Small-scale Mechanical Harvesting Project

Report

Compiled by Bruce Sonogan

Private Forestry Officer
Department of Primary Industries

Benalla
Victoria

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Background

The concept to develop a project to investigate small-scale mechanical harvesting came about because a number of trials conducted to investigate manual harvesting and processing of plantation thinnings were shown to be unprofitable. It was thought that if small-scale harvesting equipment could be used to thin eucalypt plantations, then its low capital and operating costs would be such that the process would be profitable. With this in mind, funding was sought to obtain suitable harvesting machinery, with the aim of using it under field conditions to determine its profitability.

Manual harvesting trials

The impetus to carry out manual harvesting trials came from a desire to produce a return, or at least to offset the cost, associated with the thinning and pruning operations required to manage a plantation for sawlog production. The cost to thin a plantation from 1000 to 500 stems/ha averages $300/ha and the cost to stem prune the remaining 500 trees to 2.5 metres height averages $400/ha, a total of $700/ha. If a return can be generated from plantation thinnings, then it could be used to offset the cost of the work and this would encourage growers to be more timely in the management of their plantation.

<u>Implication of stem diameter</u>

In an early harvesting trial, trees removed as thinnings were cut into logs and sorted into three grades, with small end diameters (SED) of 10, 7.5 and 5cm. They were then processed into firewood. This trial found that 63% of the total air-dried weight of the firewood was contained in the 15.4% of total log length that had a diameter greater than 10 cm. The implication of this is that there is a point at which the diameter of the log becomes too small for it to be profitably processed into firewood.

To further illustrate this point, in an additional trial, two men processed firewood from a pile of Blue Gum thinnings that were snigged from the plantation and allowed to air dry. These trees were cut to length (down to a SED of 5cm diameter) and then manually delimbed and processed into firewood. It took the men 2.5 hrs to produce 1.73 tonnes of air-dried firewood.

In theory, if only the proportion of log that had a diameter greater than 10cm (63% of total weight) had been processed, and it had taken just 15.4% of the total time, then 1.09 tonnes could have been produced in just 23 minutes.

The profitability of both scenarios can be calculated as follows:

Scenario 1 - Two men working for 2.5 hrs to produce 1.73 tonnes of air-dried firewood.

Two labour units working 2.5 hrs @ $20/hr = $100
Tractor and firewood processor – 2.5 hrs @ $35/hr = $87.50
Chainsaw – 1.5 hrs @ $3/hr = $4.50
Total costs = $192 or $110.98/air-dried tonne

Scenario 2 - 63% of the firewood (10cm diameter and greater) produced in 15.4% of the time:

Two labour units working 0.39 hrs @ $20/hr = $15.60
Tractor and firewood processor – 0.39 hrs @ $35/hr = $13.65
Chainsaw – 0.2 hrs @ $3/hr = $0.60
Total costs = $29.85 or $27.39/air-dried tonne

Note that the above calculations do not include the cost of harvesting and forwarding the timber from the plantation, which must be added to the total cost to get a realistic idea of what the farm gate price needs to be to achieve a profitable outcome.

From the two scenarios above, it can be seen that the productivity, and therefore the profitability, depends on the amount of labour input and the volume of output. Volume of output is very much related to log diameter. If the diameter of the log is doubled, then the volume of material in the log, for equivalent log length, is four times greater. It is very tempting to spend a great deal of time processing logs that are too small in diameter to be viable.

Implication of wood density

Another critical factor in determining profitability is the density of logs being processed. At a young age, sapwood (which is of lower density than heartwood) makes up a greater proportion of the volume of a tree when compared to older mature trees. Table 1 illustrates the differences in density between species and between trees of the same species but different ages.

