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Influence of residue management and soil tillage on second rotation *Eucalyptus* growth

Influência do manejo dos resíduos e dos sistemas de preparo do solo no crescimento de eucaliptos em segunda rotação

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Resumo

O manejo dos resíduos da colheita pode alterar muitas características químicas e físicas do solo, considerando as operações mecânicas envolvidas e o impacto sobre o conteúdo da matéria orgânica do solo. Sistemas de preparo do solo e uso de resíduos celulósicos e cinzas como fertilizantes podem ajudar a manter a produtividade e reduzir o efeito do sistema de colheita em uso. Este trabalho foi iniciado após o corte raso de um plantio comercial de *Eucalyptus grandis* Hill ex Maiden com 12 anos de idade, em Mogi Guaçu, São Paulo, em Latossolo Vermelho-Amarelo textura média e com baixa fertilidade natural. Foram testadas remoção e manutenção dos resíduos da colheita, adubação com resíduo celulósico e sistemas de preparo do solo no desenvolvimento do eucalipto e nas alterações das características químicas e físicas do solo. Embora as diferenças não tenham sido significativas, o crescimento (altura e DAP) das árvores foi maior com adição de resíduo celulósico comparado à manutenção dos resíduos da colheita na superfície do solo. Os resíduos industriais adicionados ao solo alteraram a sua fertilidade aumentando o pH e o teor de Ca+Mg, reduzindo o teor de Al+H e tendo pequeno efeito sobre os teores de K e P. A manutenção dos resíduos na superfície aumentou o conteúdo de água disponível na superfície do solo, comparado à retirada total dos resíduos da colheita. O cultivo mínimo teve maior efeito no crescimento das árvores do que aumentar a quantidade de resíduos industriais usados como adubo. Uma maior faixa de subsolagem nas linhas de plantio elevou a compactação do solo a níveis considerados prejudiciais ao crescimento das raízes das plantas.

Palavras-chave: Lodo celulósico decomposto, Propriedades químicas do solo, Propriedades físicas do solo, Cinzas de madeira, Resistência do solo ao penetrômetro

Abstract

Harvesting residue management can change many soil chemical and physical properties, considering the mechanical operations involved and the impact on the organic matter content of the soil. Soil tillage systems and the use of paper and pulp sludge and wood ash as fertilizers can help maintain productivity and reduce the effect of the harvesting system being used. This work was set up after harvesting a 12 year old commercial plantation of *Eucalyptus grandis* Hill ex Maiden, in the Mogi Guaçu district, State of São Paulo, Brazil, on a red-yellow latosol with less than 25% of clay and low fertility level. The influence of removal and maintenance of tree harvesting residues, soil fertilization with pulp and paper residues, and soil tillage systems was tested on eucalypts tree development and on alterations of soil chemical and physical properties. Although the difference was not significant, tree growth (height and DBH) was greater with industrial residue addition compared to maintenance of harvesting residues on soil surface. Industrial residues added to soil changed the fertility capacity, increasing pH and Ca+Mg content, reducing H+Al content, and had a small effect on K and P levels. Keeping tree-harvesting residues on soil surface increased the water content available on surface layer, compared to soil where all residues had been removed. Reducing tillage had greater effect on tree growth than increasing the amount of waste material added as fertilizer. Tilling a wider row for planting lines increased soil compaction at levels considered harmful for plant root growth.

Keywords: Paper and pulp sludge, Wood ash, Soil physical properties, Soil chemical properties, Soil penetrometer resistance

INTRODUCTION

Forest management consists in a series of individual operations that potentially affect soils, either adversely or beneficially. The overall aim is to identify the processes by which soils are changed by forest operations and to interpret information on scale and nature changes. Basic

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requirements for sustainable management are that the impacts of management operations should not exceed the natural capacity of sites to renew or recover.

Soil properties likely to be sensitive to management changes related to forest productivity include organic matter content, nutrient supplying capacity, acidity, bulk density, porosity and available water holding capacity (SCHOENHOLTZ *et al.*, 2000). Degradation of soil physical and chemical properties is likely to occur during timber harvesting and site preparation (POWERS *et al.*, 1998). These authors also stated that forest responses to soil disturbance are not universal, and need to be studied under several environmental conditions.

Forest operations affect nutrient status of soil in forest in several ways (WORREL and HAMPSON, 1997): 1- nutrient removal in harvested timber (whole tree harvesting); 2- disturbance of surface horizons (increase of losses due to mineralization of organic matter); 3- fertilizing that may lead to increased soil nutrient status. According to Grigal (2000), the amount of nutrients removed by harvesting systems combined to the nutrient capital of soils led to differing levels of concern regarding nutrient losses.

