Analysis of Semi-Mechanized Harvesting Systems in Eucalyptus Plantations in Southern China

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Abstract

Chinas forestry took less attention on wood supply aspects within the last decades. Today, there is a great gap existing between wood demand of the industry and national wood supply from forests and plantations. Unfortunately, there is only little knowledge existing and only a few studies are available on wood harvesting operations. This study analyzed the current harvesting process in Eucalyptus plantations in southern China. The harvesting process is described by mainly manual work with an exception of tree felling and cross cutting. Both work processes are done motor-manual. Overall, the time consumption of harvesting Eucalyptus was 115.07 min m ^{3} *and the productivity was 0.58* m^{3} h^{1}*. A detailed analysis was done to gain knowledge about the reasons for this low productivity. Based on this analysis,productivity models have been calculated against the tree diameter.*

Keywords: forest operations; Eucalyptus; China; semi-mechanized harvesting

1 Introduction

China has a long standing history in forestry, and within the last 70 years dramatic deforestations and in contrast enormous actions of afforestation have been done (Bull and Nilsson 2004, Shun-Ching and Ngan 1948). Today, Chinas forest cover is about 22 % (FAO 2010). These forests consists of mainly young and middle aged stands, that have been planted for ecological reasons and to limit soil erosion in steep terrain, but without any management concept. Parallel to the huge afforestation programs, national harvest quota, sometimes called *logging ban* due to the little allowed harvest volume, were launched in 1986 (Zhang, Y. et al. 2006).

Today, there exists an increasing gap between wood supply from secondary forests or wood plantations and wood demand of the wood processing industry. To reduce this discrepancy, the *Forest Industrial Base Development Program* (FIBDP) was set up in 2001 and it will continue until 2015 (Wang 2009). It is aim of the program to plant 13 million ha high productive industrial plantations and to deliver 130 million m^{3} a^{-1} of round wood, about 40 % of the national annual consumption (Zhao 2011, Wang 2009). In the southern regions of China, most of these plantations are planted with *Eucalyptus spp.* In 2011, Eucalyptus plantations occurred of 2.6 million ha, a share of 13 % at worldwide Eucalyptus plantations (Zhao 2011, Iglesias-Trabado, G., and D. Wilstermann 2009). From Eucalyptus plantations approx. 5.0 million m^{3} were harvested in 2010 (Zhao 2011).

For years, the forestry research in China focused on nature protection, tree physiology and forest growth aspects, but less on forest management and harvest operations. This led to less educated forest manager and forest worker in the area of forest operations, as well as to a low standard of mechanization, and resulted in a low efficiency of wood supplies (Kunshan 1997). Up to today, there exists only little knowledge on productivity and costs of Eucalyptus harvesting. Existing studies on Eucalyptus management in China basically focused on the net revenue of Eucalyptus production against growth rates, market prices and the use of by-products rather than on work productivity (e.g. Zhang et al. 2010, Xie 2003, Xu 2003).

Eucalyptus plantations in southern China are managed in 5 – 7 years rotation cycles, which is similar to Eucalyptus plantation management in other parts of the world (Evans 2010). The harvesting is a semi-mechanized process, where felling and cross cutting is done by using a chainsaw. All the other steps of harvesting are manual work. To analyze the work productivity of this harvest concept, was the aim of the study.

2 Material and methods

2.1 Research area

The research was conducted in the southern part of *Guangxi* province, the ninth largest province of China, bordering with Vietnam. The climate is hot and humid in summer and moderate and dry in winter. The experimental stands were located close to *Pingxiang* city. Forest stands are arranged in a small forest belt along the upper part of hills, due to the local relief and common regional landuse practices, where the valley and the lower part of the hills are in use of agriculture. The hillside extent is seldom more than 50 m. Soil conditions are unfavorable as stands stock on red soils.

Experiments have been conducted in 8 monocultural stands, managed in forest plantations. Three of those stands were of *Mytilaria laosensis* and 5 stands were of *Eucalyptus grandis x urophylla*. The planting distance was 2 x 3 m in every stand. Stand ages vary between 19 to 30 years for *M. laosensis* and 3 to 9 years for *E. grandis x urophylla*. Terrain conditions were steep in each case, slope was namely between 20 to 52 %. Essential facts describing the research stands and plots are given in table 1.

