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Temporal stability of soil moisture under effect of three spacings in a eucalyptus stand

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ABSTRACT. Soil moisture temporal variability is an important concept in understanding forest management. The objective of this study was to analyse the effect of planting density on soil profile moisture in a clonal *Eucalyptus* plantation. Soil moisture was observed every 15 days at 25 points distributed throughout the eucalyptus stand between November 2013 and October 2015 to characterize the moisture according to the following three types of spacings: 3 x 2, 3 x 3, and 3 x 5 m. At each point, the 0 - 10, 10 - 20, 20 - 30, 30 – 40, and 60 - 100 cm layers were evaluated using a Profile Probe PR2 model. Soil moisture showed high spatial variability in the 0 - 10 cm layer, whereas from 30 to 100 cm deep, the moisture tended to become more homogeneous throughout the area. The dry periods presented greater temporal soil moisture stability when compared to the rainy seasons. The 3 x 2 m spacing has greater temporal soil moisture stability when compared to the others, while the 3 x 3 m spacing presented greater temporal variability.

Keywords: planting density, oxisols, water storage in the soil profile, Minas Gerais.

Estabilidade temporal da umidade do solo sob efeito de três espaçamentos em povoamento de eucalipto

RESUMO. A compreensão da variabilidade temporal da umidade do solo é importante para um manejo adequado de culturas florestais. O objetivo neste trabalho foi analisar o efeito causado pela densidade de plantio na umidade no perfil do solo em um povoamento clonal de *Eucalyptus*. A umidade do solo foi observada em intervalos de 15 dias em 25 pontos distribuídos no povoamento de eucalipto entre novembro de 2013 e outubro de 2015 buscando caracterizar a mesma em função de três espaçamentos: 3 x 2; 3 x 3 e 3 x 5 metros. Em cada ponto foram avaliadas as camadas de 0 - 10, 10 - 20, 20 - 30, 30 - 40 e 60 - 100 cm utilizando uma sonda Profile Probe PR2. A umidade do solo apresentou alta variabilidade espacial na camada de 0 - 10 cm, enquanto que a partir dos 30 cm até 100 cm de profundidade a umidade tendeu a ficar mais homogênea em toda a área. O período seco apresenta maior estabilidade temporal da umidade do solo quando comparado ao período chuvoso. O espaçamento 3 x 2 metros apresenta uma maior estabilidade temporal da umidade do solo quando comparado aos demais, enquanto o espaçamento 3 x 3 metros apresentou uma maior variabilidade temporal.

Palavras-chave: densidade de plantio, latossolos, armazenamento de água no perfil do solo, Minas Gerais.

Introduction

After interacting with the forest canopy and individual tree trunks, the throughfall and stemflows reach the forest floor. From this moment on, two important processes of the hydrological cycle occur, namely the direct runoff and infiltration of water into the soil profile. The infiltration and redistribution processes of water in the soil profile are affected by variability in the volume of water that interacts with the soil surface and the effects of vegetation cover. Thus, identifying the processes and mechanisms that influence the variability of soil moisture is an important tool in agricultural and forest crop management.

Understanding the variability of soil moisture, using both spatial and temporal scales, is essential in quantifying water storage variation in the soil profile; this information is fundamental in flood prediction and forecasting studies and agro-climatic modelling, especially in eucalyptus plantations (Albergel et al., 2010; Bolten, Crow, Jackson, Zhan, & Reynolds, 2010; Koster, Mahanama, Livneh, Lettenmaier, & Reichle, 2010; Famiglietti, Ryu, Berg, Rodell, & Jackson, 2008).

The spatial pattern of soil moisture can be represented by a small-scale component associated with soil-vegetation interactions with relief, and a large-scale component associated with precipitation and evapotranspiration demand. Guswa (2012) shows that the horizontal variability of soil moisture is mainly affected by the spatial variability in throughfall and stemflows, while the vertical variability is mainly associated with the physical soil characteristics and, especially, the distribution of the vegetation cover root system.

