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Intercropping spatial arrangements affect pest incidence and agronomic aspects of cassava for industrial use

Disposições espaciais no consórcio afetam a incidência de pragas e aspectos agronômicos da mandioca para uso industrial

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ABSTRACT

The success of intercropping depends on the spatial arrangement between crops, aiming at the best use of the planting area and greater profitability for the farmer. Here, we evaluated the effect of cassava-peanut intercropping on several agronomic parameters. The research was carried out in the APTA experimental area, in the state of São Paulo, Brazil. The experimental design was randomized blocks with four treatments (peanut in monoculture - P; cassava in monoculture - C, cassava intercropped with peanuts planted between rows - CPb, and intercropping in alternating double rows - CPd) and eight replications. The variables analyzed were vegetative growth of cassava plants, soil vegetation cover and weed control, incidence of the main cassava and peanut pests, productivity, and the land equivalent ratio (LER). Only CPb inhibited cassava vegetative growth, significantly affecting its final height. Greater vegetation coverage and, consequently, lower occurrence of weeds, was obtained in CPb in addition to lower incidence of whiteflies in cassava. The intercropping system, regardless of the spatial arrangement used, increased the incidence of the lace bug in cassava and reduced the incidence of peanut pests. Crop productivity was lower in CPd due to the lower planting density of intercrops. However, both intercropping arrangements increased LER. Thus, despite the spatial arrangement of the intercropping system having implied different agronomic responses of the crops, planting peanuts between the cassava rows brought the best agronomic results.

Index terms: Peanuts; *Manihot esculenta*; *Arachis hypogaea*; growth curve; land equivalent ratio (LER).

RESUMO

O sucesso de consorcio de culturas depende da boa disposição espacial entre elas, caracterizando o melhor uso da área de plantio e maior rentabilidade para o agricultor. Nesse trabalho avaliamos o efeito do consórcio entre mandioca e amendoim em diferentes aspectos agronômicos. A pesquisa foi realizada na área experimental da APTA, no estado de São Paulo, Brasil. O delineamento experimental foi de blocos ao acaso com quatro tratamentos e oito repetições. Os tratamentos foram: amendoim em monocultura (P); mandioca em monocultura (C), consórcio com o amendoim plantado na entrelinha das fileiras mandioca (CPb), e consórcio das culturas em fileiras duplas alternadas (CPd). As variáveis analisadas foram crescimento vegetativo das plantas de mandioca, cobertura do solo e controle de ervas daninhas, incidência das principais pragas da mandioca e do amendoim, produtividade das culturas consortes e o índice de uso da terra (LER). Apenas CPb inibiu o crescimento vegetativo da mandioca, afetando significativamente sua altura final. CPb obteve maior cobertura vegetal e, consequentemente, menor ocorrência de ervas daninhas, além de resultar em menor incidência de mosca-branca na mandioca. O consorcio, independente do arranjo espacial utilizado aumentou a incidência do percevejo de renda na mandioca e diminuiu a incidência das pragas do amendoim. A produtividade das culturas menor em CPd, devido a menor densidade de plantio das culturas consortes. Porém qualquer arranjo do consorcio dessas culturas aumenta a LER. Assim, apesar do arranjo espacial do consórcio ter implicado diferentes respostas agronômicas das culturas, o plantio de amendoim na entrelinha da mandioca trouxe os melhores resultados agronômicos.

Termos para indexação: Amendoim; *Manihot esculenta*; *Arachis hypogaea*; curva de crescimento; razão equivalente de terra.

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Introduction

The spatial arrangement of plants can affect the crop yield both in monocultures and intercropping systems (Ferreira et al., 2021). Variations in the spatial arrangement can be performed by changing the spacing between planting rows or between plants in the same row (Ribeiro et al., 2018). These adjustmentshave provided several advantages, such as more efficient water use due to faster shading, better root distribution, reduced intraspecific competition, lower weed incidence, more uniform exploration of soil fertility, and better reception of solar radiation.

The intercropping system is traditionally used by small farmers in developing countries and consists of the simultaneous or non-simultaneous planting of two or more crops in the same area to maximize the use of available resources (Rodrigues et al., 2018). In general, it is interesting to reduce the impacts of intensive land use, allowing different crops to be harvested at different times of the year. Additionally, the soil vegetation cover protects the soil against erosion, the incidence of pests, diseases, and weeds is reduced, and higher intercrop yield is often achieved (Sugasti, Junqueira, & Saboya, 2013). These actions promote greater profitability, diversification of the farmer's source of income, and better use of the area (Albuquerque et al., 2015; Rodrigues et al., 2018; Araújo et al., 2019).

Cassava (*Manihot esculenta* Crantz) belongs to the Euphorbiaceae family and is native to tropical America. Cassava cultivation is widespread worldwide and plays a fundamental role in food security of developing countries. According to Food and Agriculture Organization of the United Nations - FAO (2024), more than 330 million tons of cassava were produced in 2022 on 32.04 million ha in Central and South America, Asia, and Africa. Brazil occupies the sixth position among the largest cassava producers with around 17.65 million tons in 2022 in an area of approximately 1.18 million ha. The average Brazilian cassava productivity is around 14.94 $t.ha^{-1}$, higher than the world average of 10.31 $t.ha^{-1}$, but relatively low compared to important Asian producers such as Thailand, Indonesia, and India, and the African Ghana with productivity greater than 20 $t.ha^{-1}$ (FAO, 2024). Cassava has great economic value for most rural communities in Brazil (Santos et al., 2019) and is widely used in human and animal food throughout the country (Mendonça et al., 2020). The main producing states are Pará, Paraná, São Paulo, and Mato Grosso, with 4.06, 3.48, 1.59, and 1.16 thousand tons in 2023 and an average productivity of 14.83, 25.15, 25.97, and 22.23 $t.ha^{-1}$, respectively (Instituto Brasileiro de Geografia e Estatística - IBGE, 2024).

