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ANIMAL PRODUCTION

Growth and light environment of fruit trees in silvipastoral systems for rearing of dairy herds

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ABSTRACT: Silvopastoral systems can have animal welfare and sustainability benefits because trees continually remove carbon from atmosphere, reducing greenhouse effects. Thisstudy identified the most promising fruit trees for inclusion in silvopastoral systems to dairy cattle calves. This experiment was conducted at *Embrapa Agrossilvipastoril*, Brazil, between 2014 and 2018. Five silvopastoral systems with fruit trees and 'Tifton-85' grass were designed to evaluate tree growth and light environment under the canopies. Data were analyzed using SAS® and PDIFF ($P < 0.10$). *Caja* fruit trees had the greatest tree height (5.4 m) and trunk diameter (23.4 cm), while *acerola* fruit tree had the smallest (1.8 m and 8.3 cm, respectively). At 42 months (drought 2017), *caja*, cashew, and guava trees had similar heights. Guava trees had the highest light interception (89.3%), both cashew cultivars provided medium levels of shade (50 to 60% LI) and with greater constancy between the rainy and dry seasons. The systems that showed increased light interception during the drought period were those with CCP76 in 2017 and EMB51 in 2018. Higher incidences of wavelengths of the spectral composition of light occurred between the rainfall (2015) and drought (2017) periods, and greater differences in the ratio of red:far red in 2015. By 2018, there were no more differences between the rainy and dry seasons for the spectral composition of light under the tree canopies. Cashews and guava trees have adequate growth and light environment to support silvopastoral systems but *Caja* and *acerola* fruit trees showed limitations.
Key words: cashew, caja, guava, light interception, spectral composition.

Crescimento e ambiente luminoso de espécies frutíferas em sistemas silvipastoris para criação de novilhas leiteiras

RESUMO: Sistemas silvipastoris beneficiam tanto o bem-estar animal como a sustentabilidade, pois as árvores removem o carbono da atmosfera, reduzindo o efeito estufa. O objetivo foi identificar as fruteiras mais promissoras para inclusão em sistemas silvipastoris. Este experimento foi conduzido na Embrapa Agrossilvipastoril, entre 2014 e 2018. Cinco sistemas silvipastoris com fruteiras e 'Tifton-85' foram projetados para avaliar o crescimento das árvores e o ambiente luminoso sob as copas. Os dados foram analisados com SAS® e PDIFF ($P < 0{,}10$). As cajazeiras apresentaram as maiores alturas (5,4 m) e maiores diâmetros do tronco (23,4 cm), enquanto as aceroleiras tiveram os menores (1,8 m e 8,3 cm, respectivamente). Aos 42 meses (seca de 2017), cajazeiras, cajueiros e goiabeiras apresentavam alturas semelhantes. As goiabeiras apresentaram a maior interceptação de luz (89,3%), as cultivares de cajueiro proporcionaram níveis médios de sombra (50 a 60% LI) e com maior constância entre as estações chuvosa e seca. Os sistemas que apresentaram maior interceptação de luz durante o período de seca foram aqueles com CCP76 em 2017 e EMB51 em 2018. Maiores incidências de comprimentos de onda da composição espectral da luz ocorreram entre os períodos de chuva (2015) e seca (2017) e maiores diferenças na proporção de vermelho: vermelho distante em 2015. Em 2018, não havia mais diferenças entre as estações chuvosa e seca para a composição espectral da luz sob as copas das árvores. Os cajueiros e as goiabeiras têm crescimento e ambiente luminoso adequado para suportar sistemas silvipastoris, mas as cajazeiras e aceroleiras apresentam limitações.
Palavras-chave: cajueiro, cajá, goiaba, interceptação de luz, composição espectral.

INTRODUCTION

The possibility of integrating animal and forest components in the same space has attracted interest from producers, particularly for animal welfare. One way to improve animal welfare is to increase the shaded area available to the animals, thereby reducing heat stress. The use of shade alters the incidence of solar radiation and interferes with other climatic factors such as air temperature and humidity, providing more thermally comfortable environment for the animals, with positive effects on animal welfare and productivity (TITTO et al., 2011).

Shade can be provided through silvopastoral systems: a combination of trees and pasture in the same area. The use fruit trees in the tree component of silvopastoral systems provides shade in the system, yields marketable fruits that increase and diversify the

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income potential of the rural property, and forms a source of animal feed (SOBRINHO, 2009).

