academicJournals

Vol. 8(24), pp. 3126-3135, 27 June, 2013
DOI: 10.5897/AJAR2013.7306
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Efficiency of motor-manual felling and horse logging in small-scale firewood production

Stelian Alexandru Borz* and Valentina Ciobanu

Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Şirul Beethoven, No. 1, 500123, Braşov, Romania.

Accepted 24 June, 2013

The use of chainsaw tree felling in association with horse logging is quite common in harvesting operations, especially in the case of dense stands where thinning operations are applied. Many technical procedures can be applied in tree felling operations, depending mostly by the tree diameter. Also, timber logging may be done in one step by the means of horses when terrain's slope is small. Based on a time study, this paper assesses the production rates for tree felling (using a single-cut procedure) and horse logging in a mixed broadleaved stand. Also, supplementary work elements were required as they were induced mostly by the terrain slope. The results showed that the delay-free time consumption for tree felling was affected by the diameter at the breast height and the distance between the trees to be felled. The time consumed for horse logging was affected by the logging distance, logging trail slope and number of logs per load. The net and gross production rates for tree felling were 8.42 m^3h^{-1} and 5.68 m^3h^{-1}. For horse logging, the net and gross production rates were of 2.63 m^3h^{-1} and 1.44 m^3h^{-1} respectively. The results may be useful for assessing time consumption and productivity for similar work conditions.

Key words: Chainsaw, horse logging, thinning, single-cut, time study, production rates, time estimation models, efficiency.

INTRODUCTION

The applied harvesting operations when the chainsaw tree felling is combined with horse logging are quite simple. Tree felling, limbing and sometimes bucking are done by means of the chainsaw and the resulted logs are dragged by horses to the landing. This harvesting system still represents a suitable practice for small harvesting companies and even for local farmers for many reasons such as the small investments and operating costs (Oprea, 2008); reduced impact on the soil, standing trees and seedlings (Wang, 1997); and simplified technologies for work in timber logging (Oprea, 2008).

On the other hand, animal logging is considered to be labour intensive (Rodriguez and Fellow, 1986) and less productive compared with the use of mechanized means, especially when logging distances are greater than 100 m (Oprea, 2008). However, animal logging may become efficient in the case of very dense stands from which result small logs (Oprea, 2008; Jourgholami et al., 2010) such as the first thinning. Furthermore, this harvesting system is regarded as a tradition in some countries (Oprea, 2008; Ezzati et al., 2011). The difficulties for acquiring capital for modern technology may be one of the reasons for which the horses are still used for timber logging (Toms et al., 2001; Demir and Bilici, 2010; Dinev and Trichkov, 2010; Jourgholami et al., 2010; Magagnotti and Spinelli, 2011a, b). The use of chainsaws in tree

*Corresponding author. E-mail: stelian.borz@unitbv.ro. Tel. +40 742 042 455.

felling operations was sometimes regarded as being more advantageous by comparison with other alternative means (Behjou et al., 2009; Spinelli and Magagnotti, 2011a). Their widespread use may be also the consequence of difficult terrain conditions or ecological constraints, situations in which the use of harvesters or fellers becomes technically impossible (Behjou et al., 2009). The studies done so far for tree felling using chainsaws targeted, mostly, the assessment of time consumption, production rates and costs (Brock et al., 1986; Kluender and Stokes, 1996; Lortz et al., 1997; Hartsough et al., 2001; Wang et al., 2004; Ligné et al., 2005; Ghaffarian and Shobani, 2007; Behjou et al., 2009; Mousavi et al., 2011; Çalışkan, 2012; Ghaffarian et al., 2012) by considering the intervention type, harvested species, terrain conditions, chainsaw type and the applied technical procedures for tree felling. As relevant predictors for time consumption in tree felling operations reported were, the diameter at the breast height (Kluender and Stokes, 1996; Lortz et al., 1997; Wang et al., 2004; Spinelli et al., 2006; Ghaffarian and Sobhani, 2007; Behjou et al., 2009; Mousavi et al., 2011; Çalışkan, 2012; Ghaffarian et al., 2012), tree volume (Brock et al., 1986), extraction intensity (Kluender and Stokes, 1996; Lortz et al., 1997) and the slope of trails between the trees (Mousavi et al., 2011).

