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Root system growth and eucalyptus clones performance in Vitória da Conquista, Bahia, Brazil

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ABSTRACT: Root system characteristics were studied in order to evaluate the performance of eucalyptus clones in edaphoclimatic conditions of Vitória da Conquista, Bahia, Brazil. Two experiments were carried out. First, in a nursery, seedlings had their roots pruned and were planted in transparent tubes, outlined in quadrants, for evaluating root regeneration potential (RRP) and the dry matter partitioning from shoot to roots. 30 days after planting, AEC 144 and CO 520 were the clones with highest RRP, although CO 520 is similar to the other three clones. AEC 144 showed a tendency of better performance in dry matter partitioning from shoot to roots. The second experiment was carried out in the field. Six months after planting, plant height, stem diameter, leaf area, number of leaves, main root length, shoot and root dry matter, and soluble sugar, reducing sugar, protein and amino acid contents in roots were determined. There were no significant differences in all characteristics evaluated among the clones. Despite the differences related to RRP and dry mass partitioning, we concluded that the clones have characteristics which lead to a similar plant performance in the field, in the edaphoclimatic conditions of Vitória da Conquista.

Keywords: woody plants, clonal seedlings, root regeneration.

Crescimento do sistema radicial e desempenho de clones de eucalipto em Vitória da Conquista, Bahia, Brasil

RESUMO: Características do sistema radicial foram estudadas para avaliar o desempenho de clones de eucalipto nas condições edafoclimáticas de Vitória da Conquista, Bahia, Brasil. Foram realizados dois experimentos. No primeiro, em viveiro, as mudas tiveram suas raízes podadas e plantadas em tubos transparentes, delineados em quadrantes, para avaliar o potencial de regeneração de raízes (PRR) e partição de matéria seca da parte aérea para as raízes. Após 30 dias, verificou-se que AEC 144 e CO 520 são os clones que possuem maior PRR, embora este último apresente semelhança com os demais. AEC 144 mostrou uma tendência de melhor desempenho em partição de matéria seca da parte aérea para as raízes. O segundo experimento realizou-se no campo. Após seis meses de plantio, avaliou-se altura de planta, diâmetro de colo, área foliar, número de folhas, comprimento da raiz principal, matéria seca de parte aérea e raízes e teores de açúcares solúveis, açúcares redutores, proteínas e aminoácidos em raízes. Entre os clones, não houve diferenças significativas em todas as características avaliadas. Concluímos que, a despeito de diferenças em relação ao PRR e partição de massa seca, os clones possuem características que, no campo, permitem obter desempenhos semelhantes, nas condições edafoclimáticas de Vitória da Conquista.

Palavras-chave: plantas lenhosas, mudas clonais, regeneração de raízes.

1. INTRODUCTION

The tree planting in Brazil has become a viable important way out to reach two goals: the growing demands of the domestic market of wood consumption and, at the same time, avoid the suppression of native forests. The *Eucalyptus* genre is an alternative to meet the market demand, because its species are well adapted do different environments, have relatively short term production cycles, and its management technology is already advanced.

The first brazilian eucalyptus forests were planted only in high precipitation regions. In recent years, it has become necessary to select tolerant clones to soil water restrictions, due to expansion of plantations to arid and semiarid regions. Vitória da Conquista is located in southwest of Bahia state, where the rainfall annual is considered unsatisfying (733,9 mm), with uneven distribution (SEI, 2013). The selection of species and genotypes tolerant to water deficit is an important requirement for success of eucalyptus forest planting, since the water restriction is one of the main causes of the low forest productivity.

Plant cell physiological processes and morphological aspects can be affected in response to water deficit, increasing the tolerance to environmental adversities (PIMENTEL, 2005). Osmotic adjustment is one of the strategies of plant tolerance to water stress. Cell water potential decrease, based on soluble compounds content increase, in order to preserve the relative water content, is important for avoid plant relative growth rate decreases under water deficit (AROCA, 2012). Osmotic adjustment in root cells favors the tissue growth to deeper layers of soil, where the water potential is higher (CARVALHO, 2005). For this reason, dry matter partitioning to root system is an important indicador of plant adaptation to water stress. Besides its relevance for water absorption, the root system expansion plays an important role in nutrient uptake and plant fixing in soil (PALLARDY, 2008).

