



Variables influencing working time and skidder productivity in wood extraction

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ABSTRACT: The effects of certain operational variables on working time and skidder productivity in wood extraction in *Eucalyptus grandis* stands were investigated in this research. The study was conducted at a forestry plantation located in the municipality of Telêmaco Borba, Paraná State. Through a time and motion study the operational cycle time, mechanical availability, operational efficiency and productivity in relation to the variables volume, cycle time and extraction distance were quantified. The data were analyzed using Tukey's test at 5% probability and then fitted to a statistical model to explain the behavior of the variables in terms of machine productivity. Results showed that the time consumed by the empty and loaded travel phases was 20.4 and 45.0% of the total operational cycle time, respectively. Extraction distance directly affected the elements of operational cycle time and machine productivity, making it an important variable to consider in operational planning. The independent variables used explained around 82% of the skidder productivity variation, with the proposed model being suitable for use in wood extraction under similar conditions.

Keywords: forest harvest, planning, operational efficiency.

Variáveis de influência no tempo de trabalho e produtividade do skidder na extração de madeira

RESUMO: O efeito de algumas variáveis operacionais sobre o tempo de trabalho e a produtividade de um skidder na extração da madeira em povoamentos de *Eucalyptus grandis* foram estudados nesta pesquisa. O estudo foi conduzido em uma empresa florestal localizada no município de Telêmaco Borba, Paraná. Por meio de um estudo de tempos e movimentos foram quantificando os tempos do ciclo operacional, a disponibilidade mecânica, a eficiência operacional e a produtividade em relação às variáveis volume e tempo do ciclo e distância de extração. Os dados foram analisados pelo teste de Tukey ao nível de 5% de probabilidade e ajustado um modelo estatístico para explicar o comportamento das variáveis na produtividade da máquina. Os resultados mostraram que os tempos requeridos pelos elementos viagem vazio e viagem carregado foram de 20,4 e 45,0% em relação ao tempo total do ciclo operacional, respectivamente. A distância de extração afetou diretamente os tempos dos elementos do ciclo operacional e a produtividade da máquina, sendo uma variável importante a ser considerada no planejamento operacional. As variáveis independentes utilizadas nas análises explicaram em torno de 82% da variação da produtividade do skidder, sendo o modelo proposto adequado para uso na extração de madeira em condições semelhantes.

Palavras-chave: colheita florestal, planejamento, eficiência operacional.

1. INTRODUCTION

Forestry harvesting and transportation are important activities in the productive sector, mainly from an economic point of view, accounting for 50% or more of the total costs involved for industry in wood production (MACHADO et al., 2014). Additionally, they present a high complexity and the interference of technical, environmental and ergonomic factors affect the realization of operations. Due to technological advances and an intensification of mechanization in recent years, adequate selection of machines and equipment is required for the development of efficient operating systems as well as a need for continuous evaluation of operating and

forestry operation costs (SIMÕES et al., 2010; SILVA et al., 2014).

In forestry harvesting, extraction is the stage that requires greatest emphasis, due to its complex execution, involving as it does the transportation of the wood from the interior to the edge of the section or intermediate yard. It is influenced by several factors, such as the stand characteristics, relief conditions, extraction distance, types of machines, and operator experience, amongst others (SEIXAS; CASTRO, 2014; OLIVEIRA et al., 2009).

To determine the real productive capacity and machine costs, it is necessary to know the influence variables in the operations, to allow efficient planning and productivity

predictions under different operational conditions to ensure adequate operational outcomes, as well as to determine the scale and feasibility of new wood harvesting systems (MALINOVSKI et al., 2006).

Amongst the studies that sought to identify the behavior of variables in wood extraction operations, Schettino et al. (2015), in a group study of the skidder and clambunck-skidder machines, verified that stand volumetry significantly influences machine productivity. Santos et al. (2013) verified that productivity and production costs of the skidder were directly affected by the extraction distance, such that with increased distance, a reduction in productivity and an increase in production costs is observed.

Fiedler et al. (2008) showed that the variables of greatest influence on skidder productivity were the extraction distance and the volume of the bunch of trees. Rocha et al. (2009) studying a full tree harvesting system in *Eucalyptus* spp. stands found that distance affected machine productivity, with empty and loaded travel times and maneuvering accounting for most of the operational cycle.