Logging with several animal species was studied under different conditions. Jourgholami et al. (2010) studied the timber extraction with mules in Iran and showed that the delays were responsible for about 20% from the total work time. Also, they showed that by increasing the load volume per turn, the resulted time consumption for logging will be generally greater when logging uphill. They reported production rates of 1.0 - 1.5 m^3h^{-1}, for loads of 0.1 - 0.3 m^3 and logging distances of 50 - 350 m. Jourgholami (2012) stated that the use of mules in logging involves an intensive labour level. Another study regarding the horse logging was realized by Magagnotti and Spinelli (2011b). Following their research which was done for two distinct situations (one man crew and two men crew) the authors stated that the production rate was 1.5 times greater in the second case (2.6 m^3h^{-1}) and (1.73 m^3h^{-1}) in the first case.

Compared with the alternative logging means (for example skidders), horse logging may produce improved overall economic effects due to the reduced impact (McNamara, 1983; McNamara and Kaufman, 1985). Additionally, in selective cuttings, the use of horses for logging operations may be superior to skidders when environmental concerns are considered (Wang, 1997). When thought in the context of fossil fuel depletion, it is good to know that the renewable energy inputs is far superior in case of horse use by comparison with tractors (Rydberg and Jansén, 2002). However, available information regarding the utilization and productivity of animal logging is still very limited (Jourgholami et al., 2010).

This study focused on developing time prediction models and production rates for tree felling and logging using the chainsaw-horse logging system, for firewood production in thinning conditions. Consequently, the objectives of the study were to:

(1) Develop time estimation models for tree felling and tree logging using chainsaws horses,
(2) Calculate the production rates for the two operations and,
(3) Emphasize the time distribution on work elements for the two operations.

MATERIALS AND METHODS

Study location

The research was carried out in the forest compartment No. 59 of Şinca Management Unit administrated by Pădurile Şincii Forest District. The mentioned forest compartment is located at 45° 41’ 60’’ N - 25° 09’ 00’’ E near Şinca Nouă village, Braşov County Romania. The area of the stand was of 6.5 hectares. The average altitude was 850 m (690 - 960 m) and the average slope was 47%. The investigated forest stand was an even-aged broadleaved forest composed of beech, hornbeam and birch with an average breast diameter of 12.8 cm. The average volume per tree (for trees to be harvested) was of 0.150 m^3 and the total volume to be harvested was of 74 m^3. The applied silvicultural system consisted in thinning, whereas the applied harvesting method was tree-length. All harvested wood was designated for the production of firewood assortments. Field study was carried out in the spring of 2013 (February and March). Tree felling was done by the means of a Husqvarna H55 chainsaw (Figure 1) whereas the logging was done by three crews each consisting from one horse and the necessary auxiliary materials (Figure 2).

Data collection

Two field crews collected the data. One crew collected data for tree felling operations and the other crew collected data for horse logging operations. A number of 413 work cycles were collected for tree felling and a number of 47 work cycles were collected for horse logging. In both cases the continuous time study method was used. Each felling and horse logging cycles were divided in subsequent work and time elements (Table 1). Tree processing was done by another worker. Non-work time consisted mostly of delays whereas the supportive time consisted of chainsaw refuelling, chain sharpening and chainsaw repairing. All these time categories were collected during the field study.

Independent variables for the tree felling and horse logging cycle time, including the diameters and lengths for each log, were collected during the field study (Table 1). Due to dispersed location of the logs it was required that bunching be done manually. Also, logs’ stacking at landing was done manually. Additional data regarding the number of stops for rest during the travel loaded work element as well as non-work time (delays) and supportive time was documented in the field.

Data analysis

Data regarding the volumes per felled trees was obtained from local production tables based on tree height, breast diameter and species; whereas in the case of horse logging, data regarding the

Figure 1. Tree felling using the single-cut procedure.

Figure 2. Logging using horses.

volumes per logs was computed based on the diameters and lengths recorded in the field. Data analysis was done according to the recommendations of IUFRO (Björheden et al., 1995) and the GOOD PRACTICE GUIDELINES FOR BIOMASS PRODUCTION STUDIES (Acuna et al., 2012). Time consumption estimation models were developed by the means of stepwise backward regression technique. Thus, in both cases were developed maximal models including all predictor variables collected in the field.

At each analysis step, variables which were not significant at the chosen confidence threshold were excluded, reformulating this way a new model. The net and gross production rates for tree felling and horse logging operations were calculated based on the time study data and the realized production. Three elements were used for calculus purposes, such as: total work time, delay-free time and the amount of processed wood. The net production rate was calculated by dividing the amount of felled (logged) wood by delay-free time whereas the gross production rate was obtained by dividing the amount of felled (logged) wood by total time. In the case of tree felling, production rate curves were developed for average conditions regarding the walking distance between trees, by using the average distance between trees as constant. Thus, by using the values for tree volumes (in range of this study), and time consumption equations developed for tree felling (delay-free as well as total time) and by dividing the volume of tree to the amount of time (for different tree volumes) production curves were obtained. The same procedure was used for developing production curves for horse logging in conditions in which the load volume was considered constant (average load volume as resulted from field

Table 1. Description of work elements and independent variables for chainsaw felling and horse logging work cycles.