Species	**Density of mature tree heartwood (from Bootle (1994))**		**Density of heartwood and sapwood in field test (and age)**
	Green Density	**ADD 12% MC**	**ADD 12% MC**
E. grandis	950	620	542 (11 years)
E. camaldulensis	1130	900	700 (11 years)
E. globulus	1150	900	614 (3 years)
	1125 (field)		597 (5 years)
			686 (14 years)
E. saligna	1070	850	620 (14 years)
E. sideroxylon	1220	1130	831 (8 years)
E. cladocalyx			840 (11 years)
E. microcarpa	1170	1120	
P. radiata	800	500	585 (16 years)

Table 1. Comparison of text book values (from Bootle (1994)) and field test results for wood density of selected species. (Note: ADD = Air Dry Density.

If firewood is sold on an air-dry basis (12% moisture content) then the denser timbers will be more profitable, assuming that there is no extra time required to harvest and process trees of similar diameter.

Conclusion

As a result of the information gleaned from these early trials, I have concluded that manual harvesting and processing of logs with a SED of less than 10 cm is unlikely to be profitably.

Implications for pruning and thinning

In the current departmental guidelines for pruning and thinning plantations, it is recommend that stem pruning should occur when stems are a maximum of 14 cm and a minimum of 9 cm. It is also recommended that thinning should occur at the same time as pruning. As the aim of thinning is to remove small and misshapen trees to give more space for the remaining trees to grow, it is likely that there will be few trees removed that are greater than 10-cm diameter at breast height (DBH). The issue now is that the trees that need to be removed for good plantation management, are too small for a manual harvesting and processing operation to be profitable.

Development of Small-scale Mechanical Harvesting Project

While still trying to find a way to utilise these thinnings, attention was given to the possibility of developing a mechanical harvesting system capable of high productivity. Existing harvesting processes used by the softwood industry were considered, but their high operating and transport cost ruled them out as an option. While researching options, small-scale harvesting machinery of the type available in European countries like Finland, came to our attention. With their lower capital and operating costs and their greater flexibility, it was thought that we should try to obtain this type of machinery and trial it in a plantation thinning system.

And so the concept of a Small-Scale Mechanical Harvesting Project was developed.

Small-Scale Mechanical Harvesting Project

The aims and objectives of the project were to:
1. Identify the range of harvesting equipment available and assess its suitability for the project.
2. Decide on what we want the equipment to do. Eg. Fall, delimb, debark, cut to length, load.
3. Decide on what equipment to trial.
4. Purchase suitable equipment and conduct field tests.
5. Report on findings.

1. Identify the range of equipment available and its suitability for the project.

In the early stages of the project, the steering committee became aware of a Churchill Fellowship Study Tour awarded to Jon Lambert, a forestry consultant, who was going to investigate "Economically viable systems developed for the harvest of small plantation resources" in Europe. To value add to Jon's study tour and to take the opportunity to gain first hand information, the project engaged Jon to investigate equipment options and to develop a view as to what was likely to be most suited and practical for our resource type (eucalypts) and conditions.

In particular we wanted to know which machines had the ability to:
(a) handle eucalypts
(b) collect timber in the plantation eg. pick up and process if hand fallen
(c) debark
(d) delimb
(e) minimise damage to retained trees
(f) minimise damage to trees that could result in poor coppicing ability

Other issues Jon was asked to consider included:
(a) What type of base machine can the equipment be fitted to? What is best – tracked or wheeled?
(b) What are the machines running costs?
(c) What is the machines reliability and its service and maintenance requirements.
(d) Are there machines or systems other than those we are aware of that may be suited to what we are trying to achieve?

Most importantly Jon was asked to determine the productivity of each machine and its place in a harvesting/processing system. It was thought that armed with these figures, they could be used to determine production and therefore profitability of these systems in relation to our resource type. For example, if our end product was to be firewood, we needed to harvest, extract and process the resource into firewood in the most efficient way possible. The low value of firewood and the cost of transport to Melbourne greatly effects the economics of the project. As the price of firewood and the cost of transport are not likely to vary, we needed to concentrate on harvesting and processing to improve the projects economic viability.
Jon was also asked to visit:
(a) the Finnish Forest Research Institute (METLA), which does research on farm forestry including wood fuel harvesting technology, and
(b) the Work Efficiency Institute (TTS – Institute), which is involved in wood fuel production and combustion technology for farms energy crop production, to determine if they had any information on the productivity of machinery or had been involved in trials of equipment for small scale forestry.

