Site preparation, initial growth and soil erosion
in *Eucalyptus grandis* plantations on steep terrainPreparo do solo, crescimento inicial e erosão do solo em
plantios de *Eucalyptus grandis* em região montanhosaMarcos Cesar Passos Wichert¹, Clayton Alcarde Alvares²,
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Resumo

No Brasil, e especialmente na região do Vale do Paraíba, estado de São Paulo, a silvicultura com o cultivo do eucalipto está se expandindo para as áreas declivosas, ocupadas com pastagens degradadas, devido ao limitado valor agropecuário destas topografias e sua maior aptidão florestal. O presente trabalho teve como objetivo avaliar o efeito de diferentes métodos de preparo de solo sobre as perdas de solo e água, por erosão, e sobre o desenvolvimento inicial de plantio clonal, de *Eucalyptus grandis*, em áreas declivosas. O ensaio foi instalado num delineamento fatorial 3x2, com três intensidades de preparo (coveamento manual, coveamento mecânico e subsolagem a favor do declive) e dois sistemas de manejo de resíduos de colheita (com e sem resíduos), com 4 repetições, num Argissolo Vermelho-Amarelo Distrófico (textura média/argilosa), com declividade média de 20.3%. A perda de solo e o crescimento da floresta foram avaliados durante 1 ano, entre março de 2004 e fevereiro de 2005. Em dois tratamentos, o com coveamento manual e manutenção dos resíduos (MAC) e na subsolagem sem resíduos (SUS), a erosão foi medida diretamente através do método da parcela padrão, instaladas em todas as repetições, e com dimensões de 14 x 24 metros. Uma parcela padrão adicional, sem preparo, sem plantas e sem resíduos, foi também instalada como uma parcela controle. As erosões mensuradas foram agrupadas e analisadas em três períodos (0 a 2, 3 a 7, e 8 a 12 meses). Para os demais tratamentos, a erosão foi estimada por modelos (por período e global) gerados por regressões lineares múltiplas entre a erosão observada nas parcelas padrão dos tratamentos MAC e SUS, e variáveis independentes oriundas dos atributos locais de cada parcela e a partir do método de pinos. O crescimento inicial do eucalipto foi determinado estimando-se a cobertura do solo e a biomassa da parte aérea aos 3, 6, 9 e 12 meses. Para as parcelas padrão, houve maior erosão no tratamento SUS do que no MAC, com valores médios de 12,96 e 2,4 Mg ha⁻¹ ano⁻¹, respectivamente. Para ambos os tratamentos, a erosão diminuiu com o crescimento da floresta. Quanto ao resíduo, a sua manutenção na área reduziu ligeiramente o crescimento de *E. grandis*. Ponderando-se os ganhos de crescimento inicial e as perdas erosivas esperadas, a manutenção dos resíduos no local e o coveamento mecânico podem ser identificadas como a melhor opção de preparo do solo para essas áreas declivosas.

Palavras-chave: conservação do solo, preparo do solo, *Eucalyptus*, silvicultura, erosão.

Abstract

In Brazil, and especially in the Paraíba Valley region, Southeastern Brazil, *Eucalyptus* plantations are expanding to high declivity areas formerly occupied by degraded pastures, due to the limited agricultural value of these topographies and their forestry aptitude. The objective of this study was to evaluate the effect of different methods of soil preparation and water loss by erosion, and on the initial development of clonal plantations of *Eucalyptus grandis* in areas of high slope. The experiment was installed in a 3 x 2 factorial design, with three intensities of soil preparation (manual pitting, mechanical pitting and downhill subsoiling) and two systems of residue management (with and without harvest residues), with 4 blocks, in a fine, kaolinitic, thermic type Kanhapludults soil, with an average inclination of 20.3%. Soil loss and growth of the forest were measured during one year, between March 2004 and February 2005. In two treatments, namely manual pitting and maintenance of the residues (MAY) and subsoiling without residues (SUN); erosion was measured directly through the method of the standard-plots, installed in all the replications, with a dimension of 14 x 24 meters. An additional standard plot without soil preparation, residues and

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cultivation was also installed as a control plot. Erosion measured was grouped and analyzed for three periods (0 to 2, 3 to 7, and 8 to 12 months). In the other treatments, erosion was estimated using models (per period and joint) from multiple linear regression between the erosion observed in the treatments MAY and SUN and independent variables originated from local attributes of each plot and from the pins method. The initial growth of *Eucalyptus* was determined by estimating soil cover and aboveground biomass at 3, 6, 9 and 12 months. In the standard-plots, there was more erosion in the treatment SUN than in MAY, with mean values of 12.96 and 2.40 Mg ha⁻¹ year⁻¹, respectively. For both treatments erosion decreased with the growth of the forest. As for the residue, its maintenance in the area slightly reduced the growth of *E. grandis*. Pondering the gains of initial growth and the expected erosion losses; maintenance of the residues on site and mechanical pitting can be identified as the best soil preparation option for such areas.