However, the establishment of these systems requires prolonged time for planting and maturation because juvenile trees require protection from animals. During establishment of fruit tree seedlings, the presence of animals can cause irreparable damage. Thus, the animals should only be introduced with protected seedlings, or when the trees are large enough to support coexistence with animals (PORFÍRIO-DA-SILVA et al., 2012). Tree canopy architecture directly influences the light environment under fruit trees, affecting the development and growth of forage plants and the ambience of the animals (SALLES & BUCKERIDGE, 2014). Therefore, the knowledge of variables such as light interception and canopy projection area of fruit trees is essential for planning and management of the tree component in silvopastoral systems (FEY et al., 2014). Consequently, fruits that present better crown development and require less time for propagation are of interest to producers using silvopastoral systems. Therefore, this study identified the most promising fruit trees for inclusion in silvopastoral systems that support the rearing of dairy cattle calves, through evaluation of tree growth characteristics and light environment under the tree canopies.

MATERIALS AND METHODS

The study was conducted at the experimental base of milk production in integrated systems of *Embrapa Agrossilvipastoril, Sinop – Mato Grosso* state, Brazil. The climate of the region is classified, according to Köppen as tropical savanna with dry winter (Aw), which alternates between the wet and dry seasons (SOUZA et al., 2013). The experimental area covered 3.75 ha, on a Red-Yellow latosol of flat relief and clay texture (617 g kg^{-1} clay, 137 g kg^{-1} silt, and 246 g kg^{-1} sand) (USDA, 1943). The chemical analysis of the soil was determined in June 2010, before the experiment began. The fertility levels in 0 to 20; 20 to 40 and 40 to 60 cm depth were respectively: Calcium (2.2; 1.2 and 0.9 $cmol_c$ dm^{-3}); Magnesium (0.7; 0.4 and 0.3 $cmol_c$ dm^{-3}); Aluminium (0.0; 0.4 and 0.4 $cmol_c$ dm^{-3}); Basis saturation (43.1; 30.6 and 28.7%); pH (5.6; 5.4 and 5.3); Potassium (73; 33 and 30 mg dm^{-3}) and Phosphorus (12.81 mg dm^{-3}). In July 2013, after this soil analysis and before the implementation of the silvopastoral systems, the area received 2 tons of dolomitic limestone per hectare, incorporated at a depth of 20 cm, following the fertilization and liming recommendations of Bulletin 100 of the IAC for the State of *São Paulo* (RAIJ et al., 1997). The water balance (BLACK, 2007), accumulated precipitation, temperature, and average air humidity were calculated by dataset from the *Embrapa Agrossilvipastoril* (Figure 1).

Five silvopastoral systems composed of the perennial forage grass 'Tifton-85' (*Cynodon* spp.) were tested. The associated fruit trees were *caja* fruit tree (*Spondias mombin)*, red guava (*Psidium guajava* 'Paluma'), cashew (*Anacardium occidentale* 'EMB51' and 'CCP 76'), and *acerola* fruit tree (*Malpighia glabra* 'Sertaneja'. A randomized complete block design was used with two repetition areas (two blocks) comprising ten experimental units of 1,650 m^2 each (30 m wide and 55 m long). The fruit trees were planted between 15 December 2013 and 15 January 2014 and included the main planting and replanting of seedlings that did not survive. This ensured establishment of the trees during the rainy season. The planting process was as follows; after demarcation, the planting pits of 40 cm diameter and 80 cm depth were dug in an east-west orientation using a soil drill. Each planting pit was individually fertilized with 150 g of simple superphosphate, 300 g of dolomitic limestone, 25 L of tanned bovine manure, 50 g of the micronutrient mixture, and natural phosphate, to ensure fertility conditions that would not limit tree growth. The application of reactive natural phosphate per pit varied according to species: 750 g for cashew trees, 200 g for *acerola* fruit tree and *caja* fruit tree, and 450 g for guava trees. Maintenance fertilization of the fruit trees followed the recommendation for each species and involved manual application around the plant following the crown projection at a minimum distance of 30 cm from the trunk. The *acerola*, *caja*, cashews and guava trees each received 200, 450, 400, and 500 g of ammonium sulphate; 300, 400, 750, and 250 g of simple superphosphate; and 100, 175, 100, and 600 g of potassium chloride, respectively, per tree, distributed in three equal-sized plots and applied in January, February, and March 2014. The same process was repeated in 2015 and 2017.

