LUMINOUS INTERCEPTION OF EUCALYPTUS CLONES AT DIFFERENT STRUCTURAL ARRANGEMENTS FOR INTEGRATED PRODUCTION SYSTEMS

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Abstract

Combinations of species, cultivars, clones and structural arrangements are cited as possibilities that may determine the interactions between these system components and management, needing to be better understood, especially in relation to shading capacity. In this sense, the present study aims to evaluate the light interception of *Eucalyptus* spp. clones at different structural arrangements for integrated production systems. An experiment was installed in randomized blocks design with five replications, in factorial scheme 4 x 2. Four structural arrangements A1 = Triple row (3,5 x 3,5 x 3,5) + 88 m; A2 = Double row (3,5 x 3,5) + 44 m; A3 = Single row 4 x 22 m; and A4 = Single row 4 x 11 m and two hybrids clones of *Eucalyptus urophylla* x *E. grandis*. For the estimation of the luminosity characteristics, the CI-110 imager equipment was used for estimate: the leaf area index, the average leaf angle, the coefficient of transmission, the sunflecks and the photosynthetically active radiation. Data were analyzed by variance analysis and the averages of the values of characteristics were compared by the Tukey test at 5% probability. The single row arrangement A4 promoted to the clones the greater shading capacity, characterized by high values of leaf area index, lower values of photosynthetically active radiation and by the densification of the arrangement of the other rows of alleys.
Keywords: Integration of crop-livestock-forest; leaf area index; photosynthetically active radiation.

Resumo

Interceptação luminosa de clones de eucalipto em diferentes arranjos estruturais para sistemas integrados de produção. Combinações de espécies, cultivares, clones e de arranjos estruturais são citadas como possibilidades que poderão determinar as interações entre estes componentes do sistema e o manejo, necessitando serem melhores compreendidas, principalmente em relação à capacidade de sombreamento. Nesse sentido, o presente estudo tem como objetivo avaliar a interceptação luminosa de clones de *Eucalyptu*s spp. em diferentes arranjos estruturais para sistemas integrados de produção. Foi realizado um experimento no delineamento em blocos casualizados com cinco repetições, em esquema fatorial 4 x 2 [Quatro arranjos estruturais A1= Fileira tripla (3,5 x 3,5 x 3,5) + 88 m; A2= Fileira dupla (3,5 x 3,5) + 44 m; A3= Fileira simples 4 x 22 m; e A4= Fileira simples 4 x 11 m] e dois clones de híbridos de *Eucalyptus urophylla* x *E. grandis*. Para a estimativa das características de luminosidade, foi utilizado o aparelho imageador CI-110 para estimar: o índice de área foliar, o ângulo médio foliar, o coeficiente de transmissão, a sunflecks e a radiação fotossinteticamente ativa. Em posse dos dados, foram realizadas as análises de variância e comparadas as médias dos valores das características pelo teste de Tukey a 5% de probabilidade. O arranjo de fileira simples A4, promoveu aos clones a maior capacidade de sombreamento, caracterizados pelos altos valores de índice de área foliar, menores valores de radiação fotossinteticamente ativa interceptada e pelo adensamento do arranjo das demais fileiras de renques.
Palavras-chaves: Integração lavoura-pecuária-floresta; índice de área foliar; radiação fotossinteticamente ativa.

INTRODUCTION

Among the different cropping systems used, the integration of crop, livestock and forestry (iCLF) has been gaining prominence in the Brazilian agricultural scenario, with the objective of intensifying land use, through the spatial and temporal integration of the components of the productive system, to reach ever higher levels of product quality, environmental quality and competitiveness, combining increased productivity with the conservation of natural resources (BALBINO *et al*., 2011).

The modalities contemplated in the iCLF are: crop-livestock integration; the crop-livestock-forestry integration; the livestock-forestry integration (silvopastoral practice); and crop-forestry integration (agroforestry).

In these systems, the practice of consortium, rotation or succession is adopted, being able to be in phases or cycles of cultures, efficiently integrating perennial and annual crops in the same area or the same year, for multiple years.

An important challenge in these systems is the choice of its components, since, for this, the species used need to present cultural characteristics that enable and optimize the management in this new system proposed (FARIAS-NETO *et al*., 2011). However, the majority of plant breeding programs do not develop genotypes directly targeted to these systems, thus not allowing a better productive potential through new varieties of these species.

Macedo *et al.* (2010) cite several situations of combinations of species, cultivars, clones and structural arrangements, as possibilities that may determine the interactions between the components and the management. Thus, it should be better understood in order to establish integrated (crop-livestock-forestry) systems - that are more productive and adapted to the different regions of Brazil.

Thus, for the forestry component in these systems, trees with crown characteristics of smaller sizes and densities, good natural pruning and high initial growth rate are recommended, since these characteristics favor the transmission of solar radiation to the lower canopy. Then, consequently, the growth and production of agricultural and forage species are also favored, besides the early entry of animals for grazing (OLIVEIRA NETO; PAIVA, 2010; FARIAS-NETO *et al*., 2011).