Cassava is propagated sexually and asexually, which guarantees its wide genetic variability and high heterozygosity, and, consequently, the perpetuation of the species (Aquiles et al., 2021). Approximately 5 thousand varieties exist in Brazil, grouped into two groups determined by the hydrocyanic acid (HCN) content for consumption ($\leq$50 mg $HCN.kg^{-1}$) or industrial use (Oliveira & Barreto, 2020). Cassava is one of the few crops grown in all Brazilian states, due to its adaptation under different environmental conditions (Jala et al., 2019).

Because the cassava plant has a slow initial growth, especially in the first five months, the practice of intercropping (especially common bean, cowpea, corn, sweet potato, vegetable species, watermelon, and peanut) is widely used (Jala et al., 2019). In addition to the short production cycle, it is important to take into account the rusticity and the potential of the species intercropped with cassava to bring benefits to the main crop. For conditions in southeastern Brazil, peanut (*Arachis hypogaea* L.) may be an interesting choice due to its nutritional value and nitrogen supply to cassava. According to Semba et al. (2021) and Ladha et al. (2022), legumes increase soil fertility and crop production by atmospheric nitrogen fixation, as nitrogen is one of the most limiting nutrients in agriculture (Nzepang et al., 2023). In addition, its high adaptability to the most varied conditions contributes to the wide distribution of the peanut crop in the country in terms of production and consumption. The short cycle and the easy commercialization of this oleaginous plant boost its cultivation (Santos et al., 2021).

The objective of this study was to evaluate the influence of different spatial arrangements on agronomic aspects of a cassava-peanut intercropping system such as vegetative growth, soil cover, weed control, pest incidence, crop yield, in addition to the land equivalent ratio (LER).

Material and Methods

Experimental area

The study was carried out between October 2021 and July 2022 at the Center North Regional Hub, linked to the São Paulo Agribusiness Technology Agency belonging to the São Paulo State Department of Agriculture and Supply in Pindorama, SP, at 21º 18` S and 48º 89`W, 527 m of altitude, with annual minimum, average and maximum temperatures of 17.07 °C, 22.8 °C and 30.54 °C, respectively, average annual precipitation of 1,390.3 mm, and average annual relative humidity of 71.6%. According to the Köppen classification, the climate is classified as type Aw, defined as tropical humid, with a rainy season in the summer and a dry season in the winter. Figure 1 shows maximum and minimum temperatures and rainfall. Meteorological information was collected from CIIAGRO (Integrated Center for Agrometeorological Information/IAC/APTA) of the Mid-Northern Regional Center Meteorological Station/APTA, Pindorama, SP.

The experimental area has a history of planting cassava, with soil characterized as eutrophic Red Argisol, considered favorable to the development of cassava and peanut, although it may have physical impediments due to the textural gradient between A and B horizons (Lepsch & Valadares, 1976). The chemical analysis of the soil was carried out on a sample composed of several points in the area taken from a layer of 0.00 to 0.20 m deep, in which the following average contents were found: phosphorus (46 mg dm^{-3}), potassium (3.1 mmolc dm^{-3}), calcium (21 mmolc dm^{-3}), magnesium (9.0 mmolc dm^{-3}), boron (0.16 mg dm^{-3}), copper (1.0 mg dm^{-3}), iron (44 mg dm^{-3}), manganese (9.0 mg dm-3), zinc (0.6 mg dm^{-3}), and base saturation (64.4%).

The experiment was designed in randomized blocks with four treatments (P – peanuts in monoculture; C – cassava in monoculture; CPb – cassava-peanut intercropping, a row of peanuts planted between cassava rows; and CPd - cassava-peanut intercropping, double rows of cassava and peanut planted alternately) and 8 replications. Both cassava and peanuts were planted in six rows with a spacing of 0.9 m between them. For cassava, each row consisted of 10 plants spaced 0.9 m apart. For peanuts, a density of 10 seeds per linear meter was used. For the intercropping of peanuts between the rows of cassava (CPb), six rows of cassava were planted with a spacing of 0.9 m between rows, and the peanuts were planted in the middle of the cassava rows. In the intercropping alternating double rows (CPd), cassava and peanut rows were planted with a spacing of 0.9 m between rows, totaling six double rows of cassava and five double rows of peanuts. For all tested arrangements, the useful area of the plot was the 6 central plants of the 4 central rows of each crop.

The cassava variety used in the experiment was IAC 14, which has a high resistance to bacteriosis and over-elongation, aerial part architecture favorable to cultural practices, high dry matter content, high hydrocyanic acid content, and ease of harvesting (Valle & Lorenzi, 2014).

The peanut variety was IAC Caiapó, with a creeping habit, longer cycle (between 130 and 140 days), more productive and resistant to foliar diseases, adapted to mechanization, and of better industrial quality.