In the plots containing *caja* fruit tree, cashew and guava trees, 27 tree saplings were planted in a single row arrangement, with spacings of 10 m between rows, 4 m between plants, and a projected density of 250 trees ha^{-1}. Owing to its smaller size, 36 tree saplings of *acerola* fruit were planted in a double row arrangement, with spacings of 10 m × 4 m × 4 m, and a projected density of 357 trees ha^{-1}. Each *acerola* fruit tree plot of 1,650 m^2 contained a central double row of seedlings with two single rows

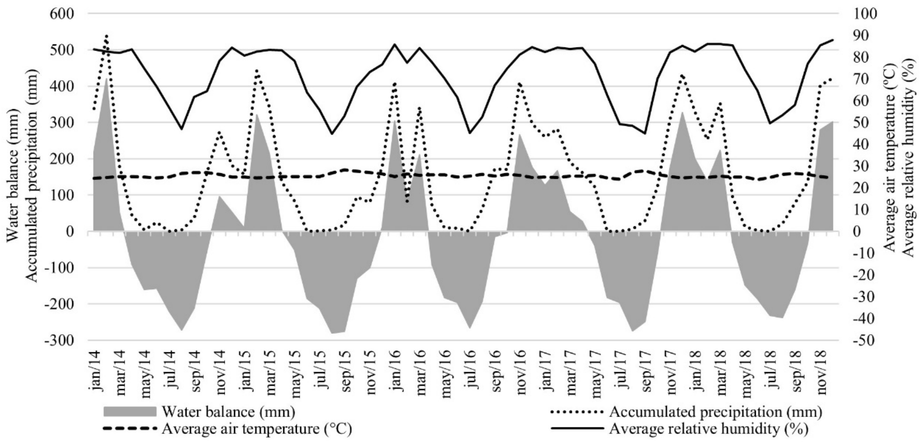

Figure 1 - Extract of the water balance, accumulated precipitation, temperature, and relative humidity of the monthly average from 2014 to 2018. Source: Database of the automatic weather station located in the experimental field of Embrapa Agrossilvipastoril, at Sinop, Mato Grosso state, Brazil.

either side. The experimental sampling units of the fruit trees included the ten central *acerola* fruit trees from the double row (five in each row) and the five central trees of the middle row of the plot for all other tree species.

The 'Tifton-85' grass was planted soon after the fruit tree seedlings were planted. Pasture management involved mechanical cutting from 50 cm to 20 cm before the cattle were introduced to the plots. Assessments of tree growth (tree height and trunk diameter) began in June 2014, and for the light environment in January 2015. Both assessments were terminated in July 2018.

Tree height and trunk diameter measurements were taken between July 2014 and July 2018, and crown diameter measurements between January 2015 and July 2018. Both variables were assessed biannually, halfway between the rainy (January-February) and dry seasons (July-August). Tree height was measured using a 5 m long ruler graduated in centimeters; the measurement was made from the base (ground level) to the top of the crown. The trunk diameter was measured at ground level using a digital calliper (PAIVA et al., 2006), and a digital probe when tree growth exceeded the capabilities of the calliper. Crown diameter was estimated as the distance between the projection lines of the outermost points of the crown and determined using two orthogonal measurements; one following the orientation of the line and the other at 90° from the line, with subsequent calculation of its average (DURLO & DENARDI, 1998). The crown projection area (m²) was calculated using mathematical formulas adapted from DURLO & DENARDI (1998) and WINK et al. (2012). For the light environment, two variables were measured: light interception (LI), and the spectral composition of light (photosynthetically active radiation). The LAI-2200 (LI-COR Inc., Lincoln, Nebraska) canopy analyzer was used to measure the light interception (LI) under the tree canopies. The first reading was taken at an open-air point near each tree, followed by eight points below the canopy, divided into imaginary quadrants. The measurements were taken when the sun was near the horizon line, as described by GIUSTINA et al. (2015) and in accordance with the LAI-2200 manual. To evaluate the spectral composition of light under the canopy, a portable spectrophotometer, SpectraPen SP-100 (Photon Systems Instruments, Czech Republic) was used. The device was positioned vertically, next to the trunk and under the canopy, in the direction of the shadow projection. Measurements were taken in the morning between 08:00 and 09:00. The red:far red ratio was obtained by the ratio between red (645 ηm) and far red (735 ηm) wavelengths. The wavelengths 446 (indigo), 464 (blue), 500 (green), 578 (yellow), 645 (red), and 735 ηm (far red) were selected for the evaluation.

