ROOT GROWTH AND DISTRIBUTION OF *EUCALYPTUS UROPHYLLA* COPPICE

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ABSTRACT

Although fine roots are important in mineral nutrient and carbon cycling, they have often been ignored in forest ecosystems. The work reported here was carried out to study the growth and spatial distribution of roots of coppicing eucalypts. The study used a 7-year-old eucalypt stand planted at 3 x 2-m spacing at the Patagônia farm in the Savanna region of João Pinheiro county in north-east Minas Gerais State, Brazil. The eucalypt plantation belonged to the V & M Forest Company. All the trees in the area were felled, and root biomass was determined in trees whose diameter at breast height corresponded to the population mean. Measurements were carried out at 0, 60, 120, 180, 240, and 330 days after harvesting in order to evaluate the distribution of root biomass. Sampling was performed in 50 x 50-cm units on the beds and at the 0–10, 10–20, 20–40, and 40–60 cm depths, distributed in half the area occupied by the selected trees, and the roots were separated into three diameter classes (fine roots < 1 mm, medium roots 1–3 mm, and coarse roots > 3 mm). Fine- and medium-sized root biomass increased with time after harvesting, particularly to a depth of 20 cm. However, there was little alteration in the biomass of coarse roots. Root biomass decreased with depth and, on average, about 73%, 54%, and 68% of the fine, medium, and coarse roots, respectively, were concentrated in the surface 20 cm of soil. Analyses of the horizontal root distribution indicated that, in general, most of the roots, mainly medium and coarse, were located close to the stumps and that the root distribution was less uniform as root diameter increased.

Keywords: root system; root growth; root distribution; root diameter; coppicing; Savanna region; soil nutrient availability; harvesting; Brazil; *Eucalyptus urophylla*.

INTRODUCTION

Lack of information on plant roots frequently limits understanding of the structure and behaviour of tropical forests (Vance & Nadkarni 1992). Although fine roots are important in nutrient and carbon cycling (Attiwill & Leeper 1987), they have often been neglected in forest ecosystem studies.

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Limited knowledge about the stages and forms of root growth restricts understanding of the differential growth behaviour of species with respect to responses to fertiliser and adaptation to adverse climatic conditions. Lack of information is particularly noticeable for the *Eucalyptus* genus (Krejci *et al.* 1986).

Plant roots have not received much attention because of the difficulty in observing and measuring them. Root growth, and root distribution and configuration in the soil are important factors influencing water and nutrient uptake and consequently plantation growth (Gonçalves *et al.* 1997). Thus, evaluation of root growth can be an important diagnostic tool. Studies on the development and configuration of the root system of trees in plantations can assist improvements in site management practices, especially those designed to increase water and nutrient uptake by stands (Nambiar 1983, 1990).

Knowledge about the physiology of coppicing of woody species is still limited. Coppicing commonly shows marked seasonal variation that depends on the environmental conditions and on the changes in the internal levels of growth regulators and stored reserves in the stumps and roots (Kramer & Kozlowski 1979). Eucalypt coppice grows much faster than stems of seedlings due to the smaller allocations required for root reserves and to the presence of an already established root system (Barros *et al.* 1997).

Harvesting induces changes in the hormonal balance in the remaining parts of the tree, and these changes cause sprouting. High cytokinin activity has been detected in stumps from felled eucalypt trees (Taylor *et al.* 1982; Itai & Birnbaum 1991). The increase in the concentration of growth regulatory substances such as cytokinin is probably a necessary precursor for growth renovation (Taylor *et al.* 1982). Auxins are generally transported from the canopy to the roots but this route is interrupted with felling and, consequently, the concentration of auxin in the roots falls drastically. This may be important for the increase in root biomass after harvesting because auxin induces ethylene synthesis, which is a root growth inhibitor. If ethylene synthesis is blocked, low auxin concentration promotes root growth (Taiz & Zeiger 1991).

Cutting and harvesting tropical forests results in nutrient loss and leads to site degradation if practised continuously. An important mechanism for maintenance of forest fertility is the growth of extensive systems of fine mycorrhizal roots that absorb nutrients otherwise lost by leaching. Forest harvesting probably reduces the efficiency of this system, at least temporarily. However, Raich (1980) showed that the fine root system is completely reconstructed a year after the forest is felled and may have an absorption capacity similar to that of a mature forest. Therefore, the nutrient losses through leaching after felling may be smaller than commonly assumed.

This work aimed to study the growth and spatial distribution of roots of *Eucalyptus urophylla* S. T. Blake coppice subsequent to harvesting, under field conditions.