On his return, Jon presented to the steering committee both a verbal and a written report on the outcomes of the study tour and identified a range of equipment as shown below. Jon's report is also attached to this report.

Shear – with or without bunching capacity

Felling and cross cutting

Stroke delimber

Multi processing head – felling, delimbing, debarking and cross cutting

2. Decide on what we want the equipment to do. Eg. Fall, delimb, debark, cut to length, load.

In meetings of the project steering committee, discussion focussed on log size and the type of log that the thinning process would produce, as well as the end products that could be harvested from this resource. The steering committee also considered the steps involved in the harvesting process to determined what would be required of the machinery.

In deciding what products would be produced from the thinned material, it was thought that there was very little chance of producing small sawlogs. This meant that the end products were likely to be posts, poles or firewood. Poles and posts require debarking before treatment, and although firewood could be sold with bark on, it was thought that the general consumer preference would be for firewood with bark off.

A machine able to pick up trees from the ground that had been hand fallen, with the hope that plantations already thinned might be able to have some material salvaged was also considered. This added an extra degree of complexity to the requirement of the machinery and it was thought that in future, the process would involve the machine doing the harvesting, as there appeared to be little benefit in hand falling prior to processing. On this basis, the requirement of a machine to pick up fallen material was not considered a priority.

For all the above reasons, the steering committee decided that the preferred machine must be able to fall, delimb and debark trees before cutting the logs to length.

3. Decide on what equipment to trial.

In light of the above, and because of the need for the machine to be able to debark the logs, of all the machines available, the only machine capable of debarking is the multi processing/single grip harvester head. Once the decision was made to use a multi processing/single grip harvester head, the question then became “What base machine should the head be fitted to?”

To operate a multi processing/single grip harvester head, the base machine must be capable of delivering very high flows of hydraulic oil. The smallest harvesting heads require flows in excess of 120 litres/minute. There are very few base machines capable of this rate of hydraulic oil flow, the commonest being an excavator. There are also purpose built tractors made in Finland designed for forest operations and suited to being fitted with harvesting heads. The only other alternative is to modify existing machinery by adding additional hydraulic flow capability.

To minimise overheads, it was thought that having a base machine capable of moving itself between sites and/or properties would reduce machine transport costs. With this in mind, a wheeled machine rather than a tracked machine was preferred.

After having decided what was required of the machinery and the type of machine that would be suitable, the Project Steering committee approached Jon Lambert. Jon was asked whether he was interested in pursuing his interests in this area by developing a partnership with the Steering committee with a view to purchasing a harvesting machine to conduct some trials. Jon agreed that he would use the contacts that he had made while on his study tour to make some inquiries to purchase a machine and then put a proposal to the steering committee.

While Jon conducted his inquiries, I reviewed the literature that Jon had provided to the steering committee as a consequence of his study trip. A literature review of these papers, as well as a search on the Internet, revealed some interesting outcomes, which are discussed, in the following detail.

3.1 Factors effecting machinery productivity

The factors that effect the productivity of harvesting machinery are:

- the number of stems per hour the machine is capable of processing,
- the volume of each individual stem, and
- the spacing of the stems (which impacts on the time taken for the machine to move between work stations.)

Kärhä et al. (2004) in their time studies found that difference in productivity between operators using the same machines was as great as 40%. This factor by itself can have a huge impact on the profitability of any harvesting operation and could be the difference between making or breaking the operation.

3.1.1 Harvesting rate

In Figure 1, Johansson (1997), clearly shows that the effective machine time taken to harvest a tree increases with the volume of the tree being harvested. The minimum time taken for a small tree being 30 seconds. Note that no account was made for the time taken in moving the machine between workstations, which ranged between 2.6 and 3 trees being harvested at each site.