The statistical program SAS® On Demand (SAS Institute Inc, 2018) was used to analyse the data. The data were tested for normality (Kolmogorof-Smirnov) using the PROC univariate model, and the analysis of variance was performed under the Mixed Procedure model (PROC Mixed). The treatment means were estimated by the LSMEANS function and compared in PDIFF (P < 0.10). The correlation between the variables *tree height* and *trunk diameter* was performed using Excel®software, confronting the means of the treatments to generate the function and Pearson's correlation coefficient and compared by the t-test (P < 0.01).

RESULTS AND DISCUSSION

All fruit trees showed growth throughout the experimental period but varied in growth intensity between species (P < 0.0001). The highest average final tree height was for the *caja* fruit (5.4 m),starting from 0.8 m in 2013 (an increase of 6.75 times), and the lowest was for the *acerola* fruit (1.8 m), starting from 1.1 m in 2013 (an increase of 1.6 times) (P < 0.0001). There was a similar response to that of tree height throughout the experimental period, whereby trunk diameter increased with the variable intensity depending on the tree species (P < 0.0001). *Caja*fruit tree had the largest average final trunk diameter (23.4 cm), an increase of 14.6 times from the starting, and *acerola* fruit tree had the smallest average diameter (8.3 cm), an increase of 4.6 times from the starting. Both cashew varieties ('EMB51' and 'CCP76') and guava exhibited intermediate trunk diameter (13.4 m on average) by the end of the evaluation period, an increase of 8.6 times from the starting (Table 1).

The average crown projection area for all tree species increased eight-fold between the 2015 and 2018 rainy seasons (1.6 m² and 13.0 m² respectively) (P < 0.0001). *Caja* fruit trees crown protection area oscillated between the rainy and dry seasons, with

Table 1 - Height, trunk diameter, crown projection area and light interception of five fruit tree in silvopastoral systems for the rearing of dairy herds between 2014 and 2018 (drought and rainy season).

Fruit trees	---Year/Period---						
	2014 Drought	2015 Rainy	2015 Drought	2017 Rainy	2017 Drought	2018 Rainy	2018 Drought
---Tree height (m)---							
Acerola	1.1 cB	1.3 bcAB	1.7 bB	1.5 bC	1.9 aB	1.8 aC	1.8 aC
Caja	0.8 dC	1.3 cAB	1.5 cB	3.6 bA	3.6 bA	5.3 aA	5.4 aA
Cash. 'CCP76'	0.6 dC	0.9 dB	1.6 cB	3.0 bB	3.5 aA	3.6 aB	3.8 aB
Cash. 'EMB51'	0.7 dC	1.4 cAB	1.8 cB	3.2 bAB	3.8 aA	3.7 aB	3.9 aB
Red Guava	1.4 dA	1.6 dA	2.3 cA	3.0 bB	3.5 bA	3.3 bB	3.9 aB
---Trunk diameter (cm)---							
Acerola	1.8 eA	3.4 dAB	4.3 cB	5.8 bD	5.5 bD	6.9 abD	8.3 aD
Caja	1.6 fA	3.8 eAB	6.6 dA	13.9 cA	15.3 cA	21.2 bA	23.4 aA
Cash. 'CCP76'	1.6 dA	2.8 dB	4.5 cB	9.4 bC	10.7 bB	12.9 aB	13.5 aB
Cash. 'EMB51'	1.3 eA	4.6 dA	6.6 cA	11.4 bB	12.1 bB	14.3 aB	14.7 aB
Red Guava	1.8 dA	3.5 cdAB	5.2 cAB	7.5 bD	8.4 bC	10.8 aC	12.0 aC
---Crown projection area (m²)---							
Acerola	-	1.6 aA	2.6 aB	2.9 aB	2.6 aC	4.0 aB	4.4 aB
Caja	-	0.8 dA	0.1 dC	6.6 cA	0.6 dC	19.5 aA	13.9 bA
Cash. 'CCP76'	-	0.8 cA	2.4 cB	7.3bA	8.9 bB	17.2 aA	16.9 aA
Cash. 'EMB51'	-	1.5 dA	2.9 dB	8.7 cA	12.5 bA	18.3 aA	14.9 bA
Red Guava	-	3.5 dA	5.0 dA	9.2 cA	10.6 cA	18.4 aA	14.9 bA
---Light interception (%)---							
Acerola	-	54.7 bA	61.2 aA	67.2 aB	38.1 cC	68.0 aB	55.6 bC
Caja	-	53.3 cA	22.5 dC	76.6 aA	29.1 dD	65.5 bB	48.6 cD
Cash. 'CCP76'	-	45.7 dB	55.3 cB	55.4 cC	71.0 aA	58.4 bC	64.7 abB
Cash. 'EMB51'	-	55.4 cA	65.3 abA	71.2 aAB	60.8 bB	52.8 cC	70.3 aB
Red Guava	-	52.6 cA	53.8 cB	72.0 bAB	22.6 dE	90.5 aA	89.3 aA

