Factsheet

Agricultural tractors

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RECOFTC
THE CENTER FOR PEOPLE AND FORESTS

Agricultural tractors

RECOFTC - The Center for People and Forests

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1. Introduction

Agricultural tractors with attached winches, grapple tongues and log trailers with cranes are the key machines for small-scale forestry work in developed countries. In the near future, a similar role is also foreseen in small-scale community forestry work in Asia and the Pacific. The choice of tractor type and equipment for forestry adaptation depends on terrain (uphill or downhill), log sizes and intensity of harvesting operations. Forestry work can be very demanding on tractors, especially on engine capacity, gear systems, tires, body as well as other parts.

Basic modifications, such as window and radiator protection, screens or grills, deflector and cab protection bars, valve stem protectors, belly pans and front weights are required. When Power Take Off (PTO)-driven attachments are used, due care must be observed in covering the PTO. The three-point hitch is sufficient for some equipment. However, heavier equipment, such as loaders, requires a firm attachment to the tractor.

One of the major problems when using a farm tractor in forestry is the orientation of the operator's cab. Almost all tractor cabs are designed with a forward-facing operating position. Many forestry implements, such as grapple-loader trailers, skidding and forwarding grapples and winch processors require the operator to face the rear of the tractor. In most cases, tractor operators have to twist their bodies or kneel on the seat to reach the respective levers of the various tractor attachments. If a tractor has a less than ergonomically suitable cab, it is important that the operator tries to diversify the workload to minimize time spent in awkward working positions. Reversible seats and controls and increased space at the rear of the cab can help overcome this difficulty. Some tractor manufacturers provide these features as standard options.

The weight distribution ratio between the front and rear axles and their effect on traction power varies significantly between two- and four-wheel drive tractors. Ideally, a 50:50 front- to rear-end weight ratio is desirable for forestry machinery. Weight distribution of two-wheel drive tractors, which have a front- to rear-end ratio of 30:70, can be improved by adding **front weights**. The weight distribution of four-wheel drive tractors, which have a front- to rear ratio of 45:55, improves stability and pulling power. It is also recommended that special tire chains with reinforced links be used to prevent wheels from slipping during extraction, especially on sloping terrain.

The ground clearance of most farm tractors is 35-45 centimeters (cm), though at least 50 cm is needed in forestry operations, mainly to prevent tractors from getting caught on tree stumps. The **drawbar** is generally the lowest point on a tractor and it is sometimes possible to modify the **drawbar bracket** to increase the tractor's ground clearance. Larger tires also help increase ground clearance, though larger tires also raise the center of gravity, which reduces the stability of the tractor. Farm tractors with four wheels of equal size are suitable for a wide range of site conditions. The hydraulic pump capacity of modern tractors with power ratings greater than 37 (kW) ranges from 40-100 l/min. A tractor intended for forest operations should have a hydraulic pump capacity of 80-120 l/min (example for grapple loaders, see Figure 6). A separate PTO-driven pump and hydraulic system can be installed to increase hydraulic oil flow. Tractors that will be coupled to implements, such as winch processors, which perform multiple handling and processing functions, require a rated PTO power of at least 60 kW (80 hp). Single grip harvesters have high tractor power (75 kW, 100 hp) and weight for better stability. Power requirements for commercial chippers are even higher.