Table 1: Description of research stands and research plots

No	Tree species	Age [year]	n_{trees} [unit]	d_g [cmo.b.]	h_L [m]	$Volume_{harvest}$ [cmo.b./plot]	$Volume_{harvest}$ [cmo.b./ha]
1.1	M. laosensis	19	43	18.4	33.4	7.93	--
1.2	M. laosensis		16	20.1		--	--
2.1	M. laosensis	19	34	15.5	18.7	4.83	108.1
2.2	M. laosensis		42	17.3		9.01	127.4
2.3	M. laosensis		34	17.0		5.95	108.9
2.4	M. laosensis		50	18.0		10.70	158.3
3.1	M. laosensis	28	35	25.5	21.5	--	--
3.2	M. laosensis		70	24.8		--	--
4.1	E. grandis x urophylla	5	31	10.1	13.7	1.81	75.1
4.2	E. grandis x urophylla		33	9.4		1.56	47.8
4.3	E. grandis x urophylla		35	10.0		1.93	51.3
4.4	E. grandis x urophylla		37	9.8		2.08	62.4
4.5	E. grandis x urophylla		52	9.5		2.28	65.6
4.6	E. grandis x urophylla		51	10.1		2.47	46.0

No	Tree species	Age [year]	n_{trees} [unit]	d_g [cmo.b.]	h_L [m]	$Volume_{harvest}$ [cmo.b./plot]	[cmo.b./ha]
5.1	E. grandis x urophylla	3	87	9.8	13.8	4.12	83.1
5.2	E. grandis x urophylla		75	9.7		3.49	67.9
5.3	E. grandis x urophylla		91	10.2		4.57	80.8
5.4	E. grandis x urophylla		67	9.9		3.03	60.9
5.5	E. grandis x urophylla		70	9.7		3.08	63.3
5.6	E. grandis x urophylla		72	10.1		3.55	81.2
6.1	E. grandis x urophylla	6	34	11.4	14.4	2.51	52.3
6.2	E. grandis x urophylla		50	11.0		4.19	79.7
7.1	E. grandis x urophylla	7	57	11.7	14.7	6.21	104.5
7.2	E. grandis x urophylla		49	12.1		5.19	108.9
8.1	E. grandis x urophylla	9	42	16.4	16.0	7.48	115.9
8.2	E. grandis x urophylla		37	16.3		7.02	107.3
8.3	E. grandis x urophylla		37	15.2		6.58	100.3
8.4	E. grandis x urophylla		64	14.3		9.93	139.5

2.2 Research design and data acquisition

This study is based on conventional time study experiments, with small adaptations in research design to be in line with common Chinese harvesting practice.

Preliminary studies were done in Pingxiang region in 2008, to gain experiences on the common harvesting practices. Two major results of these studies were: (1) Eucalyptus stands exists only in small diameter ranges and stands are young. (2) For harvesting operations, defined *work processes* (WP) does not exist and harvesting is not done tree by tree from only one person.

To enlarge the diameter basis during the study (preliminary result 1), *Mytilaria laosensis* was selected as an additional species beside *Eucalyptus grandis x urophylla*. Both tree species are common for industrial plantations in southern China, both are used for pulp and paper and both show similar habitus characteristics. The influence of the tree species on the time study results, was later proven with statistical methods.

The favored diameter range was grouped into 3 diameter classes: *small*, $d_{1.3}$ = 8 – 10 cm o.B.; *medium*, $d_{1.3}$ = 11 – 13 cm o.b. and *big*, $d_{1.3}$ = 14 – 16 cm o.b.. Following this, all experiment stands were selected according to these groups, while *E. grandis x urophylla* fell upon group ’small’ and ’medium’, and *M. laosensis* fell upon group ’big’. In addition each stand was sub organized into smaller research plots, each with a size of 10 x 40 m (preliminary result 2).

