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COMPARISON OF A SKIDDER AND A FRONT-END LOADER FOR PRIMARY TRANSPORT OF SHORT-ROTATION TREES

Raffaele Spinelli
Researcher
Wood Research Institute, National Council for Research
via Barazzuoli 23
I-50 136 Florence, ITALY

Bruce R. Hartsough
Professor
Biological & Agricultural Engineering, University of California
Davis, CA 95616, USA

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Summary:

We time-studied a Cat 950F and a Cat 528 grapple skidder as extraction devices for moving bunched whole trees to a landing in a short rotation eucalyptus plantation. The front-end loader was 40 to 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 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.

Keywords:

Forest engineering, skidding, forwarding, short rotation woody crops

Introduction

Restricted access to natural forests has made short rotation wood crops (SRWC) increasingly attractive as a source of wood fiber, and several forest products companies in the United States have established large clonal and/or seedling plantations of poplar or Eucalyptus. Forwarders are commonly used for primary transport if SRWC in Brazil and have been tested in the US (2). Cable systems have been trialed in areas with wet or fragile soils (3, 4), but they are recognized as being relatively expensive. Essentially all SRWC plantations in the US are harvested according to the whole-tree (WT) system, using feller-bunchers, grapple skidders and flail-chipper combines or irongate delimbers (3, 5, 6).

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 (1) 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 even terrain with few obstacles allow the use of less-stable machines; the small, uniform-sized trees, and single-entry harvesting allows trees to be carried on the loader's forks, and perpendicular to the direction of travel.

Assuming that forwarding guarantees lower contamination, we still have to ascertain 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 were intended for thinnings rather than for 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 that could relate productivity with the main factors influencing it.

Approach

The study was carried out at the Simpson Tehama Fiber Farm in Coming, 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 Sept.15 - 30, 1998. At the time, two local contractors were harvesting adjacent stands of seven-year-old Eucalyptus carnaldulensis of seedling origin (Table 1). Because of a severe freeze when these stands were 18 months old, many trees were multi-stemmed, so the estimated stems per acre were greater than the 1540 trees ha^{-1} (622 trees acre") planted on the original 2.1 m by 3.0 m (7 ft x 10 ft) spacing.

Table 1. Stand characteristics.

Extraction method:	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

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. The machines were respectively a Caterpillar 528 and a Caterpillar 950F. Their characteristics are listed in Table 2.

Table 2. Machine descriptions.

	Skidder	Loader
Model	Caterpillar 528	Caterpillar 950F
Configuration	Rubber-tired	Rubber-tired
Approx. Weight, kg (lb)	15000 (33000)	17300 (38000)
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	Esco - single arch	Medford 8K

The skidder and loader operators 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 six months earlier. Drivers performed all service and most of the repair work.

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 mote 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 flail-chipper infeed, within reach of the flail's loader boom. The extraction cycle was split into a number of time elements: Travel Empty, Maneuver to Load, Grab, Move While Loading, Travel Loaded, and Unload; they are defined in the appendix.

Except for few details, the working routine was identical for both machines. 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 operation with the skidder for extraction 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 loader handled both extraction and landing work.

We recorded the extraction time elements and related time-motion data on a Husky Hunter 2 hand-held field computer equipped with **Siwork3** timestudy software. We also recorded time spent by the extraction machines in landing work, and in waiting (interactive idle time) at the landing, and in other delays such as servicing, breaks and repairs. 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 1.3 factor to the weight of the clean chips, in order to account for the limbs and the bark. This was based on 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.

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.

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.

Table 3. Study time and production.

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

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

The main results of the time-motion study are shown in Table 4, and time element breakdown is shown graphically in Figure 1. 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.

