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SEÇÃO IV - FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS

SOIL FERTILITY, ORGANIC CARBON AND FRACTIONS OF THE ORGANIC MATTER AT DIFFERENT DISTANCES FROM EUCALYPTUS STUMPS⁽¹⁾

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SUMMARY

Knowledge on variations in vertical, horizontal and temporal characteristics of the soil chemical properties under eucalyptus stumps left in the soil is of fundamental importance for the management of subsequent crops. The objective of this work was to evaluate the effect of eucalyptus stumps (ES) left after cutting on the spatial variability of chemical characteristics in a dystrophic Yellow Argisol in the eastern coastal plain region of Brazil. For this purpose, ES left for 31 and 54 months were selected in two experimental areas with similar characteristics, to assess the decomposition effects of the stumps on soil chemical attributes. Soil samples were collected directly around these ES, and at distances of 30, 60, 90, 120 and 150 cm away from them, in the layers 0–10, 10–20 and 20–40 cm along the row of ES, which is in-between the rows of eucalyptus trees of a new plantation, grown at a spacing of 3 x 3 m. The soil was sampled in five replications in plots of 900 m² each and the samples analyzed for pH, available P and K (Mehlich-1), exchangeable Al, Ca and Mg, total organic carbon (TOC) and C content in humic substances (HS) and in the free light fraction. The pH values and P, K, Ca²⁺, Mg²⁺ and Al³⁺ contents varied between the soil layers with increasing distance from the 31 and 54-month-old stumps. The highest pH, P, K, Ca²⁺ and Mg²⁺ values and the lowest Al³⁺ content were found in the surface soil layer. The TOC of the various fractions of soil organic matter decreased with increasing distance from the 31 and 54-month-old ES in the 0–10 and 10–20 cm layers, indicating that the root (and stump) cycling and rhizodeposition contribute to maintain soil organic matter. The C contents of the free light fraction, of the HS and TOC fractions were higher in the topsoil layer under the ES left for 31 months due to the higher clay levels of this layer, than in

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those found under the 54-month-old stumps. However, highest C levels of the different fractions of soil organic matter in the topsoil layer reflect the deposition and maintenance of forest residues on the soil surface, mainly after forest harvest.

Index terms: nutrients, humic substances, spatial variability.

RESUMO: *FERTILIDADE DO SOLO, CARBONO ORGÂNICO E FRAÇÕES DA MATÉRIA ORGÂNICA EM DIFERENTES DISTÂNCIAS DA CEPA DE EUCALIPTO*

O conhecimento das variações vertical, horizontal e temporal de características químicas do solo sob cepas remanescentes de eucalipto é de fundamental importância para o manejo de cultivos subsequentes. O objetivo deste trabalho foi avaliar o efeito de cepas remanescentes de eucalipto (CRE) na variabilidade espacial de características químicas em um Argissolo Amarelo distrófico típico localizado na região litorânea do Espírito Santo. Para isso, foram selecionadas CRE com 31 e 54 meses de idade, em duas áreas experimentais com características semelhantes, a fim de avaliar os efeitos da decomposição delas sobre características químicas do solo. Dessa forma, amostras de solo foram coletadas ao redor dessas CRE e nas distâncias de 30, 60, 90, 120 e 150 cm, nas camadas de 0–10, 10–20 e 20–40 cm de profundidade, na direção da linha das CRE, as quais se situavam na entrelinha de povoamentos de eucalipto de mesma idade, cultivados no espaçamento de 3 x 3 m. O procedimento de amostragem de solo foi realizado em cinco parcelas de 900 m². As amostras de solo foram analisadas para: pH em água, P e K disponíveis (Mehlich-1), Al, Ca e Mg trocáveis, C orgânico total (COT) e teores de C nas substâncias húmicas (SH) e na fração leve livre. Os resultados obtidos indicaram variação nos valores de pH e nos teores de P, K, Ca²⁺, Mg²⁺ e Al³⁺ à medida que se afastou das CRE aos 31 e 54 meses, entre as camadas de solo amostradas. Os maiores valores de pH, P, K, Ca²⁺ e Mg²⁺ foram constatados na camada superficial do solo, e os menores, para Al³⁺. Os teores de C orgânico das diversas frações da matéria orgânica do solo decresceram à medida que se afastou das CRE aos 31 e 54 meses, nas camadas de 0–10 e 10–20 cm de profundidade, indicando que a ciclagem de raízes (e tocos) e a rizodeposição contribuem para manter a matéria orgânica do solo. Os teores de C da fração leve livre e das frações da SH e o COT foram maiores na camada superficial do solo sob as CRE aos 31 meses, em razão dos maiores teores de argila desta camada, em relação àqueles constatados sob as CRE aos 54 meses. Contudo, os maiores teores de C das diversas frações da matéria orgânica, na camada superficial do solo, refletem a deposição e manutenção dos resíduos florestais na superfície do solo, principalmente após a colheita florestal.