RRP is one of the parameters used for prior evaluate of some characteristics which are indicators of the later seedlings performance after planting at the field, such as survival rate and initial growth. In eucalyptus, seedlings with high RRP tend to have higher growth rate in the field (BARROSO et al., 2000).

This study was designed to observe root system characteristics related to initial performance of some eucalyptus clones in Vitória da Conquista, Bahia, Brazil. The objective of the first experiment was to evaluate the RRP of seedlings grown at a nursery. The second experiment aimed to evaluate some plant morphological, biochemical and physiological characteristics, six months after the seedlings planting at the field.

2. MATERIALS AND METHODS

The study was carried out from April to October 2013, at the State University of Southwest Bahia (UESB), Vitória da Conquista, Bahia, Brazil (14°51'S 40°50'W, altitude 937 m), where the maximum and minimum temperatures are 23 °C and 15.8 °C, respectively, and the annual mean rainfall is 733.9 mm, with irregular distribution throughout the year. The experimental area is inserted in the C1dB' climate (dry subhumid), according to Thornthwaite (SEI, 2013).

The TecnoPlant Nursery LTDA company, from Eunápolis city, south Bahia, Brazil, provided kindly the seedlings of the following clones used in this study: AEC 144 (*Eucalyptus urophylla*) and four hybrids identified as "urograndis" - CO 1404, CO 1407, CO 520 and CO 1249 (*E. urophylla* x *E. grandis*).

First, an experiment was conducted at a plant nursery for 30 days, during on April and May months. A completely randomized design was used, with five treatments (clones), four replications and three seedlings per plot. The 100 day old seedlings were removed from the tubes and their root systems were washed carefully. The secondary roots were pruned about 3-4 cm from the axis of the main root, and this was also pruned at 6 cm. The seedlings were then planted in 2 L plastic pots, coated with a black film to avoid the external light, containing Vivatto Slim Plus® substrate, with daily irrigation (0.5 mL per pot). Four quadrants were drawn by longitudinal scratches on the wall of each tube and its base was drilled to drain any water excess.

Contacts of the regenerated roots at the vessel wall were marked every two days using a brush. After 30 days, RRP was determined based on the number of regenerated root markers, in each quadrant as well as on the upper and underside. Seedlings were then removed from the vases and dried at 65 °C until constant weight, to obtain shoot and root dry weight, and the shoot / root ratio. The averages were compared by the Tukey test ($p < 5\%$) using the SAEG statistical program.

The second experiment was carried out in the agricultural field of the UESB, from April to October. A subsoiling at 15 cm depth was previously performed, in order to allow a better plant roots deepening. Fertilization was according to chemical soil analysis, and Hidrogel was applied 0,5 L hole^{-1}, to keep moisture in the rhizosphere longer. Seedlings 115 day old were transfered from tubes to the field and irrigated twice a week for the first 30 days, in order to favor a better establishment.

The experimental design was arranged in randomized blocks, with five treatments (clones), four blocks and 20 replications, 15 seedlings per replication. Six month after planting, the plants were removed from the soil, in a careful process of excavations with hoes, in order not to damage the root system. The following characteristics were then measured: a) plant height, from the stem base to the shoot apex; b) stem diameter, using a digital pachymeter; c) mean number of leaves per plant; d) total leaf area, using a leaf area meter (LI-COR, model LI-3100); e) length of the main root; f) shoot and root dry matter; g) soluble sugar (YEMM and WILLIS, 1954), reducing sugar (MILLER, 1959), protein (BRADFORD, 1976); aminoacid (YEMM and COCCKING, 1955) contents in shoot and root; h) sucrose content, based on the soluble sugar content, after abated reducing sugars.

Data were submitted to analysis of variances (ANOVA) and mean data of treatments compared by Tukey test ($p < 5\%$), using SAEG program.

3. RESULTS

Evidences of regenerated roots were more intensive in AEC 144 and CO 520 than in the other clones. Nevertheless, there was no significant difference among total number of regenerated roots in CO 520 and in other clones (Table 1). The number of regenerated roots in the four quadrants, however, was the same for all clones (Table 2).

Data showed a tendency to greater dry matter partitioning to roots, based in lower shoot/root ratio, in AEC 144 clone, although this ratio, in statistical terms, was not different from that found in CO 1249, CO 1407 and CO 1404. In these last three clones, in turn, the shoot/root ratio was not different from that in CO 520 (Tabel 3).