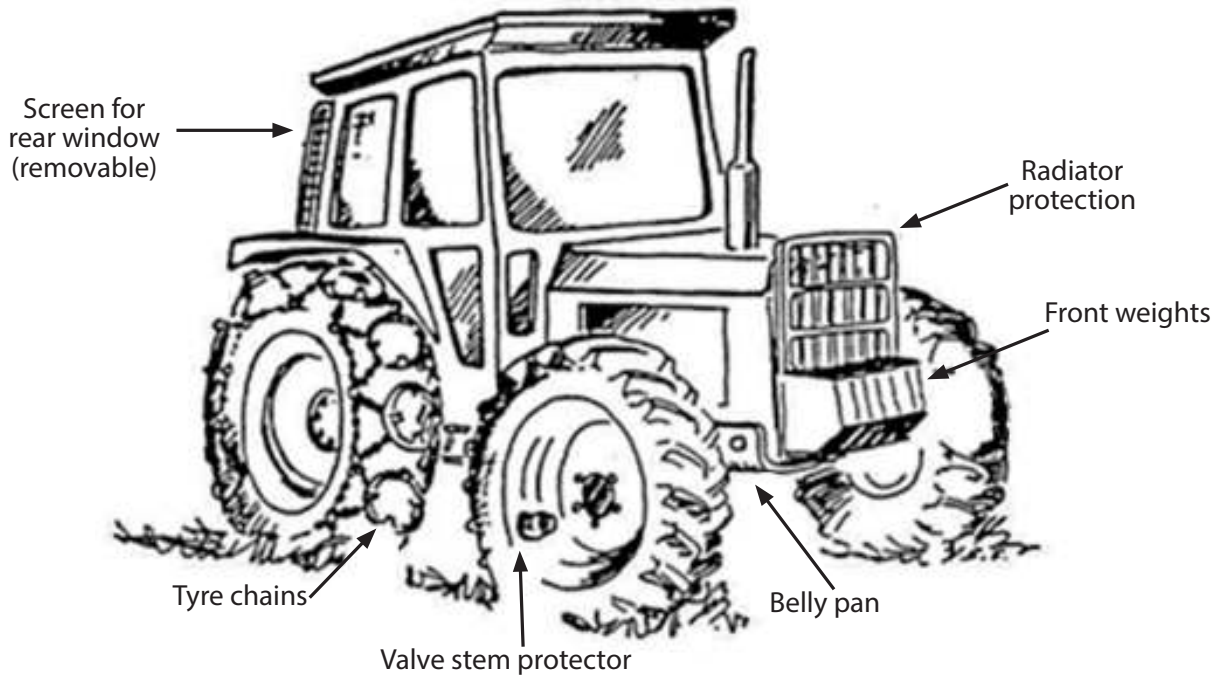


Figure 1. Agricultural tractor with forest harvesting modifications

Three-point hitch systems allow attachments, such as winches, skidders, grapples and processors. Stability deficiencies associated with a **three-point linkage** can be overcome by using a **four-point hitch**, which is best suited for grapple loaders, winch processors and double-drum winches. Additional pressure on the lower rear holding links to the shield of the logging winches, helps anchor the tractor during winch pulling. It is important, moreover, that forestry implements are matched to the sizes and power ratings of tractors. For example, it is impractical to mount a high capacity implement, such as a processor on a small 30 kW (40 hp) two-wheel drive tractor, because the tractor will become unstable and the engine or hydraulic system will be unable to power the machine. As a rule of thumb, an engine capacity of 10 kW is required for every ton of load that needs to be pulled. For steep terrain situations, a higher engine capacity is required. As White (1977) showed, soil and surface conditions play decisive roles in reducing a tractor engine's pulling power by up to 50 percent.

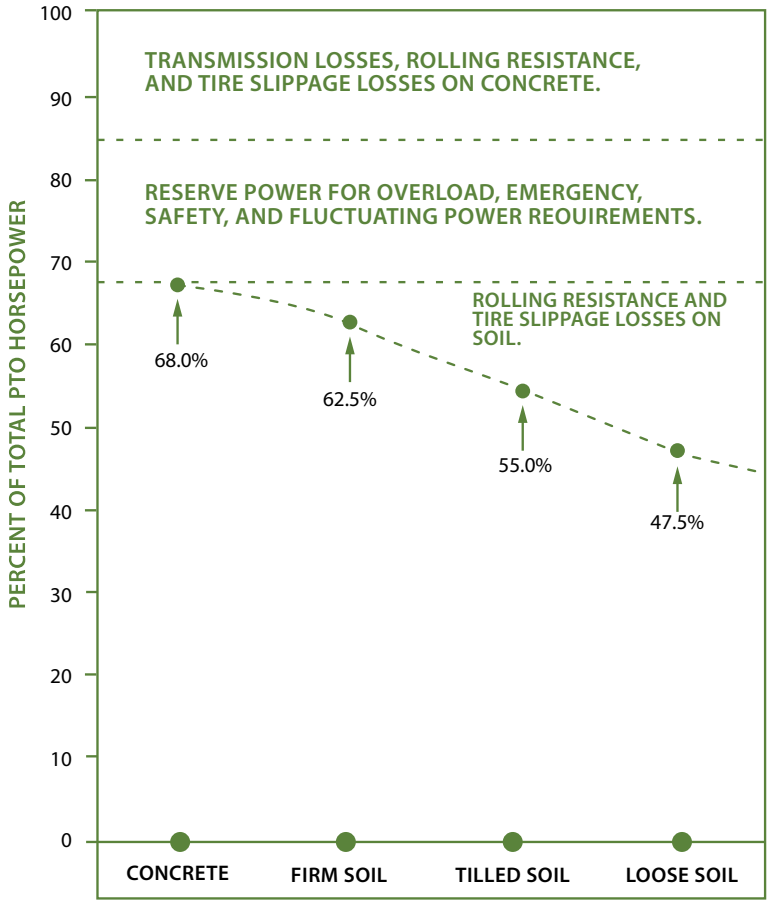


Figure 2. Net pulling power available at the tractor drawbar in relation to four surface conditions (White 1977)

The suitability of forestry implements to their intended use must also be clearly evaluated. The requirements of a part-time operator versus that of a dedicated contractor are much different. The cost of adapting an existing agricultural tractor for forestry use can vary depending on the intended use of its implements. Adaptations should not preclude a tractor's use for farming unless the machinery will be solely dedicated to forestry work. Purpose-built farm-forestry tractors, like those manufactured in the Nordic countries, are designed for dual roles. These may be a consideration for a farmer-forester when deciding on which tractor to purchase. With the attachment of suitable implements, tractors are capable of performing a wide range of forestry operations from skidding and forwarding to loading and processing. The following sections describe some of the key forestry implements used as attachments to agricultural tractors.

2. Key forestry implements for attachment to agricultural tractors

2.1 Skidding bar and plate

The notched skidding bar is a device that is attached to a tractor's three-point linkage. It is used to skid logs that are choked and attached to it. The bar is simply lifted using its links and the attached logs are dragged behind the tractor. This is a very simple piece of equipment and, with the exception of adding front-end weights, requires very little modification to the agricultural tractor. Heavier steel plates or butt plates are larger and adding these allows for a higher pulling point, which is more effective at raising logs off the ground. Most wire cranes and skid winches are equipped with skidding bars.

Advantages	Disadvantages
▪ Low cost ▪ Suited to a wide range of tractors	▪ Low productivity ▪ Limited application in thinning operations since tractor needs to drive to the log for extraction ▪ Weight distribution of many farm tractors may present safety risks ▪ Not suited to difficult or wet sites.