Termos de indexação: nutrientes, substâncias húmicas, variabilidade espacial.

INTRODUCTION

In spite of the apparent uniformity of soils in topography, color and vegetation their chemical, physical and biological properties can vary considerably (Santos & Vasconcellos, 1987). This variability can be enhanced by anthropic actions, mainly by soil fertility management, involving either the use of amendment and fertilizer along the planting row on the soil sub-surface, or by broadcasting over the surface (Schlindwein & Anghinoni, 2000) as well as by a possible residual effect of these fertilizations (Silva et al., 2003). The variations in soil organic carbon (SOC) can be due to addition of primary organic compounds to the soil that are synthesized during the photosynthesis process and distributed

heterogeneously over the soil as the eucalyptus trees age (Barreto et al., 2008).

Another factor contributing to the variation in nutrient concentrations and SOC contents is the type of soil management, particularly when the soil is revolved prior to crop planting, or when amendment and fertilizers are incorporated, which causes intense disturbance, stimulating the action of decomposing microorganisms (Bayer et al., 2000). Besides the physical, chemical and biological disturbance of the soil, this also contributes to the global warming by CO₂ emission since the soil organic matter (SOM) is the greatest C reserve in the earth ecosystem (Silva & Mendonça, 2007), and, in global terms, it is considered the third major C compartment, after the ocean and the geological partitions – mainly

petroleum, natural gas and mineral coal (Lal, 2004). Moreover, the permanence of eucalyptus stumps in the field after cutting can lead to changes in the horizontal and vertical distribution of nutrient concentrations, SOC and SOM fractions during the growth cycle.

In spite of the large area planted with eucalyptus in the whole country and its quick growth, very little is known about how eucalyptus stumps remaining from previous cuttings influence the concentration and the spatial distribution of nutrient and SOM. The implementation of a sampling system that takes this variability into consideration is indispensable. In this context, the purpose of this study was to assess the effects of remaining eucalyptus stumps at different ages upon the spatial and vertical variability of soil fertility, SOC and SOM fractions.

MATERIAL AND METHODS

This study was carried out in the county of Aracruz (19 ° 48 ' S and 40 ° 17 ' W, 50 m asl), in the coastal region of the State of Espírito Santo, Brazil. The climate, according to Köppen, is Aw; humid tropical, rainy in the summer and dry in the winter, with an average annual temperature of 23 °C.

The study investigated remaining stumps of *Eucalyptus grandis* x *Eucalyptus urophylla* clones ("urograndis"), genotype '1205', which had been planted in a 3 x 3 m spacing, in dystrophic Yellow Argisol (Embrapa, 2006) or Ultisol (Soil Survey Staff, 1999). Eucalyptus stumps (ES) were selected that had been left in the ground for 31 and 54 months after harvesting the eucalyptus trunk. These stumps were lined up in rows in between the rows of the subsequent Eucalyptus stand with 31 and 54-month-old trees. However, it should be noted that these eucalyptus stands were not side by side located. The age of the ES (31 and 54-months old) was determined

to facilitate diagnosing possible effects of stump decomposition on the soil chemical properties.

