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ABSTRACT: *The objective of this study was to evaluate the silvicultural performance of four forest species introduced in a setting for integrated livestock forest (ILF) in a pasture in Lavras, Minas Gerais, Brazil. The species included were the Australian red cedar (seminal and clonal), African mahogany, teak, and guanandi. A split plot scheme with a randomized complete block design comprising four replicates and 48 plants per plot, was used in the following arrangement: (3(3x2) +7x2) m. The evaluation times (12, 18, 31, 36, and 43 months after planting) corresponded to the subplots. Performances of all four species were evaluated on the basis of their survival rate, height (H) and diameter at breast height (DBH). Based on the performance of the species with regard to these parameters, the clonal Australian red cedar showed a greater growth in DBH and height in the ILF setting as compared to the other species, which indicates it to be a suitable species for the region of Lavras, MG as long as its survival control occurs in the implantation phase.*
Key words: *adaptation, species testing, introduction of species.*

Desempenho silvicultural de espécies florestais introduzidas em sistema de integração pecuária floresta em Lavras, MG

RESUMO: *Objetivou-se com este trabalho avaliar o desempenho silvicultural de quatro espécies florestais introduzidas em arranjo para Integração Pecuária Floresta (IPF) sobre pastagem, em Lavras, Minas Gerais. As espécies estudadas foram o cedro australiano (seminal e clonal), mogno africano, teca e guanandi. Utilizou-se o delineamento de blocos casualizados completos, em esquema de parcelas subdivididas no tempo, com quatro repetições e 48 plantas por parcela no arranjo (3(3x2)+7x2)m. As subparcelas corresponderam às épocas de avaliações (12, 18, 31, 36 e 43 meses pós-plantio). Os desempenhos das espécies foram avaliados por meio dos parâmetros de sobrevivência, diâmetro à altura do peito e altura. Com base no desempenho das espécies, o cedro australiano clonal apresentou maior crescimento em DAP e altura no arranjo para IPF sendo esta a espécie indicada para Lavras/MG, desde que na fase de implantação ocorra o controle da sobrevivência.*
Palavra-chave: *adaptação, teste de espécies, introdução de espécies.*

INTRODUCTION

In the southern region of Minas Gerais State (MG), Brazil, there is a predominance of activities that concentrate on dairy farming and agricultural cultivation, especially in small rural properties, which include underutilized areas with some degradation degree. Keeping this in perspective, the optimization and capitalization of these small degraded areas by the introduction of forest species into structural arrangements for Integrated Livestock Forest (ILF) systems is an alternative.

Wood and food production on underutilized pastures through ILF systems is a promising means of reducing the pressure on native forests. They also aid in promoting the sustainability of ecosystems, such as that under consideration in this study, which are subject to degradation, while increasing their productivity per unit area. These improvements are expected to help rural producers in capitalizing natural resources at the end of the forest species cycle (CASTRO et al., 2008).

The ILF is a diversified system that allows the recovery of degraded areas and the production of wood and food within them with low environmental

side effects. The choice of the forest-based components is fundamental to the success of such a system, since the selected species - whether native or exotic - has to adapt to the edaphoclimatic conditions of the region; the introduced species also has to acknowledge its ecophysiological conditions and acclimatize to the initial ecological groups of succession in order to minimize unforeseen environmental and ecological disturbances (CASTRO et al., 2008; MELOTTO et al., 2009).

There is a limited number of studies that evaluate the performance of forest species in ILF-specific arrangements. Therefore, in the present study, selection of fast-growing forest species with high quality wood has been prioritized for improvement in the final income of the system. The objective of this study was to evaluate the silvicultural performance of four forest species introduced in an ILF arrangement in a pasture in Lavras, MG, Brazil.

MATERIALS AND METHODS

The experiment was set up in January 2012 at the experimental farm of Agricultural Research Company of Minas Gerais (EPAMIG) located in the city of Lavras, MG. The experimental area presents a dystrophic red latosol; it has a tropical climate with mild summers, which is defined as humid mesothermal type Cwb weather according to Köppen classification. Temperature of the warmest month is lower than 22°C and the average temperature is between 18°C and 19°C. Mean annual precipitation in the experimental area is 1511mm, ranging from 16.9mm in the driest month to 293.9mm in the month with the highest precipitation (ALVARES et al., 2013, INMET, 2014).