MATERIAL AND METHODS

The study was carried out in the Patagônia farm of the V & M Forest Company, located in the Savanna region of João Pinheiro County in north-east Minas Gerais, Brazil. The dominant soil order is Oxisol with level topography. A soil chemical and physical characterisation is provided in Table 1.

TABLE 1–Soil chemical and physical characteristics at different depths

Characteristic*	Unit	Depth (cm)			
		0–10	10–20	20–40	40–60
pH H_2O (1:2.5)		3.9	3.9	3.9	3.9
C†	g/kg	9.4	6.2	5.1	6.6
P	mg/dm^3	3.2	1.9	0.5	0.4
K^+	mg/dm^3	16	16	12	10
Al^{3+}	$cmol_c/dm^3$	0.5	0.5	0.4	0.4
Ca^{2+}	$cmol_c/dm^3$	0.3	0.2	0.1	0.1
Mg^{2+}	$cmol_c/dm^3$	0.1	0.1	0.0	0.0
H+Al	$cmol_c/dm^3$	3.6	1.2	2.1	2.4
SB‡	$cmol_c/dm^3$	0.44	0.34	0.13	0.13
Effective CEC§	$cmol_c/dm^3$	0.94	0.84	0.53	0.53
Total CEC	$cmol_c/dm^3$	4.04	1.54	2.23	2.53
V‖	%	10.9	22.1	5.8	5.1
m¶	%	53.2	67.6	75.5	75.5
Coarse sand	g/kg	500	440	460	400
Fine sand	g/kg	320	380	350	380
Silt	g/kg	30	10	20	20
Clay	g/kg	150	170	170	200
Soil density	g/cm^3	1.41	1.42	1.41	1.39

* References: C, pH, K, and H+Al (Defelipo & Ribeiro 1981);
P (Braga 1980);
Al, Ca, and Mg (Vettori 1969);
SB, CEC, V, m, coarse sand, fine sand, silt, clay, and soil density (EMBRAPA 1997);
P and K: Extractor Mehlich-1;
Al, Ca, and Mg : Extractor KCl 1 mol/litre;
H + Al : Extractor $Ca(OAc)_2$ 0.5 mol/litre pH 7.0;

† Organic carbon content: Walkley-Black method;

‡ Sum of exchangeable bases;

§ Cation exchange capacity;

‖ Base saturation percentage (100 SB/total CEC);

¶ Aluminium saturation percentage (100 $Al^{3+}/(SB+Al^{3+})$

Rainfall was measured using a rain gauge located at the farm meteorological station.

A 7-year-old *E. urophylla* stand, originated from mixed parentage, planted at 3 × 2-m spacing, was chosen for the study. The soil for the original stand was prepared for planting with a "bedding" harrow and cuttings were planted on the ridge of the bed in 1987. All trees were inventoried for diameter at breast height (dbh) in an area of 1.5 ha. About 28 trees with dbh corresponding to the stand mean were selected for evaluation over the length of the study. The selected trees were divided into four groups of seven trees, and identified. Each group constituted a replication, and each tree a treatment. Six trees were used in each group and one other corresponded to a safety margin, with the objective of providing a substitute against possible failure in sprouting. Besides dbh, neighbouring tree survival was used as a selection criteria. The stand was felled and the slash was deposited between the rows during forest harvesting. The selected trees were randomly assigned to assessment dates of 0, 60, 120, 180, 240, and 330 days after harvesting, with the first assessment (at 0 days) being made immediately after harvesting in September 1994.

At each sampling time, the sprouts were cut, weighed in the field, sampled, and dried at 70°C for 72 hours (Teixeira *et al.* 2002).

Root distribution and root biomass were measured in 50 × 50-cm sample units of the bed, at depths of 0–10 cm, 10–20 cm, 20–40 cm, and 40–60 cm. The sample units were taken from half the useful area of the assessed trees (Fig. 1). The total measured area of the plot was 3.0 m^2 (1.5 × 2.0 m) corresponding to a total of 52 sample units per tree, obtained from 12 sample units per tree and per depth and four bed sample units per tree.