When planting the eucalyptus trees, 47 g of triple superphosphate and 100 g of NPK 06-30-06 mixture were applied at the planting hole. As side dressing 350 kg ha⁻¹ of a rock phosphate were incorporated 20 cm deep, in-between the row, 90 days after planting. A maintenance fertilization of 160 kg ha⁻¹ of a NPK 20-00-20 mixture was broadcast applied, 30 months after planting.

In each stand, five 900 m² plots containing 100 live trees each were established, to determine the mean diameter (DBH), according to Faria (2006). The ES were randomly selected, and soil sampling was performed at different horizontal and vertical distances.

The soil was sampled at distances of 30, 60, 90, 120 and 150 cm away from the ES, in the stump row direction, in each plot. Besides, soil samples in direct contact with the ES were collected, in the layers 0–10 and 10–20 cm. For the positions farthest away from the ES (more than 30 cm), besides the above depths, samples were collected in the 20–40 cm layer. Four simple samples were collected in the direction of the ES row (two on either side), which were combined to form a composite sample for each sample distance and depth. The soil samples were obtained using an auger (diameter 5.0 cm x height 40 cm), during the rainy season, totaling five replications for each ES age.

The soil samples were air-dried, sieved (2.0 mm mesh), homogenized, and physically and chemically characterized (Table 1), according to Embrapa (1997). The analyses were: water pH (soil: solution ratio of 1:2.5); available P and K, extracted by Mehlich-1; exchangeable Ca²⁺, Mg²⁺ and Al³⁺, extracted with KCl 1 mol L⁻¹ and total organic carbon concentration (TOC) (Yeomans & Bremner, 1988).

The free light fraction (FLF) of the organic matter was separated by means of soil flotation in NaI (1.8 kg L⁻¹) (Sohi et al., 2001); the C concentration in the fraction was determined by dicromatometry. The

Table 1. Physical characteristics of the soil samples from layers 0–10, 10–20 and 20–40 cm of depth, obtained under remaining stumps of eucalyptus 31 and 54 month-old

Depth	Sand		Silt	Clay	Textural class
	Coarse	Fine			
cm	g kg ⁻¹				
	31 month-old				
0–10	550	140	60	250	Sandy clay loam
0–20	500	150	70	280	Sandy clay loam
0–40	470	160	50	320	Sandy clay
	54 month-old				
0–10	680	140	40	140	Loamy sand
0–20	620	160	50	180	Loamy sand
0–40	580	150	40	240	Sandy clay loam

soil humic substances were fractioned based on their differential solubility in alkaline or acidic medium according to Swift (1996), resulting in fulvic acid fraction (FAF), humic acid fraction (HAF), and humin fractions (HF). From the sum of all these fractions the C content present in the humic substances (HS) was obtained. The C content in each fraction was determined by wet oxidation with external heating (Yeomans & Bremner, 1988).

Regression equations were fit to data of the distances of soil sampling, in the ES row line, at each sampling depth, to infer on the distribution of the nutrient and TOC concentrations and some SOM fractions under the 31 and 54-month-old ES. Models were selected based on the significance of the coefficients and the R^2 value (Alvarez V. & Alvarez, 2003). Finally, the mean concentration of nutrients, TOC and some SOM fractions at the different sampling depths and ES ages were compared by the Tukey test at 5 %.

RESULTS AND DISCUSSION

Soil nutrient concentrations at different distances from the eucalyptus stumps

The soil pH values decreased with the distance from the eucalyptus stumps (ES) left in the soil after 31 months, in the layers 0–10 cm and 10–20 cm, and increased with distance from the 54-month-old ES in the sampled soil layers (Figure 1). The lower soil pH values close to the 54-month-old ES may have been a consequence of the lower soil bases under the 54 than under the 31-month-old ES (Figure 1). Moreover, a greater base accumulation was observed under the 31 than the 54-month-old ES, particularly of K and Ca^{2+} , mainly in the 0–10 cm layer (Figure 1). These

variations in base concentrations between the soils under the ES were probably responsible for the differences in the soil pH values.