Work and time elements		Independent variables	
Tree felling			
Walk to tree	wt_t	Distance between trees	wd
Acquire	a_t	Diameter at stump height	dsh
Cut	c_t	Diameter at breast height	dbh
Fell	f_t	Tree height	th
Unhook	tu_t		
Horse logging			
Travel empty	te_t	Logging distance	*ld*
Logs attachment	la_t	Trail slope	*ts*
Travel loaded	tl_t	Number of logs per load	*nl*
Load detachment at landing	ldl_t	Volume of the load	*vl*
		Length of the load	*ll*
Bunching at felling area and stacking at landing			
Logs bunching at the felling area	lb_t		
Logs stacking at landing	lsl_t		

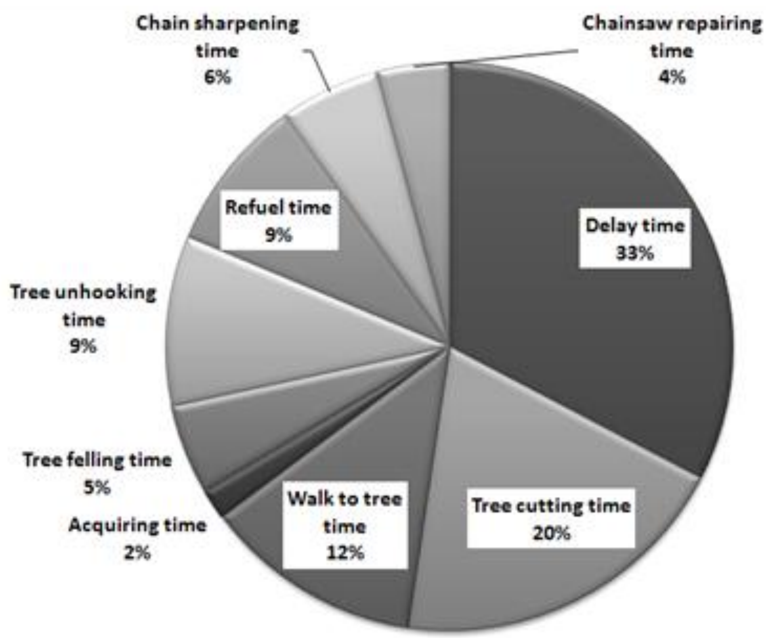

Figure 3. Time distribution for tree felling operation.

data).

RESULTS

Tree felling

A peculiarity of this study consists of the application of a single-cut procedure for tree felling. This was facilitated by the generally small diameters of the trees to be felled. During the felling operations, some technical problems interfered and they were mostly related to the increased density of the stand and the cutting procedure. Thus, in felling operations, situations appeared frequently such as, after the cutting, tree felled on a standing tree. Solving these problems took about 9% from the total work place time (Figure 3).

Table 2. Descriptive statistics for tree felling work conditions.

Parameter	Descriptive statistic				
	Minimum	Maximum	Median	Range	Mean ± sd
Diameter at the stump height - *dsh* (cm)	8	37	16.00	29	17.13±6.13
Diameter at the breast height - *dsb* (cm)	5	30	12.00	25	13.11±5.01
Tree height – *th* (m)	7.5	28.7	16.00	21.2	16.48±3.44
Tree volume – *tv* (m^3)	0.019	0.858	0.096	0.839	0.150±0.130
Distance between trees to be felled – *wd (m)*	0.0	30.0	3.5	30.0	5.0±5.21

Table 3. Descriptive statistics for tree felling time consumptions.

Parameter	Descriptive statistic				
	Minimum	Maximum	Median	Range	Mean ± sd
Walking to tree time – wt_t (s)	1	213	6.00	212	11.74±18.68
Acquiring time – a_t (s)	1	3	2.00	2	1.63±0.60
Cutting time – c_t (s)	3	219	13.00	216	18.64±19.32
Tree felling time – tf_t (s)	3	10	5.00	7	4.85±1.08
Tree unhooking time – tu_t (s)	0	355	3.5	30.0	80.42±68.34
Delay-free tree felling cycle time (s)	10	239	28	229	36.87±28.52

Table 4. Time estimation models for tree felling (N=413).