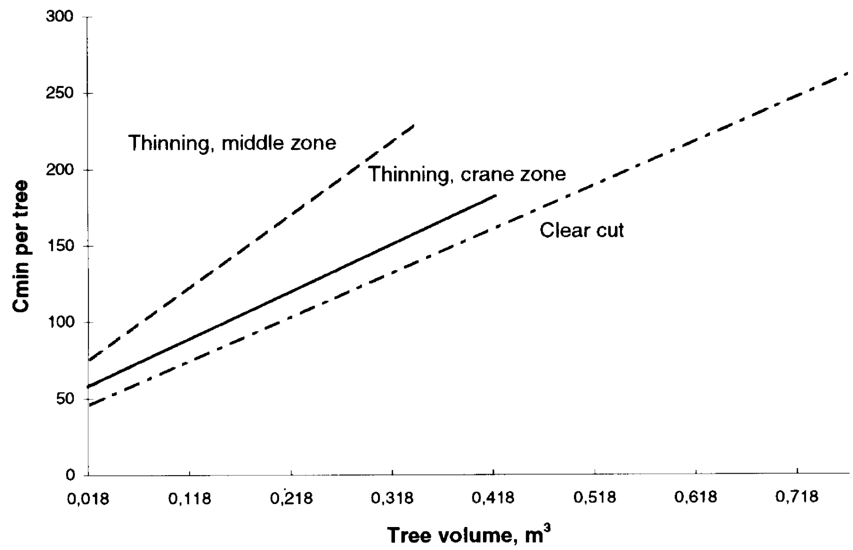

Figure 1. Time per tree (cmin) by tree volume in clear cut and thinning.

3.1.2 Effect of stem volume on productivity

While investigating small tree harvesting with a range of machinery, Johansson (1997) found harvesting productivity ranged between 3.7 and 5.1 m^3/hr, where stem volumes were in the order of 0.044 m^3, (Table 2).

Machine Name	Operation type	Machine type	No. stems/hr	Mean Stem diameter	Productivity (E_{15}) (m^3/hr)	Av. Stem Volume
Nokka/Timberjack	Thinning	Commercial harvester	85		8.2	0.097
	Final harvest	Commercial harvester	57		16.4	0.290
Sampo/Valtra	Thinning		81		7.9	0.097
Case5120/GM 728	Clearcut	Tractor - front crane	52	16.40	10	0.192
	thinning	Tractor - front crane	62	12.90	6	0.097
	thinning	Tractor - front crane	48	12.70	4.4	0.092
Valmet 901		Commercial harvester	105	10.10	4.6	0.044
		Commercial harvester	115	10.10	5.1	0.044
Rottne Rapid		Commercial harvester	85	10.10	3.7	0.044
Bruun Two		Commercial harvester	110	10.10	4.8	0.044
MB Trac 1000/Tapio 250		Tractor - rear mounted	106	10.50	4.6	0.043
		Tractor - rear mounted	93	10.30	3.9	0.042
Ford 276 Versatile/Trufab GS 302		Tractor - rear mounted	89	13.80	12.4	0.139
		Tractor - rear mounted	78	14.80	13.3	0.171
Ford 276 Versatile/Trufab GS 301		Tractor - rear mounted	86	14.20	13.9	0.162
		Tractor - rear mounted	68	17.00	16	0.235

Note E_{15} = Effective hour with breaks not exceeding 15 minutes.

Table 2. Productivity in harvesting of a farm-tractor-based single-grip harvester compared with Nordic single-grip commercial harvesters and tractor-based single-grip harvesters with rear mounted crane.

Note: The productivity rate shown in Table 2 includes falling, delimbing and cutting to length. It does not include debarking, forwarding, blocking or splitting.

If we make the assumption that a Blue Gum plantation, with average stem volumes equivalent to those in Table 2, has the same level of productivity (provided the harvesting machinery is comparable) to that shown in Table 2, then the productivity figures could be used to calculate profitability.