Keywords: soil conservation; soil preparation; *Eucalyptus*; silviculture; erosion.

INTRODUCTION

In recent decades, the *Eucalyptus* plantations have expanded into steep slope areas in the Paraíba Valley region, São Paulo State, Brazil; typically replacing degraded pastures and providing higher profits for landowners (SILVA et al., 2002; JANOSSELLI et al., 2016). Such practice has also occurred in other regions of southeastern Brazil (SILVA et al., 2007 and GONÇALVES et al., 2013). Paraíba Valley accounts for about 10% of the *Eucalyptus* planted area in the state of São Paulo, with more than 75,000 ha of *Eucalyptus* plantations (KRONKA et al., 2002; GONÇALVES et al., 2014). Many of these areas experienced substantial soil loss under prior land uses, and any further soil loss needs to be minimized through careful planning and adequate silviculture practices (LIMA, 1996; GONÇALVES, 2002, SILVA et al., 2011).

Steep areas are in high risk of erosion, especially by heavy machinery use. High costs of alternative manual operations may lower the profitability of plantations (FERNANDES and SOUZA, 2001; SILVA et al., 2002; STAPE et al. 2002). On flat terrain, tree growth generally increases with the volume increment of soil prepared (FINGER et al., 1996; GONÇALVES et al., 2002; PREVEDELLO, et al., 2013; SUITER FILHO et al. 1980; VARELIDES; KRITIKOS, 1995), but erosion risks on steeper slopes may counter some of the benefits of intensive soil preparation under this condition.

Few studies have been conducted in Brazil in order to better understand the relationship between the intensity of site preparation, erosion and tree growth in steep areas (BAPTISTA; LEVIEN, 2010; LIMA, 1988, 1996), underscoring the need for direct experimentation. The objectives of the study were to test three levels of soil preparation and two levels of residue retention in order to determine the responses on soil erosion and tree growth in the Paraíba Valley, Southeastern Brazil.

MATERIAL AND METHODS

Site description

The experiment was conducted in the municipality of Igaratá, in the Paraíba Valley (23°12'S, 46°09'W) at an altitude of 745 m. The climate is Cfb (Köppen system), namely as subtropical without dry season and with temperate summer (ALVARES et al., 2013a). Average annual temperature is 21.5° C and with 1265 mm of annual rainfall (ALVARES et al., 2013b). Total rainfall in the driest month is less than 40 mm, and mean monthly temperatures range from 18 to 23°C. The total rainfall during the 12 months of this study (2004-2005) was typical for the region, with 1360 mm at the research site. The distribution of monthly precipitation during the study period was plotted and compared with historical precipitation (Figure 1). On-site rainfall rates were used to calculate the average monthly erosivity index (EI) using the formula proposed by Lombardi Neto and Moldenhauer (1992) which was developed for the region of Campinas, State of São Paulo, 110 km away from Igaratá. Silva (2004) recommended using the same formula for the region of Igaratá. The total annual value of erosivity was estimated to be 6461 MJ ha⁻¹ mm⁻¹ and the rainfall erosivity in this region then classified as average, according to the full distribution of erosivity in Brazil (COGO, 1988).

Figure 1. Monthly precipitation and erosivity index in the experimental area during the evaluation period and historical precipitation, highlighting the three periods of the soil losses.

Figura 1. Precipitação observada e histórica e erosividade mensal na área de experimental durante o estudado destacando-se os três períodos de avaliação de perdas de solos.

The terrain in the study area is characterized by 100-300 m hills with slopes of 15 to 30%, with a high density of drainages, valleys, and alluvial plains; being characterized as a common type of landscape for *Eucalyptus* plantations in the coastal region of southeastern Brazil (GONÇALVES et al., 2013). The soil is classified as a Fine, kaolinitic, thermic type Kanhapludults (by Brazilian Soil Taxonomy is an Argissolo Vermelho-Amarelo Distrófico textura média/argilosa) which have a water retention capacity that supports good tree growth. The soil (0-0.15 m) averaged 57% sand, 8% silt, and 35% clay, with a bulk density of 1.2 Mg m^{-3} , 40 g kg^{-1} of organic matter, and 54% total porosity. Soil pH_{water} averaged 4.0, with 11% base saturation; overall, the soil is considered to have moderate fertility with respect to N, P and K, but low in Ca, according to the interpretation of soil fertility by Gonçalves (2011).

