Quantification of damage and initial growth of eucalyptus in integrated crop-livestock-forest systems in the Brazilian Cerrado

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Research

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Abstract

Background

The integrated crop-livestock-forest (ICLF) system is a sustainable production model composed by tree species intercropped with annual crops and forage species. The choice of the tree species that will compose the ICLF is characterized as a fundamental requirement in the adoption of the system. Therefore, this study aimed to analyze the initial growth and adaptation of two eucalyptus genotypes cultivated in ICLF systems in the Brazilian Cerrado.

Methods

The eucalyptus genotypes (*E. cloeziana* and *E. urograndis*) were intercropped with *Sorghum bicolor* and *Urochloa brizantha* in two ICLF systems in Minas Gerais State, Brazil. Qualitative data expressed by occurrences of damage and weaknesses, as well as quantitative data measured by survival rates, diameter at soil height, diameter at breast height, and total height of trees were evaluated in four periods. The data were analyzed by a correlation matrix and analysis of variance, and them qualitative and quantitative data to were analyzed in relation to the rainfall distribution during the studied period.

Results

The occurrence of *Trigona spinipes* and termite were the main biotic factors that caused damage and weaknesses to *E. cloeziana* and *E. urograndis*, respectively, directly impacting the initial growth and survival rate of eucalyptus.. The growth of *E. urograndis* was higher than *E. cloeziana* at 450, 630, 1020, and 1320 days after transplanting. On the other hand, *E. cloeziana* showed the highest survival rate (80.6%) while *E. urograndis* presented greater tolerance to the water stress.

Conclusion

The hibrid *E. urograndis* proved to be more adapted to edaphoclimatic conditions studied in the Cerrado region and can be indicated to ICLF systems implanted in regions characterized by high temperatures and irregular rainfall distribution.

Background

The Integrated crop-livestock-forest (ICLF) system, or agrosilvopastoral system, is a sustainable production strategy, composed by agricultural, livestock and forestry activities, which can be carried out in the same area in intercropping, succession or rotation. Thus, it seeks synergistic effects between the components of the agroecosystem, considering environmental adaptation, human valorization and economic viability (Alves et al. 2017). The main objective of the ICLF system adoption is to change the land use system, particularly in areas or situations where monocultures are reducing productivity, especially in degraded pasture areas (Balbino et al. 2014).

These agroforestry systems has received the attention of farmers and researchers due to its greater versatility in the use and productivity of the areas, considering all the components involved (Moreira et al. 2018). The ICLF system also provides improvements in the chemical, physical and biological properties of the soil, prevents erosion, promotes carbon sequestration, the conservation of water resources and biodiversity, in addition to several technical, economic and social benefits (Serra et al. 2012; Alves et al. 2017; Almeida et al. 2021).

In Brazil, eucalyptus occupies 72.5% of the forest area planted with 5.7 million hectares and continues to expand. In recent years, the cultivation of Eucalyptus has intensified in the Cerrado regions, with an emphasis to Minas Gerais, Tocantins and Mato Grosso do Sul States (IBÁ 2019). The Cerrado region is suitable for reforestation, despite having a water deficit in part of the year, requiring well-adapted perennial species (Macedo et al. 2006).

The choice of the tree species that will compose the ICLF system is characterized as a fundamental requirement in the adoption of this agricultural production model (Machado et al. 2013). The eucalyptus cultivated in integrated production systems can be useful to several uses, however the commercial use as wood for sawmill, is the one that has been most used by producers, due to the greater financial return (Oliveira et al. 2015). The choice of a model or the species that best adapt to the region, or with the system itself, can minimize the costs of implementation and conduction, increasing the production and profitability of the integrated production system (Alves et al. 2017).

Knowledge about the initial growth of seedlings is essential for the progress of the activity of producing quality genotypes, which in turn is of great importance for the success of the silvicultural activities (Mota et al. 2012). One of the tools to help understand the ecological relationships between the initial seedling development and the environment is the growth analysis (Souza et al. 2018). Growth analysis can be used to evaluate crop productivity and allows investigating the ecological adaptation of these crops to new environments, competition between species, management and treatments effects, and the identification of the productive capacity of the different genotypes (Alvarez et al. 2005).

In this sense, the objective of this study was to evaluate the initial growth an adaptation of two *Eucalyptus* genotypes (*Eucalyptus urograndis* and *Eucalyptus cloeziana*) in ICLF systems in the Brazilian Cerrado. We aimed to answer two questions: i) What were the factors (biotic and, or abiotic) that interfered with the initial growth of both evaluated genotypes? and ii) Which of the genotypes was more adapted to the ICLF system under the studied edaphoclimatic conditions?