3.1.3 Stem volumes in a typical early age Blue Gum plantation

In Victoria's northeast, the stem volume of individual cull trees measured in a typical 8-year-old Blue Gum plantation, overdue for thinning, ranged between 0.01 - 0.07 m^3, with diameters of between 11cm and 17cm DBH. The average volume of cull stems was 0.05 m^3.

3.2 Factors effecting Profitability

Profitability of a harvesting operation is dependent on operating cost and machine productivity, which in turn is very sensitive to stem size and stem volume.

3.2.1 Machine operating costs

The operating cost of machinery is a significant factor influencing the profitability of a harvesting operation. In Appendix A, Miyata (1980) provides a method for determining fixed and operating costs of logging equipment. By applying his methodology to harvesting machinery, a commercial hourly operating cost can be calculated. With a fixed hourly rate, harvesting profitability can only be increased through improved productivity. The operating costs for a range of machinery are shown in Table 3.

Purchase price of machinery	Cost of operator labour		
	$15/hr	$20/hr	$25/hr
$200 000	91.58	97.18	102.78
$250 000	103.80	109.40	115.00
$300 000	116.03	121.63	127.23

Table 3. Estimated hourly rate for plantation harvesting and forwarding using the methodology developed by Miyata (1980) for a range of hourly operator rates.

It is interesting to note that a change in the cost of operator labour is not as significant as the purchase price of the machinery being used.

3.2.2 Calculating profitability.

To determine the cost to produce one tonne of air-dried Blue Gum firewood, I have used:

- the upper and lower harvesting productivity levels from Table 2 for trees comparable to that in our 8-year-old Blue Gum plantations (volumes ranging between 0.01 - 0.07 m^3, and DBH of between 11cm and 17cm)
- the hourly rate for harvesting and forwarding shown in Table 3, and
- a factor of 0.62 to convert green volume to air dried tonnes

The results are shown in Table 4 below.

System Productivity		Cost of production ($/tonne)		
(m^3/hr)	(tonnes/hr)	$15/hr	$20/hr	$25/hr
5.1	3.16	65.70	69.24	72.78
3.7	2.29	90.75	95.55	100.44

Table 4. Cost of production for one tonne of air-dried Blue Gum (Euc. globulus) firewood for a range of operator labour costs using a harvester with a replacement value of $300 000 and a forwarder with a replacement value of $200 000.

During a conversation with a harvesting contractor working in north east Victoria, I discovered that the mechanical harvesting rate in a radiate pine plantation, where there was no debarking and stem volumes exceeded 0.2m^3, was estimated to be 400 trees per day. The total harvesting and forwarding cost was $190/hr. Applying these machine rates to the mechanical harvesting of first thinnings (stem volumes ranging from 0.01 - 0.07 m^3 and diameters of between 11cm and 17cm DBH) in our typical Blue Gum plantation, results in a production cost of $96/air-dried tonne. This is based on a harvest rate of 100 trees per hour, which is an average of the rates for tractor-mounted harvesters in trees of this size (Table 2) and no time taken to debark. Coincidently, the production cost of $96/air-dried tonne falls within the range of figures in Table 4, where the cost of operator labour is $25/hr.

With a harvest and forwarding cost of $96/air-dried tonne and the additional cost of processing logs into firewood (approx. $30/tonne – from Scenario 2), the overall cost of split air-dried Blue Gum firewood at the farm gate is around $126/tonne. Premium firewood species sell locally for approximately $80/$m^3$ delivered to the household. This is equivalent to $129/tonne for plantation grown Blue Gum. With the cost of firewood delivery on top of the production cost, it can be seen that using existing softwood harvesting equipment to thin Blue Gum plantations for firewood will not viable.