Experimental design

The design was a 3×2 factorial with three levels of soil preparation and two levels of residue management, with four replications. The manual soil preparation treatment involved digging holes ($0.2 \times 0.2 \times 0.2 \text{ m}$ depth) with a shovel for each seedling (Figure 2a). We used two mechanical soil preparation treatments; one that digged holes ($0.3 \times 0.3 \times 0.5 \text{ m}$ depth) for each seedling (Figure 2b) and another using a ripper for subsoiling in furrows (0.6 m depth) in favor of the slope (Figure 2c). A 2-wheel drive tractor with 110 hp nominal power was used for both mechanical soil preparation treatments. Such methods of soil preparation are commonly used on steep areas in the study region. A control plot was established where the soil was not prepared, residues were removed, and no trees were planted, providing no soil cover for the duration of the study.

The trial was monitored from the establishment in March, 2004 to February, 2005. Pre-planting fertilization included 600 kg ha^{-1} of lime, and individual-tree fertilization with 0.11 kg of 4:28:6 NPK per plant (application using lateral pits, half dose in each pit). Three months after planting, an additional 0.1 kg tree^{-1} was added of 20:0:20 NPK (spread around the plant), followed at 9 months with $0.12 \text{ kg tree}^{-1}$ of 20:0:25 NPK fertilizer (broadcast application). Glyphosate was used to keep the area free of weeds, and sulfuramid use prevented problems from leaf-cutting ants.

Post-logging residue averaged 53 Mg ha^{-1} across the site (based on four $0.5 \times 0.5 \text{ m}$ quadrants in each plot), with a range from 38 to 65 Mg ha^{-1} (Figure 2d).

Clonal *Eucalyptus grandis* trees were planted in $3 \times 2 \text{ m}$ spacing, and each plot of 288 m^2 contained 128 trees (4×12 rows). These measurement plots were surrounded by 4 additional rows of trees. The planting lines were oriented toward the slope. The total area of the trial was 1.84 hectares.

Figure 2. Manual soil preparation using a shovel (a); mechanical soil preparation digging holes for each seedling (b); mechanical soil preparation (subsoiling) in furrows done in favor of the slope (c). Treatments with residues removed (a, b, c); residue-retention treatment (d).

Figura 2. Preparo do solo manual com pá (a); preparo do solo com coveador duplo de solo (b); subsolagem a favor do declive. Tratamentos sem resíduos (a, b, c); Tratamento com resíduos (d).

Soil measurements

The intensity of soil preparation was evaluated according to the volume of mobilized soil (VMS). VMS for subsoiling treatment was calculated based on the methodology used by Sasaki and Gonçalves (2005):

$$VMS = AMS \times \frac{10000}{L} \quad (1)$$

where VMS is the volume of mobilized soil ($m^3 ha^{-1}$), AMS is the area of mobilized soil (m^2), and L = length of the spacing between tree rows (3 m). The AMS was measured by the method of resistance zone (BENTIVENHA et al., 2003; STAPE et al., 2002). The procedure involves making a preliminary evaluation of the penetration resistance of soil (to 60 cm) using an impact penetrometer (STOLF et al., 1983) before soil treatment. The survey was repeated after treatment to determine the area's extent of soil disturbance. The measurements of soil resistance were taken with three samples per plot, in transects with total length of 120 cm, being 60 cm left and 60 cm right of the planting line. The surveys were made every 15 cm.

VMS for manual and mechanical soil preparation (digging holes) was calculated similarly to subsoiling, but was also considered the planting space used:

$$VMS = AMS \times W \times \frac{10000}{L \times S} \quad (2)$$

where: VMS = volume of mobilized soil ($m^3 ha^{-1}$), AMS = area of mobilized soil, (m^2), W = width of the hole (0.20 m manual and 0.30 m mechanical), L = length of the spacing between tree rows (3 m), and S = plant spacing (2 m). Two approaches were used to estimate soil erosion (Figure 3). Soil loss was estimated in the 9 plots of the extreme treatments: manual soil preparation with residue retained and mechanical soil preparation with subsoiling and residue removed, as well as a single plot in the control treatment (no residue, no soil preparation and no trees).