Model	Descriptive statistic			
	Sig. F	R^2	Predictor	p
wt_t (s) = 2.70 *wd* (m) – 1.74	<0.000	0.56	*wd*	<0.000
c_t (s) = 1.75 *dsh* (cm) – 11.34	<0.000	0.77	*dsh*	<0.000
$DFTF_t$ (s) = 2.28 × *dbh* (cm) +2.93 × *wd* (m) – 7.75	<0.000	0.48	*dbh*	<0.000
			wd	<0.000

Delay-free cycle time for tree felling ($DFTF_t$) was mostly affected by the distance between the trees to be felled and the diameter at the breast height. Descriptive statistics regarding the work conditions and time consumptions are provided in Tables 2 and 3. The stepwise regression technique revealed that the distance between trees and the diameter at the breast height are best indicators for the delay-free cycle time for tree felling (Table 4). As proved by other studies, time consumption for walking between the trees to be felled was most affected by the distance between the trees (Table 4). In the case of tree cutting time, the diameter at the stump height was the best predictor (Table 4).

In order to assess the production rates, only the work-place time was considered. Personal, organizational and technical delays accounted for 33% of the total work-place time (Figure 3). Supportive time (chainsaw refuelling time - *rt*, chain sharpening time - *cst* and chainsaw repairing time - *csrt*) took 19% of the total time. Productive time (including tree unhooking time) had a share of about 48% of the total work-place time. By applying the single-cut procedure, the cutting time accounted for 20%.

The net production rate was calculated by considering two assumptions as seen in Figure 4. In a first assumption, only the productive work time was included whereas in the second one was included, both the productive and supportive work time. The gross production rate was calculated by including all the work-place time. For average conditions (walking distance between trees, tree volume and diameter at the breast height), the net production rates for tree felling were of 11.63 m^3h^{-1} and 8.42 m^3h^{-1} respectively. The gross production rate was 5.68 m^3h^{-1}. As it can be seen in Figure 4, the production rate for tree felling is highly dependent by the tree volume and it increases as the tree volume is greater.

Logs bunching

Due to the fact that the felled and limbed trees were not

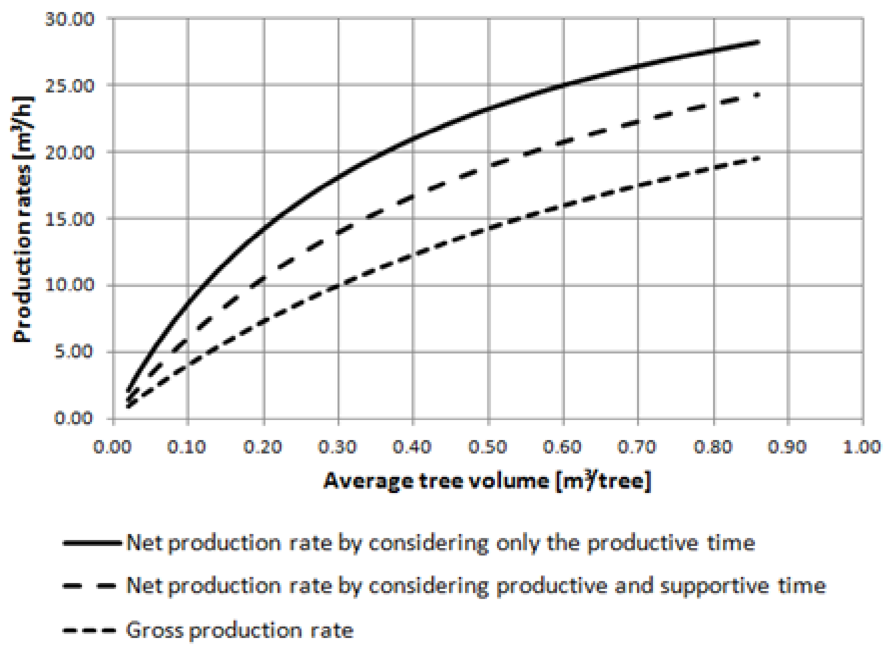

Figure 4. Net and gross production rates for tree felling operation.

Figure 5. Bunched logs.

grouped as they resulted after felling and processing, supplementary time was required for grouping the logs in order to form loads for horse logging (Figure 5). This work element was also required when the local slope was increased and the horses could not have access to the logs. Logs' bunching was done by the use of manual

Table 5. Descriptive statistics for horse logging work conditions.

