to the F test at a 5% significance level.

Analyzing the variables air temperature, soil temperature under the coffee tree canopy, relative humidity, and light intensity, it was found that there was no significant difference between the treatments evaluated at the 5% level by the F test (Table 4).

Table 4. Air temperature (°C), soil temperature under the canopy (°C), relative humidity (RH)%, and light intensity (LUX) in the coffee and soybean intercropping system.

Treatments	Air temperature (°C)	Soil temperature under the canopy (°C)	RH %	Light intensity (LUX)
No soybeans	42.33 a	26.64 a	35.60 a	886.00 a
2 soybean rows	41.70 a	24.43 a	36.00 a	846.85 a
4 soybean rows	42.01 a	26.61 a	34.29 a	930.15 a
6 soybean rows	41.74 a	26.40 a	35.14 a	904.17 a
8 soybean rows	42.04 a	23.35 a	35.92 a	852.57 a

Averages followed by the same letter do not differ significantly from each other according to the F test at a 5% significance level.

Leaves are a good indicator of water availability and light provided to a species or crop, and because they are organs with greater plasticity in their response to environmental conditions or management, their structure responds more readily than stems and roots to various stresses (MARCHI et al. 2008).

The effects of soybeans intercropped with coffee trees on the agronomic parameters of the crops are relative depending on the population density of the soybeans and the cultivar used. In a study conducted by REZENDE et al. (2000), the presence of intercropped soybeans reduced coffee productivity in coconut trees with an increase in the number of rows when the Paranaíba and IAC-8 cultivars were used. However, these factors did not affect the emission of secondary and plagiotropic branches of the coffee tree.

Although these are distinct biometric characteristics (height and crown diameter), CARVALHO et al. (2024) found that soybean populations ranging from 80,000 to 320,000 plants ha^{-1} did not promote changes in these parameters, as evidenced by the high values of the NDVI vegetation indices (normalized difference vegetation index). 000 to 320,000 plants ha-1 did not promote changes in these parameters, as evidenced by the high values of the NDVI (normalized difference vegetation index) and GNDVI (green normalized difference vegetation index) vegetation indices.

In order to implement large-scale coffee and soybean intercropping, certain challenges must be overcome. Among them, adequate planning of an integrated system that enables the mechanization of coffee farming, using low-growing soybean cultivars. In addition, it is necessary to adapt soybean harvesters and, whenever possible, choose products that can be applied to both crops (SILVA & BARDIVIESSO 2021), enabling field management.

CONCLUSION

The intercropping of soybeans with coffee cultivation in formation is presented as a management alternative with the potential to provide income to producers without altering the development pattern of coffee plants, when the minimum distance between the soybean sowing line and the orthotropic branch of the coffee tree is respected at 0.75 m.

The research presents information that may be useful for intercropping coffee with other crops, such as soybeans. It is suggested that the minimum spacing between the soybean row and the orthotropic branch of the coffee tree should be the same as that already practiced in cover cropping and weed management. In this case, the number of soybean rows will depend on the spacing of the coffee trees.

NOTES

AUTHORS' CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, Gleice Aparecida de Assis, Edson Simão, Neidiele Martins de Souza, Jordhanna Marilia Silva, Adriana Tiemi Nakamura, Gabriel Rodrigues Querino, Sanddy Caroline Sena Loures, Virgílio Carrara Feltre, Eberton de Carvalho; software and validation, Gleice Aparecida de Assis and Neidiele Martins de Souza; research, Neidiele Martins de Souza, Jordhanna Marilia Silva, Adriana Tiemi Nakamura, Gabriel Rodrigues Querino, Sanddy Caroline Sena Loures, Virgílio Carrara Feltre, and Eberton de Carvalho; resources and data curation, Gleice Aparecida de Assis, Neidiele Martins de Souza, Jordhanna Marilia Silva; writing - preparation of the original draft, Gleice Aparecida de Assis, Edson Simão, and Adriana Tiemi Nakamura; writing - revision and editing, Gleice Aparecida de Assis, Adriana Tiemi Nakamura, and Edson Simão; visualization, Gleice Aparecida de Assis and Edson Simão; supervision, Gleice Aparecida de Assis and Edson Simão; project administration, Gleice Aparecida de Assis; funding acquisition, Gleice Aparecida de Assis. All authors have read and agreed to the published version of the manuscript.

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Not applicable to studies that do not involve humans or animals.

INFORMED CONSENT STATEMENT
Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT
Data can be made available upon request.

CONFLICTS OF INTEREST
There are no conflicts of interest.