In the 0–10 cm layer, the higher pH values of the soil under the ES at the assessed ages were possibly due to higher base concentrations in that layer (Table 2), which probably contributed to lower Al^{3+} concentrations and consequently, to an increase of Al^{3+} in depth, due to the decrease of the soil base concentrations with the deepening of the soil profile (Table 2). Moreover, the decrease in the soil pH values favored Al^{3+} solubilization. Similar results were found by Salgado et al. (2006), who attributed the reduction in Al^{3+} solubilization to the increase in soil pH, and also to the Al^{3+} complexation reaction with organic compounds. Therefore, Al^{3+} concentrations were higher in the areas nearer the 54-month-old ES than at greater distances and varied in the opposite direction, that is, increased with the distance from the 31-month-old ES (Figure 1).

In general, the P, K, Ca^{2+} , and Mg^{2+} concentrations tended to decrease with the distance from the ES, at both ages, at the evaluated depths, except in the layer 20–40 cm, where a slight increase in Ca^{2+} and Mg^{2+} concentrations was noted with the increase of the distance from the ES under stumps of both ages (Figure 1).

The higher of P and K concentrations near the ES can be explained by the addition of 47 g triple superphosphate and 100 g of the NPK 06–30–06 mixture, to each planting hole at planting time. The lower nutrient concentrations further away from the stumps can be attributed to a greater competition between trees of the stand, especially in the superficial soil layer (0–25 cm). According to Bouillet et al. (2002), at this depth, a greater density of fine roots (0.1 to 1.0 mm) is observed, usually extensive in length, since they grow on average 0.8 cm day^{-1} . Thus,

Table 2. Soil chemical properties at different depths under the remaining eucalyptus stumps 31 and 54-month-old

Depth	pH	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}
cm		mg dm^{-3}			cmol _c dm^{-3}	
31 months						
0–10	4,92 a	5,45 a	40 a	1,47 a	0,54 a	0,76 a
10–20	4,58 b	2,77 b	24 b	0,34 b	0,26 b	1,13 a
20–40	4,47 b	0,42 c	19 b	0,13 b	0,18 b	1,26 a
54 months						
0–10	5,04 a	82,05 a	27 a	0,67 a	0,31 a	0,68 b
10–20	4,83 b	68,46 ab	18 b	0,35 b	0,15 b	0,83 a
20–40	4,98 a	20,95 b	12 c	0,25 b	0,12 b	0,73 b

Values followed by equal letters, in each column, were not different at 5 % by the Tukey-Kramer test.