The pins method was used in all 24 plots, with an adaptation of the method proposed by Verdolin (1980). To calibrate the pins method, we used the method of the standard plot according

to the methodology proposed by Cogo (1978a; 1978). The pins were 12 mm in diameter, buried exactly 50 cm in to the ground with 5 cm exposed above the soil surface. Fifteen pins were placed systematically in a 14 x 24 m portion of each plot. The length of the exposed portion of each pin was measured 2, 7 and 12 months after planting.

The second method entailed measuring the mass of soil moved from a standard plot of 14 x 24. The plots were fenced with 0.4-m tall galvanized steel sheets, buried to 20 cm depth. Gutters at the lower end of each plot collected overland flow into collection ponds (Figure 4a). Two 500-L collection tanks collected the runoff and a Geib 15-type splitter was used to divert 1/15th of the runoff into a trap for measurement of sediment content (Figure 4b). Tanks were emptied after each major rain event between March, 2004 and February, 2005. The measured soil and water losses were grouped in the same three periods: the first period from establishment to 2 months, the second period of 3 to 7 months, and the third period of 8 to 12 months.

Figure 3. Experimental plot and location of the pins inside the standard plot.

Figura 3. Parcela experimental e localização dos pinos dentro da parcela padrão.

Based on the pins measurements, four rates of earth movement within each plot were calculated: the first was the earth movement within each plot in each period by the mean pins value (PVAR); the second was the earth movement based on the mean of the pins measures in cm, ignoring the surface change of soil in the plot, using the module values (PABS); the third was the maximum value measured, considering the pins to signal the change of surface, where the positive sign indicates soil loss and the negative signal the soil accumulation (PVAX); and the fourth was the maximum value measured through pins disregarding the surface change, using the module values (PABX).

Figure 4. Overview of the standard plot with the sedimentation tank (a); Sedimentation tank using a Geib 15-type splitter (b).

Figura 4. Visão geral da parcela padrão com o tanque de sedimentação (a); Detalhe do tanque de sedimentação utilizando um divisor tipo Geib de 15 janelas (b).

Stepwise backward multiple regressions were used to relate erosion estimates from the pin measurements to various properties of the plots. The regressions used as the dependent variable (y) was the erosion observed in the standard plot, and as independent variables (x1, x2, ... xn) the indices of the pins measurements in different positions within the plot (PVAR, PABS, PVAX, PABX); and local variables, which are the volume of mobilized soil (VMS), slope, soil physical characteristics (porosity, clay content) and features coverage by *Eucalyptus* plantations (coverage factor, aboveground biomass per hectare). Measurements of *Eucalyptus* growth are described in the next topic. Before making the multiple linear regression analysis, Pearson correlation ($P < 0.05$) was performed to assess the degree of collinearity among the variables analyzed, omitting variables with a high degree of correlation.

The multiple linear regressions were implemented in two ways, in order to obtain the soil erosion estimate in the year and in the plots. In the first mode, the equations were established for each of the three periods and 8 observations (disregarding the control plot). In the second mode, we used all 24 observations made during the year to get a single equation for soil erosion. This procedure was adopted due to lack of a strict validation of each of these models separately, assuming that similar trends in erosion estimates would represent greater certainty in interpretation.

Tree measurements

Measurements of total height and canopy diameter in the row and inter-rows were assessed at 3, 6, 9 and 12 months. At 12 months, the diameter at breast height (DBH) was also measured. We used the canopy cover index (ICAP) which represents the stand coverage by young trees (less 1 year). ICAP calculates the tree surface considering it as a cone, being the base diameter equal to the diameter of the tree canopy, and height equal to the tree height (Poggiani and Stape, 2003). We also calculated the mean ground cover (AGC, $m^2 m^{-2}$), which is the ratio between the sum of crown projections and the plot area.

$$ICAP = \frac{D}{2} \sqrt{H^2 + \frac{D^2}{4}} \quad (3)$$

where ICAP is the canopy cover index (m^2); D is the mean diameter (row and inter-rows) of the canopy in m and H is tree height in m.