Material And Methods

Study area

The experiment was implemented at Barra Farm (16°38'44.02" S and 43°42'43.77" W), located in the municipality of Francisco Sá, Minas Gerais, Brazil. In November 2012, soil samples were collected in the study area at depths from 0 to 20 and 0 to 40 cm, in order to characterize the soil type, thus being classified as Haplic Cambisol, a clayey and medium fertility soil (Table 1). The altitude of the study area is 590 m. The region's climate according to the Köppen climate classification is Tropical Savanna (Aw), with rainy summer and dry winter, annual rainfall of 1,009 mm and temperature of 21.6 ° C (Alvares et al. 2013). However, during the period of conducting the experiment there was a decrease in precipitation in the study region (Figure 1) (INMET 2018).

Table 1- Soil chemical characteristics at 0-20 and 20-40 cm soil depth layers before the implementation of the experimental area in the Brazilian Cerrado.

Soil depth	pH	P[1]	K	Al	Ca	Mg	H+Al	CEC	BS	SOM
(cm)	(H_2O)	—mg dm^{-3}—	———cmol/dm^3—— ——————	%	g kg^{-1}					
0 - 20	6.1	0.80	200	0	4.3	1.6	2.32	8.22	72	49.8
20 - 40	6.2	0.31	200	0	3.4	1.4	1.99	6.79	71	32.3

Legend: P (Phosphorus), K (Potassium), Al (Aluminum), Ca (Calcium), Mg (Magnesium), H+ Al (Potential acidity), CEC (cation exchange capacity at pH 7), BS (Base Saturation), SOM (Soil organic matter).

Figure 1 – Average of monthly rainfall (mm) and temperature (º C) between 2012 through 2016 (A) and distribution between January 2012 through December 2016 (B, C, D, E and F) in the studied area located at Minas Gerais State, Brazil. Source: INMET (2018).

Selection of species and arrangements of the ICLF system

For this study two eucalyptus genotypes were chosen: the specie *Eucalyptus cloeziana* and the hybrid *Eucalyptus urograndis*, which were selected due to the better quality of the wood and adaptability to regions with water deficit, respectively, when compared with other genotypes. *E. cloeziana* has an excellent shaft shape, with good natural durability and its wood is recommended for energy and construction purposes (Alves et al. 2017). *E. urograndis* hybrids are the most cultivated in Brazil due to forest improvement for greater productivity and adaptability to water deficit conditions (Kullan et al. 2012; Leonardi et al. 2015).

The experiment was implemented in an area of 3.2 hectares with two productive crop arrangements, being: (i) ICLF system with *E. urograndis*, a hybrid of *E. urophylla* × *E. grandis* intercropped with *Sorghum bicolor* (sorghum) and *Brachiaria brizantha* cv. Marandu (marandu grass); (ii) ICLF system with *E. Cloeziana* intercropped with *Sorghum bicolor* (sorghum) and *Brachiaria brizantha* (marandu grass). The two ICLF systems were organized in double rows of eucalyptus (3x2m), 3m between lines and 2m between plants and spaces of 14m (alley) between double lines (Figure 2).

Figure 2 – Schematic representation of the integrated crop-livestock-forest systems studied in the Brazilian Cerrado.

Implementation of the ICLF systems and management of eucalyptus

Pits for planting eucalyptus were opened in December 2012 and the two genotypes seedlings were planted intercropped with sorghum. In the second year, sorghum was planted again with marandu grass between the double rows of eucalyptus (Figure 2). After the second sorghum harvest, the system was conducted as a silvopastoral system with an arrangement composed by eucalyptus and marandu grass.

The initial fertilization consisted of the application of 7.2 g of N, 36 g of P and 7.2g of K per plant with micronutrients. During the experimental phase, the ants were controlled with granular bait before implanting the area and after planting. The termites were controlled before planting by immersing eucalyptus and sorghum seedlings in Fipronil solution [500 g of commercial product / 100 L of syrup, equivalent to 10 ml of syrup / seedling (BASF SE, Ludwigshafen, Germany)] and, by directed irrigation in transplanted eucalyptus seedlings. Irrigation management was carried out during December/2012, February and March/2013, with the application of 4L of water/plant in order to supply the seedlings during the water deficit in the region (Figure 1B and 1C). The mechanical control of weeds was carried out in April 2013, November 2013, August 2014, September 2015 and October 2016. A mechanical method was adopted for the control of bees (*Trigona spinipes*) with burning of identified nests. Pruning was carried out in November 2014 on trees with a minimum diameter at breast height (DBH) of 3 cm.