Cassava was planted using 20 cm stakes and a 4-row mechanized planter. In the intercropping treatments, peanuts were planted 45 days after planting cassava in 10 cm deep unfertilized furrows. Due to the levels of the main nutrients in the soil, the good phytosanitary aspect of the plants, and low-investment family farming, no fertilization or phytosanitary treatment was carried out, except for the control of weeds using manual weeding. The crops were not irrigated during the experiment, however, the rainfall distribution during the period guaranteed their development.

The IAC 14 cassava variety is usually harvested between 9 and 14 months after planting. In this study, tubers were harvested 300 days after planting as plants were already showing signs of vegetative rest (e.g., leaf yellowing and falling) due to lower temperatures and reduced rainfall (Figure 1).

The variables analyzed were vegetative growth of cassava plants, vegetation cover, weed control, incidence of the main regional pests in cassava and peanuts, crop yield, and land equivalent ratio (LER).

Evaluation of the vegetative growth of cassava plants

From 75 days after planting cassava onwards, when the two crops in the intercropping system were fully established, the height of the cassava plants was evaluated every 15 days until the cassava harvest (at 300 days after the planting - DAP). At 150 DAP, branches were counted in a sample of 20 plants per plot and measured with the aid of a millimeter ruler at the height of the first and second sympodial branches.

Evaluation of vegetation cover and weed control

At 60 days after planting cassava and 15 days after planting peanuts onwards, the vegetation cover was evaluated every two weeks by the rope method (Arruda, 1984) during the coexistence period of the crops. At the time of flowering (105 days after planting cassava and 60 days after planting peanuts), the aerial part of the weeds was randomly sampled in the plot with a hollow frame measuring 1m² in area. To determine the dry biomass of the weeds, samples were dried in an oven with forced air circulation at 65 °C until constant weight was obtained.

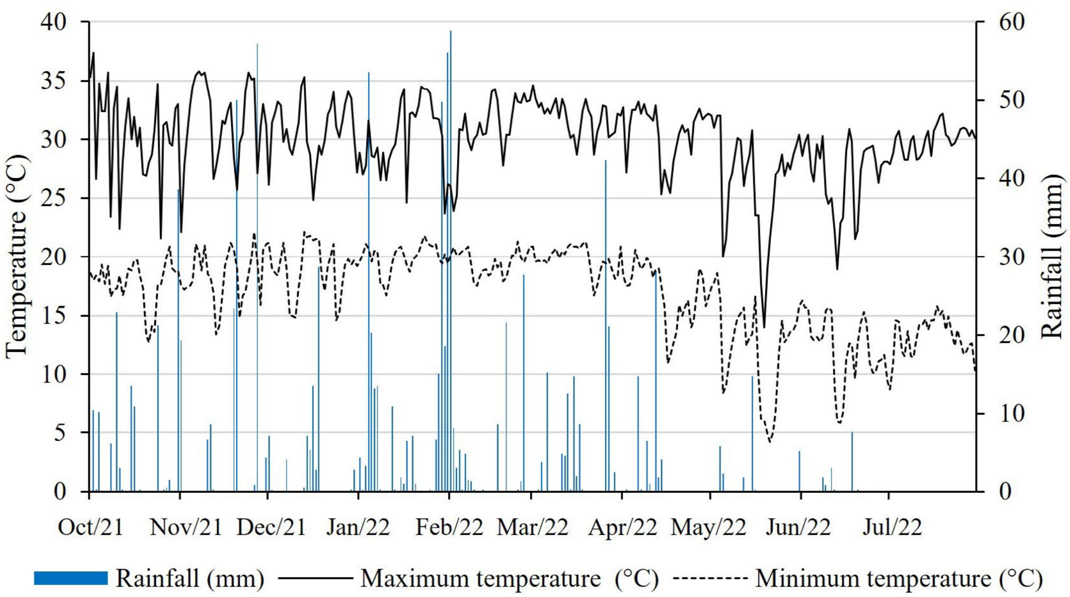

Figure 1: Daily maximum temperature (°C), minimum temperature (°C), and precipitation (mm) in the city of Pindorama, during the experimental period (October 2021 and July 2022).

Incidence of the main pests of cassava and peanut

The survey of insects in cassava was carried out 100 days after planting. Infestation of whitefly (*Bemisia tabaci)* was evaluated in three young leaves of 10 plants randomly sampled in each plot. The number of adults on each leaf side was counted. To evaluate the occurrence of lace bug (*Vatiga manihotae*), the plant was divided into two parts, upper and lower. Three leaves from each part of 10 plants were randomly sampled in each plot. The number of adults and nymphs on the leaf was counted, not discriminating against them. For the number of stink bugs, a factorial scheme of 3x2 was considered, with three spatial arrangements and two parts of the plant.

To evaluate the incidence of silver thrips (*Enneothrips flavens*, Moulton, 1941) and red-necked peanutworm (*Stegasta bosquella,* Chambers, 1875) in peanuts, 20 leaflets still closed per plot were sampled and the results were expressed as the percentage of incidence.