Table 1. Number of regenerated roots - total, in the upper and the lower portions of the tubes, in five *Eucalyptus* sp. clones, at 30 days after pruning of the root system.
Tabela 1. Número de raízes regeneradas (RG) - total, na porção superior e na porção inferior dos tubos, em cinco clones de *Eucalyptus* sp., aos 30 dias após a poda do sistema radicial.

Clone	Regenerated roots (total)	RR on the upperside	RR on the underside
AEC 144	24.65 a*	7.79 a	16.86 a
CO 1249	14.08 b	3.08 a	11.00 a
CO 1407	14.66 b	3.91 a	10.75 a
CO 1404	14.00 b	2.33 a	11.66 a
CO 520	20.41 ab	6.41 a	14.00 a
CV (%)	25.33	53.18	24.11

* For each column, means followed by the same letter indicate that they are not different from each other, according to the Tukey's test ($p < 5\%$).

Table 2. Number of regenerated roots per quadrant in *Eucalyptus* sp. clones at 30 days after pruning of the root system.
Tabela 2. Número de raízes regeneradas, por quadrante, em clones de *Eucalyptus* sp., aos 30 dias após a poda do sistema radicial.

Clone	Quadrant			
	1	2	3	4
AEC 144	6.29 a*	5.91 a	6.91 a	5.50 a
CO 1249	3.58 a	4.08 a	3.58 a	2.83 a
CO 1407	3.66 a	3.75 a	4.08 a	3.16 a
CO 1404	2.33 a	3.25 a	3.66 a	4.74 a
CO 520	5.41 a	4.66 a	4.75 a	5.58 a
CV (%)	45.90	65.51	43.93	37.85

* For each column, means followed by the same letter indicate that they are not different from each other, according to the Tukey's test ($p < 5\%$).

Table 3. Shoot/root dry weight ratio (MSPA/MSR) in five *Eucalyptus* sp. clones, at 30 days after pruning of the root system.
Tabela 3. Relação entre matéria seca de parte aérea e de raiz (MSPA/MSR) em cinco clones de *Eucalyptus* sp., aos 30 dias após a poda do sistema radicial.

Clone	SDM/RDM
AEC 144	1.96 b*
CO 1249	2.16 ab
CO 1407	2.12 ab
CO 1404	2.45 ab
CO 520	2.48 a
CV (%)	10.90

* Means followed by the same letter indicate that they are not different from each other, according to the Tukey's test ($p < 5\%$).

Six months after planting, we noted no significant difference among the clones, based on all the characteristics evaluated (Tabels 4, 5 and 6).

Table 4. Root length (CR), number of leaves (NF), leaf area (AF), stem diameter (DC) and plant height (AP) of five *Eucalyptus* sp. clones, at six months after planting.
Tabela 4. Comprimento de raiz (CR), número de folhas (NF), área foliar (AF), diâmetro do colo (DC) e altura de plantas (AP) de cinco clones de *Eucalyptus* sp., aos seis meses após o plantio no campo.

Clone	RL (cm)	NL	LA (cm²)	SD (cm)	PH (m)
AEC 144	45 a*	1,561 a	46,705 a	2.95 a	1.68 a
CO 1249	48 a	1,554 a	58,759 a	3.17 a	1.70 a
CO 1407	56 a	1,199 a	24,024 a	3.00 a	1.70 a
CO 1404	47 a	1,654 a	43,456 a	2.87 a	1.70 a
CO 520	44 a	1,590 a	49,860 a	2.97 a	1.67 a
CV (%)	11.65	10.90	34.45	15.31	8.34

* For each column, means followed by the same letter indicate that they are not different from each other, according to the Tukey's test ($p < 5\%$).

4. DISCUSSION

Root pruning, in the AEC 144 and CO 520 clones, acted as a stimulus to the emission of new roots and to the recovery of the root system as a whole, increasing root-soil contact (Table 1). This effect on the roots provides greater water and nutrients absorption and can be very important for plant establishment and performance after planting in the field, especially in areas subject to extensive periods of drought. Seedlings who have higher RRP show more ability for soil exploitation, which provides them greater growth, vigor and establishment, soon after planting in the field, especially if the seedlings face some environmental stress (BARROSO et al., 2000; BOMFIM et al., 2000). CO 1249, CO 1407 and CO 1404 had less emission of new roots after root system pruning, indicating that these clones have lower RRP (Table 1). According to Barroso et al. (2000), low RRP negatively affects the performance of plants after transplanting, reducing plant survival rate in the field.