Usually, organic nitrogen (N) mineralization is enough to meet tree demands under tropical and subtropical conditions (GONÇALVES and BARROS, 1999), but it depends on the soils mineralizable organic N reserves and the intensity of forest management (especially, harvesting systems). Plantation forestry has recently started in many tropical areas and information about improvement and maintenance of productivity is still limited. In this area, ways of managing the site to sustain productivity is required, considering that most forest soils have a low fertility level.

Long-term studies have shown that fertilizers can normally correct nutrient depletions or deficiencies, except in sites where soil physical properties have also been degraded. The use of heavy harvesting and extraction machinery and whole tree harvesting are operations that can cause long-term impacts on soil physical properties (KOBAYASHI, 1995; WORREL and HAMPSON, 1997). Fox (2000) stated that sandy soils may be susceptible to organic matter loss and nutrient depletion, but are less likely to suffer productivity declines due to soil compaction. Wronski and Murphy (1994) reported that one must consider soil compaction intensity and depth, type of soil, and forest species before choosing a soil tillage system.

Much interest has been directed to the effects of forest harvesting in soil factors, and how to help recover its original conditions. This work aimed to test harvesting residue management systems and their effects on soil physical and chemical properties, to evaluate the effectiveness of soil tillage systems, and to analyze the use of industrial waste material on reclaiming plantation sites of second rotation eucalypts.

MATERIAL AND METHODS

Description of the experimental site

The experiment was set up just after harvesting a 12 year old commercial plantation of *Eucalyptus grandis* Hill ex Maiden, in the Mogi Guaçu district, state of São Paulo, Brazil, located at 22°08'S and 48°05'W and an altitude of 660 m above sea level. The climate was classified as Cwa Köeppen type, with mean annual rainfall about 1350 mm, and the soil as red-yellow latosol (Typic haplorthox), medium textured and gentle slope. Some soil physical and chemical properties before harvesting are presented in Tables 1 and 2. Soil bulk samples were taken at 0.50 m apart from planting line, at four soil depths on every treatment plot (each sample composed by 3 sub-samplings), and analyzed for chemical characterization following laboratory routine analyses: briefly - CEC and exchangeable bases by the method of KCl N; exchangeable Al and H by buffer solution SMP; organic carbon by $K_2Cr_2O_7$ solution at 0.4 N; and available P by H_2SO_4 solution at 0.05 N (EMBRAPA, 1997). At the same spot, depths and time, undisturbed soil samples were taken using metal rings for physical analyses following methodology in Embrapa (1997). In this work, available water holding capacity was considered the difference of soil water content at 10 kPa and 1500 kPa. The lower water tension (10 kPa) is used in this case because, usually, in soil of that texture, at this tension, aeration porosity is greater than 10%, as shown on Table 5. Aeration porosity was considered the difference in porosity of soil at saturated state and at 10 kPa tension. The soil presented very low fertility, organic matter content, and available water holding capacity (Tables 1 and 2). Soil penetrometer resistance was measured at same time and place of soil sampling, and twice on every plot.

Table 1. Soil chemical characteristics before starting the experiment, Mogi Guaçu, SP, May 1998. (Características químicas do solo antes do inicio do experimento, Mogi Guaçu, SP, Maio 1998).

Soil depth	pH $CaCl_2$	K	Ca + Mg	H + Al	CEC	Organic matter	P
cm	c molc dm^{-3}					g dm^{-3}	mg dm^{-3}
0 to 10	3.78	0.05	0.96	7.5	8.5	20.2	2.3
10 to 20	3.99	0.03	0.89	6.2	7.2	12.0	1.1
20 to 30	4.03	0.02	0.89	5.3	6.2	8.1	1
30 to 50	4.10	0.02	0.81	5.0	5.8	7.0	Tr.

Table 2. Soil physical characteristics before starting the experiment, Mogi Guaçu, SP, May 1998. (Características físico-hídricas do solo antes do inicio do experimento. Mogi Guaçu, SP, Maio 1998)

Soil depth	Sand		Silt	Clay	Bulk density	Available water	Aeration porosity
	Coarse	Fine					
cm	g kg^{-1}				Mg m^{-3}	cm³ cm^{-3}	
0 to 10	480	210	110	200	1.451	0.042	0.138
10 to 20	450	230	100	230	1.379	0.048	0.178
20 to 30	450	240	90	230	1.476	0.036	0.129
30 to 50	430	240	80	250	-	-	-

Site Preparation

This work started in September 1998, and the following residue management, soil tillage and fertilization treatments were tested (Table 3).

Chemical fertilizer was placed in soil at a depth of 0.10 m in planting line, while pulp and paper sludge and wood ash were uniformly distributed on soil surface before planting. Space between rows was of 3 m and also between plants in the row. Seedlings of an *Eucalyptus grandis* clone were used. Some chemical characteristics of wood ash and decomposed pulp and paper sludge, which were used as fertilizer, are presented on Table 4, and they are fully described on Guerrini and Moro (1994).