During the experimental setup, control of leaf-cutting ants, cleaning of the area, and correction as well as preparation of the soil were carried out. These preliminary measures were taken because the area under consideration was a *Urochloa decumbens* pasture, with symptoms of degradation according to the standards outlined by DIAS FILHO (2011).

Ant control, area cleaning, and maintenance fertilization were carried out during the implantation and development of the study. The area was cleaned in two steps. Firstly, weed control was carried out between lines of planting by the application of herbicide (glyphosate) in the total area with a farm tractor (4×2 TDA), the application of weed was performed in batches over time. Soil correction and preparation of the area were done by harrowing (total area) and subsoiling (planting rows). Limestone and simple superphosphate were also applied based on initial chemical analysis of the soil.

According to the initial analysis, which was done at a depth of 0-20cm, pH of soil was 5.90, organic matter content was 1.64dag kg^{-1}, phosphorus was 7.94mg dm^{-3}, potassium was 60.00mg dm^{-3}, base saturation index was 57.12%, and aluminum saturation index was 0.00%. At the depth of 20-40cm, pH was 5.70, organic matter content was 1.52dag kg^{-1}, phosphorus was 0.56mg dm^{-3}, potassium was 40.00mg dm^{-3}, base saturation index was 41.83%, and aluminum saturation index was 0.00%.

To plant the seedlings, 400ml of hydroretentor polymer was used per plant, and after one month of planting, weed control and fertilization were performed. There was also an addition of 50g of NPK (20-0-20) fertilizer. During rainy seasons of the 1st, 2nd, and 3rd year, cover fertilization was performed providing 180g of NPK (20-5-20) per plant in each fertilization period.

The seedlings were obtained from nurseries in Lavras, MG and were planted in areas, where pasture was degraded (*Urochloa decumbens*) after initial soil conditioning. The seedlings were transplanted in an arrangement that comprised three planting rows spaced 3x2m apart, separated by a 7m planting row with plants spaced 2m in the row, which resulted in the final arrangement of (3(3x2)+7x2)m. The final arrangement that was then studied consisted of four planting rows with a total of 56 plants per plot. Forty-eight central plants were considered viable, while the remaining were used to overcome the border effect. Evaluation times of 12, 18, 31, 36, and 43 months post-planting were considered subplots.

The experimental design was a randomized complete block design with four replicates and 48 plants per plot. The treatments were composed of vegetative and seminal propagation of four forest species represented by *Toona ciliata* M. Roemer (Australian red cedar), *Calophyllum brasiliense* Cambess (guanandi), *Khaya senegalensis* A. Juss (African mahogany), and *Tectona grandis* L. f. (teak).

The response variables used to evaluate the performance of selected species in the proposed arrangement were survival, plant height (H), and diameter at breast height (DBH). In addition to these variables, the Pearson's correlation analysis was performed between DBH, precipitation, and water deficit (12, 18, 31, 36, and 43 months) values obtained from the Agroclimatology Sector of Universidade Federal de Lavras (UFLA) and from the main climatological station of Lavras, MG (EPC).

Observations regarding the survival, H, and DBH variables were subjected to the Shapiro-Wilk normality test, while the homoscedasticity of

the variances was subjected to Anscombe and Tukey's test (1963) at 5% significance level.

Survival results for field seedlings were subjected to normality tests (p-value = 0.5126) and homoscedasticity of variance (F calculated = 0.95 and F tabulated = 4.74) test, the data was observed to fulfill the assumptions from analysis of variance (ANOVA) (Table 1). The ANOVA was performed using SISVAR software. If the analysis showed significance in the survival data, the Scott-Knott's test at 5% significance level was applied on it. Regression analysis was performed for each species on their DBH and H values (FERREIRA, 2011).