Plot size, tree diameter and selected tree heights have been measured of every single plot, to calculate the standing volume and the diameter of the stem of mean basal area. All measured time consumptions within this study are calculated as the mean of one plot, referred to the diameter of the stem of basal area (d_g).

The process of harvesting was furthermore subdivided into smaller units, *work processes* (WP) and *working steps* (WS), to gain additional detailed information on the distribution of time consumption per work task. A detailed analysis at the level of working steps is not part of this paper, it is recommended to read Engler 2011. The time studies were conducted according to international standards of REFA, using *flyback time* and *activity sampling* (table 2).

Table 2: Description of analyzed working processes and used methodology

Work process (WP)	Description	Degree of mechanization	Time study methodology
WP removing grass	To remove of all kind of vegetation circular around the trees to cut	Manual work	Flyback time
WP felling	To fell the tree until crown hits the ground	Motor-manual work	Flyback time
WP debranching	To cut off the branches along the stem, includes to cut off the crown at the top end diameter	Manual work	Activity sampling
WP measuring logs	To measure and mark the logs	Manual work	Flyback time
WP cross cutting	To cross cut the logs	Motor-manual work	Activity sampling
WP hauling	To bring the logs to the forest road, excluding to pile a stack	Manual work	Activity sampling

3 Results

Overall 237.8 h of time studies have been recorded, where 121.5 m³ o.b. have been harvested. Based on the plot sections, 28 data pairs have been statistically analyzed, of which 3 data pairs represent incomplete harvesting operations. Those have been involved in separate *WP* analysis, but have been excluded for the analysis of the complete harvesting process.

3.1 Time consumption and productivity of the harvesting process

The mean time consumption of harvesting *E. grandis x urophylla* was 115.07 min m^{3} ± 36.87, while the mean time consumption of harvesting *M. laosensis* was about one third lower, 87.22 min m^{3} ± 7.12. This can be explained by the slightly bigger diameter range of *M. laosensis* (Figure 1).

In a graphic analysis of d_g and time consumption the values of *E. grandis x urophylla* and those of *M. laosensis* fit good together (Figure 1). This was proven as well by multiple linear regression analysis. Therefore, the analyzed values of both tree species are merged to calculate the models of time consumption for the harvesting process.

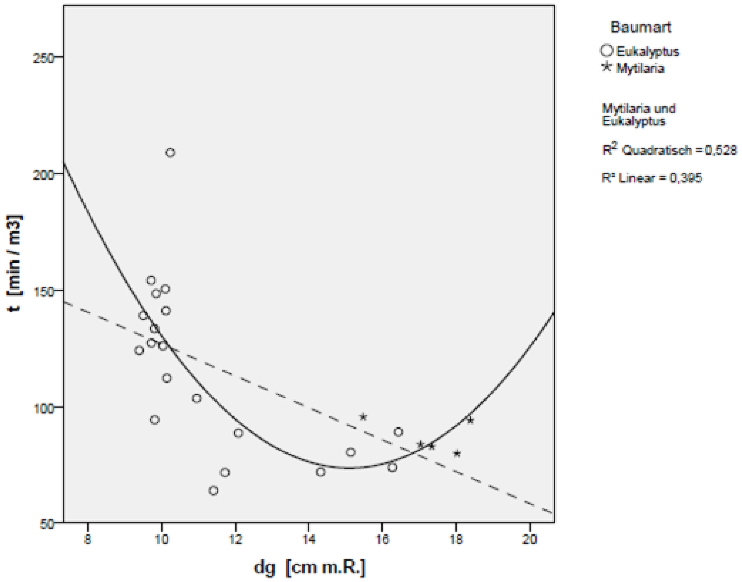

Figure 1: Time consumption of the harvesting process; quadratic equation for both tree species, E. grandis x urophylla and M. laosensis

The linear function (eqation 1) shows a negative trend of time consumption against increasing d_g and describes the expected correlation between both variables quite good. However, the middle diameter range $11.0 < d_g < 15.0$ cm o.b. seems to be overestimated. Here a quadratic regression (equation 2) gives much more precise values, even based on the relative small amount of data pairs.