To attract purchasers to plantation grown firewood, which they may consider an inferior product, a discount price may need to be offered. If it was sold for $70/m^3$ ($113/tonne), then the harvesting and forwarding cost would need to be reduced to $75/air-dried tonne. This allows for $30/air-dried tonne for processing into firewood and $8/air-dried tonne delivery. With this price structure, and assuming that the harvesting costs can not be reduced if existing softwood harvesting equipment is used, any alternate harvesting system must have either lower operating cost or higher productivity for it to be viable.

3.3 Inquiries for machinery purchase

Jon Lambert reported to the project steering committee that he was having difficulty negotiating with the Valtra tractor company, the manufacture tractors specifically suited to forest harvesting operations. He then began to follow up with a purpose built machine from Ponsse. Ponsse does not have any machinery in Australia as yet, and there were concerns raised about the availability of spare parts etc. Jon formed the opinion that if he was able to make anything happen, it was going to be a protracted process. Given the project time lines, it was considered unlikely that a suitable machine could be accessed.

On addition to this, there was also a question about whether the project could afford to lease machinery expected to have a purchase price in the vicinity of $250,00. Table 5 below shows the monthly and annual repayments for machines of varying values leased from a finance company. The figures in bold print are those supplied by the finance company for two residual values. The other figures were calculated using the company's actuarial tables.

Monthly and Annual Machinery Lease Payments

Lease Period 24 months
Interest Rate 7%

		Monthly Payment				Annual Payment			
	Machinery Cost	$150 000	$200,000	$250,000	$300,000	$150 000	$200,000	$250,000	$300,000
Residual Value (%)									
45%	27.09	$4,064	$5,418	$6,773	$8,127	$48,762	$65,016	$81,270	$97,524
50%	25.15	$3,773	$5,030	$6,288	$7,545	$45,270	$60,360	$75,450	$90,540
50% (CBFC- 7.1%)			**$5,081**	**$6,352**	**$7,622**		**$60,972**	**$76,224**	**$91,464**
55%	23.21	$3,482	$4,642	$5,803	$6,963	$41,778	$55,704	$69,630	$83,556
60%	21.27	$3,191	$4,254	$5,318	$6,381	$38,286	$51,048	$63,810	$76,572
60% (CBFC - 7.1%)			**$4,302**	**$5,378**	**$6,453**		**$51,624**	**$64,536**	**$77,436**
65%	19.33	$2,900	$3,866	$4,833	$5,799	$34,794	$46,392	$57,990	$69,588
70%	17.39	$2,609	$3,478	$4,348	$5,217	$31,302	$41,736	$52,170	$62,604
75%	15.45	$2,318	$3,090	$3,863	$4,635	$27,810	$37,080	$46,350	$55,620
80%	13.51	$2,027	$2,702	$3,378	$4,053	$24,318	$32,424	$40,530	$48,636
85%	11.57	$1,736	$2,314	$2,893	$3,471	$20,826	$27,768	$34,710	$41,652
90%	9.63	$1,445	$1,926	$2,408	$2,889	$17,334	$23,112	$28,890	$34,668

Note: Figures in the second column are derived from an Actuarial Table in the CBFC Limited Finance Guide
The Actuarial Table only went to a 55% maximum Residual Value for a 24 months lease.

Table 5. Monthly and Annual Machinery Lease Payments for a Range of Machinery Costs and Residual Values.

It can be see from Table 5, that with the money that was available ($97,500) the project could lease a machine costing $150,000 for two years leaving a residual value of 50%, or a machine costing $200,000 with a residual value of 65%. At the end of the lease, if the lessee does not want the machine at its residual value, it is sold, and if it brings less than the residual value, the lessee must make up the difference. This arrangement would have put the project in a position of unknown financial risk, which was not acceptable. Also bear in mind that the cost of machinery was likely to have been in excess of $200,000.

(4) Purchase suitable equipment and conduct field tests.

After having gone through the process described previously in this report, it became apparent that it was not going to be financially viable for the project to obtain equipment suitable for conducting small-scale mechanical harvesting trials. In part, one of the reasons for this was that the purchase price of machinery suitable for the trial was unfordable given the level of project funding. If a machine had been leased rather than purchased outright, the project would have been committing to a considerable amount of financial risk, which was seen as being unacceptable.