Measurements of the qualitative and quantitative data

For each ICLF system, 24 rectangular plots of 336m² with 24 trees/plot were randomly distributed for periodic measurements, totaling 288 trees/system. Data were collected at 90, 450, 630, 1020, 1320 and 1380 days after transplanting (DAT), corresponding to April 2013, April 2014, October 2014, November 2014, November 2015 and November 2016, respectively. The evaluation was carried out through direct observations, with a record of factors spreadsheet - presence and absence. Thus, the evaluated variables for the initial growth of eucalyptus were subdivided in:

(i) Qualitative data, including symptoms of occurrence or attack of:

a) leafcutter ant: presence in eucalyptus plants or in plots;

b) termites: observation of roots of attacked and dead plants and, or when the plants had stem roll at the soil height;

c) *Trigona spinipes*: occurrence recorded when individuals or groups were observed in eucalyptus plants;

d) stem damage: registration in plants attacked by *Trigona spinipes* through the identification of scarring or tissue damage;

e) nutritional deficit: it was identified through observation of symptoms and typical leaf characteristics;

f) water stress: plants that presented leaves with a yellowish or reddish tone, dried or withered; or with scald of the stem;

g) weed competition: occurrence of native and, or forage plants less than 50 cm far from the eucalyptus plants;

h) bifurcation in the trunk;

i) branching in the trunk;

j) Climbing plants in the trunk;

k) *dieback:* plants that presented leaves of the apex of the crown with yellowish or reddish tone, and in some cases already withered or dried.

(ii) Quantitative data:

a) survival rate;

b) total height (Ht);

c) diameter at the soil height (DSH): collection performed at 5 cm from the soil;

d) diameter at breast height (DBH): collection performed at 1.30 m from the soil.

Statistical analysis

Qualitative variables were analyzed using Pearson's Correlation Matrix. For quantitative variables the analysis of variance (ANOVA) was performed and subsequently the means were compared by the F test ($p < 0.05$), using R statistical software (R Core Team, 2019). Additionally, both quantitative and qualitative data were analyzed in relation to the rainfall distribution during the studied period.

Results

Qualitative data

In the evaluation carried out at 450 DAT (April 2014), the occurrence of competition with weeds (42.4%), climbing plants (39.6%), attack of *Trigona spinipes* (31.9%), bifurcation (21.9%), damage to the stem (20.5%) and branching (10.1%) was observed in *E. cloeziana* (Table 2). In this evaluation, a correlation ($p < 0.05$) was observed between the attack of *T. spinipes* and the presence of branching and stem damage in *E. cloeziana*, and a high correlation between the occurrence of weeds and climbing plants (Table 3). For the *E. urograndis*, there was a higher occurrence of interference with weeds (24.7%), climbing plants (20.1%) and termite attack (9.0%) (Table 2). There was also a high correlation between the occurrence of weeds and climbing plants (Table 3). After the first sorghum harvest, in May 2013, there was a severe attack of termites in the ICLF lines planted with *E. urograndis*, which resulted in serious damage, reducing the root area and resulting in high plant mortality.

Table 2
Occurrence of damages and weaknesses (%) in *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Period	Treatment	LA	TM	TS	SD	ND	WS	WC	BI	BC	CP	DB
		%										
50 DAT (Apr/ 2014)	*E. cloeziana*	0.0	0.0	31.9	20.5	0.0	0.7	42.4	21.9	10.1	39.6	0.0
	E. urograndis	0.0	9.0	0.0	0.0	0.0	0.0	24.7	1.4	5.2	20.1	0.0
630 DAT (Oct/ 2014)	*E. cloeziana*	0.0	0.0	39.2	39.2	0.0	17.0	42.4	21.9	30.6	42.4	0.0
	E. urograndis	0.0	0.0	0.0	0.0	0.0	7.3	5.6	2.1	7.6	5.2	0.0
1020 DAT (Nov/ 2015)	*E. cloeziana*	0.0	0.0	0.0	39.2	0.0	13.2	3.8	19.4	25.7	2.4	9.0
	E. urograndis	3.1	0.0	0.0	0.0	0.0	1.4	13.9	5.2	3.8	0.3	3.5
1320 DAT (Sept/ 2016)	*E. cloeziana*	2.4	3.5	0.0	55.9	0.0	24.0	42.4	31.9	64.6	15.3	0.0
	E. urograndis	1.0	5.6	0.0	0.0	25.3	0.7	39.9	27.4	32.6	2.8	0.0

Legend: DAT = days after transplanting; LA = leafcutter ant; TM = termite; TS = Trigona spinipes bee; SD = stem damage; ND = nutritional deficit; WS = water stress; WC = weed competition; BI = bifurcation; BC = branching; CP = climbing plants; DB = dieback.

Table 3
Matrix of data correlation (damages and weaknesses) at 450 DAT in *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Observation	**Treatment**	**Branching**	**Stem damage**	**Climbing plants**
Trigona spinipes	*E. cloeziana*	0.68 *	0.87 *	0.36 ns
	E. Urograndis	-	-	-
Weed competition	*E. cloeziana*	0.23 ns	0.53 ns	0.92 *
	E. Urograndis	− 0.51 ns	-	0.84 *

Legend: * = Significant; ns = not significant by *t* test ($p < 0.05$).