Upper- and lower-case letters compare means between rows and between columns, respectively. Tree height, P < 0.0001 and EPM = 0.28; Trunk diameter, P < 0.0001 and EPM = 1.11; Crown projection area, P < 0.0001 and EPM = 1.91 and Light interception, P < 0.0001 and EPM = 5.82.

a lower average coverage in the dry season than the rainy seasons (4.9 m² and 9.0 m² respectively). At the end of the experiment, *caja* fruit trees, cashews and guava trees had the largest average crown projection area (15.15 m²) while *acerola* fruit trees had the smallest (4.4 m²).

Both cashew tree varieties showed smaller variations in light interception between the dry and rainy seasons (7% on average), while the *caja* fruit tree, showed greater reductions in the dry seasons (48% on average) and greater increases in the rainy seasons (120% on average) than the other tree species ($P < 0.0001$) (Table 1).

There was a positive correlation between the variables *tree height* and *trunk diameter*, with r^2 of 0.71, 0.99, 0.99, 0.98 and 0.97 ($P < 0.01$) for *acerola* fruit tree, *caja* fruit tree, cashew cultivars CCP76 and EMB51, and guava, respectively (Figure 2).

The spectral composition of light was only influenced by the period ($P < 0.0001$) (Figure 3). During the rainy season of 2015, the highest values for the 645 ηm (red) and 735 ηm (far red) wavelengths were observed and in the dry season of 2017, the highest values for 446 ηm (indigo) and 464 ηm (blue) were recorded.

There was a significant interaction between silvopastoral system and period ($P = 0.0356$) in the red:far red ratio, with high variation between the fruit trees in their initial phase of growth (rainy and dry seasons of 2015) (Figure 4). A similar ratio was recorded in the rainy season of 2017, whereby values close to 1.0 were maintained.

All fruit trees were planted during the rainy seasons of 2013 and 2014, with similar tree height and trunk diameter, but the *caja* tree showed the highest growth (tree height and trunk diameter) by the end of the experiment (drought period 2018) (Table 1). At 42 months (drought period 2017), *caja* fruit tree, cashew, and guava trees had similar heights. However, from this period onwards there was a difference in the height growth of the trees. Although, the *caja* fruit tree showed continuous growth in tree height in the subsequent periods (rainy and drought seasons 2018) and had the greatest height, tree height growth for the guava tree declined, and no further growth occurred in the CCP76 and EMB51 cashew trees. This is attributed to the characteristics of each fruit tree, because while *caja* fruit tree can reach adult tree heights between 20 and 30 m, the CCP76 and EMB51 cashew trees dwarf varieties are characterized by an adult height of 4 m. The guava (medium-sized tree) presents an average height of 3 to 5 m and the *acerola* reaches an average height of 2.0 to 2.5 m (GONZAGA NETO et al., 1999). Thus, both cashew and guava trees reached a size close to that of adult trees (3.8 and 3.5 m on average, respectively) at 42 months post-planting (dry season 2017) (Table 1), reducing or even ceasing their growth in tree height. The *acerola* fruit tree also reached a tree height close to that described in the literature (2.0 to 2.5 m) (GONZAGA NETO et al., 1999) in the dry season of 2017, when growth ceased.