Aboveground biomass was obtained by the sum of biomass from branch, leaves and wood. The compartments were estimated based on allometric equations obtained from 16 trees at 6 months and 8 trees at 12 months. The trees were felled in the plot boundaries, which had the same mean height of each measurement plot sampled. In the field, the green weight was measured, and a sample was taken to the laboratory for determination of moisture content. These data were used to estimate the total biomass at 3, 6, 9 and 12 months through the equations below. The total biomass per hectare (BLB + BS) was calculated as the sum of each tree in the plot, and subsequent conversion to hectare (Mg ha^{-1}).

$$\text{BLB} = \frac{540 \times \text{ICAP}^{1.1908}}{1000} \quad (4)$$

where BLB (kg) is the sum of leaf and branch biomass and ICAP is the canopy area index (m^2). $n = 24$, $r^2 = 0.97$

$$\text{BS} = 0.001 \times e^{[4.3708 + 2.1455 \times \ln(\text{DBH})]} \quad (5)$$

where BS is the stem biomass (kg tree^{-1}), DBH is diameter at breast height (cm) at 12 months. $n = 8$, $r^2 = 0.70$.

RESULTS AND DISCUSSION

The soil mobilization in the treatment with manually dug holes (0.15 m^2) was about half that of the mechanical pit treatment (0.29 m^2) and subsoiling treatment (0.33 m^2 ; Table 1). Residue retention or removal had no effect on erosion.

Table 1. Treatment means for soil mobilization.

Tabela 1. Médias por tratamento para mobilização do solo.

Treatments				
Soil preparation	Residue	Acronym	Area of mobilized soil (AMS, m^2)	Volume of mobilized soil (VMS, $\text{m}^3 \text{ ha}^{-1}$)
Manual pitting	Removed	MAN	0.18	59
	Retained	MAY	0.14	46
Mechanical pitting	Removed	MEN	0.27	134
	Retained	MEY	0.30	150
Subsoiling	Removed	SUN	0.32	1,070
	Retained	SUY	0.32	1,080
Manual pitting	All	MA	0.15 b	52b
Mechanical pitting	All	ME	0.29 a	142b
Subsoiling	All	SU	0.33 a	1,076a
All	Retained	Y	0.25 a	426 a
All	Removed	N	0.26 a	421 a

Values followed by same letter not statistically different from each other (Tukey test, $P < 0.05$).

We found that the variability of the experimental area was too large for the soil loss (Table 2). This is probably due to differences in soil characteristics (total porosity, clay content, soil compaction, and soil bulk density), microrelief and slope that occurred among the experimental plots in the study area. The analysis of variance for the erosion observed between the two treatments (MAY and SUN), when performed separately for each period, and does not identify significant differences. However, when considering the period of replication there is no clear indication of differences between treatments, with the annual erosion superior to SUN ($12.96 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) when compared to the MAY ($2.4 \text{ Mg ha}^{-1} \text{ yr}^{-1}$).

A study by Bertoni and Lombardi Neto (1999) including 75 profiles of major soil types in São Paulo state showed that soil depth and a selection of soil properties are necessary to establish standardized limits for soil loss tolerances. For a similar soil of our study region, the authors found ranges of tolerance of soil losses ranging from 5.2 to $7.6 \text{ Mg ha}^{-1} \text{ yr}^{-1}$. When using as a tolerance pattern of soil losses for the study area the value of $5.0 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ (lower limit of Bertoni and Lombardi Neto, 1999); treatments MAY and SUN were contrasting with respect to conservation soil.

Table 2. Sediment and runoff (percent of precipitation) generated by manual holes + residue retention (MAY), subsoiling + residue removed (SUN), and control (CON = no soil preparation, no residue, and no trees) by periods (with accumulated rainfall).

Tabela 2. Erosão e escoamento superficial (em porcentagem da precipitação) observados nos tratamentos coveamento manual com resíduo (MAY), subsolagem com resíduos (SUN), e controle (CON = sem preparo, sem resíduo, sem árvores) por períodos de avaliação (com chuva acumulada).

Treatment	Period 1 (306 mm)		Period 2 (300 mm)		Period 3 (754 mm)		Total Year (1360 mm)	
	Erosion (Mg ha ⁻¹)	Runoff (%)	Erosion (Mg ha ⁻¹)	Runoff (%)	Erosion (Mg ha ⁻¹)	Runoff (%)	Erosion (Mg ha ⁻¹)	Runoff (%)
MAY	2.29 (2.18)	2.75 (1.91)	0.07 (0.03)	0.92 (0.69)	0.05 (0.05)	1.16 (1.01)	2.40 (2.25)	1.46 (1.14)
SUN	8.60 (4.88)	2.88 (0.87)	3.57 (1.67)	2.75 (1.17)	0.80 (0.46)	0.47 (0.21)	12.96 (6.81)	1.52 (0.47)
CON	4.96	9.66	0.42	3.51	5.5	4.46	10.88	5.44

Means (standard error of the mean)

Soil loss decreased over time in treatments MAY and SUN, even though the precipitation during period 3 was 754 mm. However, CON plot increased in soil loss with increasing precipitation in the third period. This result demonstrates that the highest soil losses occur soon after soil preparation and when the forest is in the early stage of its establishment and before closing the canopy, showing that it is necessary at this time to adopt proper methods of soil preparation. For the runoff, the trend was the same as the soil loss.