For that, it is necessary to adopt the arrangement capable of: promoting annual increments of wood; satisfactory for the number of trees per hectare; and that also favors the entrance of light for the other components, so that their productivities are not affected.

The simplest and most effective spatial arrangement is the "alley" (or rows), in which the trees are planted in strips (single or multiple lines), with wide spacing (BALBINO *et al*., 2012). Producers wishing to prioritize wood production may use narrower alleyways or greater number of lines at each strip (more trees per hectare); while those who prefer agricultural and/or livestock activity may use larger spacing (wider alleys - fewer lines in each strip) (PORFÍRIO-DA-SILVA, 2007; PORFÍRIO-DA-SILVA *et al*., 2008).

In this sense, the present study aims to evaluate the light interception of clones of *Eucalyptus spp*. in different structural arrangements for integrated production systems.

MATERIAL AND METHODS

The experiment was implemented with two hybrid clones of Eucalyptus spp. at Aliança farm, property of the company Aliança Florestal, in the municipality of Aliança do Tocantins-TO. In this municipality, the climate is tropical, classified according to Koppen as Aw, with higher rainfall rate recorded during summer. The average temperature is 21 ° C and the average annual rainfall is 1,617 mm. The soil of the study site is classified as medium-texture dystrophic Yellow Latosol (EMBRAPA, 2013).

The experiment was installed in February 2014 at coordinates (-11º 20' 12,3" S; -48º 49' 57,7" W) and 261,6 m altitude. It used randomized blocks design with five replications, in a 4 x 2 factorial scheme at four structural arrangements and two clones of hybrids of *Eucalyptus*: AEC-1528 *(E. urophylla* x *E. grandis*, belonging to the company Arcelor Mittal) and MA-2015 (*E. urophylla x E. grandis*, belonging to the company Suzano), with double border between each experimental unit/block. The treatments and the experimental arrangement are described in Table 1 and Figure 1.

Table 1. Description of the treatments used for the evaluation of structural arrangements in integrated production systems for the hybrid clones of *E. urophylla* x *E. grandis* AEC-1528 from Arcelor Mittal and MA-2015 from Suzano.

Tabela 1. Descrição dos tratamentos utilizados para avaliação dos arranjos estruturais em sistemas integrados de produção para os clones de híbridos de *E. urophylla x E. grandis* AEC-1528 da empresa Arcelor Mittal e MA-2015 da empresa Suzano.

Treatment	Name	Spacing (m)	Planting density	% of occupation ha^{-1}
A1	Triple row	(3,5 x 3,5 x 3,5) + 88 m	90 trees ha^{-1}	9,5
A2	Double row	(3,5 x 3,5) + 44 m	120 trees ha^{-1}	11,6
A3	Single row	4 x 22 m	114 trees ha^{-1}	9,1
A4	Single row	4 x 11 m	227 trees ha^{-1}	18,2

A1 - Structural arrangement of the treatment 1; A2- Structural arrangement of the treatment 2; A3 - Structural arrangement of the treatment 3; A4 - Structural arrangement of the treatment 4.

A1 – Arranjo estrutural do tratamento 1; A2- Arranjo estrutural do tratamento 2; A3 – Arranjo estrutural do tratamento 3; A4 – Arranjo estrutural do tratamento 4.

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Each experimental unit was represented by 15 trees. For data measurements, 10 samples of random hemispherical images were performed for each arrangement, at central lines of alleys of triple rows; at the central line of alleys of double rows and among each tree at lines of alleys of single rows, according to Figure 1.

The choice of the area for planting (6,0 ha) was carried out considering the homogeneity of the soil and its representativity, so that the extrapolations could be successfully performed for the other areas of the property.

During soil preparation, the chemical weed control was performed 10 days before planting in the whole area with herbicide glyphosate®. Posteriorly, subsoiling was carried out at 50 cm depth, in the distance according to arrangements, thus forming the planting lines for single, double and triple rows.

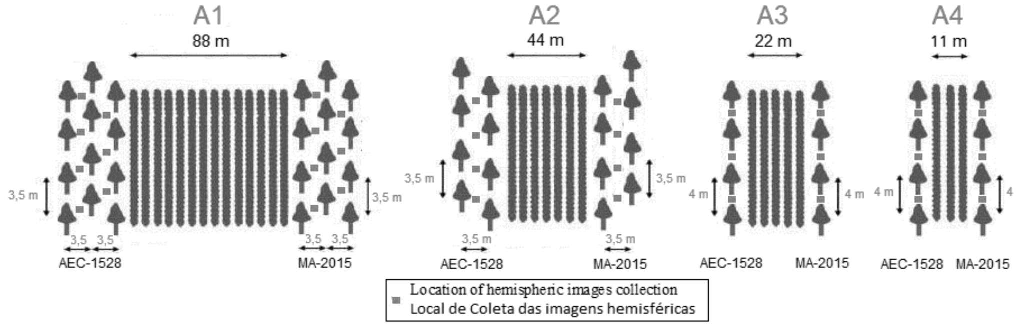

Figure 1. Structural arrangements adopted for the evaluation of the luminous interception of *Eucalyptus spp*.; A1 = triple row (3,5 x 3,5 x 3,5) + 88 m; A2 = double row (3,5 x 3,5) + 44 m; A3 = single row 4 x 22 m; A4 = single row 4 x 11 m and position of hemispheric image collection in *Eucalyptus* at structural arrangements for integrated production systems.

