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Extracting whole short rotation trees with a skidder and a front-end loader

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Abstract

We time-studied a Caterpillar 950F front-end loader and a Caterpillar 528 grapple skidder used to extract bunched whole trees to a landing in a short rotation *Eucalyptus* plantation. The loader was 40–60% more productive than the grapple skidder, depending on extraction distance. Alternatively, the single loader could both extract trees and handle the landing duties, such as moving residues from the flail-chipper, whereas the skidder required a second machine (skidder or small loader) to handle landing activities. Front-end loaders appear to be very promising as extraction devices for short rotation plantations where tree characteristics, terrain and soil conditions allow them to be used. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Restricted access to natural forests has made short rotation wood crops (SRWC) increasingly attractive as sources of wood fiber, and several forest products companies in the USA have established large clonal and/or seedling plantations of *Populus* or *Eucalyptus*. Forwarders are commonly used for primary transport of SRWC in Brazil and have been tested in the USA [1]. Cable systems have been trialed in areas with wet or fragile soils [2,3], but they are recognized as being relatively expensive. Essentially, all SRWC plantations in the USA are harvested with whole-tree (WT) systems, using feller-bunchers, grapple skidders and flail-chipper combines or irongate delimbers [2,4,5].

However, skidding may introduce dirt into the bark and foliage residues that can be used for fuel. In addition, skidder load capacity may be restricted by grapple area limitations and/or the drag force of the skidded trees. For these reasons, there is interest in alternative means of primary transport. One of these, forwarding trees with conventional front-end loaders, was proposed for SRWC over a decade ago [6] and is now being trialed in a few cases. Front-end loaders lift one or more bunches of trees with their forks, then carry the trees to the landing. The use of loaders is made possible by the characteristics of most SRWC plantations, in contrast to those of natural forest stands. Gentle slopes and easy terrain with few obstacles allow the use of less-stable machines; the

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small, uniform-sized trees and single-entry harvesting allow trees to be carried on the loader's forks and perpendicular to the direction of travel.

Assuming that forwarding produces lower contamination, there is still a need to know how it compares to skidding in terms of productivity and cost. Very few studies have addressed the use of front-end loaders as forwarding vehicles. Those focused on small loaders and dealt with log-lengths rather than whole trees [7,8], because they investigated thinnings rather than clearfell of SRWC.

This study compared the performance of a grapple skidder and a front-end loader used to extract SRWC at the same site and under similar conditions. In addition, the study aimed to build a prediction model to relate productivity to the main influencing factors such as extraction distance.

2. Approach

The study was carried out at the Simpson Tehama Fiber Farm (now Action Tree Farm) in Corning, California. The Farm consists of a *Eucalyptus* plantation of 4000 ha, with blocks that are harvested on a 7- to 8-year rotation. The study lasted 5 days, spread over the period 15–30 September 1998. At the time, two local contractors were harvesting adjacent stands of 7-year-old *Eucalyptus camaldulensis* of seedling origin (Table 1). Because of a severe freeze when these stands were 18 months old, many trees were multi-stemmed, so the number of stems exceeded the 1540 trees ha^{-1} (622 trees $acre^{-1}$) planted on the original 2.1×3.0 m^2 (7×10 ft^2) spacing.

In both cases, the trees were felled with a disc-saw feller-buncher; at both sites, trees were delivered to the landing and processed with flail-chipper combines. But while one contractor used a grapple skidder to move the bunched trees to the landing, the other employed a front-end loader (Fig. 1). The machines were respectively a Caterpillar 528 and a Caterpillar 950F. Their characteristics are listed in Table 2.

The operators of the skidder and loader both had several years of experience with that type of machine. However, the loader operator was relatively new to forest operations, having left a sawmill only 6 months earlier. The operators performed all service and most of the repair work.

Table 1
Stand characteristics

Extraction machine	Skidder	Loader
Stand at harvest, stems ha^{-1} (stems $acre^{-1}$)	2110 (855)	2630 (1063)
Avg. tree size, green kg (lb)	157 (345)	104 (229)
Avg. maximum slope, %	8.5	7.0
Terrain	Even, firm	Even, firm

Fig. 1. Caterpillar 950F loader, forwarding short rotation *Eucalyptus* to a landing.

Table 2
Machine descriptions

Machine	Skidder	Loader
Model	Caterpillar 528	Caterpillar 950F
Configuration	Rubber-tired	Rubber-tired
Approx. weight, kg (lb)	15 000 (33 000)	17 300 (38 000)
Power, kW (Hp)	130 (175)	119 (160)
Transmission	3 speed powershift	4 speed powershift
Width, m (ft)	2.9 (9.7)	2.7 (9.0)
Length, m (ft)	6.9 (22.8)	8.1 (26.5)
Height, m (ft)	2.9 (9.7)	3.5 (11.5)
Ground clearance, mm (in)	700 (27.5)	450 (17.8)
Grapple/fork	Esco—single arch	Medford 8K

Both operators would drive their machines from the landing to the loading site. Once there, they would maneuver to approach the load and grab one or more bunches; in many cases they moved with a partial load before picking up additional bunches. When a full load had been assembled, the machine would travel back to the landing and drop the load near the infeed of the flail-chipper, within reach of the flail's loader.