The results observed in the standard plot were, on average, similar to the results of Lima (1988) for the first year of *Eucalyptus grandis* in Quartzipsamment soil in São Paulo state. Cardoso (2003), in an Alfisol moderately rocky soil with *Eucalyptus* plantation at two years of age, planted with manual holes in the region of Aracruz (Espírito Santo state), measured erosion with standard plot in an area with 28.8% slope, and noted a soil loss of 2.38 Mg ha⁻¹ yr⁻¹, similar to that observed for MAY treatment in this study (2.4 Mg ha⁻¹ yr⁻¹). Brito (2004) reported a soil loss of 1.77 Mg ha⁻¹ at 14-mo after establishment using the standard plot method in the initial growth phase of a *Eucalyptus* plantation in the Guanhaes region (MS state) on an Oxisol soil, with 17.6% slope, and site prepared with manual holes. This value is lower than the observed for MAY treatment in this study, due to the lower slope of the plot, and the better physical characteristics of the Oxisol with respect to Ultisol in the experimental area. The wide variability of soil loss is inherent to the erosion evaluation method considering the high variation of soils that occurs in the same region, and the characteristics of the microrelief steep areas.

The predictive erosion equation for each period was made using a multiple linear regression, considering in the analysis all eight standard plots of the MAY and SUN treatments. In multiple linear regressions for the first period (0-2 months), period 2 (3-7 months) and period 3 (8-12 months) are shown in equations 6, 7 and 8 below:

$$y = 24.59 + 5.97x_1 + 2.36x_2 \quad (6)$$

where y is the Ln of soil erosion (Mg ha⁻¹) estimated in period 1, x₁ is the Ln of average ground cover (AGC, m² m⁻²), x₂ is PVAR (pins average value, cm); n = 8, r² = 0.70

$$y = -5.46 + 10.49x \quad (7)$$

where y is the Ln of soil erosion (Mg ha⁻¹) estimated in period 2, and x is PVAR (cm); n = 8, r² = 0.63

$$y = 1.41 - \frac{266.41}{x} \quad (8)$$

where y is the Ln of soil erosion (Mg ha⁻¹) estimated in period 3, and x is VMS (m³ ha⁻¹); n = 8, r² = 0.5

We also performed a multiple linear regression for the first year of the study, without separating the variables into three periods, thus using a joint analysis of 24 observations, as shown in Equation 9:

$$y = 2.94 - \frac{193.09}{x_1} - 1.39x_2 - 0.19x_3 \quad (9)$$

where y is the Ln of soil erosion (Mg ha⁻¹) estimated in the total period, x₁ is VMS (m³ ha⁻¹), x₂ is the Ln of average ground cover (AGC, m² m⁻²), and x₃ is the clay content (%); n = 24, r² = 0.63

PVAR was an important variable in the two earlier periods but was not considered in the last period or the joint equation, as there were most important variables of soil preparation, ground cover

and clay content. The models used tend to underestimate soil erosion, i.e. the models showed soil loss lower than in the standard plot (Table 3). The results of the erosion estimation of pin method in this study were similar to those obtained by Cardoso (2003) in his proposed mathematical model, where the values of soil loss compared with the standard plot were underestimated.

Table 3. Observed erosion and estimated erosion by the period and joint models for the 8 standard plots in all periods, and index values of pins (PVAR) used in the models.

Tabela 3. Erosão observada e erosão estimada pelos modelos por período e global para as 8 parcelas padrão, em todos os períodos, e valores do índice dos pinos (PVAR) utilizados nos modelos.