Figura 1. Arranjos estruturais adotados para avaliação da interceptação luminosa de clones de *Eucalyptus* spp.; A1= fileira tripla (3,5 x 3,5 x 3,5) + 88 m; A2= fileira dupla (3,5 x 3,5) + 44 m; A3= fileira simples 4 x 22 m; A4= fileira simples 4 x 11 m, e posição de coleta de imagens hemisférica em arranjos estruturais de *Eucalyptus* para sistemas integrados de produção.

Fertilization was performed with 300 kg ha^{-1} of North Carolina Natural Phosphate distributed at subsoiling moment; and 100 g per pit (82 kg ha^{-1}) of formulated NPK 06:30:12, incorporated into planting according to Silveira and Gava (2004) and according to the soil analysis. At 90 days after planting, the coverage was carried out; with nitrogen and potassium application at a dose of 100g (82 kg ha^{-1}) around each pit using the formulated 20:00:20.

For the evaluation of the treatments with the collection of digital hemispheric images, the equipment CI-110 Plant Canopy Analyzer was used, composed by a rod with 24 sensors to determine the intensity of Photosynthetically Active Radiation (PAR). At rod tip, the camera is fixed with lens “fish eye”, with an angle up to 180 °. The process of inversion of the openings (gaps) probability in canopy at different zenith angles allowed estimating the variables: Leaf Area Index (LAI); Average Leaf Angle (ALA), in degrees; Coefficient of Transmission (CT); points of direct illumination below the canopy - Sunflecks (%); and Photosynthetically Active Radiation (PAR) in µmol m^{-2} s^{-1}.

This imaging equipment is a passive ground sensor, used to measure the amount of incident solar radiation in the visible spectrum below the canopy, as described in the operating manual (CID BIO-SCIENCE, 2017). It can be used with a coupled GPS and, at all sky conditions (even in different lighting conditions), due to the integrated optical filter coupled, which ensures that the scattered radiation does not affect the sensor by the radiation restriction superior 490 nm. This minimizes the effect of the light transmitted by the leaf and allows the measurements to be conducted in the lower or inner part of the vegetal cover, with several different lighting conditions (SCHAEFER *et al*., 2014).

Each captured image was obtained with the support of a 1.70 m turning stabilizer always oriented to the north, through the digital compass of CI-110 software. It was configured for image capture the angle of 150º, aiming to measure only the variables of canopy of clones of eucalyptus reached by this angle; and not all the vegetation in the horizontal plane of 180 °. For this, corrections and post-processing of images, in zenith and azimuth divisions to concentrate on specific parts of the image, were performed to the study area of the canopy. In these procedures, the CI-110 software calculated the coefficient of transmission of solar beams, or the fraction of the visible sky beneath the canopy of plants, using the Gap Fraction Inversion procedure (NORMAN; CAMPBELL, 1989).

The fraction of sky (solar radiation transmission coefficient) was analyzed through the division of the sky by pixels of the image, where values were assigned from 0 to 1, which 0 means that the sky was not visible below the canopy of the plant, and 1 when the whole area was composed of sky, that is, no cover of foliage.

The data were analyzed by analysis of variance and the average values of the characteristics were compared by Tukey test at 5% probability, through ASSISTAT 7.7 software, according to Silva and Azevedo (2016).

RESULTS

The results for the analysis of variance of the five variables estimated for the two clones of *Eucalyptus spp.* are described in Table 2. It shows there were significant values at 1% (p <0,01) and 5% (0,01 ≤ p < 0,05) by the F test, at arrangements (A), clones (C) and interaction A x C for the different variables evaluated. Also, non-significance (p ≥ 0,05) was obtained for others, which shows that, for the significant characteristics, there is at least one difference between the factors evaluated, regarding arrangement, clones, interaction, treatments and blocks.

Table 2. Summary of the variance analysis of randomized blocks in factorial scheme 4 x 2 of *Eucalyptus* clones AEC-1528 and MA-2015, at four structural arrangements of integrated production systems for five estimated characteristics.

Tabela 2. Resumo da análise de variância em blocos ao acaso em esquema fatorial 4 x 2, dos clones de *Eucalyptus* AEC-1528 e MA-2015 em quatro arranjos estruturais de sistemas integrados de produção para cinco características estimadas.