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

Machine	Skidder			Loader		
Observations	154			105		
Time Element	Mean	Std.Dev.	Range	Mean	Std.Dev.	Range
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 (ft)	251 (824)	69 (225)	43-350 (140-1150)	201 (661)	91 (298)	37-366 (120-1200)
Trees/turn	17.1	3.0	1 l-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 (tons)	2.68 (2.95)	0.47 (0.52)	1.71-4.13 (1.88-4.54)	6.37 (7.01)	1.54 (1.69)	2.88-10.43 (3.17-11.47)
Extraction only						
Trees/PMH	253			648		
Green tonnes PMH^{-1}	39.7			67.5		
(tons PMH^{-1})	(43.7)			(74.2)		
Extraction + landing work						
Trees/PMH				410		
Green tonnes PMH^{-1}				42.7		
(tons PMH“)				(47.0)		

The operating conditions for the skidder and loader were not identical, the skidder 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 to 40% faster than the loader. The latter is slower, but it can move larger loads – more than twice as large. Of course, 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 the way they used it. The capacities of both the skidder and the loader exceeded the productivities of the flail-chippers, and 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 well-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 task.

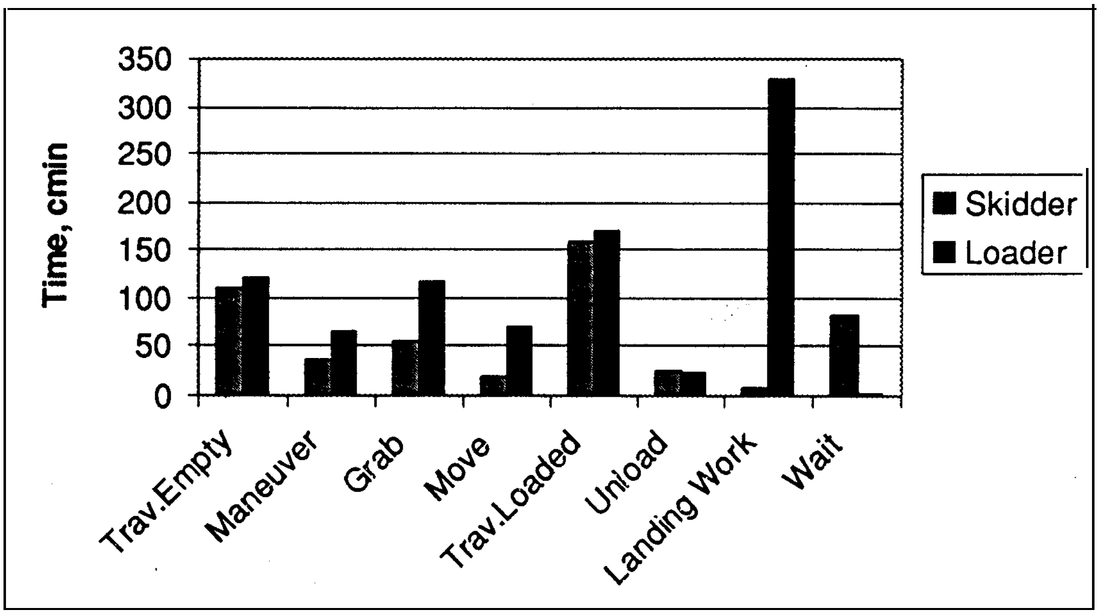

Figure 1. Time element breakdowns for the skidder and the loader.

The effects of several individual factors affecting productivity were tested with regression analysis of the extraction time elements (Table 5). The resulting relationships allow calculating time expenditure as a function of those variables that are most closely related to it. All the terms in the equations are highly significant ($p<.01$), 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 can hardly be monitored with sufficient 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 is closely related to the distance covered - and also to the size of the load in the case of loaded travel. Similarly, loading time is linked to load size -- with larger loads taking more time to assemble.

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 does 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 right lift 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 certain 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. Moreover, this effect may have been compounded with increased caution, which caused the operator to drive slowly at the beginning of the trip until he felt reassured and stepped on the gas.

Table 5. Prediction models for time expenditure.