Temporal soil moisture variability analysis is a complex and dynamic process that generally requires an extensive sample set, resulting in a significant increase in monitoring costs over time. Vachaud, Silans, Balabanis, and Vauclin (1985) were the first to observe that, despite the spatiotemporal variability, some soil moisture spatial patterns are evident and that these patterns showed little variation over time. From these observations, the authors proposed the concept of temporal stability, which is the constant association between the spatial location and statistical measures that characterize a particular soil property over time (Van Wesenbeeck & Kachanoski, 1988).

The identification of patterns in time-stable soil moisture points means that these points have soil moisture equal to the average of the samples, i.e., points that are representative of the area, thereby reducing monitoring costs (Gao & Shao, 2012). However, Hu, Shao Han, Reicherdt, and Tan (2010) indicated that while most of the efforts applied to soil moisture temporal stability analysis have been focusing on the soil surface layer, few studies have evaluated the soil profile given the difficulty of monitoring soil moisture in depths and at various points in space.

In a study conducted by Western, Grayson, and Blöschl (2002), it was found that most of the theoretical soil moisture analysis, performed by applying dynamic statistical models, ignores the effects of soil moisture seasonality and have focused only on the temporal variability of precipitation and evapotranspiration.

The *Eucalyptus* genus is the most cultivated group of species in Brazil, especially in the state of Minas Gerais, which has the largest planted area in the country. The excellent performance of eucalyptus forests, mainly in terms of productivity, is associated with the species used for breeding and the application of forest management techniques that can provide alterations in wood quality, thus influencing final product quality and increasing its commercial value (Gonçalves, Oliveira, Silva, Nappo, & Tomazelo Filho, 2010).

The aim of this study was to analyse the effect by planting density in a clonal Eucalyptus stand in southern Minas Gerais State has on soil moisture and to analyse the effects of three spacings on the temporal stability of water content in the soil by layers.

Material and methods

The study was developed in a eucalyptus stand located in the experimental unit of the Forest Management Projects and Study Laboratory (LEMAF) on the Federal University of Lavras (UFLA) campus. The forest stand is formed by *Eucalyptus* hybrid clones, with species *urophylla* and *grandis* serving as the genetic basis. This hybrid is commonly identified as "Urograndis". Individuals were distributed in the study area using the following three spacings: 3 x 2 m (0.77 ha and 1025 individuals), 3 x 3 m (0.42 ha and 398 individuals) and 3 x 5 m (0.35 ha and 262 individuals).

Two soil classes are present in the area: Red-Yellow Latosol (LVA) covers 78.6% of the area (1.21 ha), and Dark-Red Latosol (LV) covers 21.4% of the area (0.33 ha). The LVA has a block structure with moderate drainage and Leucocratic granite-gneiss as the parent material. The LV is a granular structured soil, well drained, and has Mesocratic granite-gneiss as the parent material. Table 1 shows the averaged data for organic matter (OM), soil texture, and soil saturated hydraulic conductivity (Ksat) for both the A horizon and top of the B horizon for each studied soil class.

Table 1. OM, texture and Ksat mean data, by soil class, for the eucalyptus stand.

Soil Class	Horizon	(%)				Texture	Ksat (m day^{-1})
		OM	Sand	Silt	Clay		
LVA	A	3.63	45	10	45	Clayey	0.52
	Top of B	1.84	32	13	55	Clayey	
LV	A	3.99	27	9	64	Clayey	0.64
	Top of B	2.36	23	13	64	Clayey	

For soil moisture monitoring, we used a PR2 Profile Probe device from Decagon Devices® allowing the estimation of soil moisture based on volume (m^3 m^{-3}). Twenty-five probe access tubes were installed in order to represent the soil type diversity, slope and management methods used in the study area. The probe provides moisture data for the five following soil profile layers up to a metre deep: 0 - 10, 10 - 20, 20 - 30, 30 - 40, and 60 - 100 cm.