Experimental design

The experiment was set up in randomized blocks and all treatments replicated four times. Plots were composed of 5 rows of 17 plants per row; 15 plants of the 3 central rows were measured for height. Analyses of variance were performed and mean differences were tested using Tukey at 5% for tree growth variables.

Table 3. Harvesting residue management, soil tillage and fertilization for eight treatments studied in this work. (Manejo dos resíduos da colheita, sistemas de preparo do solo e adubação para oito tratamentos estudados neste trabalho)

Treatment	Code	Harvesting residue management[1]	Soil tillage[2]	Fertilization[3]
1	None	None	3-unit-ripper	chemical
2	All	All	3-unit-ripper	chemical
3	Normal	Normal	3-unit-ripper	chemical
4	Normal 1	Normal	3-unit-ripper	chemical + ½ industrial waste
5	Normal 2	Normal	1-unit-ripper	chemical + ½ industrial waste
6	Normal 3	Normal	3-unit-ripper	chemical + industrial waste
7	Normal 4	Normal	1-unit-ripper	chemical + industrial waste
8	None 1	None	3-unit-ripper	chemical + industrial waste

[1]Harvesting residue management: None - all harvesting residues were removed from site, including litter; All – all- harvesting residues were kept on soil surface; Normal – branches and stems smaller than 3 cm in diameter and leaves were kept on soil surface.

[2]Soil tillage – Just planting line were tilled, using a ripper with one-unit (1s) and three units (3s).

[3]Fertilization – chemical – it was applied 200 kg/ha of fertilizer formula 6-26-13; ½ industrial waste (f)– it was applied 7.5 Mg/ha of pulp and paper sludge + 2 Mg/ha of wood ashes; industrial waste (F) – it was applied 15 Mg/ha of pulp and paper sludge + 4 Mg/ha of wood ashes.

Table 4. Some chemical characteristics of wood ash and decomposed pulp and paper sludge used on the experimental site. (Algumas características químicas da cinza e do resíduo decomposto de papel e celulose).

Chemical characteristics	Wood ash	Decomposed pulp and paper sludge
pH ($CaCl_2$)	8.8	7.5
Total Ca, %	1.84	1.55
Total P_2O_5, %	0.26	0.09
Total K_2O, %	0.54	0.07
Total Mg, %	0.16	0.09
C/N relationship (organic C and total N)	30/1	25/1

Font: Guerrini and Moro, 1994

RESULTS AND DISCUSSION

Changes in soil chemical characteristics due to fertilization and harvesting residue management were observed in pH, Ca+Mg and H+Al data (treatments None1, Normal1 and Normal2), due to the Ca concentration in the industrial waste used. Most of these soil characteristics changes were influenced by the amount of added calcium, causing Butler and Mays (1993) to suggest the use of wood ash as a substitute to lime, with the advantage of having other plant nutrients in it. Using industrial waste materials, Sahm *et al.* (1993) found an increase in available cations in the soil, but Guerrini and Moro (1994) stated it was mainly in calcium content. P is usually very low in tropical soils; on two treatments - None and None1 (Table 5) - where harvesting residues were removed, they showed the lowest level of this plant nutrient, independent of receiving waste material or not.

An important characteristic of the soil where this experiment is being conducted is water availability for plants. Due to its texture and very low organic matter content, the amount of available water is low. Any measure to improve this soil characteristic is very important, and following data reported in Table 6, the maintenance of harvesting residues allowed an increase of almost 50% in the amount of available water on the soil surface layer. It does not represent a huge increment in absolute terms (from 3 to 6 %), but considering the percentage of increase, it was very important.

Table 5. Soil chemical characteristics from residue management treatments, in different soil depths, 3 years after application, Mogi Guaçu, SP, 2001. (Características químicas do solo dos tratamentos de manejo de resíduos, em diferentes profundidades, 3 anos após aplicação, Mogi Guaçu, SP, 2001).

Treatment	Soil depth	pH	CEC	K	Ca + Mg	H + Al	P
	cm	$CaCl_2$	c molc dm^{-3}				mg dm^{-3}
All	0 to 5	3.67	9.5	0.05	0.40	9.0	3.4
	5 to 10	3.84	8.9	0.02	0.21	8.7	2.3
	10 to 20	3.90	8.3	0.02	0.22	8.1	0.5
	20 to 30	3.93	5.8	0.02	0.23	5.6	0
None	0 to 5	3.82	8.0	0.04	0.22	7.8	2.3
	5 to 10	3.90	7.3	0.04	0.29	6.9	1.6
	10 to 20	3.83	6.2	0.05	0.19	6.0	1
	20 to 30	3.87	6.2	0.02	0.22	6.0	0
None1	0 to 5	4.97	5.3	0.06	0.47	4.8	2.4
	5 to 10	4.59	5.0	0.05	0.28	4.6	1.1
	10 to 20	4.05	4.9	0.05	0.24	4.6	0
	20 to 30	4.29	4.8	0.09	0.23	4.4	0
Normal	0 to 5	3.35	11.1	0.06	0.21	10.9	4.1
	5 to 10	3.67	9.6	0.05	0.24	9.4	1.4
	10 to 20	3.84	8.6	0.03	0.17	8.4	0.8
	20 to 30	4.00	5.5	0.03	0.29	5.2	0
Normal1	0 to 5	4.73	5.3	0.06	0.42	4.78	5.4
	5 to 10	4.02	8.0	0.03	0.23	7.76	0
	10 to 20	3.99	5.6	0.06	0.21	5.35	0
	20 to 30	3.98	5.3	0.04	0.30	4.96	0
Normal2	0 to 5	5.11	5.3	0.07	0.64	4.61	6.9
	5 to 10	3.77	9.1	0.04	0.42	8.68	1
	10 to 20	3.76	8.4	0.02	0.36	8.05	0
	20 to 30	3.86	6.7	0.03	0.47	6.21	0