$t_{harvesting}(d) = -6.838\,d + 195.141$ $R^2 = 0.40$ (1)

$t_{harvesting}(d) = 2.173\,d^2 - 65.68\,d + 569.717$ $R^2 = 0.53$ (2)

For $d_g > 15.1$ cm.o.b the quadratic function shows increasing time consumption values against the d_g. This trend was slightly unexpected and is not in line with the law of piece and volume (Speidel 1952). However, it seems that the increasing volume of trees/ logs leads to much higher time consumption to harvest the trees. This additional time consumption can not be saved on the other side by the law of piece and volume. Looking to the *WP*, it becomes clear that this is mainly due to the time consumption of *WP* debranching and *WP* hauling (compare 3.2).

A similar situation can be seen concerning the productivity of the researched harvesting process. The mean productivity of harvesting *M. laosensis* was 0.69 $m^3\ h^{-1} \pm 0.05$. In contrast the mean productivity of harvesting *E. grandis x urophylla* was 0.58 $m^3\ h^{-1} \pm 0.184$. The productivity of harvesting *E. grandis x urophylla* stands (model exclusive *M. laosensis* values) can be calculated using equation 3.

$p_{harvesting}(d) = -0.022\,d^2 + 0.612\,d - 3.447$ $R^2 = 0.65$ (3)

In table 3 all calculated regressions for the process of harvesting *E. grandis x urophylla* stands in southern China are listed. For the entire harvesting operation, the quadratic model is used, while for the separate *WP* linear models are preferred.

Table 3: Models to calculate the time consumption (pmh) per harvested volume

Work process	Model [min/m³]	R^2	Model based tree species
Harvesting process	t(d) = –10.001 d + 228.494	0.39	*E. grandis x urophylla*
	t(d) = 2.173 d² – 65.668 d + 569.717	0.53	*E. grandis x urophylla* and *M. laosensis*
WP removing grass	–	–	–
WP felling	t(d) = –0.197 d + 3.870	0.79	*E. grandis x urophylla*
WP debranching	t(d) = –1.355 d +38.143	0.24	*E. grandis x urophylla*
WP measuring logs	t(d) = –1.660 d + 41.650	0.37	*E. grandis x urophylla* and *M. laosensis*
WP cross cutting	t(d) = –0.518 d +16.512	0.21	*E. grandis x urophylla* and *M. laosensis*
WP hauling	t(d) = –3.542 d + 86.867	0.20	*E. grandis x urophylla* and *M. laosensis*

3.2 Relative time consumption of the WP

Looking to level of *WP*, detailed information can be provided on which work task within the harvesting process is highly or slightly time consuming. In example two ratios are presented for *E. grandis x urophylla,* in Figure 2 for plots 4.1 to 4.6 (d_g = 9.8 cm o.b.) and in Figure 3 for plots 8.1 to 8.4 (d_g = 15.4 cm o.b.).

For stands with small diameter, the removing of the ground vegetation (*WP* removing grass) takes an enormous ratio of the time consumption. This seems to be not the case in older stands, where ground vegetation is limited by less light availability. Felling of the trees (*WP* felling) and cross cutting of the stems (*WP* cross cutting), both tasks seems not to be affected by the tree diameter, at least in this small range of the diameter. The ratio of marking the assortments by using a wooden stick (*WP* measuring logs), is unexpected high (22 – 26 %), but seems rarely be affected by the tree diameter. An indirect correlation between time consumption and diameter might exist, when tree hight increases strongly and additional logs have to be marked.

The *WP* debranching and *WP* hauling are closely correlated with the diameter of the trees. The time consumption of both actions increases strongly against the diameter of the trees. Clear reasons for this are a higher amount of branches and stronger branches itself, as well as bigger log volumes that have to be handled.