Table 5. Shoot dry weight (MSPA), root dry weight (MSR) and shoot/root dry weight ratio (MSPA/MSR) of five *Eucalyptus* sp. clones, at six months after planting, in Vitoria da Conquista, Bahia.
Tabela 5. Massa seca de parte aérea (MSPA), massa seca de raiz (MSR) e relação entre massa seca de parte aérea e de raiz (MSPA/MSR) de cinco clones de *Eucalyptus* sp., aos seis meses após o plantio no campo.

Clone	SDM (kg)	RDM (kg)	SDM/RDM
AEC 144	1,027 a*	163 a	7.33 a
CO 1249	1,176 a	176 a	6.60 a
CO 1407	557 a	139 a	4.08 a
CO 1404	1,133 a	126 a	8.77 a
CO 520	1,017 a	163 a	7.33 a
CV (%)	31.81	34.76	37.97

* For each column, means followed by the same letter indicate that they are not different from each other, according to the Tukey's test ($p < 5\%$).

Table 6. Soluble sugar (AS), reducing sugar (AR), sucrose (S), protein (P) and amino acid (AA) contents, expressed in mmol g^{-1} dry weight, in roots of five *Eucalyptus* sp. clones, at six months after planting.
Tabela 6. Teores de açúcares solúveis (AS), açúcares redutores (AR), sacarose (S), proteínas (P) e aminoácidos (AA), expressos em mmol g^{-1} massa seca, em raízes de cinco clones de *Eucalyptus* sp., aos seis meses após o plantio no campo.

Clone	SS	RS	S	P	AA
AEC 144	1,865 a*	32 a	1.833 a	27 a	54 a
CO 1249	1,619 a	28 a	1.578 a	29 a	52 a
CO 1407	1,466 a	29 a	1.436 a	28 a	46 a
CO 1404	1,466 a	27 a	1.439 a	31 a	49 a
CO 520	1,357 a	20 a	1.337 a	28 a	57 a
CV (%)	21.14	22.92	21.86	22.09	9.97

* For each column, means followed by the same letter indicate that they are not different from each other, according to the Tukey's test ($p < 5\%$).

On the upper side of the tubes, all of clones did not show differences with respect to roots regeneration (Tabel 1), suggesting similar ability for absorption of water and nutrient in the soil surface layer among the clones. Martins et al. (2004) evaluated the use of increasing doses of a biosolid (urban sewage sludge treated and cleansed) in the root system of *Eucalyptus grandis* and found a greater amount of fine roots in the soil surface layer. According to Lampurlanés et al. (2001), genotypes with high RRP in the soil surface layers can be benefited from a higher water absorption after an irrigation or precipitation because the root system expansion helps to reduce the soil water evaporation.

There was no difference with respect to root longitudinal growth, which suggest a possible similarity in ability to absorption of water and nutrient among the clones. The development of the root system in eucalyptus clones depends both on genetic characteristics and on environmental factors, especially on edaphic conditions (FIGUEIREDO et al., 2011). Under plant growth limitant edafoclimatic conditions, genotypes may show similar performances, making it difficult to identify which are the most promissing (VELLINI et al., 2008). However, there are genotypes that expand their root system favoring longitudinal growth, and this is an important mechanism of adaptation and tolerance to water deficit, which provides higher plant water absorption efficiency (LI et al., 2000).

In all clones, there was no difference with respect to the number of regenerated roots per quadrant (Tabel 2). This data suggests that the root expansion must be probably well distributed into the soil after planting the seedlings in the field, which provides better conditions for plant attachment to the soil, as well as absorption of water and nutrients. Novais et al. (2002) have evaluated the RRP in *Pinus taeda* seedlings and concluded that the treatments that provide a better root distribution in the four quadrants make the root system more efficient for the soil use.

AEC 144 performed the highest dry matter partitioning to the roots (Table 3), so it was the clone with the highest RRP. Pinheiro et al. (2005) verified that in *Coffea canephora* the genotypes who perform higher dry matter partitioning to the roots are the most water deficit tolerants.