Assessment of crop yields and land equivalent ratio (LER)

At the end of the crop cycle (300 days after planting cassava and 130 days after peanut sowing), plants were harvested. The yield of the useful plot was evaluated and converted to megagrams per hectare (Mg ha^{-1}) according to the planting density and plant population of each crop. LER was defined as the relative land area under isolated planting conditions, which is required to provide the yields achieved in the intercropping mixture. It is currently the index most used by researchers in evaluating the efficiency of polycultural systems (Mead & Willey, 1980). LER is calculated by the following equation (Equation 1):

$$LER = Ic + Ip \tag{1}$$

Where Ic and Ip represent LER of crops (Ic = Cc x Mc^{-1} and Ip = Cp x Mp^{-1}, respectively), Cc and Cp are the yields of cassava and peanuts in the intercropping mixture, and Mc and Mp are the yields of cassava and peanuts in monoculture. When LER is > 1, the intercropping favors crop growth and production. In contrast, when LER is < 1, intercropping negatively affects crop growth and production (Albuquerque et al., 2015; Santos et al., 2021).

Statistical analysis

R software version 4.2.1 was used for all statistical analysis (R Development Core Team, 2022). The final height, number of stems, height and percentage of primary and secondary branches, dry mass of weeds, final plant cover, and crop yield were submitted to the Shapiro-Wilk normality test, without any transformation. The pest incidence data were first submitted to the Shapiro-Wilk normality test and the number of whiteflies lace bug were transformed into (x+0.5)1/2 and log(x+0.5), respectively. The results were then submitted to analysis of variance by the F test ($p \leq 0.05$) and the means were compared by the Tukey test ($p \leq 0.05$) when significant differences were observed.

The growth curves of cassava were estimated using the Gompertz equation (1825) from plant heights measured every two weeks (Equation 2):

$$H = h_{max} \times e^{-e^{-r(t-DAP_m)}} \tag{2}$$

Where: H = plant height (m) at time *t* for each cassava spatial arrangement; e = Euler's number (2,718281828459), hmax = Potential maximum height; r = maximum relative growth rate at the inflection point of the curve (mm. day^{-1}); and DAPm = time (days after planting) at which the growth rate is maximum.

Based on the estimated equations, the growth rates (mm. day^{-1}) as a function of time (t) were calculated using the derivative of the Gompertz equations. The characteristics of the Gompertz curve are based on the inflection point, where the growth rate is maximum. Thus, the age at which the inflection point occurs is given by the DAPm parameter. At this point, height is equal to hmax/e (36.8% of the maximum height) and the growth rate is equal to (hmax x r)/e.

The evolution curves of the vegetation cover between the rows were also estimated using the Gompertz equation (1825) from the general vegetation cover data obtained weekly, from the day of peanut planting (Equation 3):

$$VC = vc_{\max} \times e^{-e^{-r(t-DC)}} \tag{3}$$

Where: VC = vegetation cover (%) at time t for each spatial arrangement; vcmax = maximum potential vegetation cover; e = Euler's number (2,718281828459), r= maximum relative rate of vegetation cover evolution at the inflection point of the curve (%. $\%^{-1}$ per day); DC = days of coexistence, in which the vegetation cover evolution rate is maximum. Based on the estimated equations, the vegetation cover evolution rates (% day^{-1}) as a function of time (t) for monocultures and each cassava-peanut intercropping arrangement were calculated using the derivative of the Gompertz equations. The age at which the inflection point occurs is given by the DC parameter. At this point, vegetation cover is equal to vc_{max}/e (36.8% of the maximum cover) and the growth rate is equal to (vc_{max} x r)/e.

The models were fitted, plant growth and vegetation cover data were compared using the statistical indices accuracy, precision, and significance level by the chi-square test, according to Equations 4, 5 and 6. Accuracy indicates the similarity between the observed value and their estimates, evaluated using the mean absolute percentage error (MAPE; Equation 4) and root mean square error (RMSE; Equation 5). On the other hand, precision is the ability of a model to repeat an estimation, evaluated using the adjusted coefficient of determination (R^2_{adj}) (Aparecido et al., 2022):

$$MAPE(\%) = \frac{\sum_i^n \left(\left| \frac{y_{est_i} - y_{obs_i}}{y_{obs_i}} \right| \times 100 \right)}{n} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_i^n \left(y_{obs_i} - y_{est_i} \right)^2}{n}} \quad (5)$$

$$R^2_{adj} = \left[1 - \frac{(1-R^2)\times(n-1)}{n-k-1} \right] \quad (6)$$

Where y_{esti} is the estimated variable, y_{obsi} is the observed variable, n is the number of points in the data, and k is the number of independent variables in the regression.

Results and Discussion

Vegetative growth of cassava

The maximum height of cassava plants was significantly lower in the CPb treatment compared to the C and CPd treatments as was the height at the moment of the curve inflection. The maximum growth rate was higher in the CP and CPd treatments when compared to the maximum rate in the spatial arrangement of the CPb consortium (Table 1; Figure 2A). The reason for the lower final height in the CPb array relative to C and CPd may be competition for factors other than light such as nutrients, since the intercropping took place in a rainy summer and the plants were not fertilized. In this condition, the lower growth observed for CPb can be balanced with soil fertilization, a topic not addressed in this study. The higher initial growth of cassava plants in CPd when compared to the other systems occurs due to the greater space between plants in the initial phase of peanut growth. After reaching the maximum growth point, competition for nutrients with cassava minimizes the difference among treatments (Figure 2B).