Parameter	Descriptive statistic				
	Minimum	**Maximum**	**Median**	**Range**	**Mean ± sd**
Diameter at the thinner end (cm)	4	24	8.32	20.00	8.32±4.13
Diameter at the thicker end (cm)	3	39	14.00	36.00	15.18±5.96
Log length (m)	1.40	19.50	7.50	18.10	7.71±2.83
Log volume	0.01	0.77	0.07	0.76	0.09±0.08
Number of logs per load - *nl*	3	16	7.00	13.00	7.28±3.05
Load length – *ll* (m)	6.80	19.50	11.00	12.70	11.24±2.66
Load volume – *lv* (m^3)	0.243	1.233	0.632	0.980	0.684±0.197
Logging distance – *ld* (m)	182	402	320.00	220.00	307.23±65.12
Logging trail slope – *ts* (%)	12	13	12.50	1.00	12.52±0.47
Number of stops for rest during loaded travel	0	3	1.00	3.00	0.91±0.80

Table 6. Descriptive statistics for horse logging time consumptions.

Parameter	Descriptive statistic				
	Minimum	**Maximum**	**Median**	**Range**	**Mean ± sd**
Empty travel - et_t (s)	250	570	408.00	320.00	407.23±80.45
Logs attachment - la_t (s)	45	391	139.00	346.00	157.00±89.84
Loaded travel - lt_t (s)	110	630	255.00	520.00	276.45±111.42
Logs detachment - la_t (s)	30	198	90.00	168.00	94.15±44.52
Delay-free cycle time (s)	948	2951	1660.00	1643.88	1671.00±378.36

Table 7. Time estimation models for horse logging (N=47).

Model	Descriptive statistic			
	Sig. F	**R^2**	**Predictor**	**p**
et_t (s) = 0.98 *ld* (m) + 105.37	<0.000	0.63	*ld*	<0.000
la_t (s) = 25.84 *nl* – 31.01	<0.000	0.77	*nl*	<0.000
			lv	<0.000
lt_t (s) = 132.88 *lv* (m^3) + 1.47 *ld* (m) – 66.49 *ts* (%)	<0.000	0.61	*ld*	<0.000
			ts	<0.050
ld_t (s) = 10.76 nl + 13.83	<0.000	0.54	*nl*	<0.000
$DFLT_t$ (s) = 2.10 *ld* (m) + 33.05 *nl* + 56.93	<0.000	0.59	*ld*	<0.000
			nl	<0.000

means by a separate team. In average, this work element took 724.28 s for a maximum distance of 15 m. No time prediction model was developed for this work element because the real movement distances for each log could not be recorded in the field. However, the time spent for this element was most affected by the number of logs grouped in order to form a load. The resulted production rate was 3.40 m^3h^{-1}.

Horse logging

Descriptive statistics for the work conditions and time consumptions on work elements for horse logging operation are presented in Tables 5 and 6 respectively. As expected, the best estimation model for a delay-free cycle time – $DFLT_t$ (Table 7) was the use of logging distance (*ld*) and the number of logs in a load (*nl*). Trail