The extraction cycle was split into a number of time elements: Travel Empty, Maneuver to Load, Grab, Move While Loading, Travel Loaded, and Unload; the elements are defined in Appendix A.

The working routines of both machines were almost identical. The main difference was that the loader lifted its load clear off the ground, whereas the skidder raised only the butt ends. A second difference was in the operation of the feller-bunchers. The one working with the skidder accumulated compact bunches, while that paired with the loader saved time by dropping trees in more of a windrow fashion. The operator had directionally felled the trees, but found it unnecessary to create large, compact bunches for the loader because the loader picked them up from the side rather than from the end.

Thirdly, the skidder operation utilized a second skidder[1] to handle most of the landing work, such as clearing residues from around and beneath the flail-chipper and piling them for comminution at a later date. On the loader operation, the one loader handled both extraction and landing work.

The extraction time elements and related time-motion data were recorded on a Husky Hunter 2 handheld field computer equipped with Siwork3 timestudy software. Time spent by the extraction machines in landing work, in waiting (interactive idle time) at the landing, and in other delays such as servicing, breaks and repairs was also recorded. The extraction cycle elements and landing work were considered productive time; waiting and other delays were not.

Daily chip output was obtained by weighing all chip loads produced during each study day. Total tree weight was estimated by applying a factor of 1.3 to the weight of the clean chips in order to account for the limbs and the bark. This was based on the operation's long-term yield of approximately 3 loads of hog fuel for every 10 loads of clean chips.

All stems contained in each turn were counted. The total daily count corresponded to the total number of trees chipped, since the study continued uninterrupted for the whole day and extraction was performed by a single machine on each operation.

[1] Normally, a small loader worked at the landing instead of a second skidder. During the study, however, the small loader was in the workshop for major repairs.

Extraction path lengths were measured with a string machine, and flags were placed at ~ 15 m intervals. The maximum slope of each path was measured with a clinometer.

3. Results and discussion

A summary of the study time and production is shown in Table 3. The difference between total observation time and productive time accounts for machine downtime, all study and organizational delays, as well as for the exclusion of uncertain data from the pool of valid observations.

The main results of the time-motion study are shown in Table 4, and time element breakdown is shown graphically in Fig. 2. Production rates for extraction only averaged 40 and 67 green tonnes per productive machine hour (PMH) for the skidder and loader, respectively. The loader's production rate for both extraction and landing work averaged 43 green tonnes per PMH.

The operating conditions for the skidder and loader were not identical; the skidder's extraction distance was longer and the average tree weight was greater than for the loader. However, the difference between the capacities of the two machines for extraction is striking. Although the loader took more time for essentially every extraction element, it could produce two-thirds more than the skidder because of its larger payload. The skidder, being designed for rapid extraction, maintained higher average travel speeds on both empty and loaded travel: 30–40% faster than the loader. The latter is slower, but it can move loads that are more than twice as large. This explains the longer times taken by the loader to accumulate a load.

Another key difference between the two machines was the amount of time they spent at the landing and

Table 3
Study time and production

Machine	Skidder	Loader
Study duration, days	2	3
Total observation time, h	14.7	26.3
Productive time, h	10.6	15.7
Valid observations	154	105
Trees harvested	1316	3212
Weight harvested, green tonnes (tons)	454 (499)	736 (809)

Table 4
Time-motion study results for the grapple skidder and front-end loader

Machine Observations	Skidder 154			Loader 105		
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range
Time Element						
Travel empty, cmin	110.2	23.6	38–174	121.7	49.2	30–240
Maneuver to load, cmin	35.3	19.2	6–113	65.8	45.2	4–246
Grab, cmin	54.9	38.5	8–187	115.8	52.9	20–283
Move while loading, cmin	19.9	30.7	0–145	69.5	49.8	0–266
Travel loaded, cmin	159.7	43.3	33–270	170.0	66.8	42–320
Unload, cmin	24.8	10.9	6–72	24.1	10.8	8–63
Total extraction cycle, cmin	404.8			566.9		
Landing work, cmin	7.5	30.9	0–245	328.4	283.6	0–1101
Extraction + landing work, cmin				895.3		
Wait, cmin	83.5	119.5	0–607	2.3	10.6	0–72
Extraction distance, m	251	69	43–350	201	91	37–366
(ft)	(824)	(225)	(140–1150)	(661)	(298)	(120–1200)
Trees/turn	17.1	3.0	11–26	61.2	17.4	22–104
Bunches/turn	1.34	0.56	1–3	5.75	2.63	2–14
Turn weight, green tonnes	2.68	0.47	1.71–4.13	6.37	1.54	2.88–10.43
(tons)	(2.95)	(0.52)	(1.88–4.54)	(7.01)	(1.69)	(3.17–11.47)
Extraction only						
Trees PMH^{-1}	253			648		
Green tonnes PMH^{-1}	39.7			67.5		
(tons PMH^{-1})	(43.7)			(74.2)		
Extraction + landing work						
Trees PMH^{-1}				410		
Green tonnes PMH^{-1}				42.7		
(tons PMH^{-1})				(47.0)		