REFERENCES
BRAVIN NP et al. 2020. Crescimento inicial do cafeeiro robusta submetido a consórcios culturais nas entrelinhas. Revista Agrarian 13: 169-177.

CARVALHO AMX et al. 2020. SPEED Stat: a free, intuitive, and minimalist spreadsheet program for statistical analyses of experiments. Crop Breeding and Applied Biotechnology 20: e327420312.

CARVALHO E et al. 2024. Intercropped Soybean Plant Population in a Coffee Plantation and Its Effects on Agronomic Parameters and Geospatial Information. Agronomy 14: 343.

CHERUBIN MR et al. 2022. Guia prático de plantas de cobertura: aspectos fitotécnicos e impactos sobre a saúde do solo. Piracicaba: ESALQ-USP. 126p.

CONAB. 2023. Acompanhamento da safra brasileira de café. Brasília: CONAB. 49p. (4°Levantamento). Disponível em: https://www.conab.gov.br/info-agro/safras/cafe/boletim-da-safra-de-cafe. Acesso em: 18 nov. 2024.

CRAVEN D et al. 2011. Seasonal variability of photosynthetic characteristics influences growth of eight tropical tree species at two sites with contrasting precipitation in Panama. Forest Ecology and Management 261: 1643-1653.

GOMES IAC et al. 2008. Alterações morfofisiológicas em folhas de *Coffea arabica* L. cv. "Oeiras" sob influência do sombreamento por *Acacia mangium* Willd. Ciência Rural 38: 109-115.

GUIMARÃES PTG et al. 1999. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais - 5ª Aproximação. Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais. 359p.

LARCHER W. 2006. Ecofisiologia Vegetal. 3.ed. São Carlos: RiMa. 531p.

MAPA. 2024. Secretaria de Política Agrícola. Sumário executivo do café. Outubro de 2024. Disponível em http://www.consorciopesquisacafe.com.br/images/stories/

noticias/2021/2024/Outubro/Sumario_Cafe_outubro_2024.pdf. Acesso em 21 nov. 2024.

MARCHI S et al. 2008. Variation in mesophyll anatomy and photosynthetic capacity during leaf development in a deciduous mesophyte fruit tree (*Prunus persica*) and an evergreen sclerophyllous Mediterranean shrub (*Olea europaea*). Trees 22: 559-571.

NASCIMENTO EA et al. 2006. Alterações morfofisiológicas em folhas de cafeeiro (*Coffea arabica* L.) consorciado com seringueira (*Hevea brasiliensis* Muell. Arg.). Ciência Rural 36: 852-857.

PELLEGRINA HS. 2022. Trade, productivity, and the spatial organization of agriculture: Evidence from Brazil. Journal of Development Economics 156: 102816.

PEREIRA LS et al. 2020. Manejo de plantas daninhas e rendimento de feijão-caupi utilizando plantas de cobertura do solo. Brazilian Journal of Development 6: 2304423059.

PINHO LGR et al. 2021. Mudanças climáticas e a produção de café conilon na microrregião Centro-Oeste do estado do Espírito Santo. Revista Ifes Ciência 7: 01-14.

REZENDE PM et al. 2000. Consórcio soja-café I. Comportamento de cultivares e do número de linhas de soja [*Glycine max* (L). Merril] sobre o cafeeiro (*Coffea arabica* L.) em sistema de consórcio. Ciência e Agrotecnologia 24: 38.

SANTOS HG et al. 2018. Sistema brasileiro de classificação de solos. 5.ed. Brasília: EMBRAPA. 355p.

SILVA AR et al. 2015. Desenvolvimento da soja em sistemas de integração lavoura pecuária-floresta. Enciclopédia Biosfera 11: 1-896.

SILVA MA et al. 2021. Plantas de cobertura isoladas e em mix para a melhoria da qualidade do solo e das culturas comerciais no Cerrado. Research, Society and Development 10: 1-11.

SILVA MS & BARDIVIESSO EM. 2021. Soja + café: Integração de alto valor. Campos e Negócios Online. Disponível em: https://revistacampoenegocios.com.br/soja-cafe-integracao-de-alto-valor/. Acesso em: 4. dez. 2024.

TREVISAN E et al. 2012. Distância de internódios, crescimento acumulado e número de nós do café conilon sombreado com seringueira e a pleno sol. In: Anais do 38º Congresso Brasileiro de Pesquisas Cafeeiras. Resumos....Caxambu: Fundação Procafé.

ZACARIAS AJ et al. 2020. Custo/benefício da adubação verde do consórcio no café conilon. Research, Society and Development 9: 2849119746.