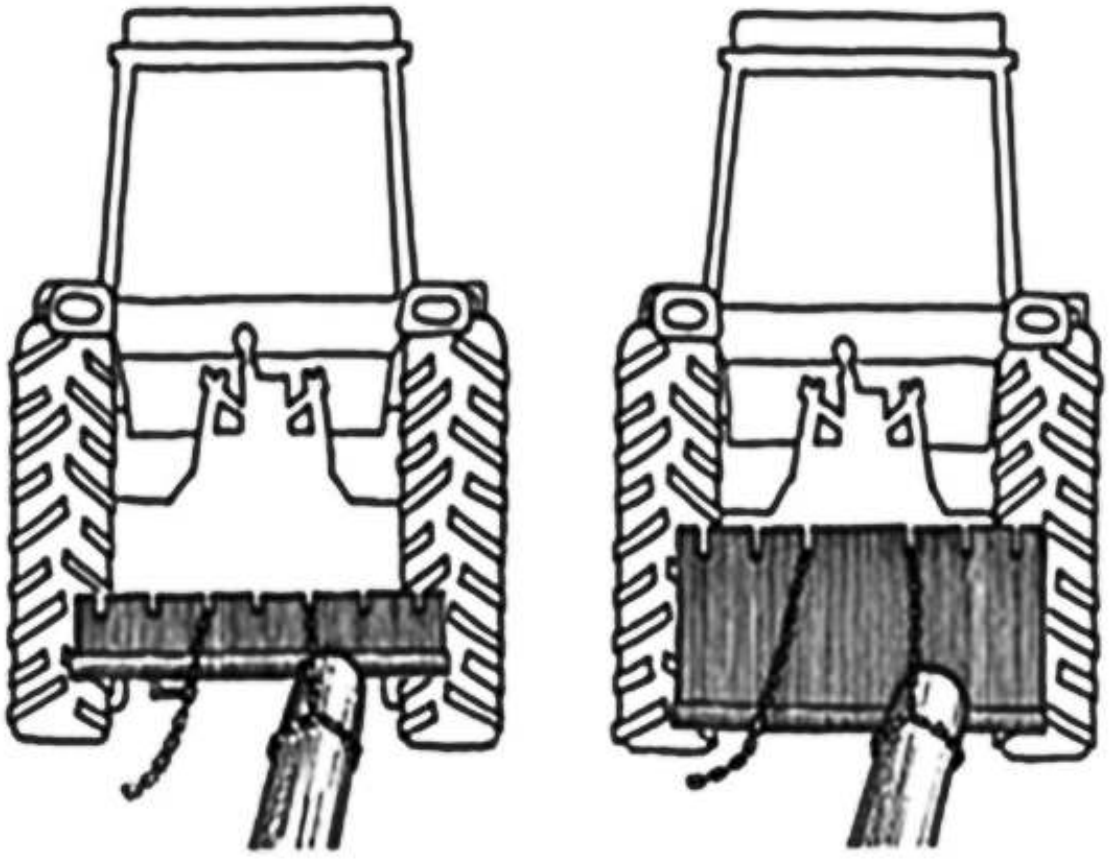


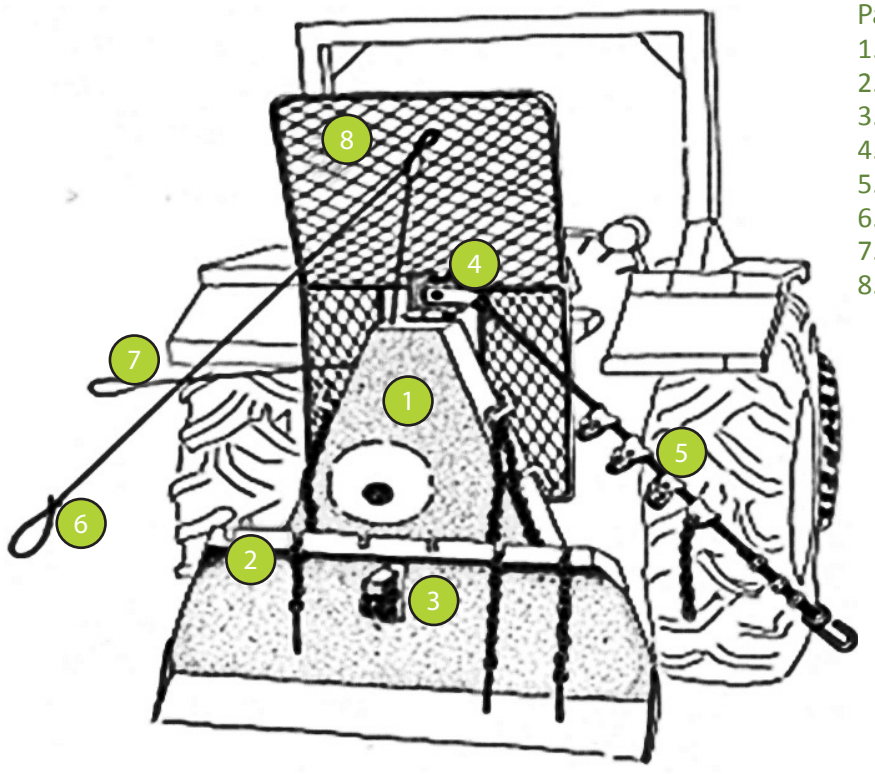
Figure 3. Skidding bar and butt plate for rear attachment (Nova Scotia Natural Resources 2006)

2.2 Skidding winch

Skidding winches use a cable and choker to pull one or more trees. The skidding winch is normally attached to the three-point hitch and receives its power from the tractor PTO. Power winches are made to suit a wide range of tractors (22 kW, 30 hp to 75 kW, 100 hp).