When the animals were introduced to the silvopastoral systems, all the fruit trees, had trunk diameters above 6.2 cm except for the *acerola* fruit tree which was 5.5 cm. The general minimum recommended trunk diameter of trees prior to the introduction of animals (even for small animals) in

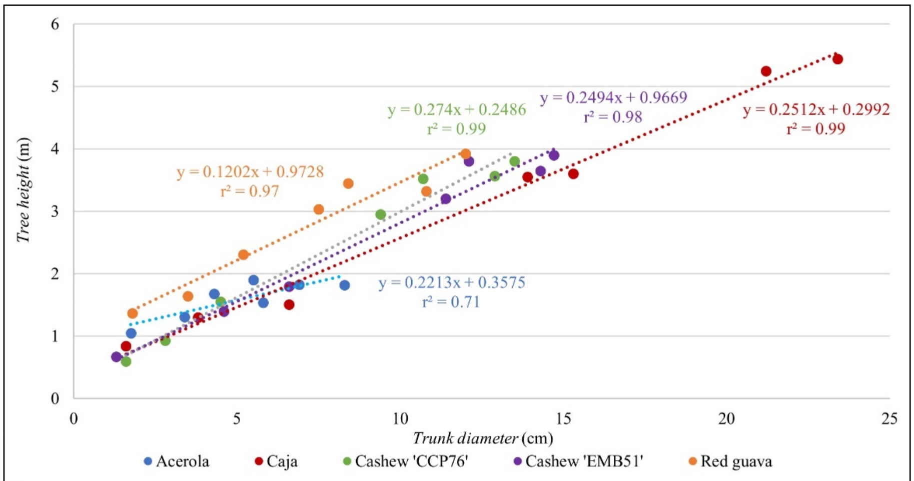

Figure 2 - Correlation of tree height and trunk diameter of five fruit tree in silvopastoral systems for the rearing of dairy herds between 2014 and 2018.

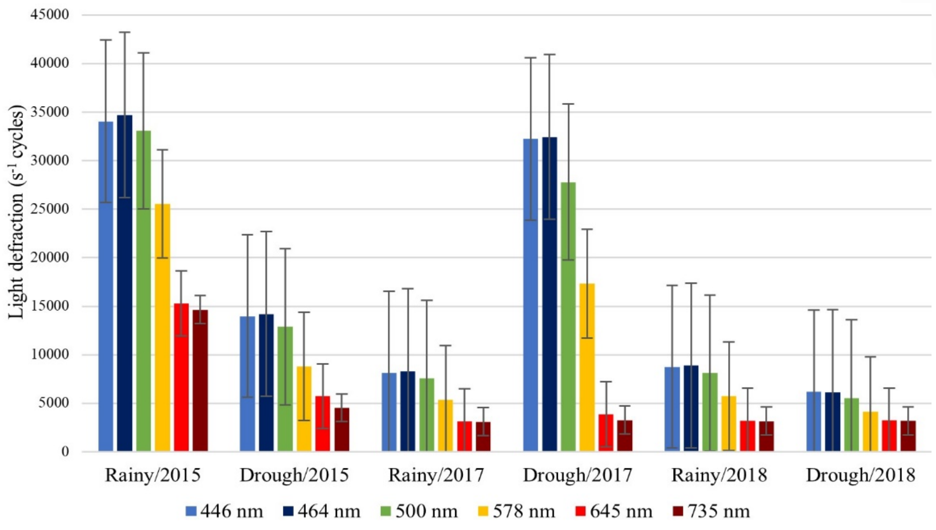

Figure 3 - Spectral composition of light under the tops of five fruit trees in silvopastoral systems for the rearing of dairy herds in the rainy and drought periods from 2015 to 2018. Indigo: P_{Period} = <0.0001; Blue: P_{Period} = <0.0001; Green: P_{Period} = <0.0001; Yellow: P_{Period} = <0.0001; Red: P_{Period} = <0.0001; Far red: P_{Period} = <0.0001.