For comparative purposes, the followed survival percentages were considered: Low (<60%); moderate (60-89%), and high (>89%) (Table 1). These values were obtained and validated by the index of replanting of seedlings (MACEDO et al., 2010).

RESULTS AND DISCUSSION

Teak (100%) and African mahogany (87%) presented higher survival percentage than other species (Table 1 and 2) with the difference being statistically significant. These values were higher for teak as compared to values that have been previously reported, such as in the results of MACEDO et al. (2005), who reported 69% survival for teak. Results obtained for African mahogany were considered moderate for the survival rate, keeping in view that MELO & GUIMARÃES (2008) obtained 89% survival for this species in the Cerrado biome in the 43rd month after planting.
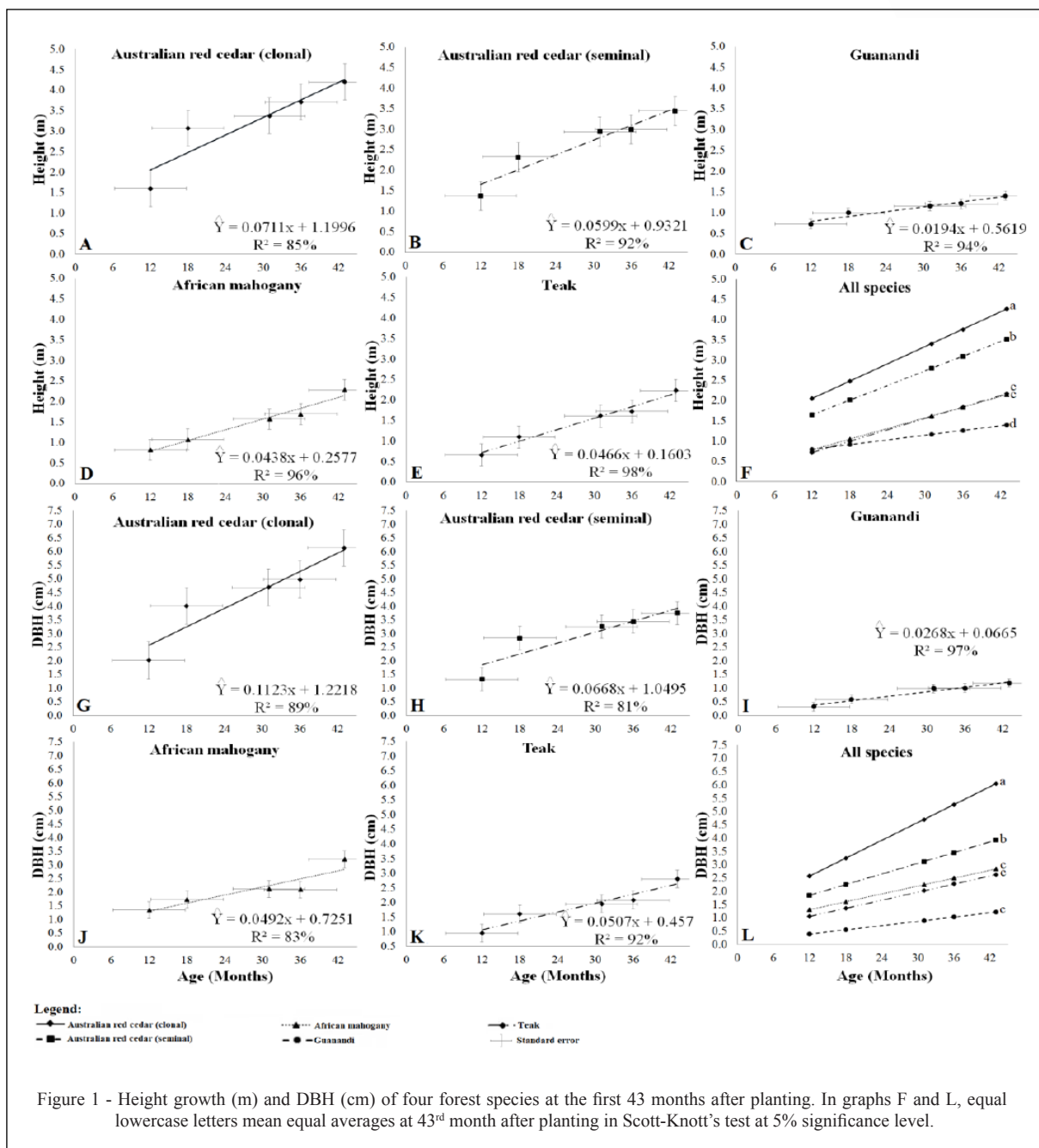
For guanandi, low percentage of survival (43%) was observed, which may reflect the inherent characteristics of the experimental site. Since this species is originally reported in areas with wet soils, unlike the study area, its requirements were not fulfilled, and thus, it was not able to establish well here and presented reduced growth as well as yellowing and drying of leaves. These characteristics support the hypothesis that guanandi adapts well in regions with higher values of precipitation or in areas near watercourses; this was corroborated by findings reported by MELOTTO et al. (2009), who observed an average survival of 44% on introduction of native species for ILF in Mato Grosso do Sul, Brazil.