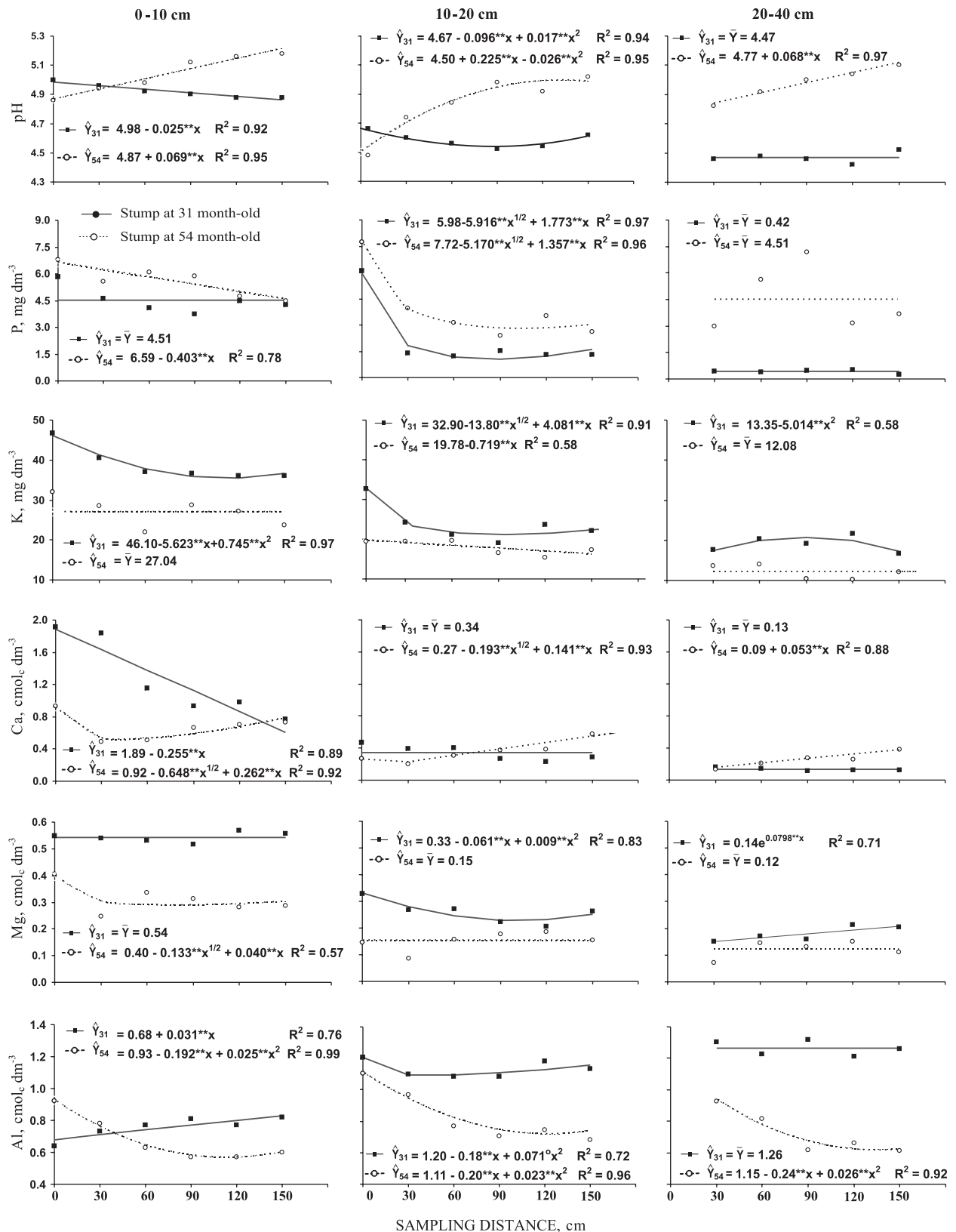


Figure 1. Average values of pH, P, K, Ca²⁺, Mg²⁺ and Al³⁺ in the row line, at different distances from the eucalyptus remaining stumps, at 31 and 54 months, in the layers 0–10, 10–20 and 20–40 cm of depth. °, * and **: significant at 10, 5 and 1 %, respectively.

the larger amount of fine roots at a greater distance from the eucalyptus trunk possibly contributed to an increased P, K, Ca and Mg uptake and, consequently, resulted in lower concentrations of these nutrients at greater distances from the ES, even 31 and 54 months after eucalyptus cutting (Figure 1). According to Barber (1995), the production of long and fine roots is a desirable characteristic to increase the efficiency of nutrient uptake, mainly of those with low mobility in the soil.

The pH values and the P, K, Ca^{2+} and Mg^{2+} concentrations were substantially higher in the 0–10 cm layer in comparison to the sub-surface layers under ES after 31 and 54 months (Table 2). Nevertheless, no significant effect for the Al^{3+} concentrations was observed under the 31-month-old ES, but an increasing tendency of this element with depth was noted. In the 10–20 cm layer, Al^{3+} concentrations under the 54-month-old ES were higher than those of the other soil layers (Table 2).

Higher P, K, Ca^{2+} and Mg^{2+} concentrations in the surface soil layer were also observed by Gatto et al. (2003). According to these authors, the higher nutrient concentrations in the soil surface layer are most likely due to the residues left after forest harvesting and the greater amount of litter layer on the soil.

The higher P concentrations observed in the 0–10 cm layer, in comparison with the sub-surface layer (Table 2), are due to the application of the rock phosphate and to the broadcast application of 2.0 t ha^{-1} tree biomass ashes on the 54-month-old stumps to the total area, as well as an application of 3.0 t ha^{-1} of that material after 31 months. These procedures were performed as part of the maintenance fertilization of the 31 and 54-month-old eucalyptus stand (Faria, 2006), since the application of ashes to the soil proved to be responsible for the increase of P, K, Ca^{2+} and Mg^{2+} concentrations (Gonçalves & Moro, 1995).