The second evaluation (630 DAT) was carried out at the end of the dry season (October 2014), a period characterized by low rainfall (Fig. 1D). In plants of *E. cloeziana* there was an increase in the occurrence of competition with weeds (42.4%) and climbing plants (42.4%), followed by the attack of *Trigona spinipes* (39.2%), damage to the stem (39.2%), tree branching (30.6%) and bifurcation (21.9%) (Table 2). There was a correlation between the occurrence of weed and climbing plants competition (Table 4). The plants of the *E. urograndis* had a better response, with a reduction in the occurrence of tree branching (7.6%), water stress (7.3%), weeds (5.6%) and climbing plants (5.6%). In addition, there was a correlation between the water stress and bifurcation variables and between the occurrence of weeds and climbing plants (Table 4).

Table 4
Matrix of data correlation (damages and weaknesses) at 630 DAT in *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Observation	Treatment	Climbing plants	Bifurcation
Weed competition	*E. cloeziana*	1.00 *	0.54 ns
	E. urograndis	0.98 *	− 0.33 ns
Water stress	*E. cloeziana*	− 0.65 *	− 0.38 ns
	E. urograndis	− 0.06 ns	0.60 *
Legend: * = Significant; ns = not significant by *t* test ($p < 0.05$).			

In the third evaluation, at 1020 DAT (November 2015), *E. cloeziana* continued to damage the stem (39.2%), as well as branching (25.7%), bifurcation (19.4%) and *dieback* (9.0%). In this evaluation, water stress symptoms (19.4%) were also found in this species, which was strongly correlated ($p < 0.05$) with *dieback* (Table 5). It was observed the occurrence of water stress (5.2%) and the presence of weeds (13.9%) in trees of *E. urograndis* evaluated (Table 2), with a correlation ($p < 0.05$) also between the occurrence of water stress and *dieback* (Table 5).

Table 5
Matrix of data correlation (damages and weaknesses) at 1,020 DAT in *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Observation	Treatment	Climbing plants	Ramification	Dieback	Weed competition
Water stress	*E. cloeziana*	− 0.10 ns	− 0.24 ns	0.84 *	− 0.42 ns
	E. urograndis	0.81 *	0.47 ns	0.63 *	0.14 ns
Climbing plants	*E. cloeziana*	-	0.29 ns	− 0.05 ns	0.79 *
	E. urograndis	-	0.66 *	0.36 ns	− 0.10 ns
Legend: * = Significant; ns = not significant by *t* test ($p < 0.05$).					

In the fourth evaluation carried out at 1320 DAT (September 2016) there was an increase in damage to the stem in *E. cloeziana*, which occurred in 55.9% of the evaluated plants (Table 2), followed by branching (64.6%), weed competition (42.4%), bifurcated plants (31.9%), water stress (24%) and climbing plants (15.3%). It was found that, over the evaluated period, the damages and weaknesses observed increased in this species. The correlation matrix for the parameters evaluated in 1320 DAT showed a direct relationship between weed competition and stem damage, and between climbing plants and bifurcation for *E. cloeziana* (Table 6). *E. Urograndis* area showed an increase in weed interference (39.9%), branching (32.6%), bifurcation (27.4%), nutritional deficit (25.3%) and termite occurrence (5.6%). Correlations ($p < 0.05$) were found between weed competition and branching, and between nutritional deficit and branching (Table 6).

Table 6
Matrix of data correlation (damages and weaknesses) at 1,320 DAT in *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Observation	Treatment	Stem damage	Branching	Bifurcation
Weed competition	*E. cloeziana*	0.73 *	0.24 ns	0.05 ns
	E. urograndis	-	0.70 *	0.38 ns
Climbing plants	*E. cloeziana*	− 0.24 ns	0.48 ns	0.62 *
	E. urograndis	-	0.51 ns	− 0.20 ns
Nutritional deficit	*E. cloeziana*	-	-	-
	E. urograndis	-	0.63 *	0.30 ns

Legend: * = Significant; ns = not significant by *t* test ($p < 0.05$).

The correlation analysis of qualitative data, including all observation periods (450, 630, 1020 and 1320 DAT) showed a significant correlation ($p < 0.05$) between stem damage and branching for *E. cloeziana* and, between branching and bifurcation for *E. urograndis* (Table 7).

Table 7
Matrix of data correlation (damages and weaknesses) at 450, 630, 1,020 and 1,320 DAT in *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Observation	Treatment	Branching	Bifurcation
Stem damage	*E. cloeziana*	0.96 *	0.71 ns
	E. urograndis	-	-
Branching	*E. cloeziana*	-	0.88 ns
	E. urograndis	-	0.97 *
Legend: * = Significant; ns = not significant by *t* test ($p < 0.05$).			

Quantitative data

E. cloeziana and *E. urograndis* showed differences ($p < 0.05$) at 450, 630, 1020 and 1320 DAT for survival rate (Table 8), DSH, DBH and Ht (Table 9). However, no differences were found between the two genotypes in relation to DSH and Ht at 90 DAT (Table 9).