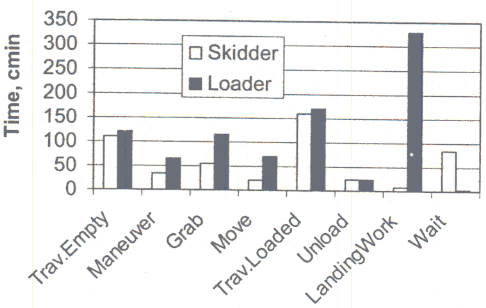

Fig. 2. Time element breakdowns for the skidder and the loader.

the way they used it. The capacities of both the skidder and the loader exceeded the productivities of the flail-chippers, so they had excess time. The loader had enough time to handle the landing work. The skidder's grapple and decking blade, however, were less suited to moving residues at the landing, and the skidder did not have much excess time, so a second machine was required for landing duties. The loader, on the other hand, could both forward trees to the chipper and remove residues from under it, an operation that it performed very rapidly, being designed primarily for such tasks.

The effects of several individual factors affecting productivity were tested with regression analysis of the extraction time elements (Table 5). The resulting relationships allow time expenditure to be calculated as a function of those variables that are most closely affect it. All the terms in the equations are highly significant ($p < 0.01$), but few accounted for more than half the variability in the data. This is common in forest harvesting operations, where times are affected by many factors that are difficult to record or even estimate. Among these factors are microenvironment, operator concentration and external pressure; they heavily affect the process, but are difficult to monitor with

Table 5
Prediction models for time expenditure[a]

Machine	Skidder Regression	r^2	Loader Regression	r^2
Time element, cmin				
Travel empty	35.5 + 0.299 dist	0.74	26.4 + 0.472 dist	0.76
Maneuver	35.3	—	65.8	—
Grab	−43.3 + 45.6 bunches + 13.8 weight	0.50	41.8 + 12.4 bunches	0.32
Move	−21.0 + 30.4 bunches	0.31	−34.5 + 16.3 weight	0.25
Travel loaded	24.0 + 0.436 dist +0.0379 (dist × weight)	0.77	11.1 + 0.604 dist + 5.8 weight	0.79
Unload	24.8	—	24.1	

[a]Dist = one-way distance, m, bunches = bunches per turn and weight = turn weight, green tonnes.

precision. Therefore, they are bound to introduce a comparably high level of uncertainty into any forest harvesting model.

The relationships in Table 5 are all rather obvious. Travel time was closely related to the distance covered, and also to the size of the load in the case of loaded travel. Similarly, loading time increased with load size.

The forms of the relationships and the specific parameters that define them are of interest. For example, the relationships for travel time reflect the higher speed of the skidder, and the load effect comes into the travel loaded equation as a speed-related function. The loader is slower, so empty travel time increases more sharply as the distance grows. The loader encounters no skidding drag, however, so the size of the load did not seem to increase the travel loaded time through a speed-reducing effect, but rather as a fixed additional time per ton. A possible explanation resides in the need to find the optimal lift height for each load, which gets more complicated as the load size increases. Larger loads might require higher lifts to avoid dragging, but a higher lift involves a risk in terms of machine stability, especially if the load is heavy. Therefore, the time required to adjust the lift will grow with load size. Even though the time spent to adjust the lift was recorded as part of the grabbing time, minor adjustments occurred at the beginning of the return trip and could not be isolated. This effect may have been compounded by the operator's caution; he drove slowly at the beginning of the loaded travel until he felt reassured and then accelerated to normal travel speed.

For both machines, loading time was related to number of bunches. The number of bunches is a good predictor of move time while loading for the skidder, but less so for the loader. That is because bunches were much less definite at the loader site, where trees had been felled directionally and essentially windrowed. Load weight was a much stronger predictor of loading time for the loader.