Given the complexity and high costs of wood extraction, the objective was to evaluate the effect of certain operational variables on the required working time and the skidder productivity in wood extraction, allowing a better understanding of the behavior of these variables and assisting in the efficient planning of forestry operations.

2. MATERIAL AND METHODS

2.1. Study area

The research was carried out in wood harvesting areas of a forestry company located in the municipality of Telêmaco Borba, Paraná State, located at the geographical coordinates 24°19'26" S and 50°36'07" W at an average altitude of 760 m.

The climate of the region according to Köppen's climatic classification system is between Cfa and Cfb, with an average temperature in the coldest month below 18 °C and in the hottest month above 22 °C. The average annual relative humidity is between 70 to 75%, with average annual rainfall of 1,400 to 1,600 mm (CAVIGLIONE et al., 2000).

The predominant soil type in the study area, according to the information obtained from the company is Red Oxisol of clayey texture, while the relief was classified as smooth to wavy, with an average slope of 6%. The management regime adopted by the company was clear-cut, with timber used for the production of pulp and paper.

Dendrometric characteristics of the studied forest stand are described in Table 1.

Table 1. Forest stand characteristics studied.

Tabela 1. Características do povoamento florestal estudado.

Species	<i>Eucalyptus grandis</i> Hill ex. Maiden
Cutting age (months)	84
Spacing (m)	2.5 x 2.5
Basal area (m ² ha ⁻¹)	38.0 ± 3.34
Average DBH (cm)	19.2 ± 1.94
Average height (m)	27.6 ± 2.20
Average individual volume (m ³)	0.36 ± 0.04
Average volume (m ³ ha ⁻¹)	430 ± 59.40

Where: DBH = diameter at breast height; ± standard deviation.

2.2. Forestry machine evaluation

The wood harvesting system used by the company was full tree, using a feller buncher, which cut the trees into four-row structures with subsequent stacking of the trees inside the section. The skidder then dragged the trees to the edge of the section, while the harvester processed the wood into logs of 7.2 m in length.

A skidder forestry tractor was tested with Eco-Tracks brand wheels and forward tracks, 6WD, 186 kW gross power; 22.7 Mg operating weight, 1.95 m² area claw, 19,900 hours of use.

2.3. Sample procedure

Sampling was realized according to the methodology proposed by Barnes (1977), by means of a pilot time and motion study, obtaining the minimum number of observations of the operational cycle of the machine, in order to provide a limit of sampling error maximum of 5%, through of the following Equation 1:

$$n \geq \frac{t^2 \times CV^2}{EL^2}$$

where: n - minimum number of cycles required; t - value of t, for the desired probability level and (n-1) degrees of freedom; CV - coefficient of variation, in percentage; and EL - permissible error limit, in percentage.

2.4. Operational variables analysis

Operational variables analysis and the determination of the mechanical and technical availability, operational efficiency and skidder productivity was carried out using a time and motion study of the wood extraction process, through a continuous timing method, with the operational cycle being divided into the following elements:

- Empty travel: Time consumed by the machine in moving from the roadside to the bunch of trees arranged inside the section.
- Maneuvering and loading: Time consumed in maneuvering and loading the bunch of trees arranged inside the section.
- Loaded travel: Time consumed by the machine in dragging the bunch of trees from the inside to the edge of the section.
- Unloading and maneuvering: Time consumed by the machine unloading the bunch of trees and maneuvering to restart a new work cycle.
- Interruptions: Time related to machine stops for various reasons.

The study was performed with an experienced operator working at a normal pace, with the data being obtained at the different extraction distances traveled by the machine, being organized into five distances: 0 to 50 m; 51 to 100 m; 101 to 150 m; 151 to 200 m; and over 200 m.

a) Mechanical availability

The time the machine was mechanically able to perform productive work in relation to the programmed time, discounting the times in preventive and/or corrective maintenance, obtained by Equation 2:

$$MA = \frac{TP - TM}{TP} \times 100$$

where: MA - mechanical availability (%); TP - time programmed for working (hours); and TM - time spent in preventive and corrective maintenance (hours).

b) Technical availability

Relation between the effective working time and the available time of the machine to work, discounting maintenance time, obtained using Equation 3:

$$TA = \frac{TD - TI}{TD} \times 100$$

where: TA - technical availability (%); TD - time available to work (hours); and TI - operational and non-operational interruptions (hours).