Table 6. Soil physical characteristics measured in two residue management treatments, three years after planting, in Mogi Guaçu, SP, Brazil, 2001. (Características físico-hídricas do solo em dois tratamentos de manejo de resíduos, três anos após o plantio, Mogi Guaçu, SP, 2001).

Treatment	Soil depth	Bulk density	Available water	Aeration porosity
	cm	kg dm^{-3}	cm^3 cm^{-3}	
None	0 to 10	1.414	0.031	0.134
	10 to 20	1.412	0.040	0.158
	20 to 30	1.303	0.022	0.181
All	0 to 10	1.278	0.065	0.218
	10 to 20	1.318	0.063	0.186
	20 to 30	1.552	0.038	0.096
Normal2	0 to 10	1.437	0.024	0.146
	10 to 20	1.306	0.042	0.240
	20 to 30	1.456	0.037	0.160

Measurements of penetrometer resistance in soil tilled using a one-unit (Normal1) and a three-unit-ripper (Normal2), starting at the planting line and moving toward interrow center at every 25 cm, are shown on Figure 1. Soil penetrometer resistance was very low at planting line for both treatments, because soil was tilled only at the planting line. As it moved farther from planting line, penetrometer resistance values rose, reaching harmful limits for plant root growth. Hamblin (1985) stated that critical values at which root growth is inhibited range from 1 to 4 MPa, depending on soil mechanical composition, pore water pressure and plant species. Same author found that a value of 3.6 MPa inhibited oat root growth in the tilled Ap horizon, but that the critical value rises to 5 MPa in the untilled subsoil because a continuous pore system had developed in that horizon. Sands *et al.* (1979), working with medium textured soils, stated that when soil penetrometer resistance was greater than 3 MPa, a severe reduction of *Pinus radiata* root growth occurred.

The increase in soil penetrometer resistance values for treatment Normal1 was observed at 0.25 m from planting line reached maximum values at 0.50 m and then decreased (Figure 1). For treatment Normal2, values of penetrometer resistance increased at a slower rate and reached its maximum values at 0.5 and 1 m from planting line. This change in the values of soil penetrometer resistance in the three-unit-ripper treatment (Normal2) was due to a wider row of tilled soil, as the tractor tires exerted greater pressure on soil surface when pulling the equipment. Besides increasing soil compaction on track rows, soil tilled with a three-unit-ripper has its aeration porosity increased, increasing soil water loss either by deep drainage or by evaporation.