In Brazil, forest companies which use the no tillage system usually renew their replant forest stands planting the tree seedlings in the middle of the interrows or of the planting row of a previous rotation. Thus, when measuring the P and K concentrations of the soil in contact with the stumps and of soil 30 and 150 cm away, in the 0–20 cm layer (sum of concentrations in the layers 0–10 cm and 10–20 cm), the following concentrations were determined: P – 10.5, 6.3 and 6.1 mg dm^{-3} and 14.3, 10.1 and 7.5 mg dm^{-3} , while K results were 79, 64 and 59 mg dm^{-3} and 47, 46 and 43 mg dm^{-3} , respectively, from the 31 and 54-month-old ES (Figure 1). It was, therefore, noted that the P concentrations of soil in contact with the 31-month-old ES and of soil 30 cm away, increased by 41.7 and 3.5 %, compared to the soil 150 cm away from the same ES. Moreover, at the same locations increments in P concentrations of 47.5 and 25.5 % were verified compared to those 150 cm away from

the 54-month-old ES (Figure 1). Similarly the K concentrations of soil in contact with the ES and of soil 30 cm away from the stumps were 25.3 and 8.3 % higher than in soil at a distance of 150 cm from the 31-month-old ES, while after 54 months, these values increased by 6.3 and 7.7 %, respectively.

Therefore, based on the P and K concentrations, measured at the nearest locations from the 31 and 54-month-old ES, it can be suggested that the new eucalyptus seedlings should be planted closer to the ES. In addition, it is pointed out that the planting of new eucalyptus seedlings would be most appropriate after harvesting the forest stand, since the amount of nutrients in the soil may be greater than 31 and 54 months after this operation. Besides, the decomposition process and mineralization of the nutrients contained in the stump root system and in the stump itself nutrients would be released to the soil, and susceptible to be taken up by the future eucalyptus seedlings. In this sense, Reis & Reis (1997) argue that the maintenance of ES in the field, after harvesting the trunk, can be positive for serving as a nutrient reserve for successive cycles of eucalyptus.

Organic carbon and fractions of soil organic matter at different distances from the remaining eucalyptus stumps

Organic C concentrations of free light fraction (FLF), of fulvic acid fraction (FAF), humic acid (HAF), humin (HF) and of humic substances (HS), and the total organic carbon (TOC) were influenced by the horizontal distance of sampling of the soil from the ES at 31 and 54 months, in the row direction, in the sampled soil layers (Figure 2). In this sense, a decrease in C of the FLF was only observed in the 0–10 cm layer with increasing distance from the 31 and 54-month stumps, while in the other layers these concentrations remained very low, but constant. Carbon concentration in FAF, HAF and HF, differed significantly in the two first layers as well as for the C concentrations in the HS and TOC, in the three sampled layers, while after 54 months, this was only the case in the 20–40 cm layer (Figure 2).

This is probably a result of the greater amount of residues, mainly branches and bark, deposited closer to the stumps before tree cutting, and of the greater root accumulation near the tree, contributing to the process of root cycling and rhizodeposition and leading to an increase in C contents of those fractions (Bouillet et al., 2002). According to Monteiro & Gama-Rodrigues (2004), branches and roots are structures with a higher level of recalcitrance, slowing down the microbial activity, contributing to the maintenance of a higher concentration of organic C in the soil, even 31 and 54 months after eucalyptus cutting. Moreover, the decomposition of the stump itself may have contributed to the higher C content in the FLF, HS and TOC closer to the ES, higher than farther away at both ages.