Period	Treatment	Observed erosion Standard plot	Estimated erosion Period model	Estimated erosion Global model
Mg ha ⁻¹				
1	MAY	2.29 (2.17)	0.71 (0.31)	0.74 (0.25)
	SUN	8.6 (4.88)	6.87 (4.82)	9.45 (3.35)
2	MAY	0.07 (0.04)	0.08 (0.03)	0.14 (0.06)
	SUN	3.57 (1.67)	3.0 (2.2)	3.07 (1.09)
3	MAY	0.05 (0.05)	0.0 (0.0)	0.01 (0.0)
	SUN	0.8 (0.46)	0.19 (0.0)	0.26 (0.08)
Mg ha ⁻¹				
All	MAY	2.4 (2.25)	0.79 (0.31)	0.44 (0.15)
	SUN	12.97 (6.81)	10.06 (4.6)	6.39 (2.21)

Means (standard error of the mean)

Due to the high variability found in the experimental area, no significant difference was found between treatments, for estimated erosion by the period model, and there was no significant difference in the effect of soil preparation factor and the residue factor (Table 4). However, there was a trend with increasing intensity of soil preparation accompanied by higher soil loss. With retained residue there was a decrease in soil loss.

Table 4. Results of the erosion of the year estimated by the period and global models.

Tabela 4. Resultados da erosão hídrica do ano estimada pelos modelos por período e global.

Treatments				
Soil preparation	Residue	Acronym	Period model	Global model
Mg ha ⁻¹ ano ⁻¹				
Manual pitting	Removed	MAN	3.78 a	0.64 .b
	Retained	MAY	0.79 a	0.44 .b
Mechanical pitting	Removed	MEN	3.28 a	2.15 .b
	Retained	MEY	7.20 a	3.07 .b
Subsoiling	Removed	SUN	10.05 a	6.39 ab
	Retained	SUY	4.26 a	13.60 a
Manual pitting	All	MA	7.16 a	10.01 a
Mechanical pitting	All	ME	5.24 a	2.61 b
Subsoiling	All	SU	2.28 a	0.54 b
All	Retained	Y	5.71 a	3.06.
All	Removed	N	4.08 a	5.72.

Values followed by same letter not statistically different from each other (Tukey test, P < 0.05).

For estimated erosion in the joint model, data variability was lower and there were significant differences between treatments. SUY and SUN treatments had higher estimated erosion than the other treatments. There was also a significant difference for the soil preparation factor, where subsoiling was greater compared to the other soil preparation methods. However, there were no effects of the residue factor. The trend of increasing the soil preparation intensity increases the soil erosion was maintained in this estimate.

Comparing the soil erosion estimates with the tolerance of soil losses for the study area, which we assumed to be 5.0 Mg ha⁻¹ yr⁻¹, it is observed that erosion estimation per periods, the treatments SUN and MEY were above the tolerance limit, and in the global model estimation for SUY and SUN treatments were above this limit.

The effect of residue factor for the conditions of the study in the first year after planting was that the plots with retained residue showed the lowest values for the analyzed variables (Table 5). However, these greater differences in the initial period (3 to 6 months) are reduced with time (12 Table 5). Furthermore, several studies have shown that the removal of residue causes a reduction of forest productivity at the end of the cycle or over the rotations (GONÇALVES et al., 2004; 2002; 2000; PAES et al. 2013; ROCHA et al., 2016), because residues work as a source of slow nutrient release to the ecosystem, and increase the organic matter in the topsoil. Thus, the small difference in productivity observed at the end of the first year does not justify the removal of residues in this region.

Table 5. *Eucalyptus grandis* growth for different treatments during the study period.

Tabela 5. Crescimento do *Eucalyptus grandis* por tratamento durante o período de estudo.

Growth	Treatment and factor	Age (month)			
		3	6	9	12
ICAP (m ²)	MAN	0.15 ab	0.47 b	3.21 a	7.44 ab
	MAY	0.12 b	0.42 b	3.03 a	7.33 ab
	MEN	0.18 ab	0.52 ab	3.48 a	7.86 ab
	MEY	0.16 ab	0.46 b	3.05 a	7.02 b
	SUN	0.20a	0.63 a	3.73 a	8.00a
	SUY	0.13 ab	0.45 b	3.17 a	7.70 ab
	MA	0.13 a	0.45 b	3.11 a	7.38 a
	ME	0.17 a	0.49ab	3.26 a	7.44 a
	SU	0.17 a	0.54a	3.45 a	7.85 a
	Y	0.14 b	0.44 b	3.07 b	7.35b
	N	0.18 a	0.54 a	3.47a	7.77 a
Total biomass (kg ha ⁻¹)	MAN	94.72 a	378.67 b	3,631.73	13,678.16 abc
	MAY	74.45 a	327.63 b	3,416.61	13,140.72 bc
	MEN	118.71 a	425.49 ab	3,993.38	14,725.04 ab
	MEY	104.56 a	362.42 b	3,414.13	12,629.11 c
	SUN	138.03 a	526.30 a	4,393.92	15,232.16 a
	SUY	84.70 a	361.05 b	3,572.85	14,149.57 abc
	MA	84.55 a	353.11 b	3,524.12 a	13,409.43 b
	ME	111.60 a	393.89ab	3,703.75 a	13,677.02 ab
	SU	111.36 a	443.64a	3,983.42 a	14,690.47 a
	Y	87.9 b	350.4 b	3,467.85 b	13,306.45 b
	N	117.1 a	443.5 a	4,006.43a	14,544.84 a