The soil in each sample unit was collected and sieved through a 2-mm-mesh screen and placed on a table. Roots were separated visually into three diameter classes (fine <1 mm,

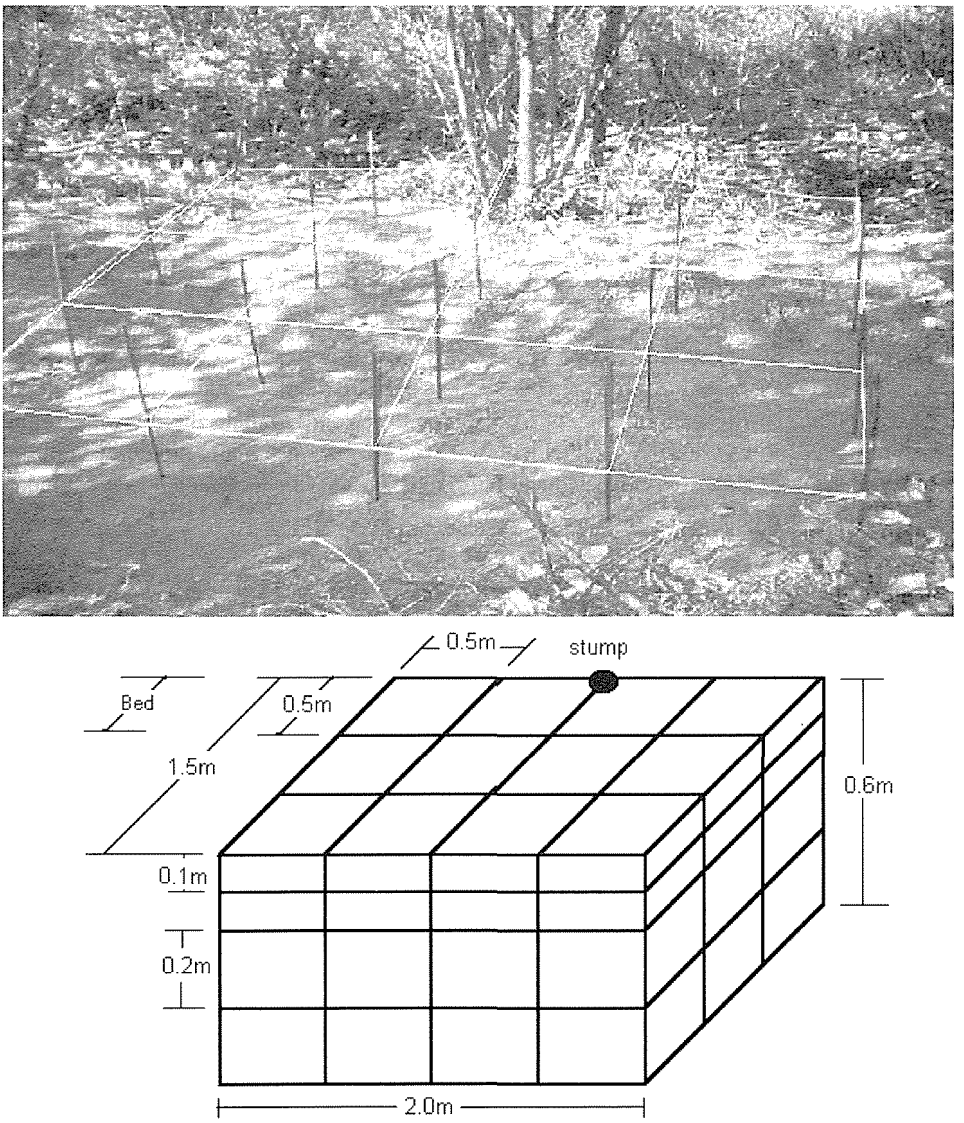

FIG. 1–Arrangement of the sample units used to determine root biomass and distribution.

medium 1–3 mm, and coarse >3 mm). Only the biomass of live roots was determined, as they were separated visually according to colour and root consistency, as suggested by Vance & Nadkarni (1992). The taproot was dug to a depth of 1.0 m, weighed fresh in the field, and sampled by removal of three discs along its length (Teixeira *et al.* 2002). The total weight of fresh roots, by diameter class, was obtained in the field, and root sub-samples were weighed and then washed in distilled water. Root losses during washing were negligible. After washing, the roots were dried on paper towels then dried in an oven at 70°C for 72 hours. After drying, the washed root samples were weighed again.

The treatments corresponded to the sampling time and a completely randomised design with four replications was used. The data obtained were submitted to analyses of variance, partitioning the degrees of freedom of the treatments into linear, quadratic, and cubic effects, using the statistical package SAEG (Genetics and Statistics Analysis System). Also, the data were submitted to the Tukey test.