E. cloeziana had a survival rate of 94.1% at 90 DAT, and this percentage decreased at 450 DAT, reaching 86.8% (Table 8). During the evaluations (450 to 1320) a 6.2% decline in the survival rate of this species was observed. Whereas, *E. urograndis* had a survival rate of 90.1% at 90 DAT (March 2013), decreasing abruptly and reaching 67.4% at 450 days (April 2014). For evaluations between 450 to 1320 DAT, the survival rate of *E. urograndis* was practically unchanged, with a reduction of only 0.7% (Table 8). Thus, the survival rate of *E. cloeziana* was 13.9% higher than that of *E. urograndis* in 1320 DAT (September 2016).

Table 8
Survival rate (%) of *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Treatment	Survival rate (%)				
	90 DAT	450 DAT	630 DAT	1.020 DAT	1.320 DAT
E. cloeziana	94.1	86.8	84.7	80.6	80.6
E. urograndis	90.1	67.4	67.4	66.7	66.7
Legend: DAT: days after transplanting.					

As for the growth parameters, at 450 DAT, the DSH was greater in *E. urograndis* in relation to the *E. cloeziana* trees. For the DBH, growth was greater in *E. urograndis* at 450, 630, 1020 and 1320 DAT (Table 9). The period between 450 and 630 DAT was characterized by the dry season (Fig. 1D). The increase in DBH in the *E. cloeziana* and *E. urograndis* was 0.30 and 0.78 cm, respectively. *E. urograndis* also showed a higher Ht at 450, 630, 1020 and 1320 DAT. At 450, 630 and 1020 DAT, the Ht of this genotype was, respectively, 1.17, 1.43 and 3.93 m higher than that of *E. cloeziana*, confirming the growth of the *E. urograndis* hybrid also during dry periods.

Table 9
Diameter at soil height (DSH), diameter at breast height (DBH) and total height (Ht) of *E. cloeziana* and *E. urograndis* genotypes cultivated in integrated crop-livestock-forest systems in the Brazilian Cerrado.

Parameters	DAT	*E. cloeziana*	E. *urograndis*
DSH (cm)	90	1.12 a	1.19 a
	450	4.10 b	5.19 a
DBH (cm)	450	2.48 b	3.47 a
	630	2.78 b	4.25 a
	1.020	5.29 b	7.96 a
	1.320	7.07 b	10.09 a
Ht (m)	90	1.11 a	1.04 a
	450	3.21 b	4.38 a
	630	3.40 b	4.83 a
	1.020	5.45 b	9.37 a
	1.320	7.64 b	12.06 a

Legend: DAT: days after transplanting. Means followed by the same letters in the lines do not differ by F test ($p < 0.05$).

Discussion

Qualitative data

In the first evaluation at 450 DAT, the occurrence of weeds was the main factor that interfered in the areas cultivated with *E. cloeziana* and *E. urograndis*, and a high occurrence of climbing plants was also recorded (Table 2). According to Serra et al. (2019), competition with weeds can cause delay in tree growth, so weed management must be planned in advance. Another factor that influenced the growth of *E. cloeziana* was the attack of the *T. spinipes*, classified by Damascena et al. (2017) as a kind of common occurrence in the Brazilian Cerrado. *T. spinipes* jaws cut the tissues of the plants causing a release of certain secretions, resins or fibrous filaments for the construction of their nests in the branches of the trees or, in abandoned termite mounds (Moura et al. 2017). In addition to the injuries caused by the direct attack of this insect, such as destruction of flower buds, new branches, flowers and fruits (Gallo et al. 2002), the exposure of tissues can allow the entry of pathogens, causing even greater problems in production (Alves et al. 2018).

Having observed termite attack in the *E. urograndis* genotype at 450 DAT (Table 2), the control of these insects has become essential, as the damage caused can induce nutritional and water deficits, which can culminate in the death of the plant (Ahmad et al 2021). Another important factor that may have influenced the result was the low rainfall observed in the months of January and February 2014 (Fig. 1D). These facts explain the damage and injuries caused mainly by the presence of insects, such as bees and termites, as well as the competition of weeds and the high number of climbing plants observed in the two evaluated systems of the ICLF, since plants with water stress have no capacity to react to the damage, presenting symptoms more easily (Katsaruware-Chapoto et al. 2017; Ramesh et al. 2017).

The second evaluation (630 DAT) was carried out in a period of low rainfall (Fig. 1D) and, probably, the development of the *E. urograndis* plants inhibited the occurrence of damage and weaknesses. For the *E. cloeziana*, the occurrence of weeds and climbing plants increased in this evaluation period (Table 2). Analyzing the effects of spacing and layout on the growth of tree species, the ICLF system contributes to the incidence of solar radiation between the double rows, increasing weed growth and infestation (Santos et al. 2012). According to Santos et al. (2010), weed interference must be controlled continuously, with direct application of herbicide or manual weeding. In relation to the season, this must be done at the beginning of the rainy season to guarantee the success of the integrated production system (Gomes, 2010).