silvopastoral systems is 6.2 cm, due to the possibility of damage to the fruit trees when animals are introduced with trees having lesser trunk diameter (PORFÍRIO-DA-SILVA et al., 2012). Thus, considering only this variable, the animals could have been introduced to all the silvopastoral systems, except the ones with *acerola* fruit tree, in the rainy season of 2017. Trunk diameter and tree height were positively correlated (r^2 = 0.96 mean; Figure 2) during the evaluation period, proving that the period was marked by the juvenile growth phase of the plants, with proportionality in the height and diameter gains. However, based on the dispersion of the points and the slope of the line of the regression plot, the juvenile phase of the *acerola* trees is reached within two years, when height stabilises at around 1.8 m and the gains in diameter continue (Figure 2). These results agree with those found by FEY et al. (2014) for *jatropha* (r^2 = 0.75) also in silvopastoral systems. Estimates of tree height, trunk diameter, and the correlation between these characteristics, should not be analyzed with the same prism of a timber tree component in crop-livestock-forest integration systems. For timber trees, the timing of animal entry, and gains in diameter and height are directly related to the increase in the economic value of the tree (PORFÍRIO-DA-SILVA et al., 2012). In the case of fruit trees, the selection of species should be reconciling the timing of animal entry with the yield and quality of the fruit produced. The final quality of the fruit is related to the height of the plants, allowing for manual harvesting and improved efficiency of phytosanitary management measures (TOMÉ et al., 2007). For most domesticated fruits, the height of the plants should reach between 3 and 4 meters. This is achieved through genetics, like the dwarf cashew trees 'CCP76' and 'EMB51' (CRISÓSTOMO et al., 2009), or with horticultural practices like pruning for formation and production, routinely performed on guava trees (SEHGAL & RANJIT, 2011).

Other important variables to consider regarding the growth and/or structure of fruit trees are the area of shade projection, shade intensity, data related to animal welfare, and forage production under the canopies (ALVES et al., 2012; LIMA et al., 2019). In this study, even with greater tree height and trunk diameter, the *caja* fruit trees did not show continuous growth in the canopy projection area, and that light interception under its canopy did not increase steadily during the experimental period (Table 1). Generally, these variables increased in the rainy seasons and decreased in the dry seasons, in contrast to the other fruit trees. This response by the *caja* fruit trees can be explained their deciduous habit (abscission of leaves and small branches) during periods of drought (SOUZA et al., [2012)]. Consequently, the canopy provided less shade during the dry

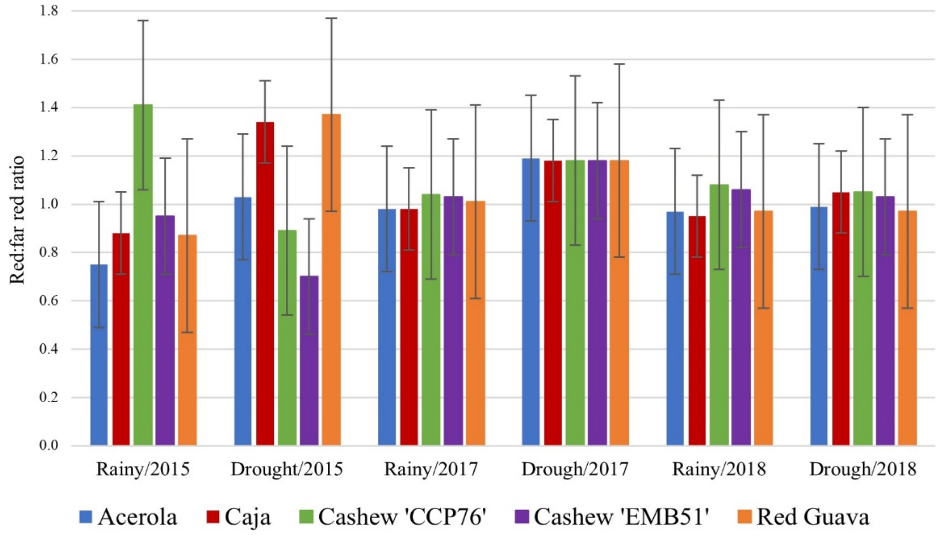

Figure 4 - Red: far red ratio of lightunder the tops of five fruit trees in silvopastoral systems for the rearing of dairy herds in the rainy and drought periods from 2015 to 2018. $P_{system\ x\ period}$ = 0.0356.

seasons of 2015, 2017 and 2018, characterizing a response pattern of this fruit tree for this period of the year in northern *Mato Grosso*. In regions where winter (July–September) is dry and hot e.g. northern *Mato Grosso*, the presence of shade is essential for protection against adversity (ALVES & KARVATTE JUNIOR, 2019).

The reductions in light interception of guava trees in the dry season of 2017 (Table 1), were attributed to the attack of the guava beetle (*Costalimaita ferruginea*) that feeds on the leaf lamina, leaving it with a partial or totally perforated (GALLI et al., 2017). The *acerola* fruit trees also showed leaf fall in the dry season of 2017, with a consequent reduction in light interception (Table 1), due to concurrent water stress (Figure 1). Similarly, ALVES et al. (2009) showed that in regions with low rainfall in the dry season, such as the study area (Figure 1), the *acerola* fruit trees lose some leaves at this time, with subsequent recovery of the leaf area in the rainy season.