The differences observed in growth parameters throughout the experiment significantly impacted the final height of cassava plants in CPb, with lower values when compared to C and CPd. The number of stems per plant and the percentage of branches were not significantly affected by the spatial arrangements analyzed, being more strongly related to the plant architecture, a genetically controlled characteristic and less prone to environmental influence (Table 2).

As observed during the experiment, the final height in the CPb treatment was affected by the restriction of the soil area to be explored and, consequently, the competition for resources from the early stages of the intercropping system due to the greater density of the crops. However, with the adequate resource supply, such as fertilization and irrigation, these differences found for plant height can be minimized.

These results diverge from several authors who did not observe a significant difference in plant height when cassava was intercropped with other crops (Aguiar et al., 2011; Rós, São João, 2016; Schons et al., 2009).

However, competition for nutrients, mainly potassium, may explain the lower height of the plants in the intercropping system. The potassium (K) level in the soil of the study site was 3.1 mmolc dm^{-3}. However, this nutrient is the second most absorbed by peanuts (Gascho & Davis, 1995) and the one extracted in the greatest quantity by cassava (Silva et al., 2017), thus establishing an important competition. According to Silva et al. (2017), the low K content restricts the plant's growth in height, contradicting reports in the literature about the plant's tolerance to low levels of fertility.

Table 1: Parameters estimated by the Gompertz equation and its related equations of interest for plant height in the different spatial arrangements of cassava (cassava in monoculture – C; cassava intercropped with peanuts planted between the rows - CPb; and cassava intercropped with peanuts in double rows - CPd) and their respective statistical indices of significance, accuracy, and precision.

Intercrop spatial arrangements	Maximum height	Relative maximum rate	Day of maximum growth	Height on the day of maximum growth	Maximum growth rate	Chi-square	MAPE	R^2_{adj}	RMSE
	h_m (m)	r (mm.m^{-1})	DAP_m(day)	h_m/e (m)	$h_m.r/e$ (mm. day^{-1})	x^2	(%)		
Cassava in monoculture (C)	2.05±0.07	23.62±3.22	110.67±3.29	0.76	17.84	1.1147	10.85	0.90	0.17
Cassava/ Peanut between rows (CPb)	1.78±0.06	25.28±3.60	107.24±3.19	0.66	16.58	0.9041	16.95	0.73	0.24
Cassava/ Peanut double rows (CPd)	2.03±0.05	24.62±2.43	108.22±2.26	0.75	18.36	0.5593	6.20	0.95	0.12

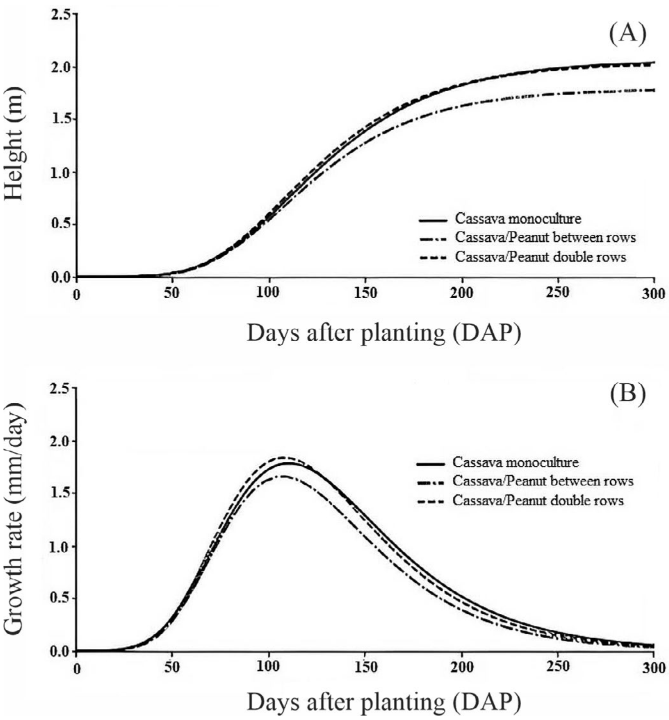

Figure 2: Height (A) and growth rate (B) of cassava plants in monoculture or intercropped with peanuts in different spatial arrangements.

Table 2: Phytotechnical characteristics: height at 300 days after planting, number of stems per plant, and % branching at 150 DAP of cassava (IAC 14) in monoculture or different intercropping arrangements with peanuts.

Spatial arrangements	Final Height	Number of stems/plant	Branching (%)
Cassava in monoculture (C)	2.06 a[1]	1.32 a	42.51 a
Cassava/ Peanut between rows (CPb)	1.76 b	1.45 a	41.27 a
Cassava/ Peanut double rows (CPd)	2.01 a	1.53 a	40.20 a
F	9.2900 **	3.1408^{ns}	0.201^{ns}
HSD	0.19381	0.26392	0.1118
VC (%)	7.6412	8.5099	12.4699

*Significant differences (Tukey's test at 5% probability) are indicated by letters.

Vegetation cover and weed control

Vegetation cover increased during the period analyzed, with maximum values above 90% in all production systems, being the lowest in CPd and highest in CPb, with intermediate results for C and P. There was little variation on the day of maximum percentage of vegetation cover (between 34.17 and 36.79%).

The maximum relative rate of vegetation cover evolution varied between 0.036 for cassava in monoculture and 0.062% for peanut in monoculture) (Table 3). The maximum growth rate was lower for C and higher for P, with intermediate values for CPb and CPd (Table 3). These results were expected since the peanut has faster growth than cassava, which also explains the intermediate results of the intercropped treatments.