Low survival of clonal and seminal Australian red cedar is attributable to the timing of the experiment, which was implemented at the end of the rainy season, due to which the seedlings did not completely harden-off. This conclusion was drawn considering the little observable change in the morphological characteristics of leaves that is meant to confirm the hardening-off process (DAVIDE et al., 2015). This result is reinforced, when compared with the results obtained by RODRIGUES et al. (2002), who grew Australian red cedar in consortium with coffee. These researchers reported 60% survival after one year of planting at the end of the rainy period. According to DAVIDE et al. (2015), the hardening-off process is fundamental to obtaining high survival of the species in the field, since the gradual process of exposure of the seedlings to the sun and reduction of the irrigation period helps them adapt more to the conditions of water stress present in the field.

Table 1 - Summary of variance analysis for height (m) and DBH (cm) for clonal and seminal Australian red cedar, teak, African mahogany, and guanandi at the ages of 12, 18, 31, 36, and 43 months.

SV[1]	DF[2]	Survival (%)	Height (m)	DBH (cm)
		MS[3]	MS	MS
Species	4	12952.110736[*]	15.687156[*]	35.006073[*]
Block	3	481.067972[ns]	0.058836[ns]	0.594972[ns]
Error 1	12	405.577882	0.317226	0.490127
Time	4	223.205351[*]	8.018156[*]	13.360528[*]
Error 2	12	10.973870	0.022156	0.056089
Time[*] Species	16	29.310037[*]	0.354441[*]	0.918212[*]
Error 3	46	10.123232	0.042311	0.107340
CV 1[4] (%)	-	29.54	28.57	28.98
CV 2[5] (%)	-	4.86	7.55	9.8
CV 3[6] (%)	-	4.67	10.43	13.56
Overall average	-	68.17	1.97	2.42

[1]Source of variation; [2]Degree of freedom; [3]Mean square; [4]Coefficient of variation referring to error 1; [5]Coefficient of variation referring to error 2; [6]Coefficient of variation referring to error 3; [ns]Not significant at 5% significance level; [*]Significant at 5% significance level.

Figure 1 - Height growth (m) and DBH (cm) of four forest species at the first 43 months after planting. In graphs F and L, equal lowercase letters mean equal averages at 43rd month after planting in Scott-Knott's test at 5% significance level.

Survival of a species is the initial parameter that can demonstrate its potential to adapt in a given region. However, according to TERRA et al. (2016), it is necessary to analyze the values of parameters that are important from silvicultural aspect (such as H and DBH) in order to measure the development of the species meant to be used in the arrangement, and thus, highlighting species with the greatest potential for plantation in the rural properties of the region under consideration.

It is observable in figure 1 and table 2 that the species studied here presented a linear behavior,

demonstrating that they remained in a state of full growth until the last evaluation. Clonal Australian red cedar presented the highest height growth rate (4.45m year^{-1}), confirming its potential to adapt to the local edaphoclimatic conditions of MG.