Figure 1 shows the spatial distribution of the soil moisture monitoring points in the eucalyptus stand.

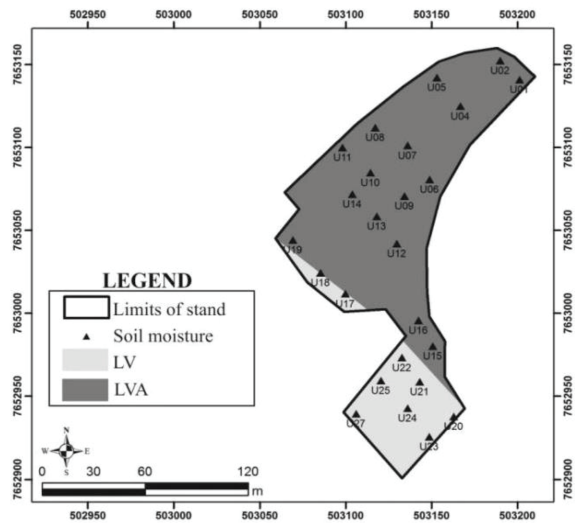

Figure 1. The spatial distribution of the soil moisture monitoring points in the eucalyptus stand.

From November 1, 2013 to October 31, 2015, 83 soil moisture readings were taken, with an average interval of seven days in the 2013/2014 hydrological year and 15 days for the 2014/2015 hydrological year. In the case of occurrences of rainfall events of relevant magnitude, additional readings were conducted to capture a more detailed variation of storage over time. Based on these readings, an average soil moisture behaviour analysis, recorded as a percentage, was conducted in each layer during the study period.

To analyse the temporal soil moisture stability, the relative difference technique proposed by Vachaud et al. (1985) was applied. This technique allows the characterization of the temporal persistence of the soil moisture pattern and identification of soil moisture monitoring points that are statistically representative of the study area. The relative difference (δ_{ij}) is expressed by Equation 1:

$$\delta_{ij} = \frac{\theta_{ij} - \overline{\theta_j}}{\overline{\theta_j}} \tag{1}$$

where: θ_{ij} corresponds to the soil moisture in position i in time j and θ_j represents the average moisture of all positions in time j.

For each position i, the mean temporal relative difference ($\bar{\delta}_i$) and its standard deviation ($\sigma(\bar{\delta}_i)$) were calculated according to Equations 2 and 3, respectively:

$$\overline{\delta_i} = \frac{1}{m}\sum_{j=1}^{m} \delta_{ij} \tag{2}$$

$$\sigma(\overline{\delta_i}) = \sqrt{\frac{1}{m-1}\sum_{j=1}^{m}\left(\delta_{ij} - \overline{\delta_i}\right)^2} \tag{3}$$

where: *m* is the number of readings (in this case, 83).

Subsequently, the data of the mean relative difference was plotted in ascending order, where the point closest to zero would be the representative point for the study area, presenting higher temporal stability. According to Brocca, Tullo, Melone, Moramarco, and Morbidelli (2012), the relative difference values both near zero and with low standard deviations indicate the possible representative soil moisture location.

The temporal stability study was applied to the five layers analysed, considered the entire study period, and was split into the dry and wet periods of the hydrologic years.

Results and discussion

On average, soil moisture increases as soil depth increases. The surface layer (0 - 10 cm) has the lowest average soil moisture among the layers, the greatest range observed in the time series, and high variability, with a 35.8% coefficient of variation. Table 2 presents the descriptive statistics for the average soil moisture for all evaluated layers in the eucalyptus plantation.

Table 2. Basic statistics for the average soil moisture for each studied layer in the eucalyptus stand.