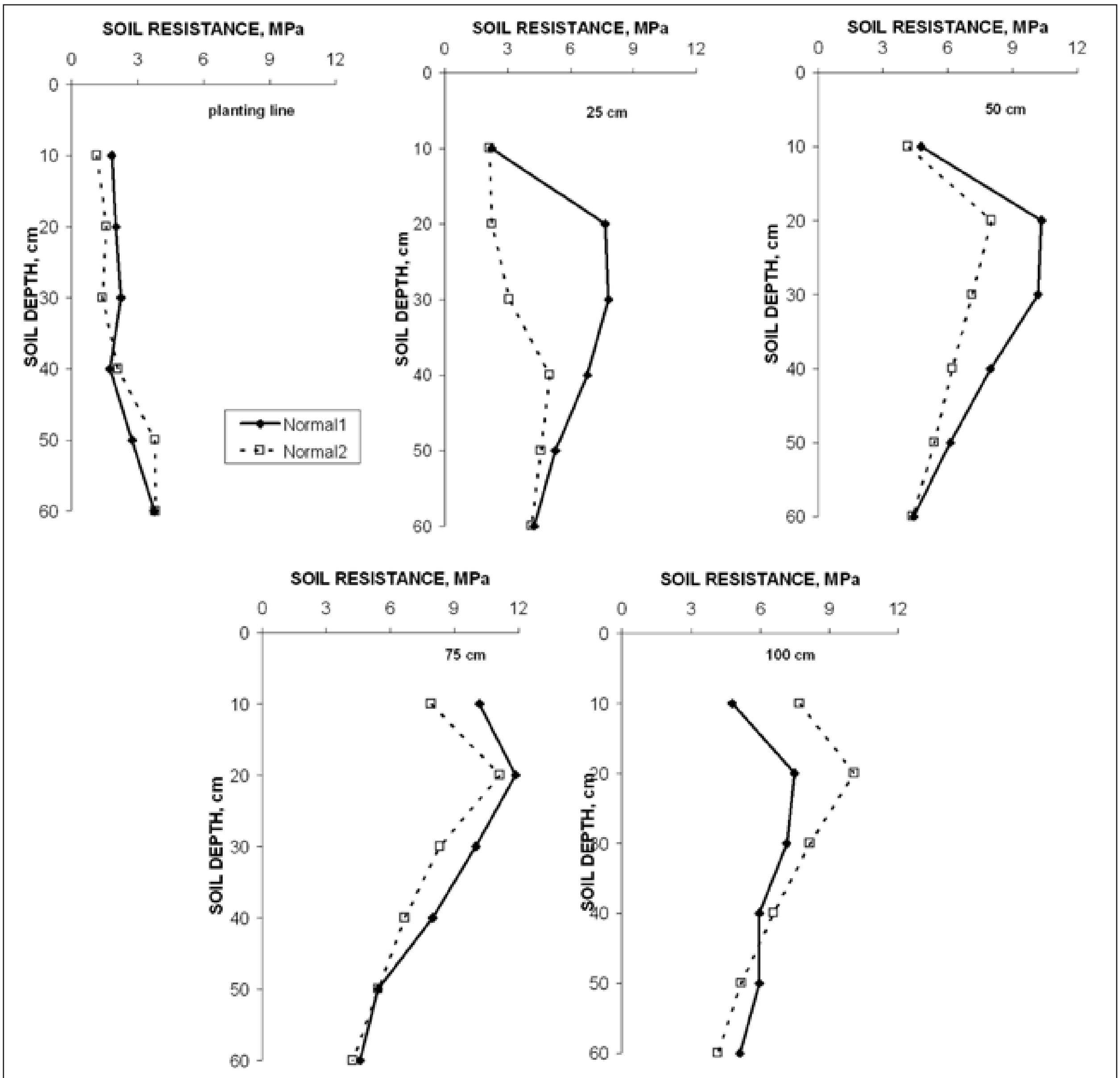

Figure 1. Soil penetrometer resistance data (MPa) measured by soil tillage treatments at different distances from planting line (planting line, 25, 50, 75 and 100 cm) and soil depths, in Mogi Guaçu, SP, 2001. (Resistência do solo ao penetrômetro por sistemas de preparo de solo a diferentes distâncias da linha de plantio (linha de plantio, 25, 50, 75 e 100 cm) e profundidades do solo, Mogi Guaçu, SP, 2001).

The greatest penetrometer resistance values were observed around 20 to 30 cm from soil surface for both soil tillage systems being tested. Soil bulk density and penetrometer resistance had greater values at the same depth on a similar sandy soil (DEDECEK e GAVA, 2005), while on a clay soil, the depth of greatest penetrometer resistance values was at the 10 to 20 cm soil layer.

Eucalyptus height and DBH measurements are presented on Table 6, from the first (1999) to the fourth year (2002) after planting. The lowest values for both measurements of tree growth were observed on treatment 1 (None), where all residues had been removed from the site (Table 7). Treatment 8 (None1), which also had all the harvesting residues removed but received, besides chemical fertilization, an addition of pulp and paper sludge and wood ash, showed high tree growth. This industrial material, added to supplement soil fertility, has been able to balance the removal of harvesting residues from soil surface.

In 2002, there was no significant statistical difference in DBH among the treatments that kept residues in place or those that added them (treatments 2 to 8). Likewise, treatments 1, 2 and 3, which had different harvesting residue management and received only chemical fertilizers, did not differ in the same variable (Table 7). Differences among these three treatments were greater in the second and third years (2000 and 2001) and declined at the last measurement (2002). Considering tree height, differences among treatments were smaller and changed very little from the first (1999) to the last year of measurement (2002).

The following figures (2, 3 and 4) were separated to allow a better understanding of the effects of harvesting residues, industrial wastes and soil tillage on tree growth.

Table 7. *Eucalyptus* height and DBH measurements from one (/99) to four years (/02) after planting for each treatment tested. (Altura e DAP das plantas de eucaliptos de um (99) aos quatro anos (02) após plantio para cada tratamento testado).