RESULTS AND DISCUSSION

The biomass of fine and medium roots tended to increase over time after harvesting, mainly to the depth of 20 cm (Table 2). On the other hand, the coarse root biomass did not change significantly. Teixeira *et al.* (2002) observed that the soil is an important nutrient source, except for potassium, even in the initial sprout growth stages, indicating low root nutrient dependency. Therefore, coppices depend on soil nutrients to satisfy their initial demands. Nutrient acquisition is carried out by roots of small diameter, and eucalypt coppice has high initial growth rate (Barros *et al.* 1997), so this would explain the increase in the amount of small roots with time. As the coppice leaf area is large, there would be enough photosynthate to be allocated to fine and medium root formation, increasing nutrient uptake capacity (Teixeira 1996).

Even though fine roots are maintained by carbohydrate fixed in leaves, it has been difficult to identify above-ground parameters that can be used to predict how much carbon is allocated to root growth and maintenance (Vogt *et al.* 1997).

In this study, it was also observed that the root growth peaks coincided with periods of greater rainfall, particularly growth of fine and medium roots in the bed at the 10–20, 20–40, and 40–60 cm depth (Table 2, Fig. 2). This tendency was detected during the length of this study, except at 330 days after harvesting, i.e., a greater biomass was detected at 330 days in spite of lower moisture levels. According to Mello *et al.* (1998), moisture availability is the main factor affecting fine root density (FRD) in deep soil layers, and nutrient availability in shallow ones and in the litter.

Martins *et al.* (1997) commented that elimination of water consumption by transpiration due to harvesting allowed an increase in the soil water potential adjacent to the roots, which may influence root proliferation and, consequently, the increase in root biomass over time.

The lower root biomass was detected at time zero. This can be attributed to the fact the trees were already 7 years old and had a low growth rate and a smaller demand for nutrients fromthe soil, which could be met by a smaller root biomass. In this stage, a large proportion of the nutrient requirement of the tree is supplied by the biochemical and biogeochemical cycles (Miller 1995; Gonçalves & Mello 2000). On the other hand, coppice presents high

TABLE 2–Root, coppice, and canopy dry matter (kg/ha) (mean ± standard error) at various depths and at various times after harvesting 7-year-old *E. urophylla*

Plant part	Depth (cm)	Time after harvesting (days)						Average	Level of significance†				CV (%)
		0	60	120	180	240	330		Treat	Lin	Qua	Cub	
Fine root	Bed	112 ± 19	275 ± 64	214 ± 75	363 ± 65	258 ± 37	424 ± 34	274	**	**	ns	ns	38.6
	0–10	248 ± 25	419 ± 41	528 ± 213	535 ± 63	608 ± 67	685 ± 7	504	ns	**	ns	ns	38.4
	10–20	113 ± 10	233 ± 23	169 ± 69	231 ± 52	241 ± 25	320 ± 26	218	*	**	ns	ns	36.3
	20–40	121 ± 26	249 ± 55	173 ± 43	304 ± 61	157 ± 27	244 ± 11	208	*	ns	ns	ns	39.5
	40–60	109 ± 25	173 ± 37	142 ± 36	265 ± 41	152 ± 12	166 ± 5	168	*	ns	ns	ns	34.7
Medium root	Bed	46 ± 12	70 ± 7	50 ± 12	132 ± 20	60 ± 7	170 ± 25	88	**	**	ns	ns	35.2
	0–10	184 ± 30	203 ± 17	129 ± 12	236 ± 25	227 ± 29	331 ± 40	218	**	**	*	ns	24.7
	10–20	139 ± 20	230 ± 35	112 ± 18	260 ± 52	211 ± 33	273 ± 37	204	*	*	ns	ns	33.6
	20–40	177 ± 51	254 ± 44	156 ± 31	343 ± 82	191 ± 19	299 ± 8	237	ns	ns	ns	ns	38.8
	40–60	182 ± 36	227 ± 33	145 ± 40	249 ± 51	172 ± 13	213 ± 11	198	ns	ns	ns	ns	34.1
Coarse root	Bed	837 ± 262	354 ± 117	700 ± 645	1 841 ± 1167	954 ± 162	574 ± 139	877	ns	ns	ns	ns	128.6
	0–10	1 481 ± 178	1 495 ± 477	901 ± 337	1 897 ± 463	2 126 ± 716	1 693 ± 7	1 599	ns	ns	ns	ns	53.6
	10–20	1 146 ± 395	1 608 ± 362	1 256 ± 250	1 678 ± 530	1 892 ± 599	2 043 ± 9	1 604	ns	ns	ns	ns	50.6
	20–40	842 ± 268	1 408 ± 461	1 432 ± 306	2 284 ± 634	1 952 ± 264	1 465 ± 48	1 564	ns	ns	*	ns	48.2
	40–60	609 ± 201	1 275 ± 129	1 131 ± 371	1 574 ± 275	1 829 ± 335	1 400 ± 24	1 303	ns	*	ns	ns	45.5
Taproot‡		11 093 ± 1435	11 159 ± 328	11 881 ± 485	10 998 ± 1416	12 060 ± 346	12 083 ± 478	11 546	ns	ns	ns	ns	15.0
Sprouts‡		0 ± 0	91 ± 34	1563 ± 327	5 772 ± 786	10 326 ± 1495	21 579 ± 1783	-	**	**	**	ns	30.9
Canopy‡		87 218 ± 1981	-	-	-	-	-	-	-	-	-	-	-