F.V.	GL	Quadrado Médio do Resíduo				
		LAI	ALA	CT	SUNFLECKS	PAR
Arrangements (A)	3	0,19418**	729,24644**	0,05149**	118,24292^{ns}	68361,50178**
Clones (C)	1	0,43264**	48,37800^{ns}	0,09997**	39,40225^{ns}	4996,56609^{ns}
Interaction A x C	3	0,39702**	1514,76915**	0,07847**	56,17492^{ns}	20857,91382**
Treatments	7	0,31518**	968,63211**	0,06998**	80,37939^{ns}	38950,68755**
Blocks	4	0,31518*	187,92017^{ns}	0,00069^{ns}	51,88900^{ns}	158,52985*
Residue	28	0,00061	14182,288	0,0015	5424,314	3025,89131
General Average		0,41	21,73	0,67	28,65	290,66
CV (%)		19,41	54,81	5,76	9,55	18,93

**significant at 1% probability (p < 0,01) *significant at 5% probability (0,01 ≤ p < 0,05) ^{ns} not significant (p ≥ 0,05). Leaf Area Index (LAI); Average Leaf Angle (ALA) in degrees; Coefficient of Transmission (CT); Sunflecks in %; and Photosynthetically Active Radiation (PAR) in µmol m^{-2} s^{-1}.

** significativo ao nível de 1% de probabilidade (p < 0,01) * significativo ao nível de 5% de probabilidade (0,01 ≤ p < 0,05) ^{ns} não significativo (p ≥ 0,05). Índice de Área Foliar (IAF); Ângulo Médio Foliar (AMF) em graus; Coeficiente de Transmissão (CT); Sunflecks em %; e Radiação Fotossinteticamente Ativa (RFA) em µmol m^{-2} s^{-1}.

Table 2 shows that, for the characteristics in which the F test (interaction) was not significant, Tukey test (averages comparison) at 5% (0,01 ≤ p <0,05) was not applied, which occurred only for the SUNFLECKS characteristic.

According to the analysis of variance (Table 2), the coefficient of variation (CV%) varied from 5,76% for the variable coefficient of transmission (CT) to 54,81% for the variable average leaf angle (ALA). There were values considered as low, medium, high and very high for data analysis, showing good conduction of the experiment and data collection. Despite presenting values classified as very high, it becomes acceptable since they are morphophysiological data, as well as because they have abiotic influence (windstorms).

At Table 3, the results regarding light interception and radiation studies are initiated, which can be interfered by morphometric and morphophysiological characteristics, presenting the average values for leaf area index (LAI) and average leaf angle (ALA) of clones of *Eucalyptus*: AEC-1528 and MA-2015, at four structural arrangements for integrated systems.

It is observed that, for the LAI characteristic, there was significant difference at 5% by Tukey test for the two clones evaluated at four arrangements. Values ranged from 0,16 for clone MA-2015 to 0,96 for clone AEC-1528; both clones at A4 single arrangement, which represented a difference of 83,33%, with no difference between clones at other arrangements.

Regarding the ALA characteristic, the values presented variations from 9,55° to 43,56 ° with significant differences at 5% by Tukey test, for both clones evaluated at four arrangements and regardless of the arrangements (Table 3).

Table 3. Average values for leaf area index (LAI) and average leaf angle (ALA) of *Eucalyptus* clones AEC-1528 and MA-2015, at four structural arrangements for integrated systems.
Tabela 3. Valores médios paras as características índice de área foliar (IAF) e ângulo médio foliar (AMF) dos clones de *Eucalyptus* AEC-1528 e MA-2015 em quatro arranjos estruturais para sistemas integrados.

ARRANGEMENTS	CHARACTERISTICS					
	Leaf Area Index			Average Leaf Angle (°)		
	AEC-1528	MA-2015	Average	AEC-1528	MA-2015	Average
A1	0,30 cA	0,31 bA	0,31 b	41,71 aA	15,14 bB	28,43 a
A2	0,31 cA	0,25 bcA	0,28 b	21,28 abA	23,06 abA	22,17 ab
A3	0,49 bA	0,50 aA	0,50 a	9,55 bA	9,55 bA	9,55 b
A4	0,96 aA	0,16 cB	0,56 a	9,55 bB	43,56 aA	26,77 a
Average	0,51 A	0,31 B		20,63 A	22,83 A	

The averages followed by the same lower case letter in the column and upper case in the row do not differ statistically from each other by the Tukey test at 5% probability. A1 = (3,5 x 3,5 x 3,5) + 88 m; A2 = (3,5 x 3,5) + 44 m; A3 = 4 x 22 m; and A4 = 4 x 11 m. As médias seguidas pela mesma letra minúscula na coluna e maiúscula na linha não diferem estatisticamente entre si pelo teste de Tukey ao nível de 5% de probabilidade. A1= (3,5 x 3,5 x 3,5) + 88 m; A2= (3,5 x 3,5) + 44 m; A3= 4 x 22 m; e A4= 4 x 11 m.