Advantages	Disadvantages
▪ Low to medium cost ▪ Suited to a wide range of tractors and site types ▪ When using winches on difficult terrain, the load can be dropped and the tractor can move to a more favorable location and winch the log from that distance.	▪ Limited application in thinning ▪ Skidding often produces dirty logs, which can cause difficulties at the processing stage, especially when chipping at the roadside ▪ Can contribute to both soil and residual tree damage

The following table provides an overview of key relationships to consider when selecting a tractor-winch combination. Key factors include: the traction power range of the winch (expressed on first turn of cable and complete drum), the cable holding capacity as a function of cable diameter, the dimension of the rear shield (mainly its width, which should not exceed the rear wheel outer breadth), the weight of the winch and the tractor's engine power.



Parts of a skidding winch
1. Main Frame
2. Butt Plate
3. Lower Pulley
4. Upper Pulley
5. Cable with Hook and slides
6. Clutch Cord
7. Brake Cord
8. Protective Grill

Figure 4. Basic skidding winch for tractor attachment

Table 1. Tractor-winch combination (Maxwald, Austria)

Equipment and type	A300	A300S	A400S	A501	A501S	A516S	M2000 Premium	A611S
DISC BRAKE	**Series**	**Series**	**Series**	**Series**	**Series**	**Series**	**Series**	**Series**
Tractive power of the cable's 1st turn	4.5 tons	4.5 tons	5.0 tons	6.5 tons	6.5 tons	6.5 tons	6.5 tons	7.0 tons
Tractive power of the complete drum	2.5 tons	2.5 tons	3.0 tons	4.5 tons	4.5 tons	4.5 tons	4.5 tons	5.0 tons
Cable's maximum holding								
8 mm	100 m	100 m	100 m					
9 mm	70 m	70 m	70 m					
10 mm	50 m	50 m	50 m	100 m	100 m	160 m	160 m	
11 mm				80 m	80 m	130 m	130 m	90 m
12 mm				60 m	60 m	100 m	100 m	70 m
Rear shield								
Width	1.0 m	1.4 m	1.4 m	1.4 m	1.5 m	1.5 m	1.7 m	1.6 m
Height	50 m	50 m	60 m	50 m	70 m	70 m	75 m	70 m
Option: high rear shield**			A4000		A5000			A6000
Operation and control								
Pulling line's operation (traction)	series	series	series	series	series	series		series
HP cylinder, Var. 0 (coupling's actuation)	option	option	option	option	option	option		option
HP cylinder, Var. IV (Prepared for radio control)					option	option	series	option
Radio control					option	option	option	option
Further data								
Cable's speed (0.5 m/sec to 1.0 m/sec.)	series	series	series	series	series	series	series	series
Cable's speed (0.3 m/sec to 0.8 m/sec.)	option*	option*	option*	option*	option*	option*	series	option*
Tractor's recommended power	15 HP	30 HP	40 HP	45 HP	50 HP	50 HP	60 HP	60 HP
3-point category	I+II	I+II	I+II	I+II	I+II	II+III	II+III	II+III
Weight without cable, approx.	135 kg	180 kg	200 kg	250 kg	295 kg	350 kg	450 kg	355 kg
Desired equipment and accessories								
Wide cable drum	A300XL***					series	series	
Cable - winding device						series	series	option
Cable inlet brake, mechanical	option	option	option	option	option	option	option	option
Cable inlet brake and cable ejection, hydraulic					option	option	series	option
Lower cable inlet roller	option	option	option	option	option	option	series	option
Hope guard on the side					option	option	series	option
Handbrake (for cableway)	option	option	option	option	option	option	option	option
Combination with grapple				option	option	option	option	option

Figure 5. Agricultural tractor with logging winch in action

2.3 Skidding and forwarding grapple

Hydraulic grapples mounted on the three-point hitch or in the front of the tractor can be used equally well for transporting cut-to-length logs and full pole-length timber. To do this, the operator reverses the tractor up to the logs or timber stack and 'grapples' the load, which is then hydraulically lifted for transportation.

Power requirement: Optimal front-to-rear weight ratios are needed to meet tractor power requirements. The skidding and forwarding grapple attachment is best suited to four-wheel drive tractors with compensatory front weight attachments. The actual size of the tractor depends on the size of the implement and the weight of the wood to be carried or skidded. The minimum size required is approximately 41 kW (55 hp).

Advantages	Disadvantages
▪ Relatively inexpensive ▪ Short wood can be extracted clean ▪ The operator does not need to leave the cab during loading.	▪ Requires careful bundling of material and does not have the flexibility and versatility of skidders ▪ Needs good sites, detailed planning and site lay-out is required especially when thinning

Figure 6. Rear mounted skidding grapple (www.maxwald.com).

Figure 7. Front grapple loader (www.worksaver.com/product/compactgrapple.html).

2.4 Back fork

Back forks are low-cost extraction implements that are mounted on the three-point hitch to forward short wood.