† Levels of significance for the F values obtained in the analysis of variance, partitioning the degrees of freedom of the treatment effect (Treat) in linear (Lin), quadratic (Qua), and cubic (Cub) effects.
‡ Source: Teixeira *et al.* (2002);
* significant at the 5% level of probability
** significant at the 1% level of probability
ns not significant at the 5% level of probability.

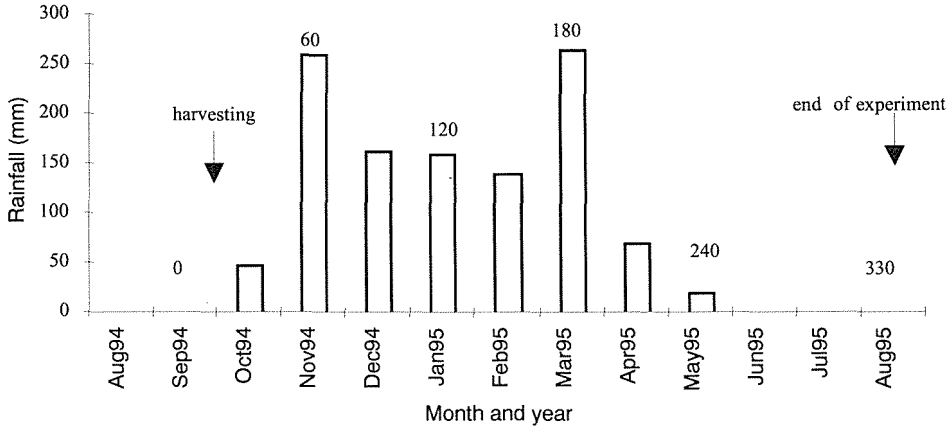

FIG. 2–Monthly rainfall during the experiment on the Patagônia Farm in João Pinheiro county, Minas Gerais State, Brazil.

initial growth rate and the nutritional dependency on soil is high during the early stages in tree growth (Barros *et al.* 1997; Teixeira *et al.* 2002).

Root biomass decreased with depth (Table 2). About 67%, 68%, 74%, 66%, 78%, and 77% of the fine roots, 51%, 51%, 49%, 51%, 58%, and 60% of the medium roots, and 70%, 56%, 53%, 58%, 56%, and 60% of the coarse roots were concentrated in the top 20 cm at 0, 60, 120, 180, 240, and 330 days after harvesting, respectively. On average, about 73%, 54%, and 68% of the fine, medium, and coarse roots, respectively, were concentrated in the top 20 cm. Several authors have reported that root biomass decreases with depth (Lawson *et al.* 1970; Krejci *et al.* 1986; Gower 1987; Cavelier 1992; Vance & Nadkarni 1992; Gonçalves 1994; Leles 1995; Teixeira 1996; Martins *et al.* 1997; Mello *et al.* 1998). The low nutrient availability that limits growth has been suggested as the main factor governing carbon allocation models (Grier *et al.* 1981; Keyes & Grier 1981; Vogt *et al.* 1985). This decrease in fine root biomass with depth was possibly a consequence of the decrease in nutrient concentration in the soil, specially phosphorus and calcium (Table 1). The greater root biomass accumulation at lower depths represents a nutrient conservation mechanism in forest ecosystems (Jordan 1985; Vance & Nadkarni 1992).

Also, it was verified that the FRD was higher at 0–10 cm depth than at the other depths, showing high non-uniformity in soil profile (Fig. 3). At 20–40 and 40–60 cm depth, the FRD was almost the same at all times, presenting lower values. Medium root density and distribution were more uniform in profile than the FRD. Root density tended to increase over time at 0–10 and 10–20 cm depth; however, root growth rate was higher to fine roots at 0–10 cm depth.