Table 4 also verifies that there was significant difference at 5% by Tukey test for both clones evaluated at four arrangements, in which the values ranged from 0,40 for clone AEC-1528 to 0,76 for clone MA- 2015. Both clones at the single arrangement A4, which represented a difference of 47,37%; there was no significant difference between the clones at other arrangements.

Table 4. Average values for the characteristic coefficient of transmission (CT) of *Eucalyptus* clones AEC-1528 and MA-2015 at four structural arrangements for integrated production systems.
Tabela 4. Valores médios para a característica coeficiente de transmissão (CT) dos clones de *Eucalyptus* AEC-1528 e MA-2015 em quatro arranjos estruturais para sistemas integrados de produção.

ARRANGEMENTS	CHARACTERISTICS Coefficient of Transmission		
	AEC-1528	MA-2015	Average
A1	0,72 aA	0,72 abA	0,72 a
A2	0,72 aA	0,74 aA	0,73 a
A3	0,64 bA	0,67 bA	0,65 b
A4	0,40 cB	0,76 aA	0,57 c
Average	0,62 B	0,72 A	

The averages followed by the same lower case letter in the column and upper case in the row do not differ statistically from each other by the Tukey test at 5% probability. A1 = (3,5 x 3,5 x 3,5) + 88 m; A2 = (3,5 x 3,5) + 44 m; A3 = 4 x 22 m; and A4 = 4 x 11 m
As médias seguidas pela mesma letra minúscula na coluna e maiúscula na linha não diferem estatisticamente entre si pelo teste de Tukey ao nível de 5% de probabilidade. A1= (3,5 x 3,5 x 3,5) + 88 m; A2= (3,5 x 3,5) + 44 m; A3= 4 x 22 m; e A4= 4 x 11 m.

Table 5 presents the Photosynthetically Active Radiation (PAR) characteristic, which designates the spectral range of solar radiation (400-700 nm) analyzed by the CI-110 optical filter. This type of reading allows accurate measurements below or within the canopy under varying light conditions, since the transmitted and dispersed radiation does not affect the sensor.

Table 5. Average values for the characteristic Photosynthetically Active Radiation (RFA) in µmol m^{-2} s^{-1} of the *Eucalyptus* clones AEC-1528 and MA-2015 at four structural arrangements for integrated systems.
Tabela 5. Valores médios paras a característica radiação fotossinteticamente ativa (RFA) em µmol m^{-2} s^{-1} dos clones de *Eucalyptus* AEC-1528 e MA-2015 em quatro arranjos estruturais para sistemas integrados.

ARRANGEMENTS	CHARACTERISTIC		
	Photosynthetically Active Radiation (µmol m^{-2} s^{-1})		
	AEC-1528	MA-2015	Average
A1	450,98 aA	348,94 aB	399,96 a
A2	255,83 bA	305,69 aA	280,763 b
A3	270,17 bA	295,65 aA	282,91 b
A4	140,93 cB	257,04 aA	198,99 c
Average	279,48	301,83	

The averages followed by the same lower case letter in the column and upper case in the row do not differ statistically from each other by the Tukey test at 5% probability. A1 = (3,5 x 3,5 x 3,5) + 88 m; A2 = (3,5 x 3,5) + 44 m; A3 = 4 x 22 m; and A4 = 4 x 11 m.
As médias seguidas pela mesma letra minúscula na coluna e maiúscula na linha não diferem estatisticamente entre si pelo teste de Tukey ao nível de 5% de probabilidade. A1= (3,5 x 3,5 x 3,5) + 88 m; A2= (3,5 x 3,5) + 44 m; A3= 4 x 22 m; e A4= 4 x 11 m.

It is verified that for PAR there was significant difference at 5% by Tukey test for both clones evaluated at four arrangements, with the highest value of 450,98 µmol m^{-2} s^{-1} obtained for clone AEC-1528 at the triple arrangement A1. This value 68,75% superior than the lowest value of PAR (140,93 µmol m^{-2} s^{-1}), also obtained for the same clone, at the single arrangement A4 (Table 5).

Figures 2, 3, 4 and 5 show, respectively, the hemispherical images obtained at the structural arrangements for integrated systems A1, A2, A3 and A4, for both clones studied. It is verified that among the arrangements, there are different accumulations of foliage for crown formation, which contribute for the differentiation of the morphometric parameters, according to the evaluated treatments.

Thus, with the values obtained among Tables 3 and 5, it is possible to visualize the differences between the clones studied, correlating them with the average values obtained at the different arrangements. So, it is verified that there are different forms of crown, which allows greater and smaller light interceptions, which also differs among clones within the same structural arrangement (Figure 2, 3, 4 and 5).

In this sense, it is verified that for the arrangement A1, the clone AEC-1528 (Figure 2 A), obtained the greatest capacity of passage of PAR (450,98 µmol m^{-2} s^{-1}), the lowest LAI (0.30), the highest ALA (41,71°), and the highest CT (0,72). Since it is a triple arrangement and there is more competition, individuals grow more in height than in foliage through the canopy, thus allowing the passage of radiation to the sub-forest. Regarding MA-2015, at arrangement A1, according to Figure 2 B, it also allowed the highest RFA (348,94 µmol m^{-2} s^{-1}), below the crown, the second largest LAI (0,31), the second lowest ALA (15,14°), and the second lowest CT (0,72), which shows a larger crown closure for the same arrangement when compared to clone AEC-1528.