Power requirement: Tractors need optimal front-to-rear weight ratios, which makes this implement best-suited to four-wheel drive tractors with compensatory front weight attachments.

Advantages	Disadvantages
▪ Low cost ▪ Can be used for both forestry and agriculture ▪ Wood is held off the ground and therefore stays clean	▪ Requires manual loading ▪ Needs fairly even ground to ensure load stability

Figure 8. Tractor mounted back fork (www.lizardtractors.co.uk/acatalog/info_RMPF.html)

2.5 Grapple loading crane

Grapple loading cranes are hydraulic cranes with a grapple. This attachment can be used to pick up single trees or bunched logs for loading or unloading when using a trailer. The crane can be mounted on the tractor's three-point hitch or on the trailer.

Power requirement: Most tractors can easily supply the hydraulic pump capacity requirement of 25 l/min to 50 l/min.

Advantages	Disadvantages
▪ Allows fast, efficient loading and unloading of logs and eliminates manual handling ▪ Larger payloads can be moved compared to skidding systems when used with trailers ▪ Well-suited for short wood extraction. Can be used for both forestry and agricultural operations. Tractor stability is not affected if mounted on the trailer	▪ High cost ▪ Position of loaders on tractors must be considered ▪ A longer loader reach is required if the loader is mounted on the tractor, though a shorter trailer drawbar may be used, which allows for tighter turning ▪ Loaders mounted on the trailer drawbar may need stabilizing legs, which are susceptible to damage when moving off ▪ Loaders on the tractor (three-point linkage) are flexible for use in non-forestry operations

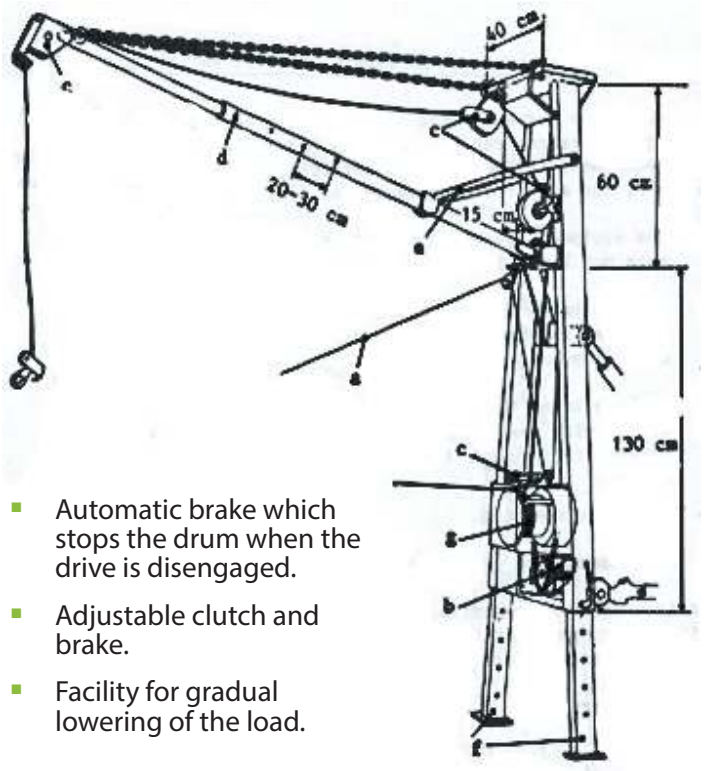
Figure 9. Grapple loading crane in combination with wood chipper (www.farmiex.php?option=com_tuotekatalogi&view).

2.6 Wire-crane loader

The wire crane is essentially a PTO-powered winch with a high A-shaped steel frame and stabilizer legs. Wire cranes are commonly used with a forestry trailer for winching, loading and forwarding wood. The operator walks up to each bundle, puts a wire around it and follows the bundle as it is winched back to the tractor. This tool is compatible with nearly all tractor sizes.

Advantages	Disadvantages
▪ Suitable for thinning operations with widely spaced racks ▪ Short wood can be extracted cleanly ▪ Wire-crane loaders are the least expensive mechanical loading systems available ▪ Ideal implement for start-up operations and when financial resources are limited since no additional loading equipment is required	▪ Operator safety is decreased ▪ Substantial wood handling and walking is required ▪ Productivity tends to be lower than that of grapple loaders ▪ Requires well-trained operators

- Automatic brake that stops the drums when the drive is disengaged.
- Adjustable clutch and brake.
- Facility for gradual lowering of the load.
- Remote control via a cable (a).
- Guard round input shaft (b).
- Input shaft with splines rather than screw thread.
- Line guides at the drum and block (c).
- Adjustable luffing boom (d).
- Lock on boom to prevent the boom swinging during transport (e).
- Adjustable stabilizers with spring-loaded cotter pins that cannot be shaken loose (f).
- When raised, stabilizers level with the bottom of the crane, well clear of the trailer dragpole.
- Drum with a diameter at least ten times that of the cable (g).



- Automatic brake which stops the drum when the drive is disengaged.
- Adjustable clutch and brake.
- Facility for gradual lowering of the load.