Treatment	Height				DBH		
	1999	2000	2001	2002	2000	2001	2002
	m				cm		
None	4.3b	10.7b	19,2a	22.9b	7,7c	11.0c	12.1b
All	4.7ab	11.8ab	21.1a	24.0ab	8.5b	12.6ab	13.1ab
Normal	4.4b	11.7ab	20.3a	24.0ab	8.6ab	11.8bc	13.0ab
Normal 1	4.8ab	12.0ab	21.3a	25.2ab	9.3a	12.8a	14.0a
Normal 2	5.0a	12.9a	21.9a	25.3a	9.1a	13.1a	14.0a
Normal 3	4.7ab	12.5a	21.5a	24.7ab	9.2a	13.3a	14.0a
Normal 4	5.2a	12.6a	22.0a	25.4a	9.2a	13.3a	14.4a
None 1	4.9ab	12.8a	21.8a	25.2ab	9.5a	13.1a	14.2a
CV, %	3,8	4,1	6,7	5,0	2,9	2,6	4,6

Obs: Different letters after average means that they differed from each other by Tukey test at 5%.

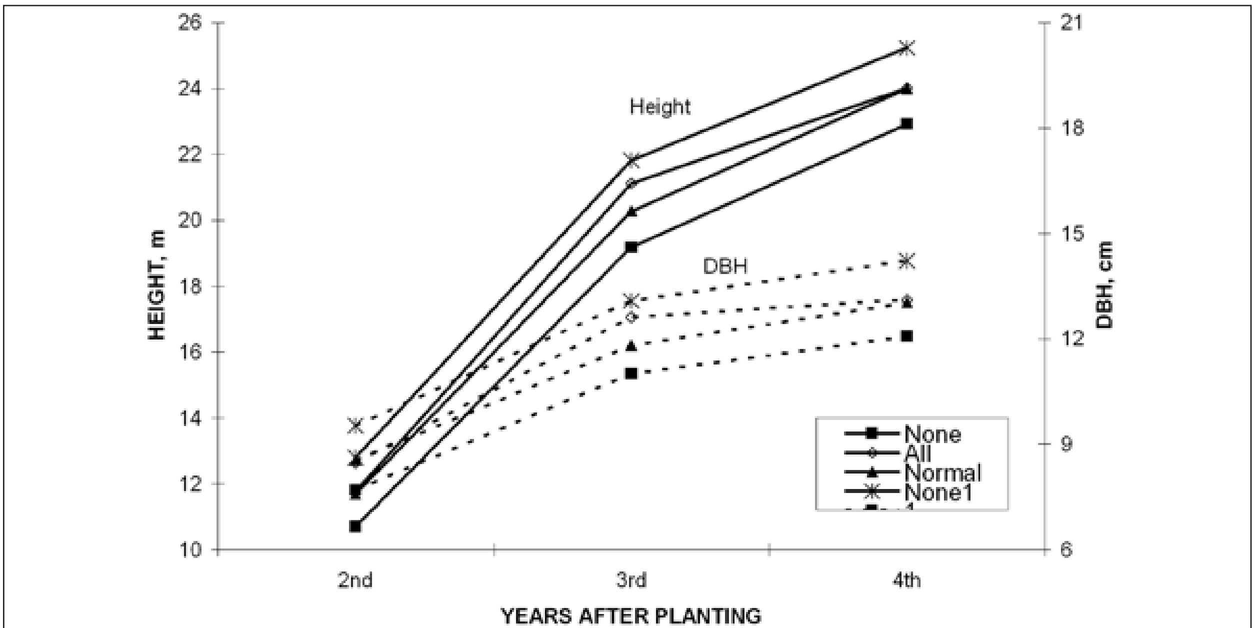

Figure 2. *Eucalyptus* tree height (full line) and DBH (dashed line) measured by residue management treatments from second (/00) to fourth (/02) years after planting, Mogi Guaçu, SP, 2002. (Altura e DAP dos eucaliptos por tratamentos de manejo de resíduos do segundo (00) ao quarto (02) ano após o plantio, Mogi Guaçu, SP, 2002).

Comparing measurements from third and fourth years, it can be noticed on Figure 2 that the difference between treatment with all residues (All) and the one with residues smaller than 3 cm in diameter on soil surface (Normal) has been overcome. It seems that the amount of harvesting residues that remained after planting is no longer important, and part of nutrients for tree growth come from its own leaves and branches recycling. The same could not be seen when comparing treatments 2 and 3 to treatment 1(None).

Increase in tree growth, obtained by addition of pulp and paper sludge (None 1), implies in additional costs. All harvesting residues are removed from field to industry for energy purposes and then the industrial residues and ashes are taken back to the field to increase soil fertility. Costs involved in transportation have to be considered and compared to growth increase, besides considering soil sustainability. This is a more important matter; as the prices of gas or diesel raise and/or the distance from field to the industry increases, it becomes an important issue.