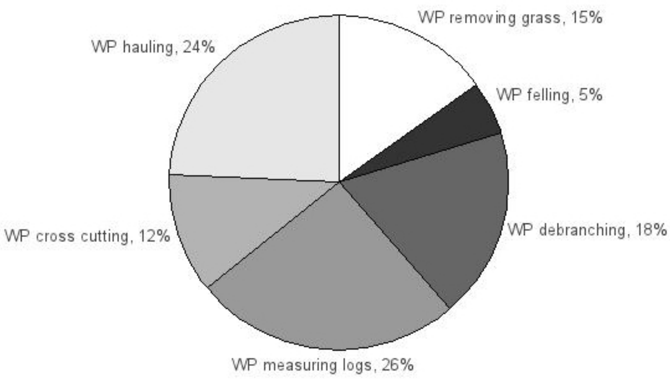

Figure 2: Mean ratio of work processes based on pmh for *E. grandis x urophylla*, 4.1 to 4.6

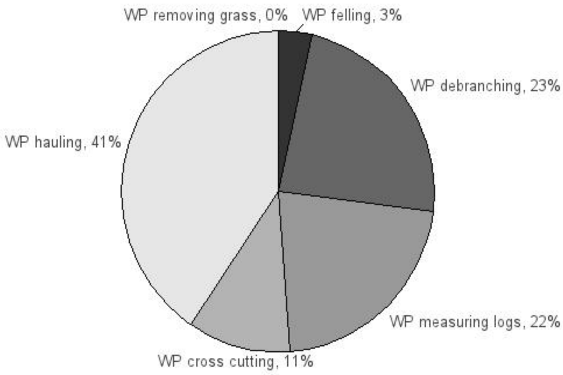

Figure 3: Mean ratio of work processes based on pmh for *E. grandis x urophylla*, 8.1 to 8.4

3.3 Costs

Referred to the pmh, average costs of 2.13 Euro m^{-3} ± 0.682 for harvesting *E. grandis x urophylla* have been calculated. These costs are based on typical labor costs of 1.11 Euro h^{-1} in China. Machine costs for the chainsaw are yet not included.

4 Conclusion

This study is one of the first studies analyzing the harvesting process in southern China for pure Eucalyptus stands. Due to historical developments in Chinese forestry, there exist no defined working processes for harvesting. Describing the current harvesting operations according to international standards, was one objective within this study.

From the time studies done in Pingxiang region, the following conclusions can be drawn:

⇒ The current (motor-manual) harvesting process in Eucalyptus stands is very time consuming, compared to an international level, respectively the work productivity is low in this case.

⇒ The supply of wood from Eucalyptus plantations is, even with this high demand of working time, cost efficient, because labor costs are low. However labor costs tend to rise strongly in the near future.

⇒ Work organization and management, to increase work efficiency and to decrease work risks, are not in the focus of forest operations in southern China, today. It would be appreciated to include both aspects into forest work, however this would require an education and all-the-year employment of the forest worker.

⇒ Work organization and education could lead to a significant increase in harvesting productivity, even when using the same/ similar harvesting techniques. Amongst other, Grammel 1978 observed this aspect for German forest workers.

⇒ Improved work operations, e.g by introducing mechanized work, should focus on *WP* debranching and *WP* hauling.

5 Discussion

The design of the researched harvesting process is the result of intensive preliminary studies and discussions with researchers at the ECTF. However, the process, as described in the study, does not exist in this time-activity order in southern China. Usually two or more work process/ activities are done parallel, e.g. felling at the to of the hill and debranching at the bottom. To analyze the harvesting operations in the way of a continuous process, was done for safety reasons and to be able to observe all working activities by a limited number of observer. This method assumes that there is no influence between the work processes existing.

The used methodology of a plot wise time study was sufficient under the common harvesting practice in southern China. However, this led to a dataset of only 28 pairs. The size of the plots was approximate 40 x 10 m, which was enough to provide work for about two days. An influence of the worker on the time measurement is assumed, but it was tried to limit this factor by observing a longer time period of more than two days per plot.

The calculated models give a good first impression on the ration of several work processes and the overall time consumption/ productivity of the current harvesting process. Additional work has to be done, to develop concepts and models for an improved Eucalyptus harvesting.

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