Figure 10. Sketch of wire crane loader for attachment to farm tractors

Figure 11. Loading small diameter logs with wire loader

2.7 Log trailer

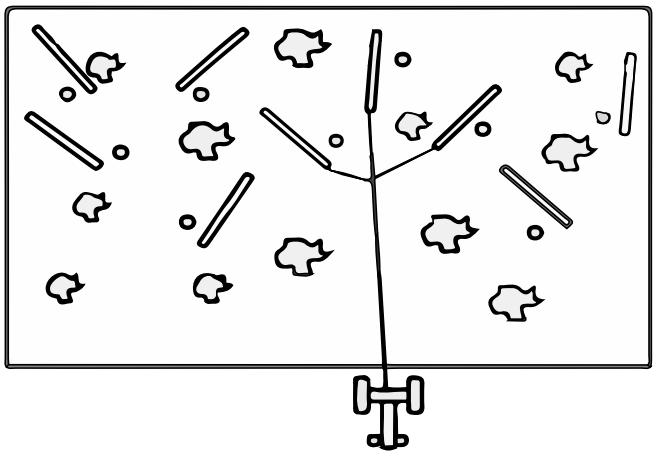
There is a wide range of log trailers available for agricultural tractors from non-driven units to more sophisticated power-driven trailers. Most popular tractor-drawn models may have payloads ranging from three meters $(m)^3$ to eight m^3 with five-ton models being the most common. Three- to five-ton trailers are suitable for lower-powered tractors (less than 37 kW, 50 hp) and part-time usage.

Forestry trailers are built with a skeletal construction in order to maximize payload capacity. The smallest capacity trailers may only have two wheels. However, most forest models have a four-wheel 'bogie' or centrally-suspended axle joint construction. Such combinations start with agricultural tractors of about 30 hp and 3.5-ton trailers, as shown in Figure 12.

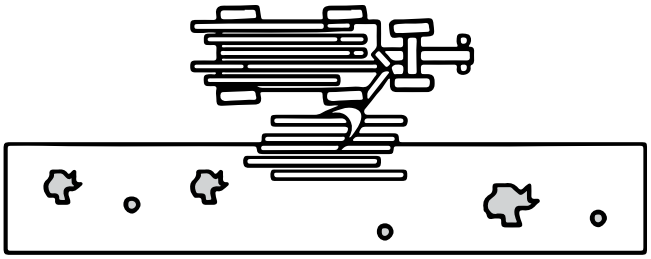
Figure 12 illustrates a typical combination of a farm tractor and logging winch used for skidding and forwarding to first landing, followed by the subsequent transportation of logs using a tractor-trailer combination on forest roads to second landings.

Advantages	Disadvantages
▪ High load capacity to remove large volumes at once; ▪ Short wood can be extracted cleanly; and ▪ Can be used in agricultural applications.	▪ Detailed planning and site layout is re-quired, especially in thinning activities; and ▪ Can be expensive, especially the more sophisticated models.

Figure 12. Agricultural tractor with 3.5 tonne log trailer and grapple crane (www.com%25257Cuserbilder%25257C513)



1: Skidding operation with a farm tractor.



2: Forwarding operation with a farm tractor.

Figure 13. Typical skidding and forwarding operations with farm tractors (Akay 2005)

2.8 Tractor-based harvesters and processors

The most advanced farm-forestry implements for tractors are the harvester and the processor, which can either be front or rear attachments (Johansson, J 1996). The difference between a harvester and a processor in forestry terms is that a harvester *fells*, delimbs and cross-cuts trees into products, while a processor takes *previously felled* trees and delimbs and cross-cuts them. There are, moreover, two categories of processors: grapple and wire. The first uses a grapple loader to bring the tree to the processor while the wire processor uses a winch. These systems are only briefly mentioned here since the costs for both types of tractors with engine capacities well over 100 kW (costing over US$ 80 000) and their respective attachments (costing over US$ 25 000) are beyond the small-scale category covered by this guidebook.

Figure 14. Farm tractor with front mounted harvester (www.Naarva-boom-kit-S23-agricultural-tractor-logging.jpg)

3. Performance studies for agricultural tractors in wood extraction

3.1 Cordero, w and howard, a (1995)

Cordero, W and Howard, A (1995) compared the cost structure between traditional log extraction by oxen and the modern method of using tractors. As shown in Figure 15, 83 percent of system costs in oxen logging are attributed to labor, which can be reduced to as low as 20 percent by using tractors. It is important to understand this relationship in consideration of increasing labor shortages in many rural regions and in view of competition with agricultural income opportunities. In many situations, however, animal logging is not in place or has vanished (e.g. elephant or buffalo logging in Southeast Asia) and it is doubtful that introduction or re-introduction is the recommended pathway. It appears to be more advantageous to adopt agricultural mechanization and adapt farm tractors in forest harvesting systems.

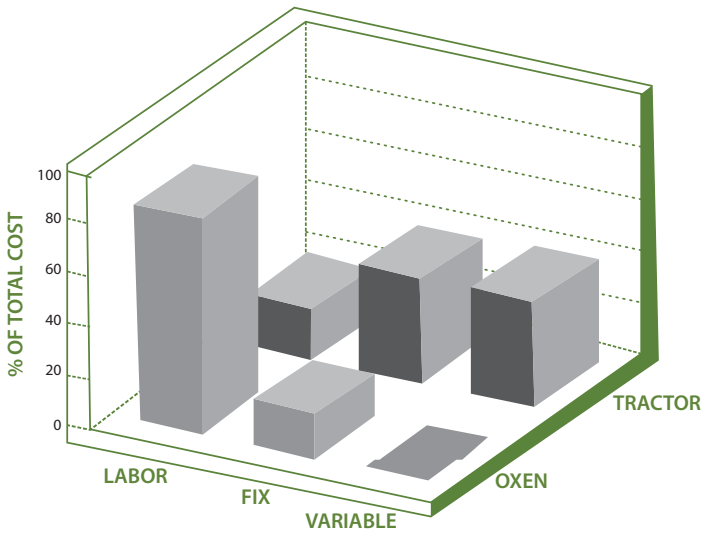


Figure 15. Percentage cost distribution in oxen and tractor based log extraction (Cordero W, and Howard, A 1995)