Parameter	Layers (cm)				
	0 - 10	10 - 20	20 - 30	30 - 40	60 - 100
Average (%)	15.5	22.4	26.6	27.8	28.6
Maximum (%)	32.0	36.5	37.5	39.4	41.6
Minimum (%)	6.4	15.0	20.6	23.3	24.0
Standard Deviation (%)	5.6	5.0	4.1	3.5	3.3
CV (%)	35.8	22.2	15.3	12.7	17.5

The dispersion in the soil profile increases from the deepest layer (60 - 100 cm) to the uppermost layer (0 - 10 cm) as shown in Figure 2. The standard deviation confirms this statement, following the same behaviour and presenting greater deviation in the surface layer than in the deeper layer of the soil profile.

Figure 3 presents the average soil moisture time series for all layers monitored in the eucalyptus stand, and the series of rainfall events observed on monitoring days.

A wide fluctuation in soil moisture average data during the study period for the layers 0 - 10, and 10 - 20 cm can be observed. These layers feature a quick response to rainfall events, which are responsible for meeting the soil evaporative demand, and are the most explored by the root system of individuals, contributing to more accentuated moisture decay. Additionally, a greater accumulation of organic matter takes place in the surface layer, helping to maintain the soil structure preserved in these layers, thus contributing to a greater water flow, both at depth and laterally, and increasing the variability over time.

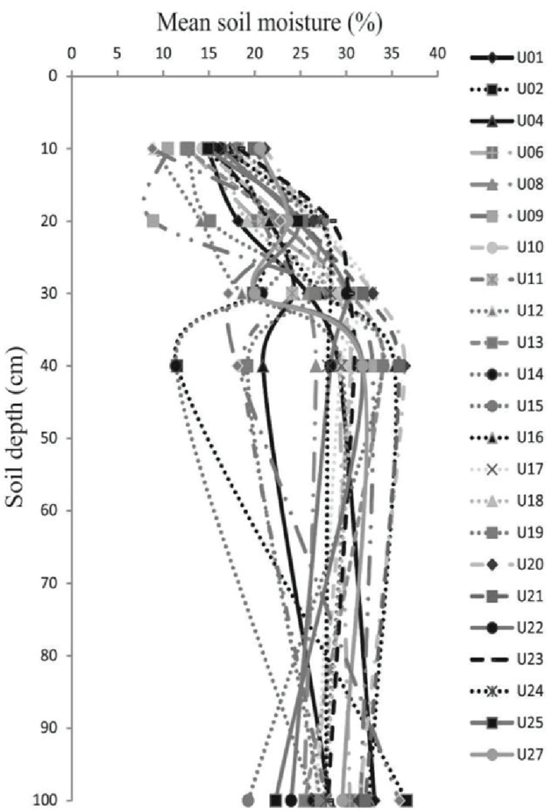

Figure 2. Average soil moisture, by layer, for the sampled points in the eucalyptus stand.

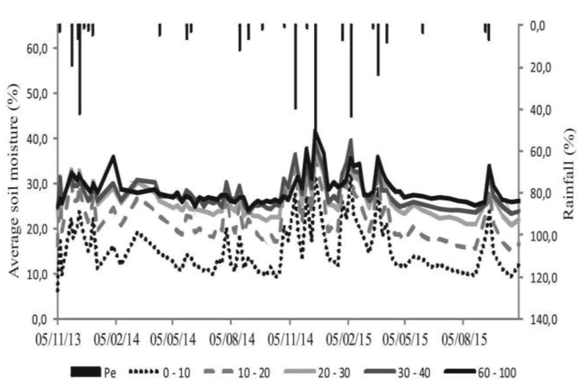

Figure 3. Time series of average soil moisture, by layer, in a eucalyptus stand.

Hu, Shao, Han, Reicherdt, and Tan (2010) and Trevisan, Salemi, Groppo, Silva, and Martinelli (2012) also observed similar behaviours by studying the soil moisture variability in a watershed in China and in a watershed with eucalyptus in Serra do Mar, in the state of São Paulo, respectively.