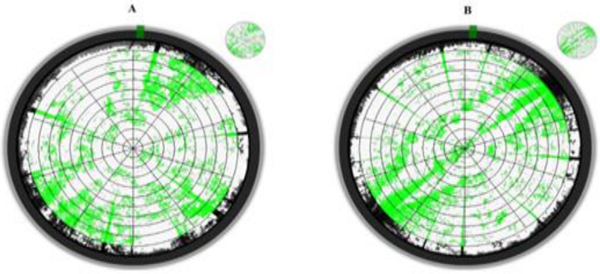

Figure 2. Images in 150° of the crown of the *Eucalyptus* clones AEC-1528 (A) and MA-2015 (B) at the structural arrangement for integrated production systems A1 = (3,5 x 3,5 x 3,5) + 88 m.
Figura 2. Imagens em 150° do dossel dos clones de *Eucalyptus* AEC-1528 (A) e MA-2015 (B) no arranjo estrutural para sistemas integrados de produção A1= (3,5 x 3,5 x 3,5) + 88 m.

For the arrangement A2, clone AEC-1528 (Figure 3 A), obtained the second largest LAI (0,31), the second largest ALA (21,28°), the largest CT (0,72) and the second lowest PAR (255,83 µmol m^{-2} s^{-1}), so that, since it is a double arrangement and there is less competition, individuals grow more in crown than in height.

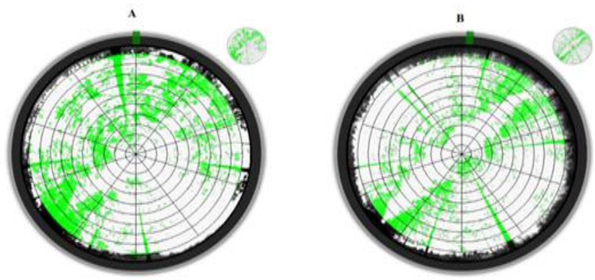

Figure 3. Images in 150° of the crown of the *Eucalyptus* clones AEC-1528 (A) and MA-2015 (B) at the structural arrangement for integrated production systems A2 = (3,5 x 3,5) + 44 m.
Figura 3. Imagens em 150° do dossel dos clones de *Eucalyptus* AEC-1528 (A) e MA-2015 (B) no arranjo estrutural para sistemas integrados de produção A2= (3,5 x 3,5) + 44 m.

Considering clone MA-2015, at arrangement A2 according to Figure 3 B, it allowed the second largest PAR (305,69 µmol m^{-2} s^{-1}), below the crown, the second lowest LAI (0,25), the second largest ALA (23,06°), and the second largest CT (0,74), which shows a larger crown closure when compared to clone AEC-1528 for the same arrangement.

For the arrangement A3, clone AEC-1528 (Figure 4 A), it allowed the second largest PAR (270,17 µmol m^{-2} s^{-1}), below the crown, the second largest LAI (0,49), the lowest ALA (9,55°), and the second lowest CT (0,64),

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evidencing its greater shading capacity or light interception at single line arrangement when compared to clone MA-2015.

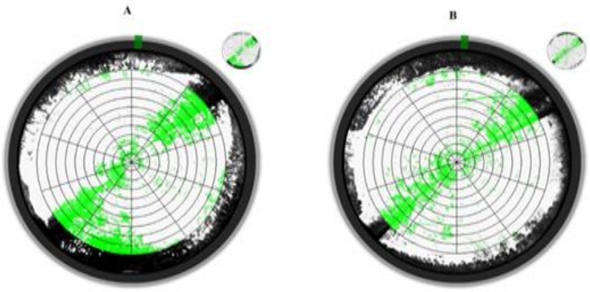

Figure 4. Images in 150° of the crown of the *Eucalyptus* clones AEC-1528 (A) and MA-2015 (B) at the structural arrangement for integrated production systems A3 = 4 x 22 m.
Figura 4. Imagens em 150° do dossel dos clones de *Eucalyptus* AEC-1528 (A) e MA-2015 (B) no arranjo estrutural para sistemas integrados de produção A3= 4 x 22 m.

The clone MA-2015 (Figure 4 B) at A3 arrangement obtained the highest LAI (0,50), the lowest ALA (9,55°), the lowest CF (0,67), and the second lowest PAR (295,65 µmol m^{-2} s^{-1}), so that since it is a single arrangement and there is competition just inside the line, individuals tend to grow more in canopy than in height.