Using the observed averages for load weight and bunches per turn for each machine, we calculated cycle times and productivities as a function of extraction distance. The results are shown in Fig. 3. Thanks to its larger payload, the loader can out-produce the skidder as an extraction machine at any distance. The capacity of the loader to both extract and work the landing was estimated by adding the observed average landing work time per turn to the calculated extraction time. At longer distances, the loader can handle both functions as rapidly as the skidder can extract. Whether a single loader can be used for both functions, however, depends on the production rate of the chipper and on average extraction distance. For example, a loader can match a chipper processing 50 green tonnes PMH^{-1} of whole trees at an average skidding distance of up to about 100 m.

The loader as an extraction machine may be used to reduce the number of landings and possibly roading requirements by extending the maximum extraction distance. For example, a skidder can produce 60 green tonnes PMH^{-1} out to about 100 m average distance, whereas the loader can produce the same amount at nearly 300 m.

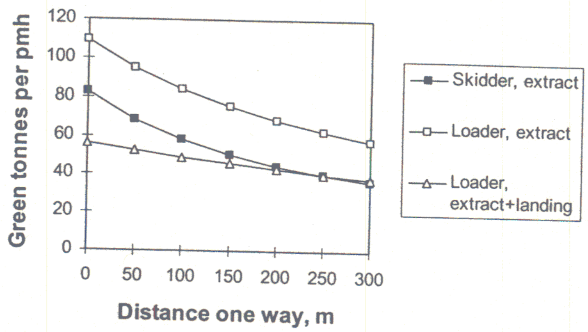

Fig. 3. Productivity as a function of extraction distance.

Even though the skidder is designed to extract and the loader to handle, the loader proved to be a better extraction machine under the study conditions because of its ability to move larger loads.

The loader does have potential drawbacks. It is somewhat more expensive than a skidder: purchase prices for new equivalent machines are \$210, 000 for a 950G loader, versus \$175, 000 for a 525 grapple skidder. Using standard costing formulae [9], the estimated hourly cost for the loader is \$83 PMH^{-1}, about 10% higher than the \$74 PMH^{-1} for the skidder. In addition, because of its heavy weight (about 30% more than the skidder when both were loaded) and the resulting high ground pressure, it was not capable of traversing clay soils soon after heavy rains. Skidders had to be used until the soils dried somewhat. The loader's weight and ground pressure would also cause more compaction and to greater depth on moist soils.

One might expect a loader to produce less breakage than a skidder because the loader keeps stems from dragging on the ground. In Simpson's experience, however, breakage with the loader depended primarily on stem form. Crooked stems are more readily broken by the clamp on the loader because they are gripped at a smaller diameter midsection, while the skidder grapples the trees by the butts. Although no quantitative data were collected, visual inspection of the harvested units indicated that breakage loss was relatively minor in both cases.

4. Conclusions

Under the conditions of the study the loader performed better than the skidder, extracting more wood and handling landing activities as well.

As an extraction vehicle, the loader benefits from a much larger payload, which it can move over reasonably long distances at an acceptable speed. To its superior productivity, the loader couples the advantage of forwarding versus skidding, i.e. reduced contamination. Of course, this is true for flat, solid terrain only; when the slope gets steep or the ground soft, the loader is penalized by its high center of gravity and its low flotation.

From an organizational perspective, the loader is again the best choice. It is more versatile than the skidder and can take care of both extraction and landing management. This was evident in this study, where the alternative was between a single loader and two skidders—one to extract and the other to keep the landing clean.

The loader might be termed task-versatile, while the skidder is terrain-versatile. Where the terrain allows it, the loader is a better choice because it can perform more jobs at a faster pace. Contractors who operate primarily in SRWC plantations on dry and gentle terrain should opt for the loader. On the contrary, those who harvest a variety of different stands should stick to the skidder, which has a wider range of operational capabilities.

A concluding remark must be made on the adaptation of loaders to wood extraction. The standard loader is designed for operation in a wood yard and lacks some of the features that make a safe forest machine, in particular adequate guarding. Loaders used in forestry often show extensive damage, which is particularly evident in the underbody and around the cab. If a loader is used to extract wood, it should be fitted with the appropriate guarding to protect both the machine and the operator.

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Appendix A. Cycle element definitions

Travel empty: begins when the machine starts from the landing and ends when it reaches the loading site.

Maneuver to load: begins when the machine changes the direction of travel in order to approach the first bunch of trees and ends when it is positioned and ready to grab the bunch.

Grab: begins when the machine is positioned and lowers its grapple or forks, and ends when the grapple or forks are raised to lift the load.

Move while loading: moving between adjacent loading spots.

Travel loaded: begins when the machine sets off for the landing with a full load and ends when it reaches the landing.

Unload: begins when the machine reaches the landing and ends when it has dropped the load.

Landing work: any job performed at the landing—decking, moving piles of trees, removing residues from the flail-chipper, etc.

Wait: all waiting caused by interactive delays at the landing.

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