c) Operational efficiency

Percentage of the time during which the machine was effectively operational, discounting time for preventive and corrective maintenance and operational and non-operational interruptions, obtained using Equation 4:

$$OE = \frac{ET}{TP} \times 100$$

where: OE - operational efficiency (%); ET - effective working time (hours); and TP - time programmed for working (hours).

d) Productivity

Productivity was obtained by means of the mean volume of trees, provided by the company inventory, multiplied by the total number of trees dragged, and then the total value divided by the hours actually worked, according to Equation 5:

$$Pr = \frac{N \times V}{He}$$

where: Pr - productivity ($m^3 \text{ he}^{-1}$); N - total number of trees dragged; V - average volume per tree with bark (m^3) and; He - actual hours of work.

2.5. Statistical analysis

For the statistical analysis, a completely randomized design was adopted, and the variables: operational cycle time and productivity at the different extraction distances were evaluated. Initially, the kolmogorov-smirnov normality test was performed, followed by the Bartlett test to verify the homogeneity of the variances, and then, when necessary, the averages compared using the Tukey test at 5% error probability level.

A multiple linear regression analysis was carried out to verify the relationship between the dependent variable "productivity" and the independent "cycle time", "cycle volume" and "extraction distance" variables. Fitted equation was evaluated by means of the coefficient of determination and standard error of the absolute estimate.

3. RESULTS

A total of 479 operational cycles were assessed, with only 151 being necessary to achieve an allowable error limit of 5%.

Table 2 shows the average duration of the elements of the skidder operating cycle at the different extraction distances. Loaded and empty travel times occupied most of the operational cycle, being 45.0 and 20.4% of the total time, respectively. Maneuvering and loading, and unloading and maneuvering times consumed 17.8% and 17.0% of the total operational cycle time, respectively. Additionally, the empty and loaded travel stages presented significant differences between all the extraction distances evaluated.

The average mechanical and technical availability of the skidder was 83.8% and 89.2%, respectively, and average operating efficiency was 74.7%.

Figure 1 shows the operational cycle time and the effective skidder productivity in the different extraction distance classes. There was a significant difference in practically all the extraction distances, where the productivity ranged from 160.5 m^3 .

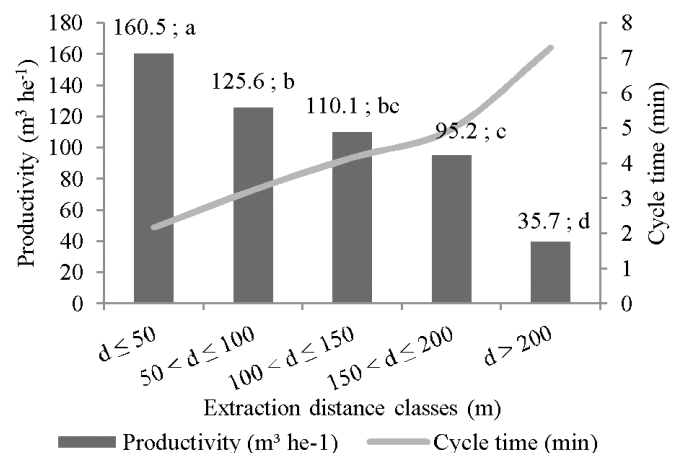
Table 3 shows the average productivity and the variables of extraction, volume and operational cycle time, while Figure 2 shows the estimated skidder productivity at the different extraction distances. As can be seen, 82% of the variability of the dependent variable was explained by independent variables, with an absolute error of 31.88 $m^3 \text{ he}^{-1}$.

Table 2. Average time of the operational cycle elements of skidder over different distances of wood extraction.

Tabela 2. Tempo médio dos elementos do ciclo operacional do skidder nas diferentes distâncias de extração da madeira.

Cycle elements	Extraction distance classes (m)					Average
	0-50	51-100	101-150	151-200	201-250	
	Time (minutes)					
ET	0.41 d	0.65 c	1.00 b	0.97 b	1.45 a	0.90
ML	0.46 c	0.77 b	0.85 ab	0.79 ab	1.07 a	0.79
LT	0.71 e	1.23 d	1.74 c	2.42 b	3.83 a	1.99
UM	0.71 a	0.74 a	0.68 a	0.72 a	0.90 a	0.75
TT	2.29 e	3.39 d	4.27 c	4.91 b	7.26 a	4.42

Where: Averages followed by the same letter in the lines do not differ statistically (Tukey, $p > 0.05$); ET: empty travel; ML: maneuvering and loading; LT: loaded travel; UM: unloading and maneuvering; TT: total operational time of the operational cycle.