Maximum evolution of the vegetation cover was faster in cassava monoculture, which was already established and in full development at the time of the first evaluation (90 days after planting). On the other hand, the greatest evolution in peanut vegetation cover was at 25.23 days after planting in monoculture areas (P), as there was no vegetation cover before planting the crop, while the other plots already contained the planted cassava.

The evolution of the ground cover is more accentuated for peanuts compared to cassava, mainly due to the differences in the growth habit and architecture of the plants. Peanuts of the Virginia type such as IAC-Caiapó, considered runner type, that is, with prostrate growth, have plant architecture suitable for mechanized harvesting (Erismann, Machado, & Godoy 2006) while cassava has an erect growth habit with medium size and high, closed branches (Irolivea et al., 1998) (Table 3). This contrasting vegetation cover behavior between the two species is one of the factors that make the intercropping system agronomically interesting. Due to its slow initial growth, cassava is very susceptible to soil and water losses by erosion and to the interference of weeds (Soares et al., 2019), so intercropping with plants that promote rapid soil cover is advantageous for the producer.

The intercropping, especially in the case of peanuts planted between the cassava rows, improved the plant cover for a longer period of coexistence (Figure 3), allowing good soil plant cover for as long as possible in the area. At the end of the coexistence period, all treatments already had vegetation cover above 90% (Table 3), however, in the period between 45 and 75 days, the vegetation cover in the cassava intercropped with peanuts planted between the rows was higher than the other treatments, especially the cassava monoculture (Figure 3). Planting in double rows maintains the lack of soil protection due to the large spacing between the cassava rows while the peanut is at the beginning of its development. However, at the end of the period of coexistence, this treatment is equal to the others.

Vegetation cover is inversely proportional to the dry mass of weeds, as observed at 105 days. Cassava monoculture, despite allowing an intermediate plant cover, had a higher weed infestation (Table 4). This is due to the plant architecture in a bushy format with high branching, which increases the incidence of sunlight directly on the soil and, consequently, stimulates weed growth On the other hand, CPb presented higher vegetation cover and had a lower presence of weeds, indicating that the vegetation cover suppresses the incidence of weeds (Table 4).

Table 3: Parameters estimated by the Gompertz equation and its related equations of interest for vegetation cover in the different spatial arrangements of cassava cultivation (monoculture - C, cassava intercropped with peanuts planted between the rows CPb, and cassava intercropped with peanuts in double rows - CPd) and their respective statistical indices of significance, accuracy, and precision.

Intercropping spatial arrangements	Maximum vegetation cover	Relative maximum rate	Day of maximum cover growth rate	Day of maximum vegetal cover	Cover on the day of maximum growth	Maximum growth rate	Chi-square	R²adj	RMSE
	VC_m (%)	r(%.%$^{-1}$)	DC_m(day)		h_m/e (%)	$h_m.r/e$ (%.day^{-1})	x^2		
Cassava in monoculture (C)	94.99±6.75	0.0362±0.01	7.71±2.22	91.04	34.94	1.26	23.1435	0.923	4.4353
Peanut in monoculture (P)	99.63±3.99	0.0627±0.01	25.23±1.24	98.69	36,65	2.30	33.9086	0.864	15.6738
Cassava/Peanut between rows (CPb)	100	0.0530±0.00	10.03±0.89	99.15	36.78	1.95	23.3406	0.972	5.7324
Cassava/Peanut double rows (CPd)	92.88±2.91	0.0524±0.01	18.61±0.96	91.00	34.17	1.79	13.1465	0.984	4.1960

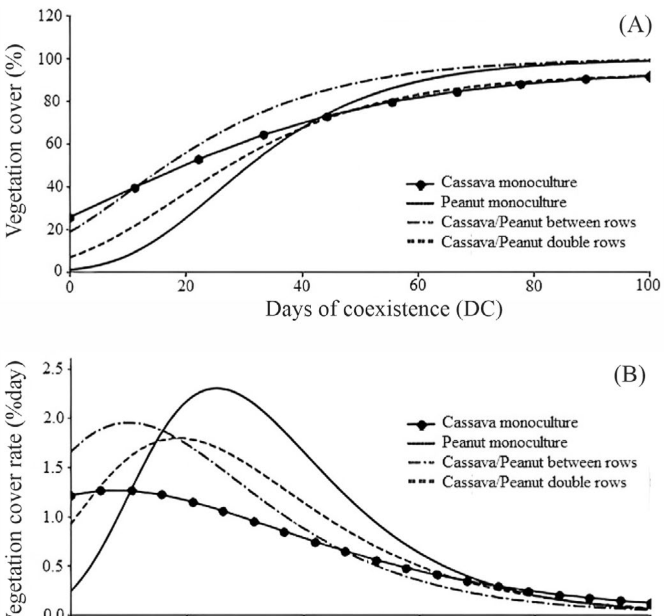

Figure 3: Vegetation cover (A) and vegetation cover rate (B) of cassava and peanuts in monoculture or intercropped with peanuts in different spatial arrangements.

Coelho Filho et al. (2017) found greater plant cover for cassava intercropped with beans when compared to monoculture. Vasconcelos et al. (2019) state that the intercropping system accelerates the coverage of the area due to the use of two crops, even though there is competition between them. However, some authors disagree about the vegetation cover and the incidence of weeds (Aguiar et al., 2011; Rós & São João, 2016).