Regarding horizontal root distribution, it was observed that, in general, a large part of the roots was located close to the trunk (Fig. 4, 5, and 6). However, with time, there was a major increase in fine roots biomass between the tree rows compared with the region close to the cut trunk, particularly until 240 days after harvesting. This increase in fine root biomass between the rows may be related to the decomposition of the organic cover deposited between the rows during tree felling, which caused an increase in the nutrient concentration

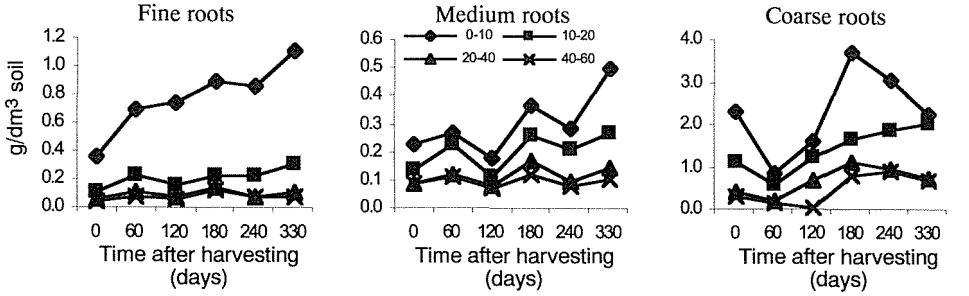

FIG. 3–Fine, medium, and coarse root density in the soil at various depths (cm) and at various times after harvesting 7-year-old *E. urophylla*.

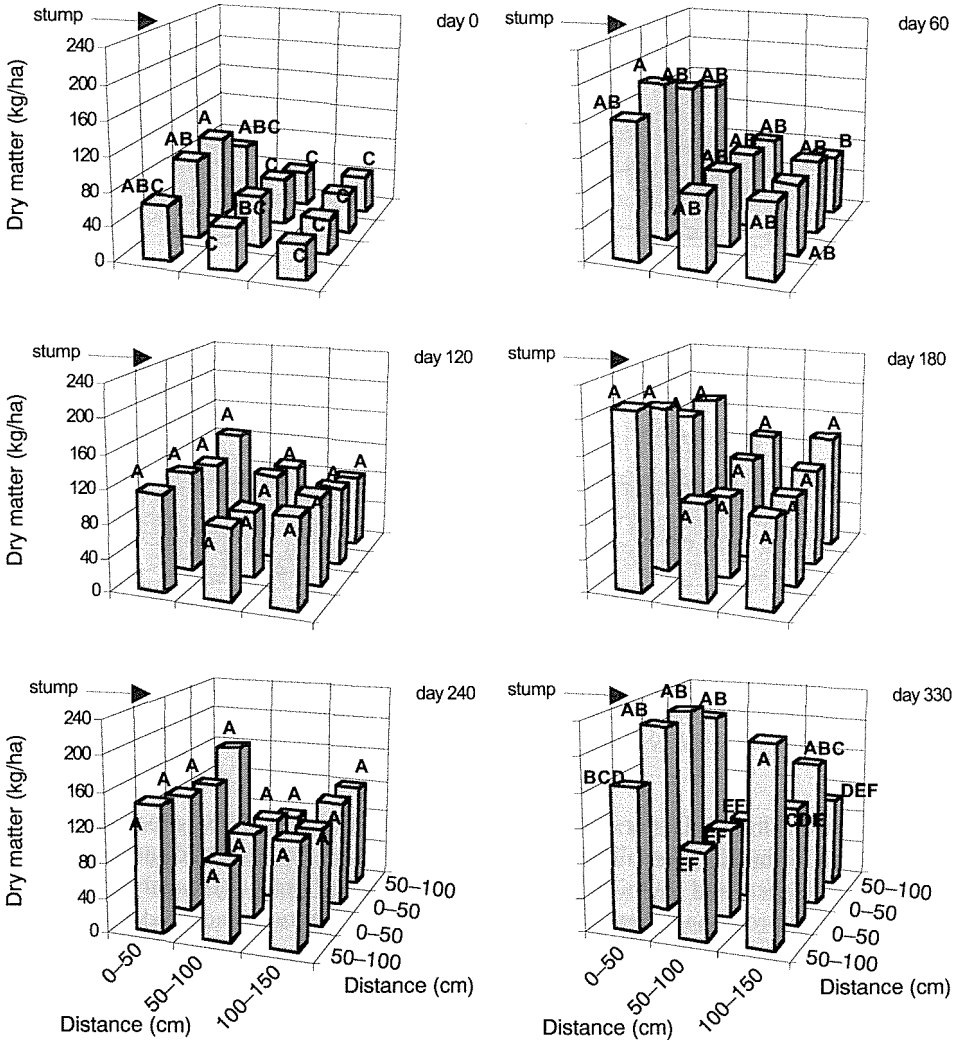

FIG. 4–Horizontal distribution of fine roots relative to the stump at depths from zero to 60 cm, from zero to 330 days after harvesting 7-year-old *E. urophylla*.