Figure 4(a, b, c, d, and e) show the mean relative differences and the respective standard deviations for soil moisture in a eucalyptus stand in the 0 - 10, 10 - 20, 20 - 30, 30 – 40, and 60 - 100 cm layers, respectively.

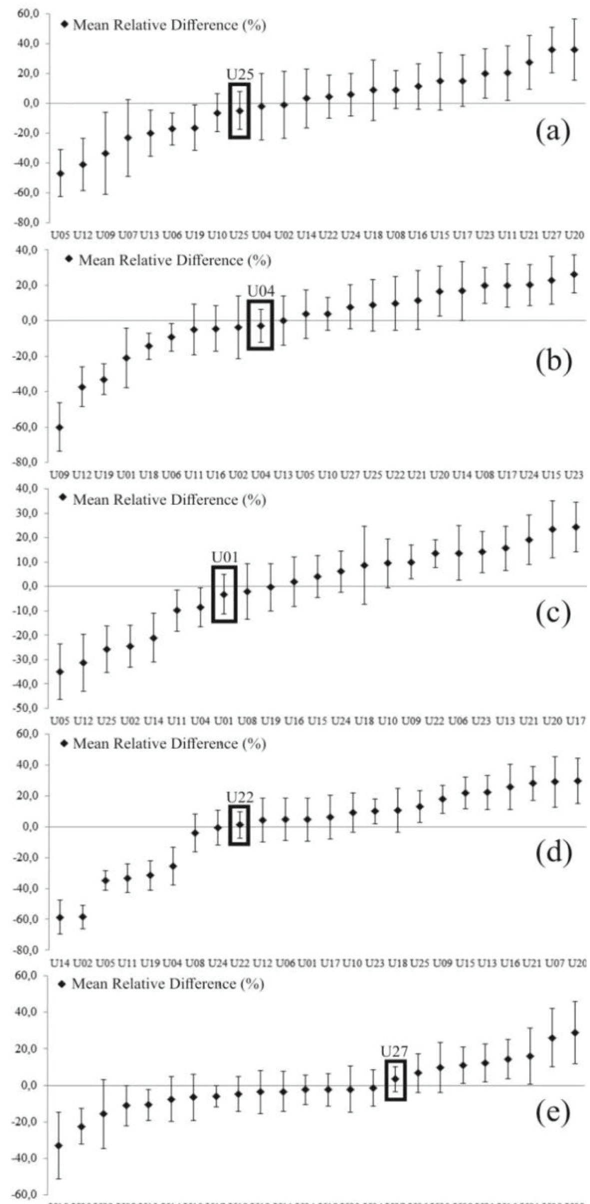

Figure 4. Mean relative difference and standard deviation of soil moisture for the 0 - 10 cm (a), 10 - 20 cm (b), 20 - 30 cm (c), 30 - 40 cm (d), and 60 - 100 cm (e) layers.

A wide range among the Mean Relative Difference (MRD) data was observed for all layers studied. These ranges were 83.1, 86.4, 59.4, 88.5, and 61.8% for the 0 - 10, 10 - 20, 20 - 30, 30 - 40, and 60 - 100 cm layers, respectively. Gao and Shao (2012) found ranges between 93.2 and 172.3% while studying the temporal patterns of soil moisture up to three metres deep in the soil profile predominantly used by grassland.

Brocca et al. (2012) suggested using the point which provides both a MRD module less than 5% and the lowest standard deviation as selection parameters for points representative of average soil moisture over an area. Following these criteria, points U25, U04, U01, U22, and U27 were indicated as representative of soil moisture patterns for the 0 - 10, 10 - 20, 20 - 30, 30 – 40, and 60 - 100 cm layers, respectively, in the studied eucalyptus stand. Points U05 and U20 presented the lowest and highest average soil moisture over time, respectively, among all studied layers. Point U05 is located in LVA with a higher soil density and lower saturated soil hydraulic conductivity and porosity when compared to U20 which is under LV. The results demonstrate that it was not possible to obtain a single stable point to represent the entire area and at all depths.