Where: vertical bars with averages followed by the same letter do not differ statistically (Tukey, $p > 0.05$).

Figure 1. Behavior of the operational cycle time and skidder productivity at the different distances for wood extraction.

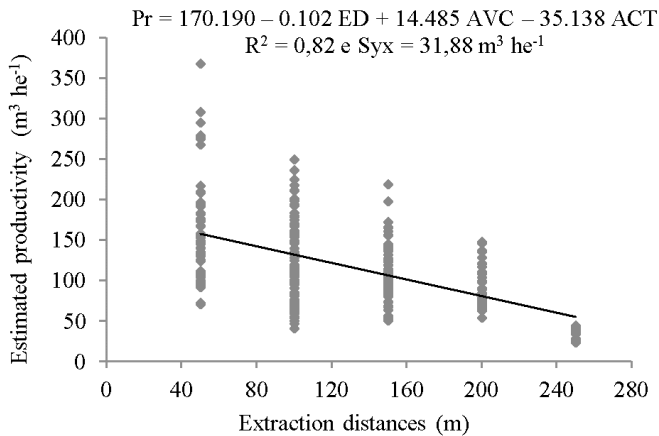
Figura 1. Comportamento do tempo do ciclo operacional e produtividade do skidder nas diferentes distâncias de extração.

Table 3. Descriptive statistics for productivity, extraction distance, average volume per cycle and time cycle of the skidder at the different distances for wood extraction.

Tabela 3. Estatística descritiva da produtividade, distância de extração, volume médio por ciclo e tempo médio do ciclo do skidder na extração de madeira.

Variable	Average	Standard deviation	CV (%)	Medium	Maximum	Minimum
Pr (m ³ he ⁻¹)	105.41	53.68	50.92	110.17	368.67	23.77
ED (m)	124.82	57.62	46.16	100.00	250.00	50.00
AVC (m ³)	8.93	2.96	33.13	8.76	17.24	2.90
ACT (min)	4.42	1.58	35.79	3.57	8.70	0.67

Where: Pr = machine productivity; ED = extraction distance; AVC = average volume of the operating cycle; ACT = average operating cycle time and; CV = coefficient of variation (%)



Where: Pr - estimated productivity (m³ he⁻¹); ED - extraction distance (m); AVC - average volume of the operational cycle (m³); ACT - average operating cycle time (min); R² - coefficient of determination; and Syx - standard error of the absolute estimate (m³ he⁻¹).

Figure 2. Observed and estimated skidder productivity at the different distances for wood extraction.

Figura 2. Produtividade observada e estimada do skidder nas diferentes distâncias de extração.

Behavior of the skidder productivity in relation to the variables average cycle time, average cycle volume and extraction distance in three extraction distance situations (50, 150 and 250 m) are presented in Figure 3, 4 and 5. It was observed that the increase in the volume of wood dragged during the operating cycle and the smaller extraction distances provided higher machine yields.

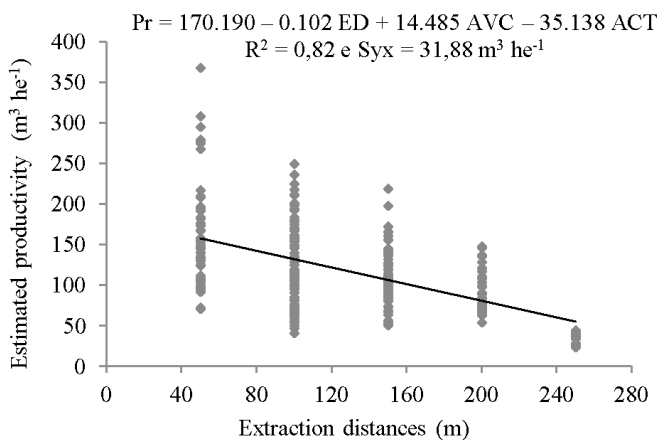


Figure 3. Behavior of the estimated skidder productivity as function of average volume and operational cycle time at the extraction distances of 50 m.