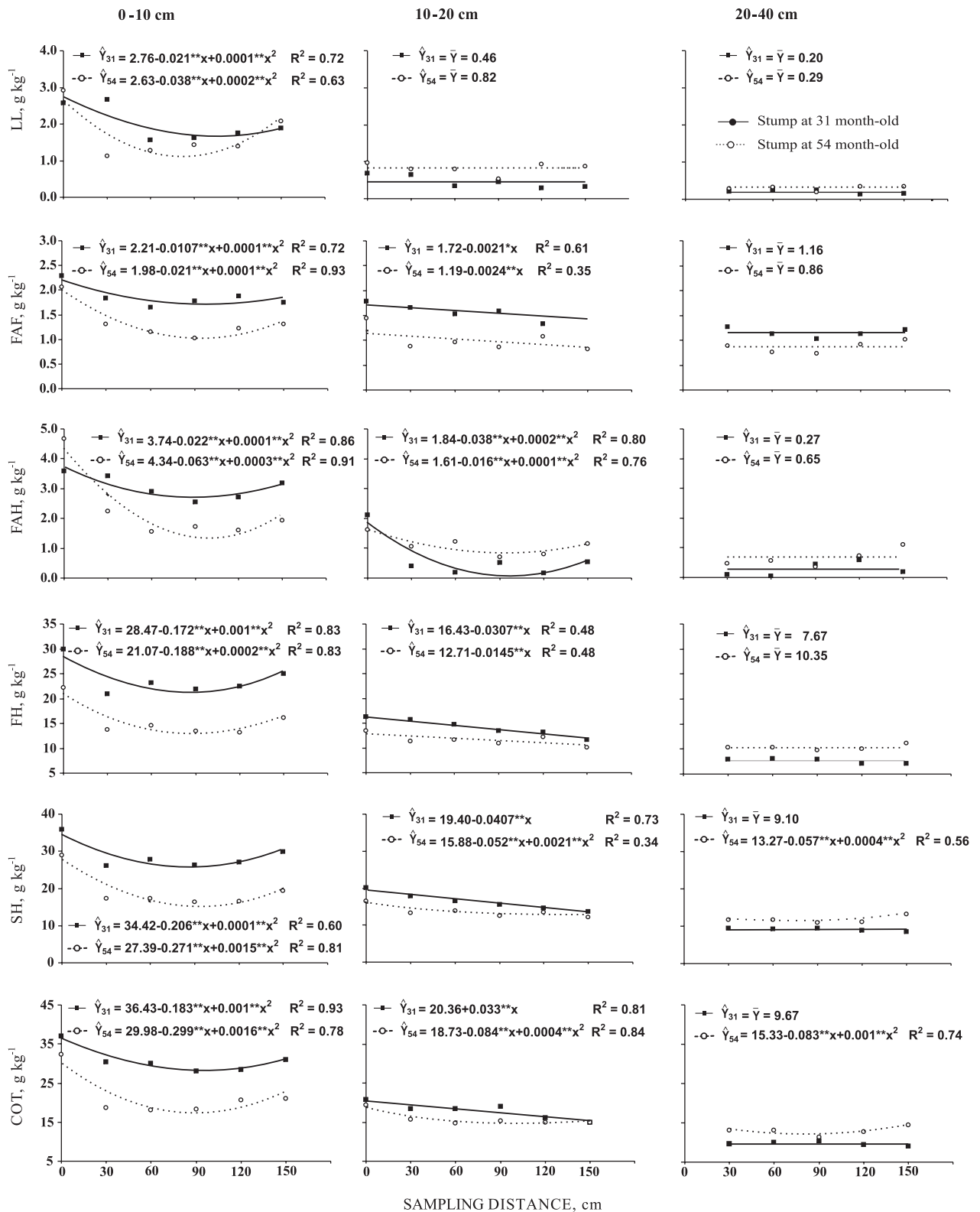


Figure 2. Concentration of carbon in the different fractions of soil organic matter at different distances from eucalyptus stump from the previous rotation, 31 and 54-month-old, collected following the row line, at 0–10, 10–20 and 20–40 cm of depth. FAF: free light fraction; FAF: fulvic acid fraction; HAF: humic acid fraction; FH: humin fraction; HS: humic substances; TOC: total organic carbon. * and **: significant at 5 and 1 %, respectively.