Six months after transplanting, there was no difference among the clones with respect to plant height and stem diameter - 1,69 m and 3,0 cm respectively (Table 4). These data, as well as the root length, allow us to deduce that all clones had similar growth. Reis et al. (2006) reported that in eucalyptus clones whose roots have lower expansion, there is also a lower shoot growth, both in plant height and in stem diameter. Forest species with larger stem diameter are the ones that present a higher survival rate, because this characteristic generally reflects a greater root system ability of expansion and regeneration (SOUZA et al., 2006). According to Sharma et al. (1993), plant growth-related characteristics analisys are important because they generate knowledge about the plant behavior under specific environmental conditions, which may help the selection of species and genotypes who are more adaptable to each region.

There was no difference among the clones, either in number of leaves or in total leaf area (Table 4). Thus, the dry matter production, both in shoot and roots, was also not different (Table 5). We found no difference with respect to shoot/root dry matter ratio, which indicates similar ability among the clones for dry matter partitioning.

The root longitudinal growth is often a physiological response of tolerant plants to water deficit (STETTLE and BRADSHAW, 1994). According to Gonçalves and Passos (2000), increase of dry matter partitioning to the root system favors its longitudinal growth, providing greater water uptake in soil deeper layers, where the water potential is higher than in surface. Nevertheless, Fernandes et al. (2013) also found no differences in shoot/root ratio among the same clones described here, even in plants subject to water deficit, in a greenhouse.

The growth rate and root system architecture are determinant for water and nutrient efficiency of absorption, both in normal and adverse cultivation conditions (SAMAL et al., 2010), playing a direct influence on whole plant growth (GAITÁN et al., 2005). As we found no difference among the clones with respect to root system growth (Tabel 4), this suggests that clones have similar ability for plant stablishment in the field and water and nutrient uptake, even with the low rainfall index (160 mm) during on the experimental period (INMET, 2013).

Similarity among eucalyptus clones, with respect to several agronomic characteristics, has been reported by some researchers. Lopes et al.(2011) found no significant difference in stem diameter in *Eucalyptus grandis* and *Eucalyptus urophylla*, six months after planting under the edaphoclimatic conditions of São Paulo state. Matos et al. (2012) found no difference in plant mean height of several eucalyptus clones, five months after planting, in northeast of Pará state. A rapid height growth in the first months after planting is considered as a positive characteristic in eucalyptus clones, because it ensures greater competitiveness in relation to weeds (QUEIROZ et al., 2009).

Several plant species and genotypes show adaptability to eventual occurrences of environmental stresses, especially the water deficit, due to the root system cells ability to increase the osmotically active solutes content, such as soluble and reducing sugars (SS and RS), sucrose (S) and amino acids (AA). McLaughlin et al. (1996) found positive correlation between root growth and SS content increasing in *Acer saccharum* in diverse ecosystems, and this result was related to a possible osmotic adjustment. In corn under water deficit, Pimentel (1999) noted signs of osmotic adjustment, based on AA content increasing related to a greater protein hydrolysis.

There was no difference among the clones, with respect to SS, RS, S and AA contents in root tissues (Table 6). We have assumed these results as one of the possible reasons for there being no difference in root length among the clones, since root expansion depends on the assimilate importation from the leaves. Even under eventual environmental stress, roots may not necessarily change the organic solute cellular contents, as reported by some researchers. Arabzadeh (2012) found no difference between *Haloxylon persicum* and *Haloxylon apphyllum* under to water deficit, with respect to root RS content. In *Solanum lycocarpum* plants subject to different water regimes, Chaves Filho and Stacciarini-Seraphin (2001) found no difference in S contents among control and treated groups, although water stress caused an increase in SS and RS contents. In *Paspalum paniculatum* L. plants, Melo et al. (2007) found no changes in protein and AA contents of roots, even after 11 days without irrigation.

5. CONCLUSIONS

AEC 144 and CO 520 have the highest RRP among the clones, although CO 520 is similar to the other three clones. This performance is probably related to dry matter partitioning from shoot to roots, for which AEC 144 shows a tendency of better performance. However, the RRP differences among the clones become non-significant if RRP is evaluated in each quadrant of in the tubes.

Referring to the plants behaviour under the edaphoclimatic conditions of the field, there is no difference among AEC 144, CO 1404, CO 1407, CO 520 and CO 1249 clones, with respect to all growth characteristics evaluated, both in shoot and roots.

The results allow us to conclude that, despite the differences between the clones with respect to RRP and dry matter partitioning for the roots, they all have similar performances during the six early months after planting in the field, under edafoclimatic conditions of Vitória da Conquista.

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