Figure 3 shows the effect of different tillage systems being tested with the same harvesting residue management. Treatments Normal 1 and 2 received half the amount of industrial waste (7.5 Mg ha^{-1}of pulp and paper sludge and 2 Mg ha^{-1}of wood ash) and treatments Normal 3 and 4, total amount (14 Mg ha^{-1}of pulp and paper sludge and 4 Mg ha^{-1}of wood ash) (Table 3). *Eucalyptus* growth was superior using a one-unit-ripper (treatments Normal 2 and 4) than using a three-unit-ripper (treatments Normal 1 and 3), independent of the amount of waste being added. It is likely that soil moisture availability, in this condition, is far more important than soil nutrient content. Tilling soil in wider strips would increase the amount and the speed in which rainfall water would be lost by deep drainage. Stape (2002) found, in areas with a longer drought period, that water was the most limiting resource, and eucalypts net production increased by 2.3 Mg ha^{-1} yr^{-1} for each 100 mm yr^{-1} increase in rainfall.

Aeration porosity reported on Table 2 was calculated at the same water tension range used for macroporosity (soil pores greater than 5 mm), and it was around 40% of total porosity. Considering these values, there is no need to loosen the soil deeper and more intensively. Cavichiolo (2001), working on a commercial *Eucalyptus saligna* coppice, reported that loosening a sandy soil with a ripper or harrowing, reduced tree growth, compared to the control plot without any soil tillage. A high negative correlation between aeration porosity and DBH increments, one year after tilling soil with harrow and ripper, was also found.

Treatments reported in Figure 4 differ from each other by the amount of industrial waste added, since soil tillage and tree harvesting residues are the same for all of them. In that situation, use of pulp and paper sludge and wood ash has increased tree growth, compared to treatment Normal, which did not receive this material.

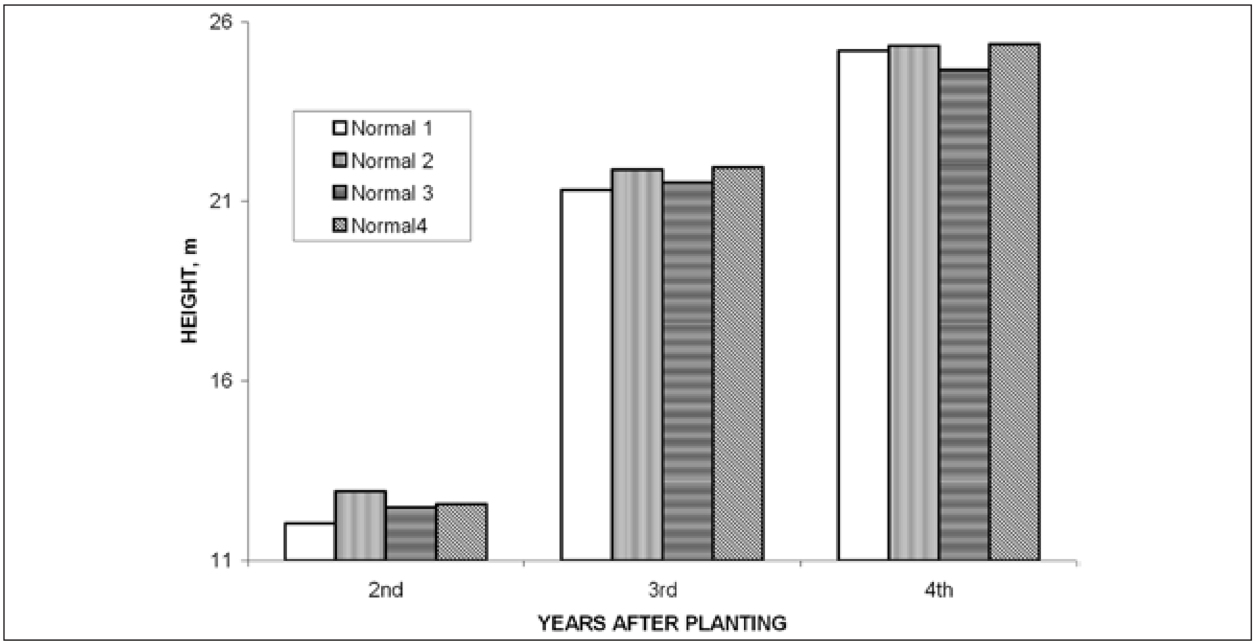

Figure 3. Data of *Eucalyptus* tree height measured by soil tillage treatments from second (2000) to fourth (2002) years after planting, Mogi Guaçu, SP, 2002. (Altura dos eucaliptos por sistemas de preparo do solo do segundo (2000) ao quarto (2002) ano após plantio, Mogi Guaçu, SP, 2002).