The average standard deviations, among all the points, were 17.5, 12.7, 9.7, 11.5, and 11.7% for 0 - 10, 10 - 20, 20 - 30, 30 - 40, and 60 - 100 cm layers, respectively. Gao and Shao (2012) and Hu, Shao, and Reichardt (2010) found similar behaviours for this statistical parameter when studying the temporal stability of soil moisture stratifying the profile in layers.

Figure 5 shows the correlations between the average soil moisture time series in the layers at the point indicated as their representative.

By analysing the results from Figure 5, there is, in fact, a strong relationship between the points identified as representative and average soil moisture in the analysed layers. A decrease in the average standard deviation of the MRD as the soil depth increases up to 30 cm followed by an increase up to the depth 100 cm is observed.

Of the five soil moisture pattern representative points for the layers studied, three are located in LV; of these points, two represent the deeper layers of the analysed soil profile. This soil class is better structured, when compared to LVA, having lower soil density and consequently, higher total porosity in the three layers studied.

Another crucial related physical-hydric characteristic is the hydraulic conductivity (Ksat), which was higher in LV. This characteristic favours drainage to deeper layers, allowing these layers to reach moisture equilibrium faster than in LVA.

The presence of an impervious layer, observed in the field at 20 - 30 cm depth, is also noteworthy, with lower Ksat values for the entire area. This condition favours soil moisture uniformity over the surface layer, resulting in a better condition for reaching a temporal stability pattern.

Table 3 shows the mean relative differences and standard deviations of the representative points of temporal soil moisture stability for the five layers studied and spacing in the eucalyptus stand.

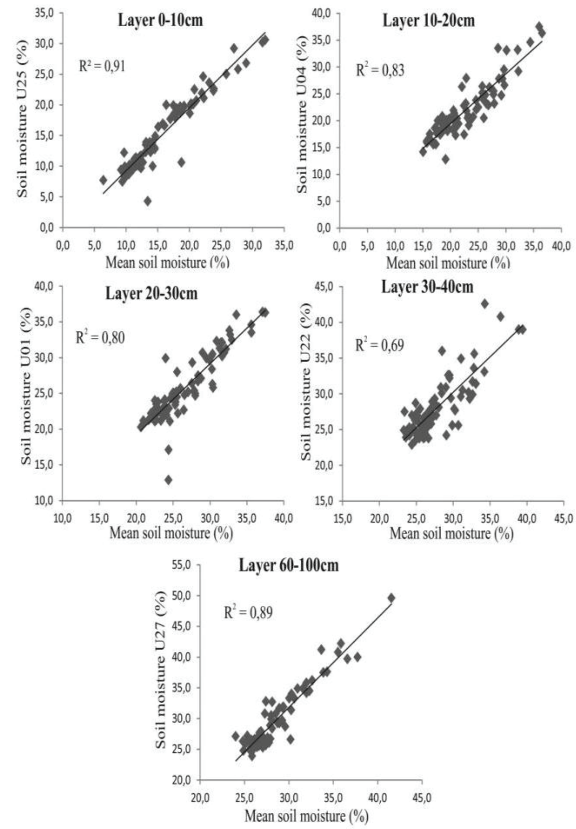

Figure 5. Correlation between the average soil moisture in the area studied and representative points found for each soil layer in the eucalyptus stand.

Table 3. Mean soil moisture relative difference in spacing in the eucalyptus stand.

Spacing (m)	3 x 2		3 x 3		3 x 5	
Layer (cm)	MRD (%)	SD (%)	MRD (%)	SD (%)	MRD (%)	SD (%)
0 – 10	3.2	19.7	-11.0*	17.7*	-4.9	12.6
10 – 20	-3.1	9.3	-4.4	13.0	15.5*	13.6*
20 – 30	-3.2	8.2	1.9	10.1	4.0	8.5
30 – 40	4.7	13.9	4.7	13.7	1.2	8.6
60 – 100	-4.8	9.7	-2.4	9.0	3.4	6.9

*This symbol indicates values with a MRD higher than the 5% criteria adopted.