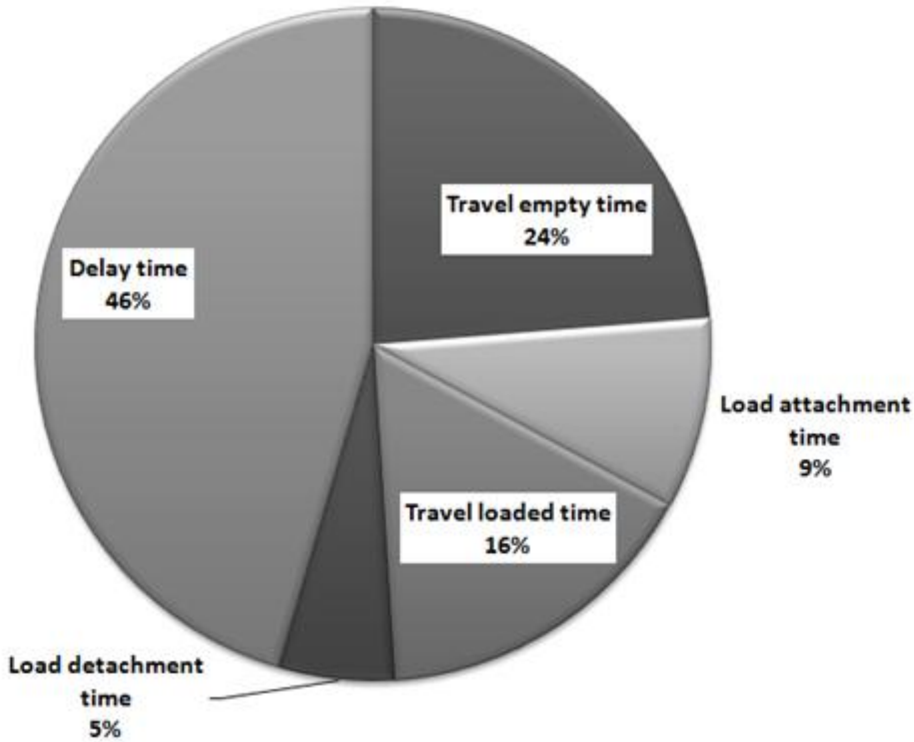

Figure 6. Time distribution for horse logging operation.

slope did not have a significant influence on the consumed time for a logging cycle and for the empty travel work element. The empty travel took more time than the loaded travel, mostly due to the higher speed during downhill logging (Table 7). Both load attachment and load detachment time elements were affected by the number of logs in a load (Table 7). Time consumptions for load attachment and detachment accounted for 9 and 5% of the total time (Figure 6). Production rates for the horse logging operations were obtained by dividing the total realized production by the spent time.

The net production rate considered only the delay-free time whereas the net production rate considered the total spent time. The net production rate for the average conditions (logging distance, load volume and number of pieces per load) was 2.63 m^3h^{-1}. However, due to the important share of delays in the logging operation (about 46 % from the total time) the gross production rate was of only 1.44 m^3h^{-1} (1.9 times smaller). Most of the delays occurred for operational and personal reasons.

In Figure 7 is presented the distribution of the net versus gross production rate curves for the studied conditions. As can be seen, production rates in case of horse logging are highly dependent by the logging distance. For instance, in case of an average load of 0.684 m^3, the net production rate was 1.5 times greater for a logging distance of 200 m by comparison with a logging distance of 400 m.

Logs stacking at landing

After the load detachment at landing, the worker responsible for horse logging had to group the logs in stacks. This work element was also done by manual means. When beginning a new stack, this work element was not required anymore. The time consumption was mostly affected by the number of logs in the load and the height at which the log had to be stacked. In average, time spent for this work element was 266.79 s (for average work conditions of 7.28 logs per load and 0.09 m^3/log). This work element was not affected by delays. Consequently, a production rate of 9.19 m^3h^{-1} was obtained.

DISCUSSION AND CONCLUSION

Tree felling using chainsaws followed by horse logging is a practise conducted in many countries. In Romania for example, this harvesting system is mostly applied in very young and dense stands where thinning operations are done.

When applying the single-cut felling procedure, the time consumption was mostly affected by the breast diameter and the distance between the trees to be felled. This result was confirmed by those of other studies (Kluender and Stokes, 1996; Wang et al., 2004; Behjou et al., 2009;

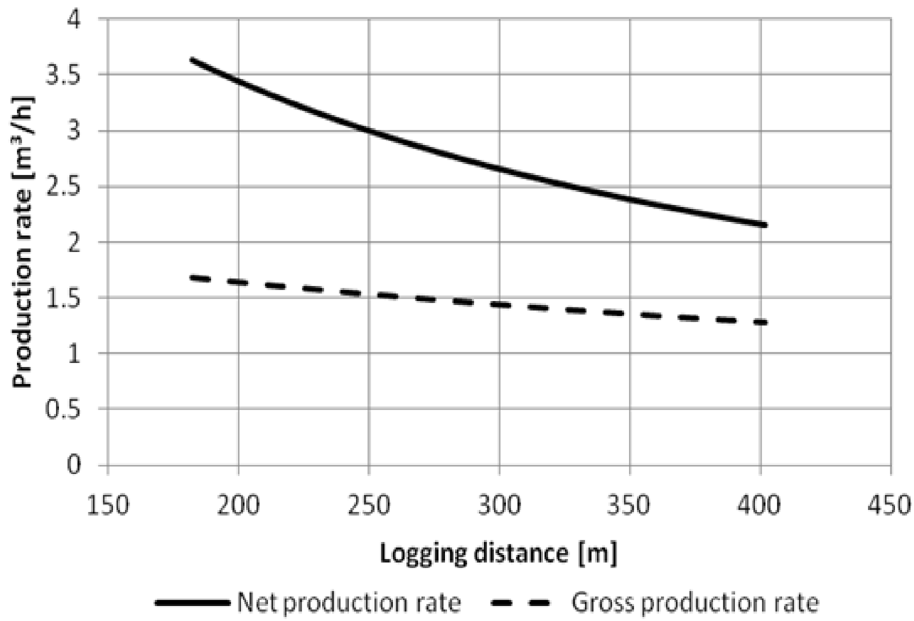

Figure 7. Net versus gross production rates for horse logging operation.