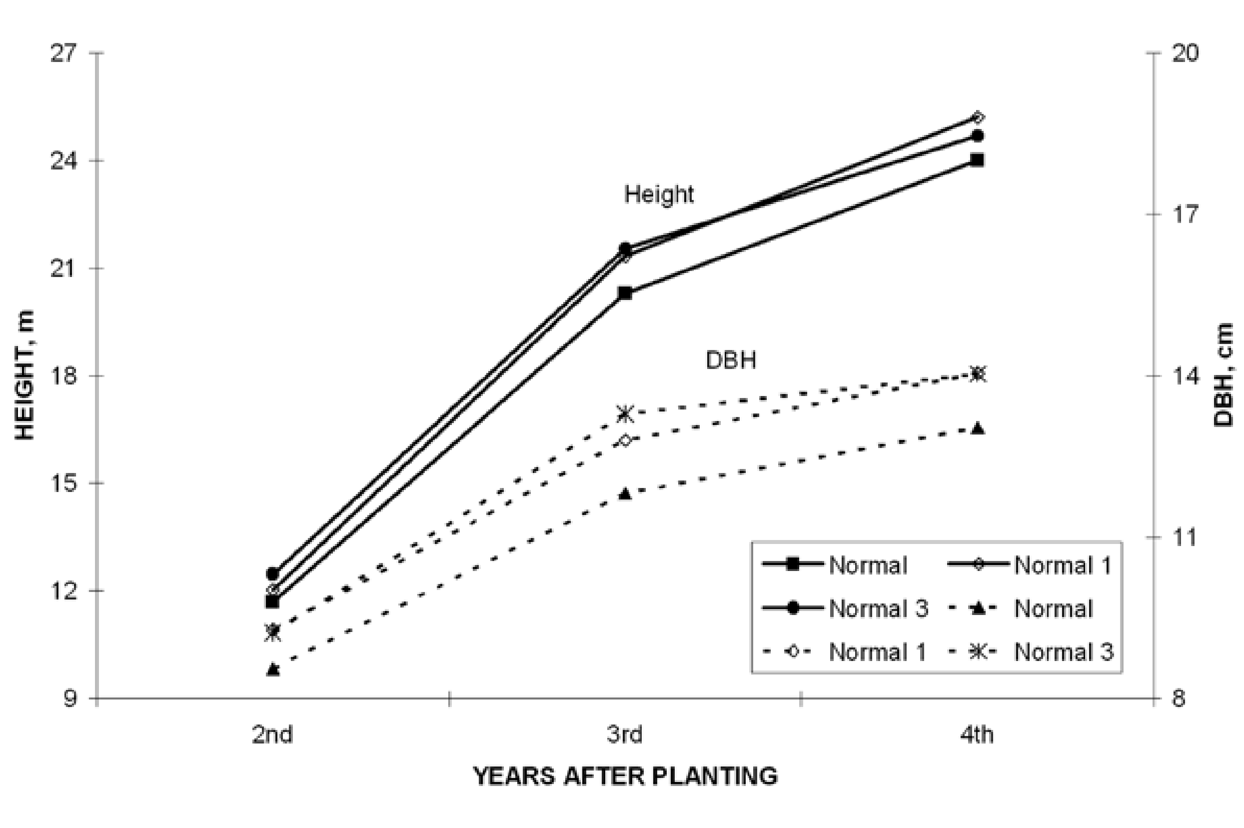

Figure 4. *Eucalyptus* tree height (full line) and DBH (dashed line) measured by fertilizer level treatments, from second (/00) to fourth (/02) years after planting, Mogi Guaçu, SP, Brazil, 2002. (Altura e DAP dos eucaliptos por tratamentos de adubação, do segundo (00) ao quarto (02) ano após plantio, Mogi Guaçu, SP, 2002).

Although the effect on tree growth was not significantly different, there is a very slight difference between using the total (treatment Normal 3) or just half (treatment Normal 1) of the amount of industrial waste. As reported by Guerrini and Moro (1994), macronutrient content, either in pulp and paper sludge or in wood ash, is less than 0.5%, except for Ca, which is over 1.5% for both. These authors concluded that applying pulp and paper sludge and wood ash increased soil fertility for about two years, after which it would level down to the natural soil fertility.

On Table 4, it is observed that the contribution obtained with the addition of industrial residues in tree growth is about the same obtained keeping harvesting residues in place, with increased transportation costs. There are also some questions about the appropriate nutrient balance of this waste material being added to the soil to meet plant requirements, especially compared to the tree harvesting residues.

CONCLUSIONS

Four years after planting, it was possible to conclude, considering soil type and the species that:

• maintenance of all tree harvesting residues on soil surface favors a greater *Eucalyptus* growth, concerning height and DBH;
• addition of paper and pulp sludge and wood ash has a positive effect on tree growth, that can, in the short run , overcome harvesting residues removal;
• industrial residues can be used to improve tree growth, but keeping harvesting residues on soil surface is less costly and has a better nutrient availability;
• keeping tree harvesting residues on soil surface allows an increment in soil available water content, mainly on the surface layer;
• reducing soil tillage width increases tree growth, and it is more effective than increasing amount of waste material added to soil;
• values of soil penetrometer resistance are greater than the critical ones at the 20 to 30 cm soil layer and at around 1 m from planting lines.

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