Values followed by same letter not statistically different from each other (Tukey test, P < 0.05).

Concerning the aboveground biomass of *Eucalyptus* (leaves, branches, wood, and bark) at the ages of 3 and 9 months there was no significant effect of tillage factor in the treatments (Table 5). At 6 and 12 months, there was a difference between the three tillage factors: with increasing tillage intensity, there was an increase in biomass production.

The positive effect of subsoiling is due to the larger volume of mobilized soil (VMS) in this soil preparation method, providing better physical condition for the initial growth of seedling roots, thus corroborating other studies that found the positive effect of tillage on the tree growth (BAPTISTA; LEVIEN, 2010; CAVICHIOLO, 2005; FINGER et al. 1996; NZILA et al., 1997; PREVEDELLO et al., 2013; SUITER FILHO et al., 1980; OLIVEIRA et al., 2013; VARELIDES; KRITIKOS, 1995). However, there was no statistical difference between mechanized digging and subsoiling. As for the negative effect of the presence of residue on the growth, this may be occurring as a function of nutrient competition, especially for N and P, which are used by soil microorganisms in the decomposition process of residues which by chance have been incorporated into the soil during the tillage operation, thereby reducing the availability of these elements to the *Eucalyptus*. This process is temporary and its duration is determined by the C/N and C/P ratios from plant material. With confirmation of this assumption, a small increase in base fertilization or covering fertilization could eliminate this effect.

To verify the duality between production and soil conservation, it is necessary to associate the soil loss with the forest growth. For that, we relate the variable total biomass at 12 months of age (productivity), and the obtained erosion estimated by both models (sustainability), periods and

joint. Considering as the tolerance limit of soil loss the value of $5 \text{ Mg ha}^{-1} \text{ yr}^{-1}$, and as an appropriate value of initial productivity at 12 months the value of 12 Mg ha^{-1} , and plotting these limits of productivity and soil loss in the graph we obtain four quadrants, where the desired result is that the management result is to obtain more biomass than the stipulated limit (12 Mg ha^{-1}) and with soil losses below estimated tolerance limit ($5 \text{ Mg ha}^{-1} \text{ yr}^{-1}$), which occurs in the upper left quadrant of the graph (Figure 5). This condition is approved for all treatments, except for the subsoiling with no residue (SUN). Moreover, the mechanical digging (MEN), and the subsoiling with no residue (SUN), showed the highest biomass values. This indicates that mechanized digging is an adequate tillage to enable the rapid initial growth of eucalypts, for preparing a soil mobilized area (AMS) similar to the subsoiling area, without preparing a larger volume of mobilized soil (VMS) which is detrimental to soil conservation in steep areas.

Figure 5. Relationship between total shoot biomass at 12 months (productivity) and soil loss estimated by the models per periods and joint (sustainability) for the treatments.

Figura 5. Relação entre a biomassa total do lance aos 12 meses (produtividade) e perda de solo estimada por modelos por período e articulação (sustentabilidade) para os tratamentos.

The difference between the biomass of treatment with mechanical digging and, with and with no residue (MEY and MEN), is not due to tilling factor, since the volume of mobilized soil was similar in both systems, but to the waste factor. This effect is probably due to competition for N and P by soil microorganisms, as mentioned earlier in the process of residue decomposition, and could probably be diminished by the uptake of these nutrients through mineral fertilization.

CONCLUSIONS

Soil preparation with subsoiling in favor of the slope in an area without residue (SUN) was more erosive than the manual tillage with residue (MAY).

The variability found within these two treatments (SUN and MAY) was high, indicating the importance of the repetition of erosion studies in sloping areas.

The aboveground biomass increased with the greater volume of prepared soil. However, there was no statistical difference for biomass, at 1 year of age, between mechanical soil preparation by digging holes and subsoiling in furrows dug in favor of the slope.

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