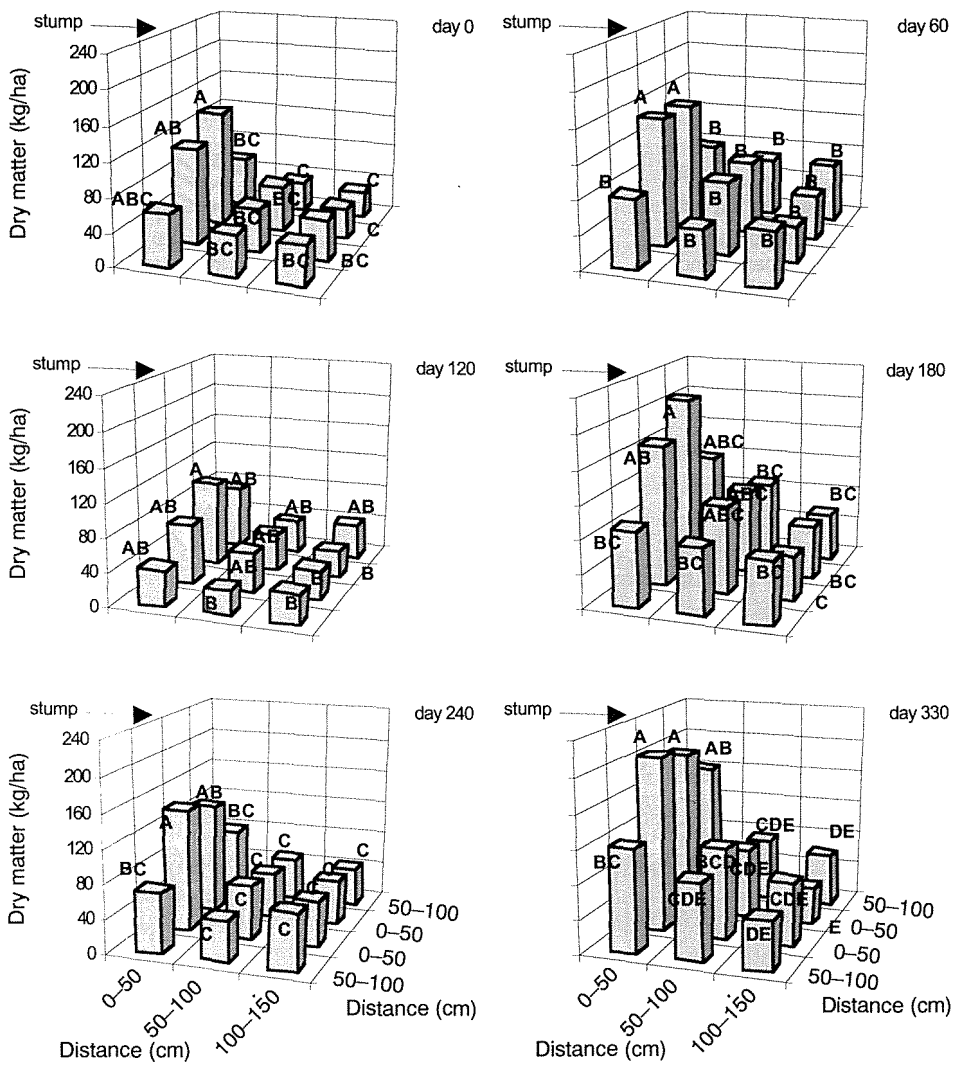

FIG. 5–Horizontal distribution of medium roots relative to the stump at depths from zero to 60 cm, from zero to 330 days after harvesting 7-year-old *E. urophylla*.

in that soil area with time. Under similar management conditions, absorbing roots tend to be distributed evenly in the upper soil layers, although changes may be observed due to localised variations in physical and chemical characteristics of the soil profile (Gonçalves & Mello 2000). For second-rotation forests, where minimum site preparation is adopted, the existing forest floor protects the soil and allows the fine roots to grow at a shallow level as the stand ages (Gonçalves & Mello 2000).The fine root distribution reflects the distribution of the nutrients available in an ecosystem (Jordan 1985; Reis *et al.* 1985; Vance & Nadkarni 1992) and studies have suggested that root growth may be very responsive to changes in soil fertility (Dighton & Harrison 1983).