	Skidder		Loader	
Time Element cmin	Regression	r^2	Regression	r^2
Travel Empty	35.5 + 0.299 Dist	.74	26.4 + 0.472 Dist	.76
Maneuver	35.3		65.8	.
Grab	-43.3 + 45.6 Bunches + 13.8 Weight	.50	41.8 + 12.4 Bunches	.32
Move	-21.0 + 30.4 Bunches	.31	-34.5 + 16.3 Weight	.25
Travel Loaded	24.0 + .436 Dist + .0379 (Dist * Weight)	.77	11.1 + .604 Dist + 5.8 Weight	.79
Unload	24.8		24.1	

. *Where:* Dist = one-way distance, m
Bunches = bunches per turn
Weight = turn weight, green tonnes

	Skidder		Loader	
Time Element (cmin)	Regression	r^2	Regression	r^2
Travel Empty	35.5 + 0.09 1 Dist	.74	26.4 + 0.144 Dist	.76
Maneuver	35.3		65.8	.
Grab	-43.3 + 45.6 Bunches + 12.5 Weight	.50	41.8 + 12.4 Bunches	.32
Move	-21.0 + 30.4 Bunches	.31	-34.5 + 14.8 Weight	.25
Travel Loaded	24.0 + .133 Dist + .0105 (Dist * Weight)	.77	11.1 + .184 Dist + 5.3 Weight	.79
Unload	24.8		24.1	

Where: Dist = one-way distance, ft
Bunches = bunches per turn
Weight = turn weight, green tons

For both machines, loading time is related to number of bunches. The number of bunches is a good predictor of move time while loading for the skidder, but not for the loader. That is because bunches were much less definite at the loader site, where trees had been felled directionally and essentially windrowed. In this case, load weight was a much better parameter.

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 Figure 2. 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 flail-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.

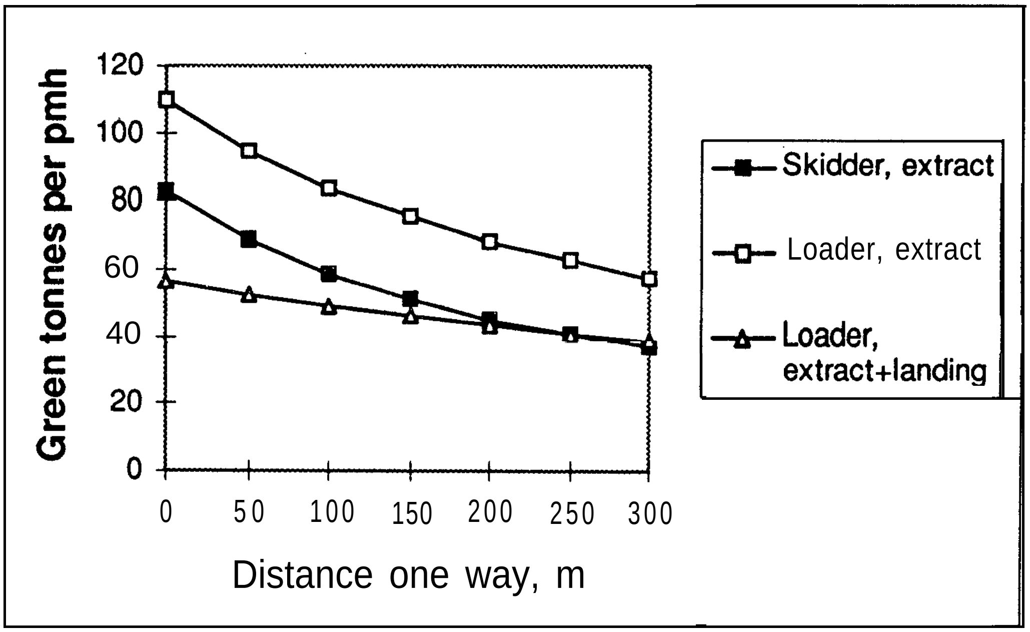

Figure 2. Productivity as a function of extraction distance.

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.

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, the estimated hourly costs for the loader is $83 PMH^{-1}, about 10 percent higher than the $74 PMH^{-1} for the skidder. 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 the clay soils at Simpson's plantation 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 we don't have firm data, visual inspection of the harvested units indicate that breakage loss is relatively minor in any case.

Conclusions

Under the conditions of the study the loader performed better than the skidder, extracting more wood and proving more helpful in general.

As a mere 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 - 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 our study, where the alternative was between a single loader and two skidders -- one to extract and the other to keep the landing clean.

To use quick definitions, we may say that the loader is 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 with 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 conclusive 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. 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 load and ends when it is positioned and ready to grab it.

Grab: begins when the machine is positioned and lowers its grapple, and ends when the grapple is 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 it.

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.