In the evaluation at 630 DAT, the plants of *E. Cloeziana* continued to be attacked by the bee *T. spinipes*, which contributed to the appearance of lateral ramifications and bifurcation of the plants. According to a study by Chiaradia et al. (2003), plants are more susceptible to the attack of *T. spinipes* in the early years of planting in their apical shoots, causing damage to the young tissue to obtain secretions for the construction of their nests. Thus, when the attack of the bees causes damage to the young stems and growth points to remove the resin and exudates, it also induces stress in the plant, leading to the emission of lateral branches. In addition, other factors such as water stress, weed competition and climbing plants may have contributed to the delay in the development of *E. cloeziana* in the ICLF system (Ngugi et al. 2004; Muller et al. 2017).

At 1020 DAT there was a recurrence of damage to the stem, branches of bifurcations in trees of the *E. cloeziana* genotype (Table 2). In the five months preceding this assessment (June to October 2015), low rainfall was recorded in the study area (Fig. 1E), which may be directly related to records of pointer drought and water stress recorded for this genotype. In the two genotypes of eucalyptus analyzed, a correlation between water stress and pointer drought was observed, and this is common in eucalyptus, due to the nutritional deficit that occurs during the dry season or under conditions of low precipitation, even with the availability of macro and micronutrients in the soil. According to Alfenas et al. (2009), up to 3 years of age, plants may present water deficit symptoms such as leaf lesions and death in parts of the main branches.

The damage and weaknesses reported at 1020 DAT in *E. Cloeziana* trees continued to increase at 1320 DAT. For *E. Urograndis*, the presence of weeds, branches and bifurcations was recorded again (Table 2). In addition, between February and September 2016, all precipitation records were very low (Fig. 1F), which directly influenced the observed results, especially in relation to the occurrence of water stress, weed competition and nutritional deficit in the two genotypes evaluated (Hu et al. 2008; Borken and Matzner 2009; Valdés et al. 2013; Maseda and Fernández 2016; Barbosa et al. 2016).

Quantitative data

Regarding survival rate, *E. cloeziana* showed better results in all evaluations when compared to *E. urograndis*, which can be referred to a favorable adaptation of *E. cloeziana* to the study site. According to Borges et al. (2012), the survival rate of eucalyptus plants depends directly on climatic conditions. Reis et al. (2017) also found higher survival rates in *E. cloeziana* when compared to *E. urograndis* in the Brazilian Cerrado.

The possible causes of mortality in *E. cloeziana* in evaluations between 90 and 450 DAT may be associated with late planting, weed competition, severe attack of *Trigona spinipes* and occurrence of water stress at the initial moment of plant growth, factors already reported by Joern and Mole (2006). While for *E. urograndis*, the high mortality rate between evaluations at 90 and 450 DAT may be associated with the severe attack of termites, since there is an increase in damage and weaknesses in the plants after the attack of these insects as mentioned in others studies (Gauchan et al. 1998; Debelo and Degaga 2017).

Is important to note that chemical control with fipronil was performed in *E. urograndis*. However, after the sorghum harvest there was a greater attack of termites in this genotype, increasing plant mortality (Table 8). In addition, the survival rate of this species was practically unchanged between the evaluations performed at 450 and 1030 DAT, even though there was a period of low rainfall in the study region (Fig. 2). It can be inferred from this that there was resistance of this eucalyptus hybrid to the water stress (Silva et al. 2014).

E. urograndis showed greater growth, which can be attributed to the greater number and intensity of damage and weaknesses observed in *E. cloeziana*, due to the continuous attack of *Trigona spinipes*, causing branches and bifurcations and also weed interference (Table 2). According to Santos et al. (2017), it is important to use eucalyptus clones that are more adapted to local edaphoclimatic conditions and that are more productive and have quality wood for multiple uses.

Pulrolnik et al. (2010) studied the growth of *E. cloeziana* and *E. urograndis* in the Cerrado of the Amazon region and reported higher DSH and Ht values than found in the present study. At 540 DAT, the authors found higher DSH values, with 1.14 and 2.42 m for *E. urograndis* and *E. cloeziana*, respectively. For Ht, the values were 1.42 and 3.06 m higher for *E. urograndis* and *E. cloeziana*, respectively. However, it is important to note that the rainfall in the study region of Pulrolnik et al. (2010) were larger and better distributed than in the region of the present study, which directly influences the growth rates of the evaluated genotypes. Comparatively, in the present study, *E. cloeziana* was more affected by the frequency and distribution of rainfall than *E. urograndis*.

Conclusions

Trigona spinipes and termite attacks were the two main biotic factors that caused damage and weaknesses in *E. cloeziana* and *E. urograndis*, respectively, reducing growth and increasing mortality rates of the two genotypes.