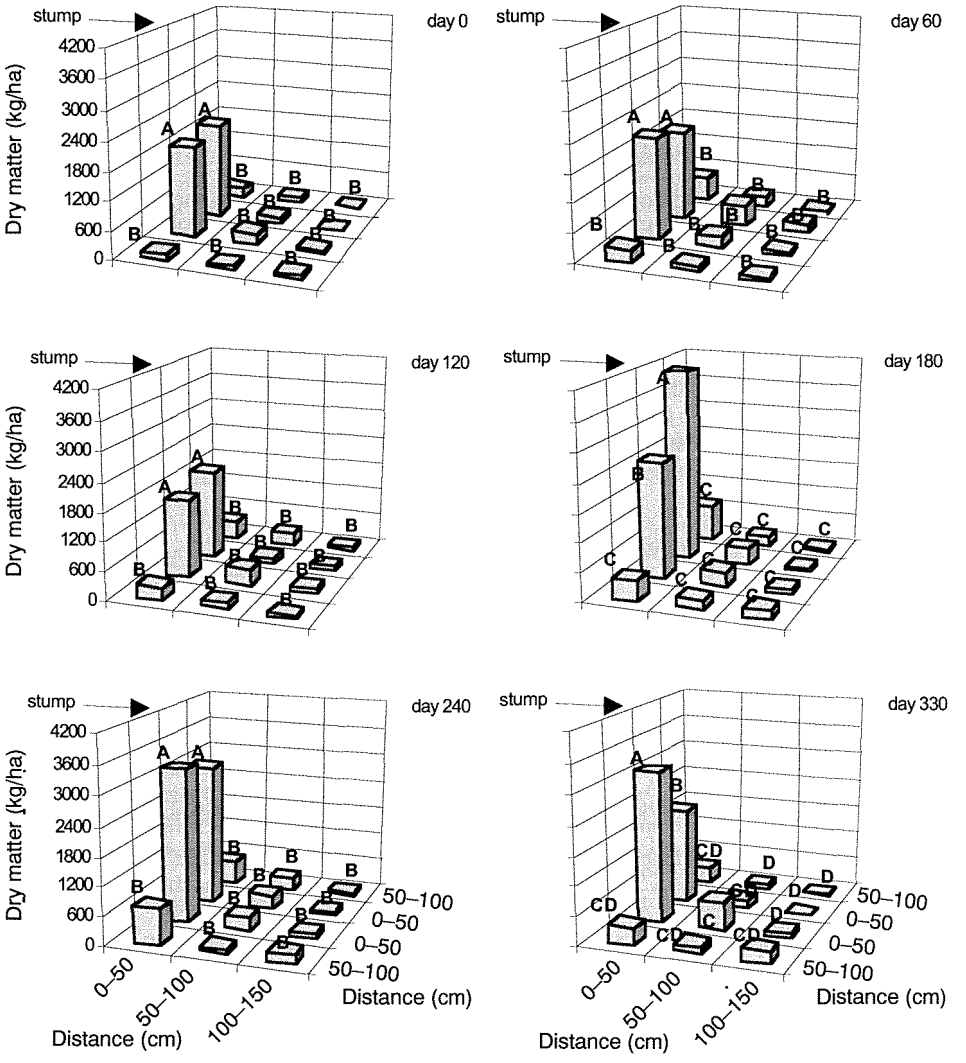

FIG. 6–Horizontal distribution of coarse roots relative to the stump at depths from zero to 60 cm, from zero to 330 days after harvesting 7-year-old *E. urophylla*.

The horizontal distribution of fine roots was more uniform than that of the medium and coarse roots (Fig. 4, 5, and 6). Most medium and coarse roots were found in positions closest to the stump; however, the distribution of medium roots was more uniform than the distribution of coarse roots. Martins *et al.* (1997) also reported lack of uniformity in root distribution patterns as root diameters increased. The findings of these authors corroborate the results of this study showing greater biomass accumulations of medium and mainly coarse roots in positions closest to the trees.

CONCLUSIONS

After harvesting, coppicing resulted in an increase in biomass of the fine and medium roots, mainly in the bed at 0–10 and 10–20 cm depth.

Root biomass decreased with depth, and most of the roots, specially fine roots, were concentrated in the top 20 cm.

Most of the medium and coarse roots were localised close to the stumps and the non-uniformity in horizontal distribution increased as their diameters increased.

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