According to the selection criteria adopted in this study, 3 x 3 m spacing at 0 - 10 cm depth and 3 x 5 m spacing in the 10 - 20 cm soil layer did not produce statistically representative points for average soil moisture. This condition indicates that the sampling points adopted were not enough to represent the soil moisture variability in these layers, requiring either a relocation or expansion of the monitoring network in these layers and spacing patterns.

The lowest average standard deviation observed in the soil profile was found in the 3 x 5 m spacing, followed by 3 x 3 and 3 x 2 m. For the 3 x 5 m spacing, other than a wider canopy opening, which facilitates the throughfall reaching the ground, there was a lower root system presence, which favours a greater persistence of soil moisture patterns and was probably related to less water consumption by the plants.

Such observations about the persistence of soil moisture patterns in a planted eucalyptus forest, associated with different spacings, may become another tool to assist in the genetic improvement and production of hybrids with high productivity characteristics, making them able to achieve the optimum production point associated with planting density and soil water availability. The lack of studies relating moisture patterns in soil profiles to the planting densities for eucalyptus stands is also a noteworthy point.

By evaluating the temporal stability of moisture in the soil profile for the rainy (Figure 6) and dry (Figure 7)

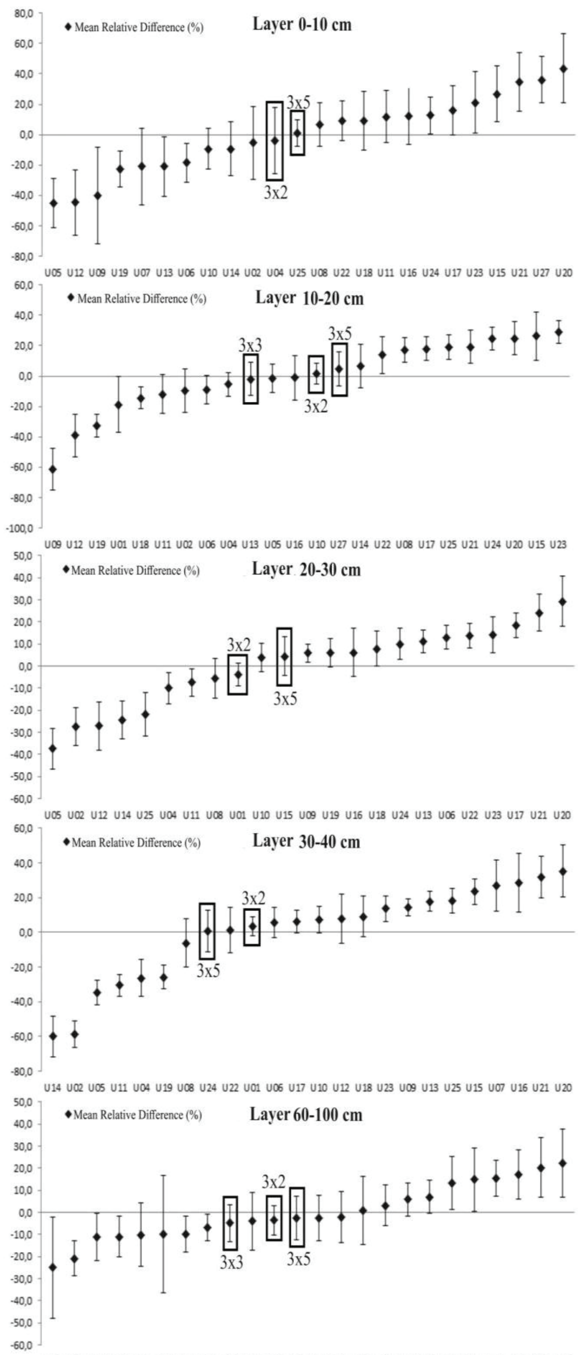

Figure 6. Soil moisture MRD for the rainy seasons in a eucalyptus stand.