Nevertheless, it is important to note that C concentrations in FLF are probably underestimated, due to the use of NaI as a densimetric fractionation technique of organic matter (OM) of the soil. This technique is less efficient in recovering C in FLF than sodium polytungstate solution. The latter promotes C recovery in FLF in more advanced OM decomposition stages and is therefore more efficient than NaI solution; it has also been recommended in a study of densimetric OM fractionation of the soil (Conceição et al., 2007).

In relation to the depth of soil sampling, it was observed that the C concentrations in FLF, FAF, HAF, HF, HS and TOC were substantially higher in the 0–10 cm layer than in the sub-surface layers under ES after 31 and 54 months (Table 3), reflecting the effect of residue deposition and maintenance on the soil surface, mainly after forest harvesting. Similar results were found by Rangel & Silva (2007), who attributed the increased organic C concentrations in the soil mainly to the greater input of vegetation residues on the surface. This is particularly true for FLF, which consists basically of partially decomposed vegetation residues and is highly influenced by the amount and quality of the residue deposited on the soil surface (Six et al., 2001).

Comparing the C concentrations of FLF, FAF, HAF, HF, HS and TOC of the soil under the stumps, at both ages, it was observed that they generally decreased according to the order of age: 31 months > 54 months (Table 3). These results can be explained by the textural differences of the soil samples collected from the studied areas. In this sense, it was observed that the clay content under the 54-month-old ES was by 33.3 to 78.6 % lower than under the 31-month-old ES in the layers 0–10, 10–20 and 20–40 cm (Table 1).

According to Silva & Mendonça (2007), under similar environmental conditions, soils with greater

clay concentration usually have a higher C concentration, which is due to the capacity of the soil organic matter (SOM) to form different types of connections with particles with high specific surface, such as the clay fractions, favoring the colloidal protection of SOM. This positive relationship between the clay content and the OC concentration was demonstrated by Zinn et al. (2005). Moreover, in the soils with the highest clay content, clay flocculation and stable aggregate formation are favored. A consequence is the physical protection by SOM occlusion within the aggregates, hindering or impeding the access to the microorganisms and their enzymes (Silva & Mendonça, 2007). On the other hand, Christensen (1992) stated that due to the reduced specific surface and surface charge density of sands, this particle has little or no highly connected organic matter. It is also poor in organo-mineral complexes, which results in a greater amount of readily available OC to microorganisms, resulting in a lower OC concentration in soils with higher sand contents (Zinn et al., 2005).

CONCLUSIONS

1. The soil pH values, P, K, Ca²⁺, Mg²⁺ and Al³⁺ contents vary substantially as the distances from the eucalyptus stumps increase and are highest in the topsoil, except for Al³⁺.
2. The C concentrations of FLF, HS and TOC fractions of the soil were highest near the eucalyptus stumps, in the layers 0–10 cm and 10–20 cm.
3. Highest C concentrations of FLF, and HS and TOC fractions occur in the surface layer of the soil with highest clay concentration, independent of the age of the eucalyptus stumps.

Table 3. Concentrations of organic carbon in the several fractions of the soil organic matter at different depths under the remaining eucalyptus stumps at 31 and 54 months

Depth	FLF	FAF	HAF	HF	HS	TOC
cm	g kg ⁻¹					
	31 months					
0–10	2,01 a	1,86 a	3,06 a	23,90 a	28,82 a	30,78 a
10–20	0,46 b	1,57 b	0,65 b	14,13 b	16,35 b	17,89 b
20–40	0,20 b	1,16 c	0,27 b	7,67 c	9,10 c	9,67 c
	54 months					
0–10	1,70 a	1,35 a	2,29 a	15,57 a	19,21 a	21,50 a
10–20	0,81 b	1,01 b	1,09 b	11,62 b	13,72 b	15,83 b
20–40	0,29 b	0,86 b	0,65 c	10,35 b	11,86 c	12,87 c

FLF: free light fraction; FAF: fulvic acid fraction; HAF: humic acid fraction; HF: humin fraction; HS: humic substances; TOC: total organic carbon. Values followed by equal letter, in each column, were not different at 5% by the Tukey-Kramer test.

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