The silvicultural performance of the clonal Australian red cedar may be considered satisfactory, when compared to the study conducted by SAKCHOOWONG et al. (2008), who reported a height of 1.66m in the 12th month of plantation for Australian red cedar. FASSOLA et al. (2010) reported

Table 2 - Average survival, height and DBH of four forest species in the arrangement (3(3x2)+7x2) m for Lavras, MG, in 12, 18, 31, 36 and 43 months after planting.

Species	--Months---									
	12		18		31		36		43	
	Survival (%)									
Australian red cedar (Clonal)	49	b	49	b	49	b	49	b	45	b
Australian red cedar (Seminal)	54	b	54	b	51	b	49	b	43	b
Guanandi	58	b	56	b	49	b	49	b	42	b
African mahogany	97	a	95	a	90	a	90	a	87	a
Teak	100	a	100	a	100	a	100	a	100	a
	---Height (m)---									
Australian red cedar (Clonal)	1.60	a	3.07	a	3.37	a	3.71	a	4.20	a
Australian red cedar (Seminal)	1.37	a	2.32	b	2.93	a	2.99	b	3.45	b
Guanandi	0.73	b	1.00	c	1.16	b	1.22	d	1.41	d
African mahogany	0.82	b	1.07	c	1.57	b	1.69	c	2.28	c
Teak	0.66	b	1.10	c	1.61	b	1.72	c	2.23	c
	---DBH (cm)---									
Australian red cedar (Clonal)	2.02	a	4.01	a	4.69	a	4.98	a	6.13	a
Australian red cedar (Seminal)	1.33	b	2.84	b	3.25	b	3.44	b	3.74	b
Guanandi	0.33	c	0.59	d	0.99	d	1.00	d	1.19	d
African mahogany	1.35	b	1.74	c	2.12	c	2.12	c	3.20	c
Teak	0.95	c	1.61	c	1.95	c	2.08	c	2.80	c

*Averages that are followed by the same lowercase letters in the column do not differ significantly as per the Scott-Knott's test at 5% significance level.

an average height of 4.00m in the 24th month after plantation, which demonstrates the potential of the species to adapt in the region, since in the 18th month, the species had a height of 3.07m.

The results recorded for African mahogany (0.82m) and guanandi (0.73m) in the 12th month were satisfactory, when their values were compared to those obtained by FALES and BUENO (1999) and SOUZA et al. (2001), who reported an average height of 0.75m in a silvipastoral system for African mahogany and 0.30m for guanandi, respectively, in the recovery areas of the Rio Grande basin in MG.

MACEDO et al. (2004) studied teak growth in Lavras, MG and reported an average height of 0.71m in the 12th month after planting. Similar values (0.66m) were recorded in the present study, which is attributable to the comparable edaphoclimatic conditions. However, MORETTI et al. (2014) obtained seedlings with a height of 1.09m in the 12th month in Figueirópolis D'Oeste, MS, which may due to the lower altitude, i.e., 266m above sea level, in case of their site of study as well as the higher annual average temperatures that were between 25ºC and 38ºC, in comparison to the climatic conditions of Lavras, MG that has monthly average temperatures varying

between 15 and 28ºC and the average altitude of 890m above sea level. These factors, according to DANTAS et al. (2007), limit the growth of the species.

The height observed for teak plants (1.61m) in the 31st month was considered low as compared to the results reported by MACEDO et al. (2005), who obtained plants with 2.8m height in the 24th month in Paracatu, MG. This poor performance of teak is probably due to the large number of sprouts that grew during the evaluation period along with the lowest average monthly temperatures and the highest local altitude. The secondary sprouting process of teak usually results in a reduction in the average height of the plant, as sprouting requires more energy for the secondary meristem to grow than the primary meristem (MACEDO et al., 2004).

For DBH (Figure 1 and table 2), it was reported that all species studied here exhibited full growth because they had a linear behavior for this parameter during the period in which the evaluations were done. However, after the 12th month, it was observed that the clonal Australian red cedar had a higher increase in DBH as compared to the other plants analyzed in this investigation.