Both cashew cultivars (EMB51 and CCP76) provided medium levels of shade (50 to 60% LI) and with greater constancy (less variation in shade) between the rainy and dry seasons. The systems that showed increased light interception during the drought period were those with CCP76 in 2017 and EMB51 in 2018. This pattern of response may have occurred due to the hardiness of this fruit tree that is native to the region and well-adapted to water deficits (CRISÓSTOMO et al., 2009). Stability in shade supply is a known benefit to animal welfare, especially in regions with climatic adversity, such as in the north of *Mato Grosso* state (Figure 1) (INMET, 2019).

In contrast to the cashew varieties, the guava trees had higher light interception values at the end of the study (drought 2018) than the other fruit trees. This may be due to them having reached adulthood in the last dry season of the study period, thereby having a well-developed root system. This would allow the tree to have access to sufficient water and to avoid a reduction in leaves during periods of water stress (GALLI et al., 2017). Sehgal & Ranjit (2011) described the guava tree as a rustic fruit tree, adapted to the soil and climate conditions of the region and providing dense shade. Being an important factor in plant production (LIMA et al., 2019), more intense shade can also benefit animal behaviour, physiological responses, and production (ALVES & KARVATTE JUNIOR, 2019).

For the spectral composition of light, the greater incidence of wavelengths on the forage canopy during the rainy period of 2015 (Figure 3) can be attributed to the smaller size and structure of the fruit canopies in the initial phase of juvenile growth, occupying a small amount of space in the experimental plot and having low light interception (Table 1). With the growth and development of the fruit trees, there was a consequent increase in light interception, resulting in a constant reduction in the incidence of all wavelengths on the pasture located below the crowns of the trees throughout the experimental period (Figure 3).

The higher incidence of wavelengths on the forage canopy in the 2017 drought period compared to the rainy period (Figure 3), occurred due to lower light interception values, especially for *acerola* fruit trees, *caja* fruit trees and guava, caused by water deficit, deciduous habit, and pest attack, respectively. Notably, the increase was proportionally more intense for wavelengths 446 ηm (indigo), 464 ηm (blue), 500 ηm (green) and 578 ηm (yellow), and less intense for 645 and 735 ηm (red and far red, respectively). Although, blue wavelengths are available in greater abundance in shaded environments (RODRIGUES et al., 2012), their use in the photosynthetic process can reduce the production of forage dry mass through higher energy dissipation, but concomitantly may be beneficial for other morphophysiological activities of plants as the tillering of grasses (TAIZ & ZEIGER, 2017). An increase in the incidence of light spectrum can affects simultaneously benefit plant production while negatively affecting the animal ambience. This is due to thermal stress created by air temperature, relative humidity, solar radiation, and wind speed (ALVES & KARVATTE JUNIOR, 2019).

By 2018, there were no more differences between the rainy and dry seasons for the spectral composition of light under the tree canopies of the silvopastoral systems. This supports that once the fruit trees used in this study reach adulthood, their spectral composition remains more stable (Figure 3), even if light interception is altered (Table 1).

Similarly, the red:far red ratio (Figure 4) varied only during the rainy and dry seasons of 2015 (initial phase of fruit plant growth), showing that this ratio also stabilises after the fruit plants reach adulthood. It is known that higher red:far red ratios are important for stimulating the development of the growth points (apical and basal buds) of plants, especially forage plants (LEMAIRE & CHAPMAN, 1996). Concomitant with the lower incidence of light interception, the periods of greater canopy openness are beneficial for the development and growth of new tillers and/or branches of forage plants and essential for pasture perennialism (RODRIGUES et al., 2012). The red:far red ratio that reaches the base of the fruit trees remained practically constant to adulthood (48 months, corresponding to the 2017 rainy season). This is a rare occurrence in silvopastoral system studies; however, detailed comparisons with previous studies are not yet possible due to the novelty of this current study.

CONCLUSION

The cashew trees CCP76 and EMB51 and guava trees present adequate growth and light environment to support silvopastoral systems. *Caja* and *acerola* fruit trees have limitations for inclusion in silvopastoral systems because they do not provide sufficient shade for animals during drought periods when shade is most needed due to the deciduous nature of the *caja* fruit trees and the low positioning of *acerola* fruit tree branches, in the first 48 months post-planting.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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