Incidence of the main pests of cassava and peanut

Whitefly (*B. tabaci*) infestation was influenced by the planting systems, being highest in C and CPd (2.56 and 2.86, respectively) and lowest in CPb (1.54) (Table 5). It is likely that the smaller spacing and higher density of plants in CPb when compared to C and CPd, favored the lower incidence of these insects, probably by making their aerial dispersal difficult. On the other hand, the lower vegetation cover and the greater weed infestation in C and CPd (Table 4) ensure the presence of host plants for these insects.

For the lace bug (*V. manihotae*) infestation, there was a significant interaction between the tested arrangements and the part of the plant evaluated. In general, the top of the cassava plant was less infested by the lace bug than the bottom (0.10 vs. 0.50 insect per plant in C, 0.10 vs 0.85 in CPb, and 0.13 vs. 0.78 in CPd), and cassava plants in monoculture have less infestation (0.30 insect per leaf) than plants intercropped with peanuts (0.475 for CPb and 0.45 for CPd).

No significant differences between the spatial arrangements regarding the number of lace bugs per leaf at the top of the plant were observed, while at the base, a greater number of insects was observed in the intercropping system (0.85 per leaf in CPb and 0.78 in CPd) than in the monoculture (0.50) (Table 6).

The results show that the intercropping system increased the incidence of lace bug, especially in the lower half of cassava plants, which are closer to peanut plants. This higher foliar mass in this region combined with a greater soil vegetation cover may have increased proliferation of these insects, creating a microclimate with less wind and solar radiation, in addition to favorable temperature and humidity.

Table 4: Vegetation cover and weed dry mass at 105 days after cassava planting and 60 days after peanut planting, in monoculture or intercropped with peanuts in different spatial arrangements.

Spatial arrangements	Vegetal cover ¹ (%)	Weed dry mass ($g.m^{-2}$)
Peanuts in monoculture (P)	50.75 c	55.50 b
Cassava in monoculture (C)	57.75 b	95.25 a
Cassava/ Peanut between rows (CPb)	76.75 a	20.80 c
Cassava/ Peanut double rows (CPd)	51.50 c	65.15 b
F	56.9851**	29.1344**
HSD	7.39	25.1
VC (%)	5.7	20.19

*Significant differences (Tukey's test at 5% probability) are indicated by letters.

Table 5: Average number of adults of whitefly (*Bemisia tabaci*) per cassava leaf in monoculture or intercropped with peanuts in different spatial arrangements**.**

Spatial arrangements	Whiteflies per leaf
Peanuts in monoculture (P)	-
Cassava in monoculture (C)	2.55915 a
Cassava/ Peanut between rows (CPb)	1.54066 b
Cassava/ Peanut double rows (CPd)	2.86073 a
F	8.8758 **
HSD	0.85906
VC (%)	28.30395

*Significant differences (Tukey's test at 5% probability) are indicated by letters.

In general, the infestation by pests was lower in peanuts, but a significant difference was observed when cassava was intercropped with peanuts (Table 7).

The intercropping of cassava with peanut provided a significantly lower infestation of silver thrips both in CPb (0.42 insect per plant) and CPd (0.43 insect per plant), when compared to P (0.53 insect per plant). No significant differences were found between the intercropping systems.

For the red-necked peanutworm, peanut in monoculture (P) and planted in intercropped with cassava in double interspersed rows (CPd) showed the same level of infestation (0.13 insect per plant), while the intercropping with the peanut planted between the cassava rows (CPb) showed significantly lower infestation (0.06 insect per plant).

The intercropping changes the microhabitat and behavior of plants where pests develop. The spatial arrangement of crops affects the dynamics of insect populations (Huffaker, 1962). Four aspects can be influenced by the intercropping system (Perrin, 1977): a) the colonization of cultures, within which visual and olfactory effects and host diversity are mentioned; b) the development of pest populations; c) dispersion; and d) the abundance of natural enemies. However, research on the incidence of pests in isolated and intercropped crops presents conflicting results depending on the type of intercropping and pests, proving to be suppressors or enhancers of infestations. Although there is controversy (Smith & Mcsorley, 2000), many studies have shown that, in diversified systems, phytophagous insects occur at lower population density than in simplified systems, particularly in monocultures (Perrin, 1977; Andow, 1991).

Cassava belongs to the group of cyanogenic plants with cyanogenic glycosides in its composition. There are reports of high levels of HCN in cassava fresh matter: 1,140 mg kg^{-1} in leaf blades; 1,110 mg kg^{-1} in petioles; and 900 mg kg-^{1} in the stems (Oliveira et al, 2012), with differences in concentrations depending on the cultivar and being higher in cassava used in the industry, as is the case of the IAC 14 variety. According to Cagnon, Cereda and Pantarotto (2002), such glycosides, known as linamarin and lotaustralin, after rupture of the cellular structure, come into contact with enzymes (linamarase) degrading these compounds, releasing HCN. HCN is an extremely volatile compound that contains the cyanide anion (CN^-) responsible for insecticidal, acaricidal, and nematicidal actions. In the present study, the volatilization of hydrocyanic acid by wounding the cassava plants or by the decomposition of senescent leaves may have been decisive in the lower infestation by pests in peanuts.