In the 12th month, the results for clonal (2.02cm) and seminal (1.33cm) Australian red cedar

resembled the ones reported by SAKCHOOWONG et al. (2008), who reported a 2.30cm DBH for individual plants of Australian red cedar that had been genetically improved to be resistant against *Hypsipyla robusta* attack and DBH of 1.30cm for individuals susceptible to *Hypsipyla robusta* (without genetic improvement). These values, in addition to the genetic material, explain the difference in performance of clonal and seminal seedlings of Australian red cedar; the higher secondary growth rate is a result of the degree of improvement for this species.

African mahogany and teak seedlings with DBH of 0.82cm and 0.66cm, respectively, in the 12th month showed poor performance as compared to the seedlings in the research performed by GUIMARÃES NETO et al. (2004) in Brasília, DF and TONINI et al. (2009) in Paraná. These research groups observed 2.60cm and 1.43cm DBH for African mahogany and teak, respectively, in the 12th month.

Growth of clonal Australian red cedar with regard to DBH was 5.00cm in the 36th month after planting in comparison to the data presented in RICKEN et al. (2011), with observed a DBH of 5.00cm in the 36th month after planting Australian red cedar in the municipality of Adrianopolis, PR. The values of DBH rported for teak (1.72cm) and African mahogany (1.69cm) are; however, lower than those reported by MACEDO et al. (2005), who

observed a DBH of 4.10cm for teak in the 36th month. These values are also lower that those obtained by GUIMARÃES NETO et al. (2004), who recorded a DBH of 3.89cm for African mahogany. Low performance in DBH for African mahogany, teak, and guanandi may possibly be due to the climatic conditions that are characterized by a reduction in annual average precipitation and an increase in water deficit between 31st and 36th month (Figure 2).

When correlating the average precipitation in the periods that were evaluated in the investigation with the increase in DBH, a positive correlation was reported for clonal (0.98) and seminal (0.93) Australian red cedar, teak (0.87), African mahogany (0.60), and guanandi (0.60). It is concluded from this correlational analysis that there is an increase in DBH, when precipitation decreases. Conversely, when correlating water deficit and DBH, a negative correlation was observed for clonal (-0.81) and seminal (-0.63) Australian red cedar, teak (-0.79), guanandi (-0.45), and African mahogany (-0.57), i.e., higher water deficit reduces the secondary growth of all four species.

It was also observed that the lowest average annual precipitation occurred in the 3rd year with 1148.90mm year^{-1}, which is considered below average for the region of Lavras, MG, with the normal average being 1510mm year^{-1} (INMET, 2014). On analysis of past climate in the region of Lavras for the period between
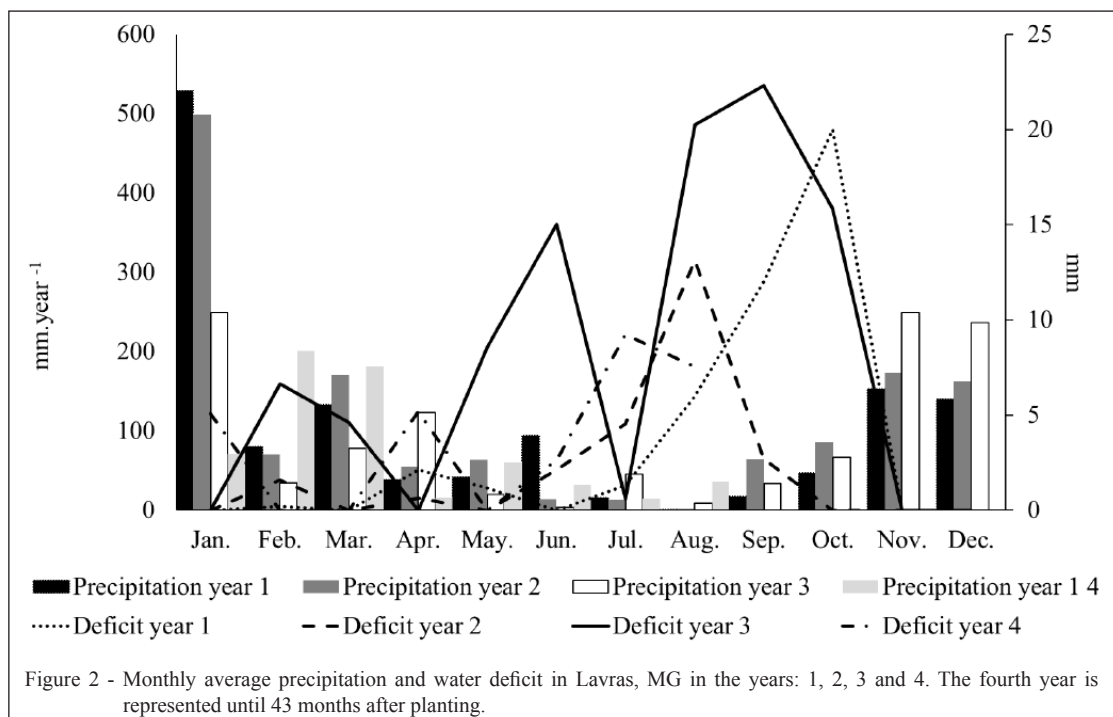