In the two evaluated arrangements of ICLF systems, *E. cloeziana* genotype showed the highest survival rate, but *E. urograndis* hybrid showed greater resistance to the water stress condition observed by its growth performance evaluated by BSH, DBH and Ht.

The *E. urograndis* showed tolerance to water stress and adaptation to edaphoclimatic conditions in the present study, Therefore, it can be indicated do ICLF systems implanted in regions characterized by high temperatures and irregular rainfall distribution.

Abbreviations

Al = Aluminum; BC = branching; BI = bifurcation; BS = Base saturation; Ca =Calcium; CEC = Cation exchange capacity at pH 7; CP = climbing plants; DAT = days after transplantation; DBH = Diameter at breast height; DB = dieback; DSH = diameter at the soil height; H+ Al = Potential acidity; Ht = Total height; ICLF = Integrated crop-livestock-forest; K = Potassium; LA = leafcutter ant; Mg = Magnesium; N = Nitrogen; ND = nutritional deficit; P = Phosphorus; SD = stem damage; SOM = Soil organic matter; TM = termite; TS = Trigona spinipes bee; WC = weed competition; WS = water stress.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

Conceived and designed the study: Barbosa DLA, Frazão LA, Veloso ALC, Lana AMQ and Tuffi LDT. Collected data and samples in the field: Barbosa DLA, Frazão LA and Veloso MDM. Processed samples in the lab: Barbosa DLA, Frazão LA, Freitas DA and Souza e Brito BG. Analyzed the data: Barbosa DLA, Leite AMP, Oliveira MRL and Lana AQ. Wrote de paper: Barbosa DLA, Freitas DA, Souza e Brito BG, Leite AMP, Oliveira MRL, Tuffi LDT and Frazão LA. All authors read and approved the final manuscript.