Productivity and Land Equivalent Ratio (LER)

Table 8 presents the yield of cassava and peanuts in each analyzed arrangement and the LER. Peanut production was higher in P and CPb than in CPd. Likewise, the values for cassava observed in C and CPb were higher than those obtained in CPd.

The fact that the CPb and monocultures had similar results in productivity for both crops indicates that the high density of individuals in the plot, although it may have increased competition for nutrients between plants, was not enough to cause productivity losses. It is possible that the supply of nitrogen promoted by peanut crop residues within the cassava lines compensated for the competition between crops during their period of coexistence. The CPd spatial arrangement affected crop productivity, since productivity is a variable dependent on the area and, therefore, on the density of plants per hectare. The area used by each species in CPd was 50% smaller than the area used in monocultures and planting between rows. The total LER was strongly influenced by intercropping. In CPb and CPd, the LER was 1.90 and 1.38, respectively. This means that the LER was 90% and 38% higher in CPb and CPd than in M, respectively. Although the productivity of individual crops is lower in the intercropped systems analyzed than in their monocultures, the opposite was found for LER, making these arrangements viable.

Table 6: Analysis of the interaction of the average number of lace bugs (*Vatiga manihotae*) per leaf in the top and bottom parts of cassava plants in monoculture or intercropped with peanuts in different spatial arrangements.

Spatial arrangements	Lacebugs per leaf/ Part of cassava plant(B)		Mean	F
	Top of plant	Botton of plant		
Peanuts in monoculture (P)	-	-	-	
Cassava in monoculture (C)	0.10 aB	0.50 bA	0.30 b	18.56**
Cassava/ Peanut between rows (CPb)	0.10 aB	0.85 aA	0.48 a	65.26**
Cassava/ Peanut double rows (CPd)	0.13 aB	0.78 aA	0.45 ab	49.02**
Mean	0.11 B	0.71 A		125.30**
F	0.05^{ns}	7.88**	4.16*	
F(AxB)		3.77*		
VC (%)		45.47		

* Significant differences (Tukey's test at 5% probability) are indicated by letters. Lowercase and uppercase letters compare data in the same column or different rows, respectively.

Table 7: Incidence of silver thrips (*Enneothrips flavens*) and red-necked peanutworm (*Stegasta bosquella*) in peanuts in monoculture or intercropped with cassava in different spatial arrangements.

Spatial arrangements	Incidence (%)	
	Silver Thrips	Red-necked Peanutworm
Peanuts in monoculture (P)	0.53 a	0.13 a
Cassava in monoculture (C)	-	-
Cassava/ Peanut between rows (CPb)	0.42 b	0.06 b
Cassava/ Peanut double rows (CPd)	0.43 b	0.13 a
F	7.1890 **	4.4872 *
HSD	0.07	0.06
VC (%)	13.22	46.25

* Significant differences (Tukey's test at 5% probability) are indicated by letters.

Table 8: Average yield of cassava roots and peanut kernels at 13% moisture and the Land Equivalent Ratio (LER) in monoculture or intercropping systems in different spatial arrangements.

Spatial arrangements	Yield (Mg. ha^{-1})		Land Equivalent Ratio (LER)		
	Peanuts	Cassava	Peanuts	Cassava	Total
Peanuts in monoculture (P)	3.28 a	-	1	-	1
Cassava in monoculture (C)	-	40.94 a	-	1	1
Cassava/ Peanut between rows (CPb)	3.05 a	38.74 a	0.95	0.95	1.90
Cassava/ Peanut double rows (CPd)	2.23 b	27.29 b	0.70	0.68	1.38
F	14.5612 **	9.1434 *			
HSD	0.6288	10.523			
VC (%)	10.14	13.6			

* Significant differences (Tukey's test at 5% probability) are indicated by letters.

These results are corroborated by other authors. Rós and São João (2016) observed higher values of LER (between 5 and 15%) for the intercropping of cassava with sweet potato compared to the monocultures of the crops. Albuquerque et al. (2012), in an experiment with cassava and cowpea, stated that 1.28 ha of cassava are needed for the same yield obtained in intercropped cultivation, that is, LER is 28% higher in intercropped areas than in monoculture areas.

Studies carried out by Tang et al. (2020) with cassava and peanuts intercropping revealed an improvement in several attributes of soil quality when compared to the monoculture of these two species, with an increased amount of rhizospheric microorganisms and the levels of nitrogen, potassium, pH, and the activity of urease in the soil. The study of the proper spacing between cassava and peanut intercropping rows can bring even more positive results (Tang et al., 2015).

Conclusions

The growth of cassava plants was affected by intercropping with peanuts. While the intercropping system increased the incidence of the main cassava pests, it reduced the incidence of the main pests in peanut. Crop productivity was only significantly affected when peanuts and cassava were grown in alternating double rows, being negatively affected by poor use of the space and not by competition between species.

Author Contribution

Conceptual idea: Finoto, EL; Soares, MBB; Methodology design: Finoto, EL; Soares, MBB.; Data collection: Finoto, EL; Soares, MBB.; Data analysis and interpretation: Soares, M. B. B; Finoto, EL; Dionisio, LFS.; and Writing and editing: Soares, MBB; Dionisio, LFS; Finoto, EL; Albuquerque, JAA; Silva, ES; Monteiro Neto, JLL.

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