In relation to the arrangement A4, clone AEC-1528 Figure 5 A, allowed the lowest PAR (140,93 µmol m^{-2} s^{-1}), below the canopy, the highest LAI (0,96), the lowest ALA (9,55°), and the lowest CT (0,40). These results show a greater ability to intercept light, caused both: by the efficiency of space occupation, that is, a larger canopy area; and by the arrangement itself being denser between the rows, when compared to the MA-2015 clone.

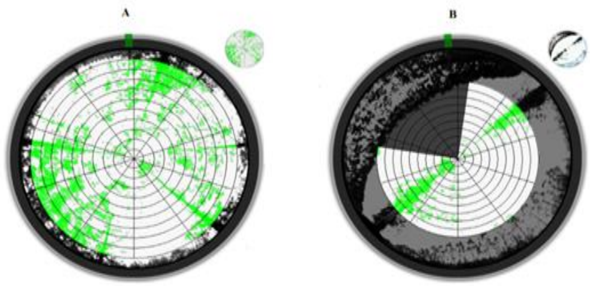

Figure 5. Images in 150° of the crown of the *Eucalyptus* clones AEC-1528 (A) and MA-2015 (B) at the structural arrangement for integrated production systems A4 = 4 x 11 m.
Figura 5. Imagens em 150° do dossel dos clones de *Eucalyptus* AEC-1528 (A) e MA-2015 (B) no arranjo estrutural para sistemas integrados de produção A4= 4 x 11 m.

The clone MA-2015 (Figure 5 B), at arrangement A4, obtained the lowest LAI (0,16), the highest ALA (43,56 °), the highest CT (0,76) and the lowest PAR (257,04 µmol m^{-2} s^{-1}), below the canopy, demonstrating that when compared to the other arrangements, it tends to intercept more light, which indicates a greater crown closure at single row lines.

DISCUSSION

The significant values at 1% ($p <0,01$) by the F test for the treatments at all estimated variables, except for the variable Sunfleck - which did not present significance ($p \geq 0,05$), demonstrate that there is at least one significant difference between them. It evidences that the interaction between the clones and arrangements allows distinguishing the different behaviors promoted by arrangements and clones in the present study. Considering blocks, there was significant effect by the F test at 5% ($0,01 \leq p <0,05$), only for LAI and PAR characteristics, showing that there is at least one significant difference in these variables caused regarding blocks.

It is also verified that for the Sunflecks characteristic, there was no significant effect for any source of variation in the analysis of variance, which did not allow carrying out the average test. According to the manufacturer of the Plant Canopy Analyzer CI-110 imager, this variable describes the percentage of bright areas under the canopy where direct radiation from the solar beam penetrates without interception from the canopy, caused by wind movements in leaves in the canopy or by the movement of the sun throughout the day. In this sense, regarding this characteristic, therefore, it becomes difficult to verify the significant effects among the sources of variations of the present study for integrated systems, due to the wind causing great interference, regarding the percentage of light beams that enter the canopy towards the sub-forest.

However, the values of Sunflecks below the canopy can be useful for the determination of canopy density and can be directly related to the other characteristics of the canopy structure, at different arrangements of an integrated system that contemplates more trees and lines in rows per hectare.

In integrated systems, the forest component occupies a certain percentage of the area, which may vary according to the number of trees and the spacing occupied among and within the rows. In this sense, the remaining space of the area at each structural arrangement can be occupied in a consortium and / or rotated way, with livestock components (forage / animal) and / or crop components (grain culture or agricultural interest). It corresponds to 90,5% for the arrangement A1, 88,4% for the arrangement A2, 90,9% for the arrangement A3 and 81,8% for the arrangement A4.

It is noticed that the clones presented statistical differences at 5% among the LAI values for the different arrangements, although with little variation among them within each arrangement, except for the single arrangement A4 - that provides a lower density of individuals at alleys and between alleys.

According to Watson (1947), LAI values interpreted vary from 0 (exposed soil) to 6 or 7 (dense tropical forests/not visible soil), since it is a parameter defined as the total leaf area of a leaf face divided by the total area of soil.

For Jonckheere *et al.* (2004), the value of LAI for forests varies from 0,40 for low density of individuals to 16,9 in ancient settlements, being the highest values reported for conifers, with maximum values from 6 to 8, for deciduous forests. In transition forest Amazon-Cerrado, the leaf area index generated through hemispheric photographs ranges from 0,52 to 4,12 (SANCHES *et al*., 2008).

It is possible to verify with this methodology of LAI estimation that its value is lower at rows that contemplates larger numbers of lines with larger spacing between rows, when compared to rows with smaller alleys (spaces between rows), which may be related to the greater growth in height than in crown.

Therefore, the LAI values of the present study are in agreement with the literature, showing that, associated to other characteristics, allow the choice of the best arrangement and clone; thus, arrangements that promote lower LAI values, therefore with higher heights and higher wood productivity, are recommended.