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Figures

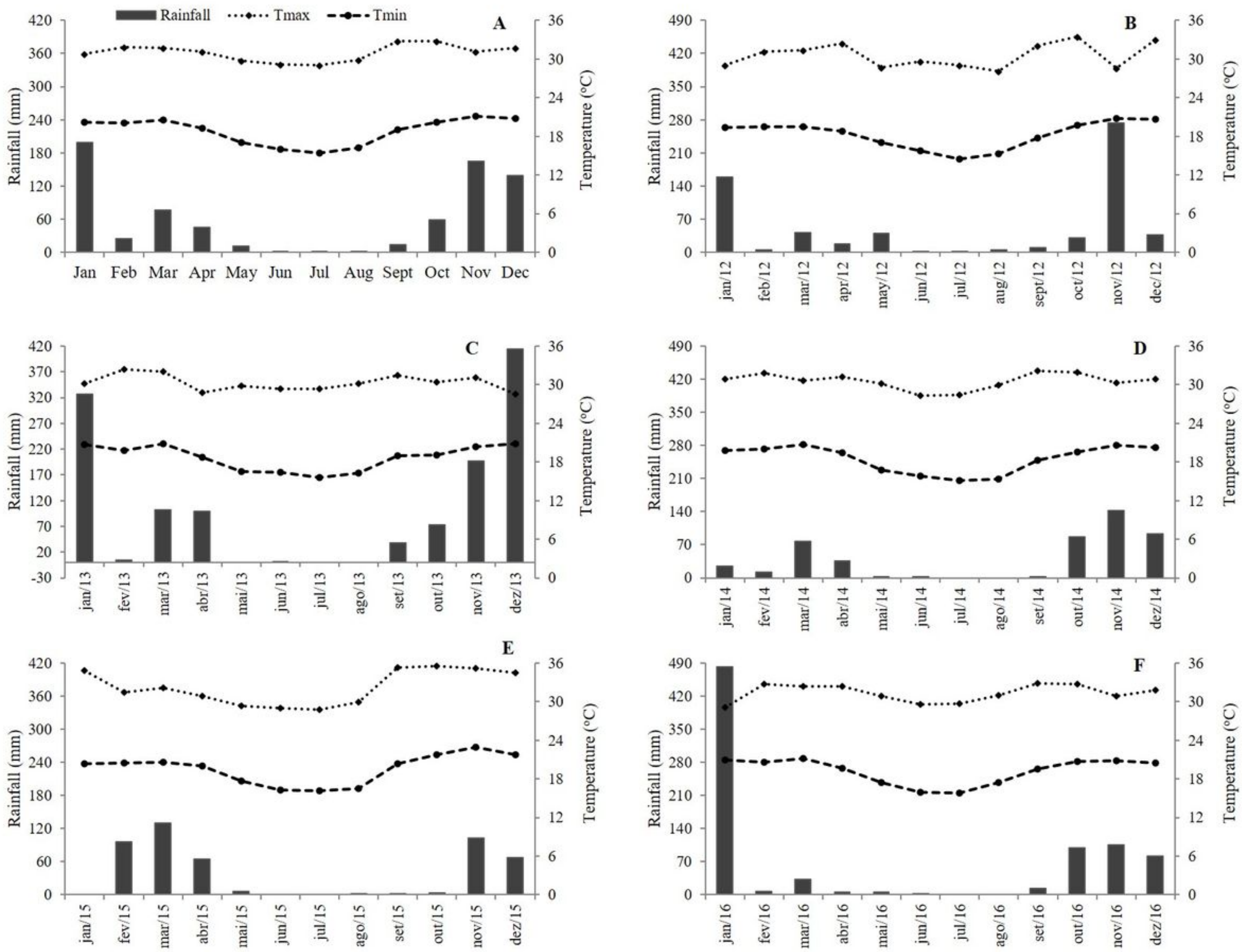

Figure 1

Average of monthly rainfall (mm) and temperature (o C) between 2012 through 2016 (A) and distribution between January 2012 through December 2016 (B, C, D, E and F) in the studied area located at Minas Gerais State, Brazil. Source: INMET (2018).

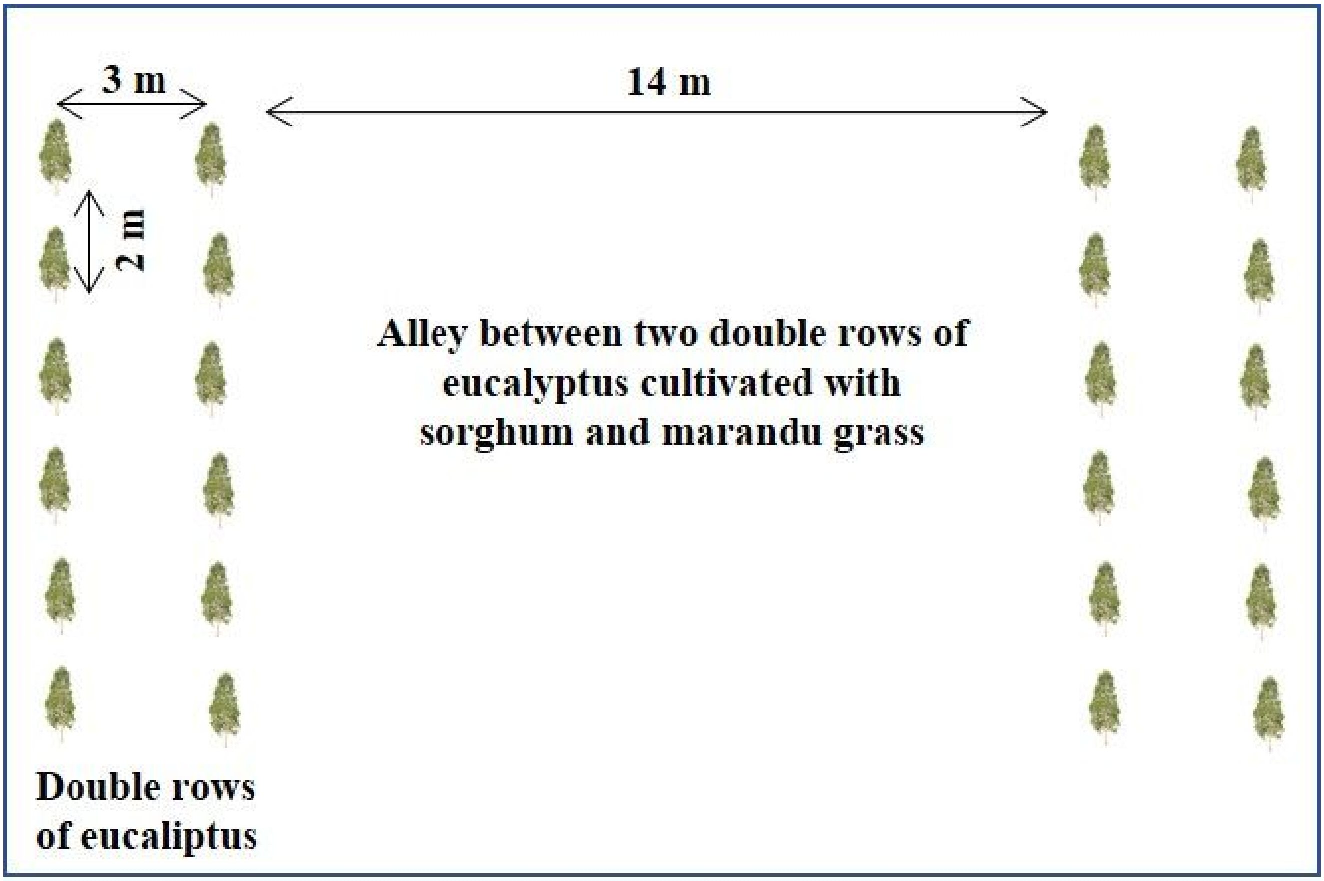

Figure 2

Schematic representation of the integrated crop-livestock-forest systems studied in the Brazilian Cerrado.