(5) Report on findings.

As a consequence of the high cost and the high level of financial risk involved in obtaining a suitable small-scale harvesting machine, the small-scale mechanical harvesting trial concept was abandoned. Of the $97,500 of project money remaining, $25,000 was retained to conduct a manual harvesting trial, while the remainder was returned to the North East Box Ironbark Project for redistribution within this project.

The findings of the manual harvesting trial will be the subject of a future report.

Conclusion

The difficulty with the economics of dealing with early thinnings is a problem that is recognised worldwide. In his report following an international conference on "Improving the economics of early thinnings", Lyons (2003) stated that "there is no easy solution". Lyons recognised that harvesting low value products required high machine productivity in order to be viable, however, this was not possible on small sized trees as was evidenced by the low productivity figures presented from many sources at the conference. He stated that in countries where labour is expensive, technology has to be used and he felt that cheaper machinery and multipurpose machines would have a role to play in small scale harvesting in the future.

On the basis of the trial work that I have completed to date, and a review of available literature on harvesting machinery productivity, I would fully support the above comments by Lyons as being as applicable to Australia as they are to they are to Europe.

APPENDIX A

Machine Cost

Description and Data:

Manufacturer:	Model:	HP:
Purchase price (f.o.b, delivered):	$200 000	
Less: tire cost	$5000	
INITIAL INVESTMENT (P)		$195 000
Salvage Value (S) (20% of P)		$39 000
Estimated Life (N)	5 years	
Scheduled operating time (SH)	1680 hrs/yr	
Utilisation (U)	75 %	
Productive time (H)	1260 hrs/yr	
Average value of yearly investment (AVI)		$132 600/yr.
AVI = [((P-S)(N+ 1))/2N]+S		

I. Fixed Cost:

Depreciation = (P-S)/N	= $31 200/yr.
Interest (8%), Insurance (2%), Taxes (0%)	
Total 10% x $132 600/yr)	= $13 260/yr.
(1) Fixed cost per year	$44 460
(2) Fixed cost per H (1 + H)	$35.29

II. Operating Cost: (based on productive time)

Maintenance and repair (50% x ((P-S)/(NxH))	$12.38
Fuel (...........gph x $ _/gallon)	$20.80
Oil & lubricants	$3.17
Tires (1.15 x (tire cost)/tire life in hrs.)	$2.26
(3) Operating Cost per H	$38.61

III. Machine Cost per H (without labor) (2 +3)	$73.90
IV. Labour Cost ($25/hr/U)	$33.33
V. Machine Cost per productive hour with labour (III.+ IV)	**$107.23**

References

Bootle, K. R., (1994). Wood in Australia – Types, properties and uses. McGraw-Hill Book Company Australia Pty Limited.

Johansson, J. (1997). Small Tree Harvesting with a Farm Tractor and Crane Attached to the Front. International Journal of Forest Engineering, Vol.8, No. 1, pp 21-33.

Kärhä, K., Rönkkö, E. and Gumse, S. (2004). Productivity and Cutting Costs of Thinning Harvesters. International Journal of Forest Engineering, Vol.15, No. 2.

Lambert, J. (2004). Investigation of Economically Viable Systems that have been Specifically Developed for the Harvest of Small Plantation Resources. Churchill Fellowship Study Tour Report.

Lyons, J. (2003). Improving the Economics of Early Thinnings. Coford Short-Term Research Mission Report. IUFRO Meeting, May 7–9th 2003.

Miyata, E. S., (1980). Determining Fixed and Operating Costs of Logging Equipment. North Central Forest Experiment Station, Forest Service – US Department of Agriculture.

Sirén, M., (2003). Productivity and Costs of Thinning Harvesters and Harvester-Forwarders. International Journal of Forest Engineering, Vol.14, No. 1.