Figura 3. Comportamento da produtividade estimada do skidder em função do tempo e volume médio do ciclo operacional na distância média de extração de 50 m.

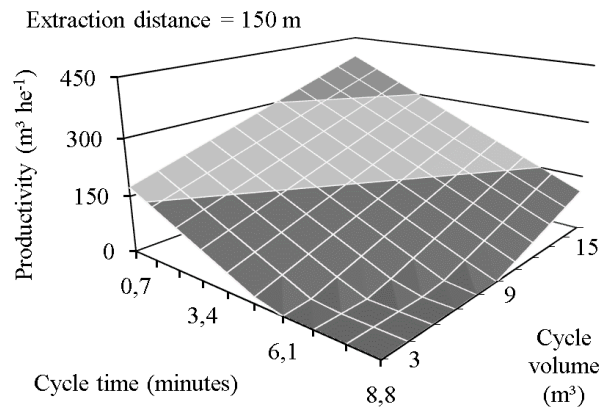


Figure 4. Behavior of the estimated skidder productivity as function of average volume and operational cycle time at the extraction distances of 150 m.

Figura 4. Comportamento da produtividade estimada do skidder em função do tempo e volume médio do ciclo operacional na distância média de extração de 150 m.

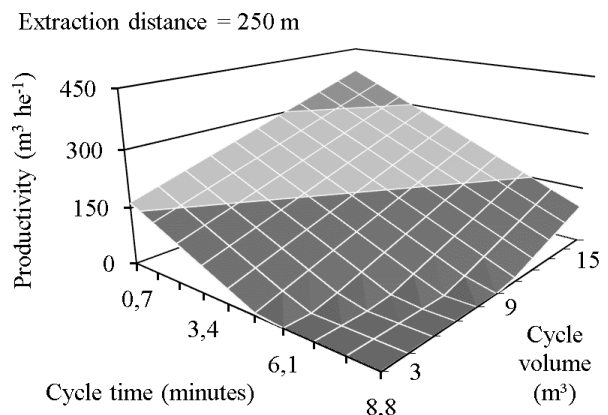


Figure 5. Behavior of the estimated skidder productivity as function of average volume and operational cycle time at the extraction distances of 250 m.

Figura 5. Comportamento da produtividade estimada do skidder em função do tempo e volume médio do ciclo operacional nas distâncias média de extração de 250 m.

4. DISCUSSION

The large amount of time taken by the empty and loaded travel stages is in agreement with several authors, who affirm that this type of machine is active throughout most of the operational cycle, that is, undertaking empty and loaded travel (BEHJOU et al., 2008; LOPES et al., 2014). This shows that, in order to optimize the extraction operation with the skidder, it is necessary to perform the operation over shorter distances, because over longer distances, the time consumed during travel increases.

Mechanical availability was found to be low when assessed. This result can be explained by the elevated number of interventions with more time being consumed to carry out corrective and preventive maintenance, due to the age of the machine, which presented an average of 19,900 hours of use.

Extraction distance directly influenced average skidder productivity, such that the farther the extraction distance, the lower the machine productivity. These results were also obtained by several other authors (BEHJOU et al., 2008; FIEDLER et al., 2008). Given this, there was an increase in the overall operational cycle time, showing the high sensitivity of productivity to this operational variable.

Another variable of significant relevance in the prediction of machine productivity was the average volume of the operational cycle. This volume is determined by the area of the claw and the quality of the pile of trees, used in the cutting operations. This result showed the need to optimize the operation by dragging a large volume of wood over a medium distance in line with equipment capacity.

Through the time and volume of the operating cycle and the extraction distance, the fitted model showed that these variables explained 82% of skidder productivity. Similar results were also observed by Fiedler et al. (2008), who reported that the variables extraction distance and average volume of the cycle accounted for 58% of productivity. Therefore, the results show the feasibility of the use of statistical modelling as a tool in the planning of wood harvesting operations, allowing the prediction of machine productivity in situations similar to the one studied.

5. CONCLUSIONS

Empty and loaded travel times consumed the greatest amount of time for the operational cycle of the skidder in the wood extraction.

Average effective skidder productivity was significantly affected by longer extraction distances.