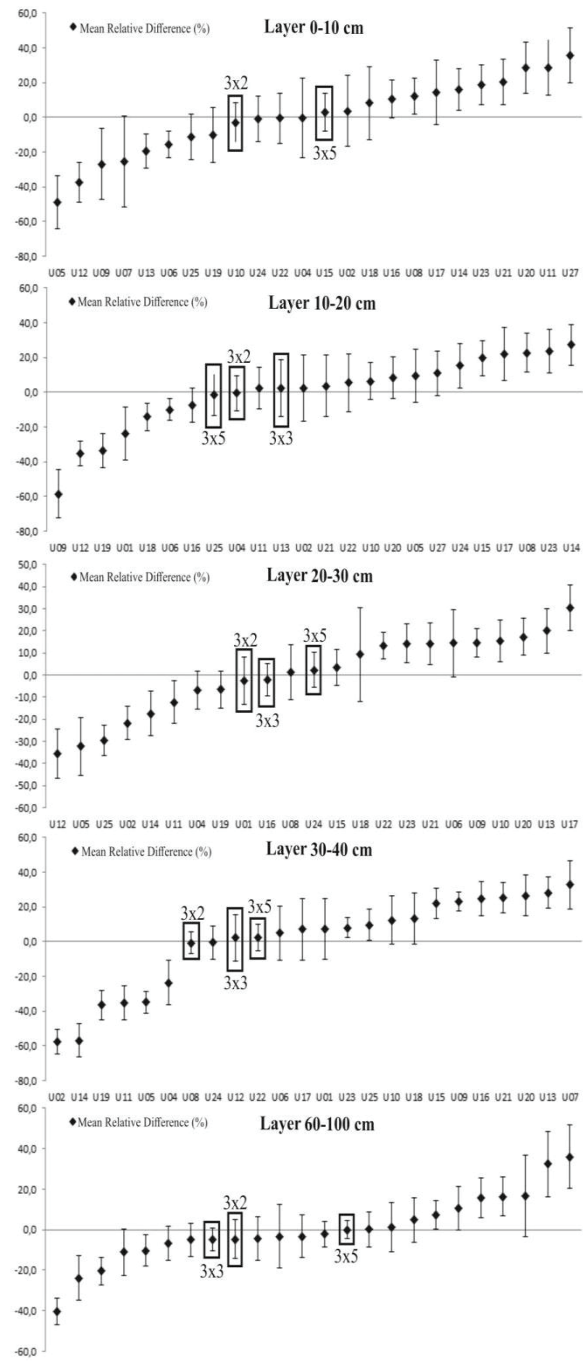

Figure 7. Soil moisture MRD for the dry seasons in a eucalyptus stand.

periods in the eucalyptus stand, we identified a behaviour similar to that observed for the entire study period. In general, the dry seasons had less MRD variation in relation to the rainy seasons, except for the 60 - 100 cm layer, which showed an inverse relationship with the rainy seasons with a lower range than the dry seasons.

For the rainy seasons, no average soil moisture representative points were identified for the 0 - 10, 20 – 30, and 30 - 40 cm layers in the 3 x 3 m spacing in the eucalyptus stand. As for the dry seasons, only the 0-10 cm layer did not present a soil moisture representative point in the 3 x 3 m spacing

Conclusion

The average soil moisture throughout the observation period showed high variability, mainly in the surface layer. Soil moisture tends to become more homogeneous from 30 to 100 cm in depth.

In the 0-10 and 10-20 cm layers, points representative of a soil moisture stability pattern were not identified for 3 x 3 and 3 x 5 m spacings, respectively, indicating the need for a refinement of the observation grid.

The dry periods had higher temporal soil moisture profile stability when compared to the rainy seasons, with less variation in the average relative differences and their standard deviations for all the studied spacings.

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