3.2 Spinelli (2005)

Spinelli (2005) studied the effect of average piece size and large extraction distances of up to 1 400 m, which is typical for many areas in the target regions of this guidebook. Spinelli's study involved six tractor models ranging from 48 kW to 116 kW in three high forest and three coppice forest areas in Italy. Piece sizes ranged from 0.1 m^3 to 1.5 m^3 per piece and had an influence of around 100 percent in each distance situation. Distance affected extraction performance and dropped by 75 percent for small pieces and by 40 percent for big pieces. The relationship is extremely important and is reflected in basically all studies with tractors. Implements bundling smaller size materials into bigger loads are decisive in addressing the volume (weight) per piece ratio. Similar results for farm tractors were found in a study by Özturk (2011) in the mountainous regions of northern Turkey.

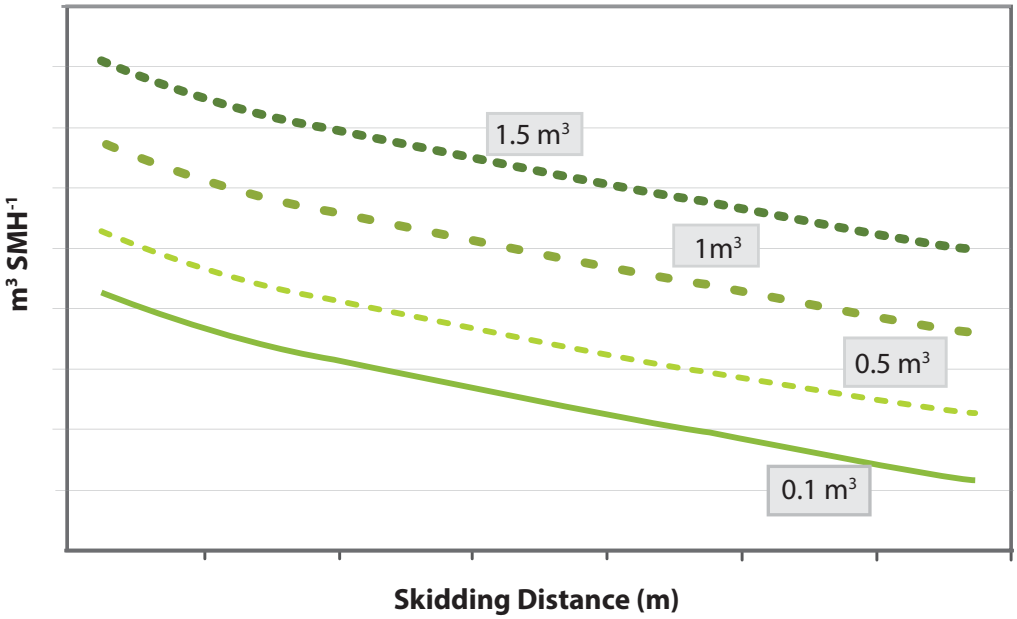


Figure 16. Extraction productivity as a function of skidding distance and piece size.

Note: the curves were calculated for a 70kW tractor, a two-man crew and a winching distance of 15 m (Spinelli 2005).

3.3 Le doux and huyler (1992)

Le Doux and Huyler (1992) carried out a comparative study between small agricultural tractors with winch and boom loader attachments over an extraction distance of 400 m. Productivity of the systems varied by up to 100 percent. Huyler (1984) provided similar results derived from comparable machines. It is interesting to note that the example of a highly specialized small-scale harvesting machine like the *Forest Ant* with only 12 hp gave comparatively high performance in log extraction (refer to Table 2).

Table 2: Performance of small agricultural tractors in log extraction trials in small-sized broadleaved stands (Le Doux and Huyler 1992).

Tractor	Winch/Loading type	HP	Stems/ turn	Volume/ turn (m^3)	Volume Production/hr Without delays (m^3)	Volume Production/hr With delays (m^3)
Massey Ferguson 184-4	Farmi JL-456	60	3.78	1.31	4.78	3.76
Same Minitaurus	Farmi JL 30	60	3.96	1.85	4.05	2.89
Holder A60	IGLAND double drum 3000	48	5.67	1.38	6.70	5.58
Pasquali 993	Farmi JL 25	30	3.94	0.65	3.66	2.46
Forest Ant	Knuckleboom loader	12	7.10	1.0	5.03	3.40

3.4 Hoffman r.e. et al (1982)

Hoffman, R.E. et al. (1982) studied the differences between a rear mounted cable winch and a grapple attachment on a 55 hp Holder Mini tractor. Over short distances (30 m), the grapple-based system had a higher productivity of 35 percent compared to the cable winch. This gradually decreased to 20 percent when distance was increased to 150 m due to the corresponding increase in travel time during the extraction cycle. If logs are pre-bundled at intermediate landings, the advantage of the grapple system is particularly striking as shown by Akay (2005).

Table 3: Comparison of cable and grapple skidding cycle times and production rates for the Holder A55F tractor in relation to extraction distance (Hoffman 1982).