In relation to the ALA, it is verified that the highest value was obtained by the clone MA-2015 at the single arrangement A4, showing that there is greater capacity to intercept the light when compared to the other arrangements for the same clone. The opposite occurred for clone AEC-1528, that presented higher ALA at triple arrangement A1 with 41,71°, showing that at arrangements that promote greater competitions, with consequent increase of height of trees and reduction of canopy, there is increase in the ALA, in order to obtain a greater light interception.

Ong and Huxley (1996) emphasize that the leaf angle and leaf distribution influence on the light penetration in the canopy and, consequently, on the coefficient of extinction, which is the fraction of the visible sky below the plant canopy. Therefore, this characteristic is important, since it is related to the horizontal projection of the foliage, influencing the entrance of light through the canopy and crown of trees.

In this sense, the single arrangement A3 was the one that promoted the lowest ALA with 9,55°, regardless of the clone evaluated, showing a smaller capacity to intercept the light for the other components to be installed in this system at three years age.

The coefficient of transmission characteristic, which designates the fraction of visible sky at each division (zenith and azimuth divisions of the captured image), becomes important, because it serves as a reference on which arrangement can exert luminosity limitation for components such as crop and/or pasture that grow below the canopy between rows. In this sense, it is noticed that for the different arrangements evaluated, the CT indicates little variation among clones, with no significant difference at 5% by Tukey test among triple and double arrangements and among clones. Thus, shows high fraction of visible sky in the different combinations of arrangements and clones evaluated, evidencing that there is less interception of light by the canopies regardless of the clones.

Thus, it is verified that the arrangement that provides the highest sky visibility is the A4 for MA-2015 clone, since it obtained the highest average value (0,76). The lowest CT obtained (that indicates little sky visibility below the canopy) was also obtained at A4 arrangement for clone AEC-1528. This demonstrates the importance of using the right clone for each structural arrangement used in integrated systems, in order to reduce the shading effects of crops that will grow below the canopy of the crown.

In relation to the values of PAR, it is verified that the densification of trees or reduction of distances between rows contribute to the reduction of their values for both clones below the crown, which may promote a detrimental effect on livestock/crop components, due to the restriction of light.

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Moreover, this characteristic becomes important because it is part of the spectrum of the global radiation fraction (Gr), comprised in the spectral range from 0,4 to 0,7 µm. It is also important for growth and development of plants, serving as one of the input variables in models that simulate the accumulation of dry matter during the crop cycle (TEI *et al*., 1996).

Thus, the greater the PAR analyzed under the canopy of clones, the smaller the interception by the morphometric components of trees. In this sense, it is possible to verify that the PAR, measured below the crown, at the fixed height of 1,75 m in the present study, is reduced at rows that present smaller numbers of lines, regardless of the clones evaluated, showing that trees grow more in crown than in height under less competitive conditions.

In addition, the PAR estimated below the crown, associated with forestvcomponent productivity characteristics and the tolerance of the other components in integrated systems, allows the choice of the ideal arrangement, and for this study, the intermediate values obtained at A2 and A3 arrangements are recommended for allowing an average PAR passage through the canopy of the crowns.

These results demonstrate the importance of studies that involve different arrangements and clones regarding integrated systems. Therefore, more studies are required, such as the methodologies that evaluate the microclimate (MARTINI *et al*., 2017), the temperature variation (LEAL *et al.,* 2016), the emission of greenhouse gas (TOSATO; PELISSARI, 2017), the biomass increase (SEGER *et al*., 2016) and morphometrics (SANTOS *et al*., 2014; BOBROWSKI *et al*., 2017) as a way of providing information to correct and work around the aggravating effects of inappropriate agricultural practices and respective global warming.

In this sense, the present study defines that the four arrangements evaluated are models for integrated production systems, and should be adopted the one that best meets the property objective. For producers who prioritize more trees per hectare, adopt the arrangement A4, using at the alley the consortium, rotation or succession of crops more tolerant to shading. For producers who prioritize large agricultural crops and fewer trees, adopt A1 and A2 arrangements, using at the alley consortium, rotation or succession. For producers who prioritize the intensive system of trees, crops and livestock, use the arrangement A3 in consortium, rotation or succession at the alley.

CONCLUSIONS

The study concluded that:

- For the triple row arrangement A1, clones AEC-1528 and MA-2015 grew more in height than in foliage through the crown, characterized by the higher photosynthetically active radiation estimated below the crown
- For the double row arrangement A2, clones AEC-1528 and MA-2015 grew more in crown than in height, characterized by the highest values of average leaf angle, coefficient of transmission and leaf area index, estimated below the crown.
- For the single row arrangement A3, clones AEC-1528 and MA-2015 showed average shading capacity or light interception, characterized by low values of photosynthetically active radiation, estimated below the crown; and high values of leaf area index, estimated below crown.
- For the single row arrangement A4, clones AEC-1528 and MA-2015 promoted greater shading capacity, characterized by high values of leaf area index; lower values of photosynthetically active radiation and by the densification of the arrangement of the other rows.
- The single arrangement A4 presented differences between the evaluated clones for all estimated variables, except for the Sunflecks characteristic.

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