Mousavi et al., 2011; Çalışkan, 2012). However, when comparing with other results, the differentiation is made by the regression equation coefficients and intercepts, as a result of different study conditions and applied procedures for tree felling, which is, ultimately translated in much smaller production rates for the conditions covered in this study. This is mostly the consequence of much reduced volumes per tree as well as of more difficult work conditions which were specific to this study.

Tree unhooking after felling has not been reported until now as a necessary work element, probably due to the increased distances between the trees (mature stands), when the feller could choose more accurately the felling direction. This is true in case of most of the studies done so far (Behjou et al., 2009; Mousavi et al., 2011; Çalışkan, 2012). However, in the present study, this was not possible at any moment when the feller had to deal with a very dense stand. Consequently, additional time had to be considered for this study purpose. Delay time (33%) was far greater than that stated by other studies. Some of the mentioned studies reported delay times between 6% (Behjou et al., 2009) and 24% (Ghaffarian and Shobani, 2007). The important share of the delays in the present study was the consequence of the increased slope of terrain, which required more stops for resting. However, in this category was included also the time for meals which took less than one hour each day. 19% of the total time was spent as supportive time. Due to the work conditions it was absolutely necessary to stop the work for refuelling, chain sharpening and chainsaw repairing. If the production rates for tree felling are to be compared with those presented by other studies, they are quite close by those reported by Çalışkan (2012). However, Çalışkan (2012) studied tree felling by applying quite different procedures for an average breast diameter of 81.53 cm. Other studies reported results for average diameters which were greater than that of the present study (Behjou et al., 2009; Ghaffarian et al., 2012).

One of the main peculiarities of this study was the necessity to bunch the logs before the horse logging operation. For this reason, a supplementary work time was required for all the studied work cycles. The production rate for this work element was very small (3.40 m^3h^{-1}) and it was affected mostly by the reduced volumes per logs (0.09 m^3), movement distance and the involvement of manual labour. In the case of horse logging, it was quite obvious that the logging distance will affect the consumed time. This was previously demonstrated by other studies (Jourgholami et al. 2010; Magagnotti and Spinelli, 2011a).

However, this study demonstrated that, along with the logging distance, the number of pieces contained in a load affected significantly the consumed time. This was mostly, the effect of the consumed time for the load attachment, which was considerably high when the number of logs which formed a load was increased (the mean was of 7.28 logs/load). Nevertheless, the load volume did not affect significantly the consumed time. This could be related with the reduced mean volumes per load (0.684 m^3). The gross production rates were greater than those reported by Magagnotti and Spinelli (2011a), for a single man crew even if the average logging distance was smaller in the second case. This could be the effect of increased volumes per load which in the present study were 0.684 m^3 whereas those reported by Magagnotti and Spinelli (2011a) were 0.33-0.39 m^3. The delays accounted for 46% from the total time, this being, mostly, the result of operational delays due to the fact that the three logging teams had to work on the same logging trail. No additional logging trails could be developed because of the slope. Stacking the logs at landing was required in order to ensure suitable conditions for transportation.

As earlier mentioned, this work element was done manually and it was facilitated by improved working conditions (no slope, logs were grouped as they were detached from the logging devices). Consequently, the production rate was approximately three times greater by comparison with that of the logs bunching at the felling site. Of course, no distances were involved when stacking the logs.

AKNOWLEDGEMENT

The authors would like to thank Mr. Bogdan Bucur and Mr. Alexandru Pădurice for their active involvement in the data collection activity, also Eng. Răzvan Popovici for making this study possible.

REFERENCES

Acuna M, Bigot M, Guerra S, Hartsough B, Kanzian C, Kärhä K, Lindroos O, Magagnotti N, Roux S, Spinelli R, Talbot B, Tolosana E, Zormaier F (2012). Good practice guidelines for biomass production studies. In: Magagnotti N, Spinelli R. (eds.), CNR IVALSA, Sesto Fiorentino.

Behjou FK, Majnounian B, Dvorak J, Namiranian M, Saeed A, Feghhi J (2009). Productivity and cost of manual felling with chainsaw in Caspian forests. J. Forest Sci. 55(2):96-100.

Björheden R, Apel K, Shiba M, Thompson MA (1995). IUFRO Forest work study nomenclature. Swedish University of Agricultural Science, Dept. Of Operational Efficiency, Garpenberg.