Extraction distance, volume and mean cycle time satisfactorily explained skidder productivity in the conditions studied, being important parameters to consider in planning timber harvesting.

6. REFERENCES

- BARNES, R. M. **Estudos de movimentos e de tempos - projeto e medida do trabalho**. Tradução da 6 ed. Americana. São Paulo, Edgard Blucher. 1977. 635 p.
- BEHJOU, F. K.; MAJNOUNIAN, B.; NAMIRANIAN, M.; DVRAK, J. Time study and skidding capacity of the wheeled skidder Timberjack 450C in Caspian forests. **Journal of Forest Science**, Heidelberg, v. 54, n. 4, p. 183-188, 2008.
- CAVIGLIONE, J. H.; KIIHL, L. R. B.; CARAMORI, P. H.; OLIVEIRA, D. **Cartas climáticas do Paraná**. Londrina: IAPAR, 2000. CD.
- FIEDLER, N. C.; ROCHA, E. B.; LOPES, E. S. Análise da produtividade de um sistema de colheita de árvores inteiras no norte do Estado de Goiás. **Floresta**, Curitiba, v. 38, p. 577-586, 2008. <http://dx.doi.org/10.5380/ufv.v38i4.13153>
- LOPES, E. S.; OLIVEIRA, D.; SAMPIETRO, J. A. Influence of wheeled types of a *skidder* on productivity and cost of the forest harvesting. **Floresta**, Curitiba, v. 44, n. 1, p. 53-62, 2014. <http://dx.doi.org/10.5380/ufv.v44i1.31356>
- MACHADO, C. C.; SILVA, E. N.; PEREIRA, R. S. O setor florestal brasileiro e a colheita florestal. In: MACHADO, C. C. **Colheita Florestal**. 3ª Ed. Viçosa, MG, Editora UFV, 2014. 543p.
- MALINOVSKI, R. A.; MALINOVSKI, R. A.; MALINOVSKI, J. R.; YAMAJI, F. M. Análise das variáveis de influência na produtividade das máquinas de colheita de madeira em função das características físicas do terreno, do povoamento e do planejamento operacional florestal. **Floresta**, Curitiba, v. 36, n. 2, p. 169-182, 2006. <http://dx.doi.org/10.5380/ufv.v36i2.6459>
- OLIVEIRA, D.; LOPES, E. S.; FIEDLER, N. C. Avaliação técnica e econômica do *forwarder* na extração de toras de pinus. **Scientia Forestalis**, Piracicaba, v. 37, n. 84, p. 525-533, 2009.
- ROCHA, E. B.; FIEDLER, N. C.; ALVES, R. T. Produtividade e custos de um sistema de colheita de árvores inteiras. **Cerne**, Lavras, v. 15, n. 3, p. 372-381, 2009.
- SANTOS, P. H. A.; SOUZA, A. P.; MARZANO, F. L. C.; MINETTE, L. J. Produtividade e custos de extração de madeira de eucalipto com *clambunk skidder*. **Revista Árvore**, Viçosa, v.37, n.3, p.511-518, 2013. <http://dx.doi.org/10.1590/S0100-67622013000300014>
- SCHETTINO, S.; MINETTE, L. J.; SOUZA, A. P. Correlação entre volumetria de florestas de eucalipto e produtividade e custos de máquinas de colheita de madeira. **Revista Árvore**, Viçosa, v.39, n.5, p.935-943, 2015. <http://dx.doi.org/10.1590/0100-67622015000500016>
- SEIXAS, F.; CASTRO, G. P. Extração. In: MACHADO, C. C. **Colheita florestal**. 3.ed. Viçosa: UFV, 2014. p. 106-177.
- SILVA, E. N.; MAHADO, C. C.; FIEDLER, N. C.; FERNANDES, H. C.; PAULA, M. O.; CARMO, F. C.; MOREIRA, G. R.; COELHO, F. E. Avaliação de custos de dois modelos de *harvester* no corte de eucalipto. **Ciência Florestal**, Santa Maria, v. 24, n. 3, p. 741-748, 2014. <http://dx.doi.org/10.5902/1980509815733>
- SIMÕES, FENNER, P. T.; ESPERANCINI, M. S. T. Avaliação técnica e econômica da colheita de florestas de eucalipto com *harvester*. **Scientia Forestalis**, Piracicaba, v. 38, n. 88, p. 611-618, 2010.