Figure 2 - Monthly average precipitation and water deficit in Lavras, MG in the years: 1, 2, 3 and 4. The fourth year is represented until 43 months after planting.

1960 and 2004, DANTAS et al. (2007) reported average rainfall to be 1495mm year^{-1}. According to STAPE et al. (2010), during the dry season, growth and CO_2 fixation in the aerial parts of plants decrease, whereas they increase in the root system, causing a reduction in H and DBH. In general, a reduction in precipitation and an increase in water deficit was observed to influence the growth of plants. However, during the 36th and 43rd months, growth in diameter and height resumed; this incident coincided with an increase in precipitation, and consequently, a reduction in water deficit.

It has been deduced from the observations made in this research that specific factors determine the different performance of species in ILF arrangements. The main limiting factor for Australian red cedar growth probably was the reduction in annual mean precipitation. According to PUMIJUMNONG & BUAJAN (2013), the species does not develop in dry periods because water deficit reduces the rate of cambial activity, which is reestablished with the increase in average annual precipitation.

According to soil analysis performed at the experimental site, Ca content and the base saturation for teak in the area were below the recommendations by BARRA (1996), who stressed that the Ca content should be between 21 and 30cmol$_c$ dm^{-1} for teak to develop adequately.

For guanandi, the limiting component for development was possibly water restriction, which was caused by the reduction in the annual average precipitation. This species is normally reported in humid sites with sufficient water and high precipitation (SOUZA et al., 2001). However, for African mahogany, reduction in precipitation period was probably the limiting factor responsible for its low performance. This is true considering PINHEIRO et al. (2011) and CORCIOLI et al. (2016) observation that this species needs deep soils with high fertility and average annual precipitation of 1300 to 1800mm for healthy growth.

It is worth mentioning here that studies on silvicultural performance, based on dendrometric variables, such as H and DBH, make it possible to express the potential of establishment, growth, and differentiated development of different species, which are essential for the development of agroforestry. These studies are also important to evaluate and analyze the behavior of the herbaceous components inserted in ILF systems so that a better understanding of the interaction between the components involved in such forest systems can be ensured.

CONCLUSION

The species studied here had different potentials for survival, which were as follows: Teak, high potential: African mahogany, moderate potential; Australian red cedar (clonal and seminal) and guanandi, low potential.

The clonal Australian red cedar exhibited superior silvicultural performance with regard to its DBH and H for its use in ILF arrangement, which indicates the species to be suitable for growth in Lavras, MG as long as its survival control occurs in the implantation phase.

Among the species studied, guanandi had the lowest silvicultural performance (survival, DBH, and H) with maximal symptoms of maladaptation to the experimental site.

ACKNOWLEDGEMENTS

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