Brock SM, Jones KD, Miller G (1986). Felling and skidding costs associated with thinning a commercial appalachian hardwood stand in Northern West Virginia. N.J.A.F. 3:159-163.

Çalışkan E (2012). Productivity and cost analysis of manual felling and skidding in Oriental spruce (*Picea orientalis* L.) forests. Ann. Forest Res. 55(2):297-308.

Demir M, Bilici E (2010). Assessment of timber harvesting mechanization level in Turkey. In: Proceedings of FORMEC 2010 Conference: Forest Engineering: Meeting the Needs of the Society and the Environment July 11 – 14, Padova – Italy.

Dinev D, Trichkov L (2010). Logging and realization of wood harvested in plantations of introducted forest tree species in Eastern Bulgaria, In: Proceedings of FORMEC 2010 Conference: Forest Engineering: Meeting the Needs of the Society and the Environment July 11 – 14, Padova – Italy.

Ezzati S, Najafi A, Durston T (2011). Impact of animal logging on soil physical properties in mule trail in Hyrcanian forests. Transport. Res. Part D. 16:316-320.

Ghaffarian MR, Naghdi R, Ghajar I, Nikooy M (2012). Time prediction models and cost evaluation of cut-to-length (CTL) harvesting method in a mountainous forest. Small Scale Forestry DOI 10.1007/s11842-012-9204-4.

Ghaffarian MR, Shobani H (2007). Cost production study of motor-manually felling and processing of logs. Forest Sci. 3:69-76.

Hartsough BR, Zhang X, Fight R (2001). Harvesting cost model for small trees in natural stands in the interior northwest. Forest Prod. J. 51(4):54-61.

Jourgholami M (2012). Small-Scale Timber Harvesting: Mule Logging in Hyrcanian Forest. Small Scale Forest. 11:255-252.

Jourgholami M, Majnounian B, Feghhi J, Visser RJM (2010). Timber extraction with mules: A case study in the Hyrcanian Forest. Afr. J. Agric. Res. 5(22):3108-3115.

Kluender RA, Stokes BJ (1996). Felling and skidding productivity and harvesting cost in Souttiet pine forests. In: CWF/IUFRO Conference, WSI 3423.

Ligné D, Eliasson L, Nordfjell T (2005). Time consumption and damage to the remaining stock in mechanised and motor manual pre-commercial thinning. Silva Fennica 39(3):455-464.

Lortz D, Kluender L, McKoy W, Stokes B, Klepac J (1997). Manual felling time and productivity in southern pine forests. Forest Prod. J. 47(10):59-63.

Magagnotti N, Spinelli R (2011a). Integrating animal and mechanical operations in protected areas. Croat. J. Forest Eng. 32(2):489-499.

Magagnotti N, Spinelli R (2011b). Financial and energy cost of low-impact wood extraction in environmentally sensitive areas. Ecol. Eng. 37:601-606.

McNamara D (1983). Horse logging at Latour. California Forestry Note 88:1-10.

McNamara D, Kaufman A (1985). Can horses compete with tractors? California Forestry Note. 95:1-7.

Mousavi R, Nikouy M, Uusitalo J (2011). Time consumption, productivity and cost analysis of the motor manual tree felling and processing in the Hycarnian Forest of Iran. J. Forest. Res. 22(4):665-669.

Oprea I (2008). Tehnologia exploatării lemnului. Transilvania University Press, Braşov.

Rodriguez EO, Fellow AM (1986). Wood extraction with oxen and agricultural tractors. FAO Forestry Paper. P. 49.

Rydberg T, Jansén J (2002). Comparison of horse and tractor traction using emergy analysis. Ecol. Eng. 19:13-28.

Spinelli R, Magagnotti N (2011). The effects of introducing modern technology on the financial, labour and energy performance of forest operations in the Italian Alps. Forest Policy Econ. 13:520-524.

Spinelli R, Nati C, Magagnotti N. (2006). Biomass harvesting from buffer strips in Italy: three options compared. Agroforest. Syst. 68:113-121.

Toms CW, Dubois MR, Bliss JC, Wilhoit JH, Rummer RB (2001). A Survey of animal-powered logging in Alabama. South. J. Appl. For. 25(1):17-24.

Wang J, Long C, McNeel J, Baumgras J (2004). Productivity and cost of manual felling and cable skidding in central Appalachian hardwood forests. Forest Prod. J. 54(12):45-51.

Wang L (1997). Assessment of animal skidding and ground machine skidding under mountain condition. J. For. Eng. 8(2):57-64.