Travel distance	Total productive cycle time		Cycles per scheduled hour		Production per scheduled hour			
					Cunits		Trees	
	Cable	Grapple	Cable	Grapple	Cable	Grapple	Cable	Grapple
Ft.	Min.	Min.	Cycles	Cycles	Cunits	Cunits	Trees	Trees
100	6.34	4.30	6.62	9.77	1.3207	1.9491	19.86	29.31
150	6.81	4.79	6.17	8.77	1.2309	1.7496	18.51	26.31
200	7.29	5.28	5.76	7.95	1.1491	1.5860	17.28	23.85
250	7.76	5.76	5.41	7.29	1.0793	1.4543	16.23	21.87
300	8.24	6.25	5.10	6.72	1.0175	1.3406	15.30	20.16
350	8.71	6.73	4.82	6.24	0.9616	1.2449	14.46	18.72
400	9.19	7.22	4.57	5.82	0.9117	1.1611	13.71	17.46
450	9.66	7.70	4.35	5.45	0.8678	1.0873	13.05	16.35
500	10.14	8.19	4.14	5.13	0.8259	1.0234	12.42	15.39

[1] Assumptions: Average DBH = 8.00 in.; average total height = 55ft.; volume per stem = 6.65 cu.ft. (U.S.Forest Service, 1929); average number of stems per load = 3.

4. Farm tractor and winch attachment in bamboo harvesting

RECOFTC – The Center for People and Forests carried out intensive harvesting trials on bamboo (Dendrocalamus membranaceus, local name Mai Sang) during the dry season of 2013-2014 in Bokeo province, northern Lao PDR (Salakka, 2014). These trials studied extraction costs for bamboo culms – with and without branches – that were transported to roadsides and converted into biomass chips to assess the feasibility of using biomass fuel chips value chain for power generation. The trials were the first trials of their kind on record. A Kubota 35 HP farm tractor was used with a Juwel 3 logging winch iron horse and a local crawler converted from a Yanmar rice harvester hand sulky. Motor winches were also used for skidding in the comparative trials.

The tractor was used for both winching and skidding bamboo while assisting in the extraction process during felling of whole bamboo clumps of about 15 to 25 culms, including dead materials. Due to the large size of the bamboo bundles, rough delimbing had to be undertaken to reduce volume. The extraction distance was 100 m. The winch wire was 60 m long and it was necessary to move the tractor once or twice before it had to be re-winched. Besides re-winching, forwarding was tested after winching by removing bundles by dragging them behind the tractor. However, due to the heavy weight of the bundle, the tractor's front wheels rose up from the ground. This method would be faster but requires an additional weight pack attached to the front of the tractor.

Winching and delimbing phases were studied separately due to the long distance (100 m) separating felling sites from delimbing sites. Productivity was 0.490 tons per hectare (before delimbing/stacking) when bundles were extracted from 100 m. The productivity of one person was calculated at 0.245 tons per hectare. The average cycle time was 43.5 minutes and over half of this time (52.15 percent) was spent waiting, essentially the period that the chainsaw operator was felling the logs. The extraction volume was computed to be 0.355 tons. The winch productivity for a distance of 100 m, if recalculated to remove the waiting time, would be 1 024 tonnes per hectare. The productivity of rough delimbing was 1 772 tonnes per hectare. The next phase, stacking, achieved a performance level of 0.890 tonnes per hectare. The average cycle time was 40.6 minutes. The combined productivity of delimbing and stacking was 0.590 tons per hectare.

In a situation where two operators work simultaneously, the total productivity can be improved if one person is in charge of both chainsaw and winch work, while the other is in charge of delimbing and stacking. Presuming that 52.15 percent of the winch operator's waiting time can be eliminated by assigning chainsaw work and improving extraction speed by gaining the tractor driving speed, these changes will significantly improve each person's productivity: Total productivity per person can be increased to approximately 0.450 tonnes per hectare. This productivity rate, if repeated within a period of eight hours, would give the result of 3.6

Figure 17. Extraction of bamboo using Juwel 3 to winch with a Kubota 35 HP farm tractor

tons per day. If overall productivity of rough delimbing and stacking can be sustained at the level of 0.590 tons per hectare, it would require approximately six hours to delimb and stack 3.6 tons. This result is equivalent to 1.8 tons/day/person or 0.225 tons/hectare/person. Given the extremely small weight-piece ratio of 11 kilogram (kg) fresh weight, these preliminary results are very encouraging for work involving bamboo.

Recommendations

For most situations in Southeast Asia, agricultural tractors in the range of 50 hp or more are ideal for introducing small-scale forest harvesting technologies. The price range of a reasonably used tractor of this kind is below US$ 20 000. Its engine capacity is sufficient to accommodate a wide range of harvesting implements that offer skidding and forwarding solutions in both downhill and uphill operations. Studies from various countries show that total extraction distances of up to 500 m are realistic in forwarding operations that use winch skidding bars or grapple tongues if log trailers are not used. Since tractors will also be used in agricultural work, they can achieve a very high total annual operational time, which is a key factor in the reduction of hourly systems costs.

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APPENDIX

1. Machine cost calculation

Manufacturer: _____ Model: _____ HP: _____		
	Purchase price: $ _____	
	Total price of transportation to site: $ _____	
	Total: $ _____	
(P)	INITIAL INVESTMENT	$_____
(S)	Salvage Value (____% of P)	$_____
(N)	Estimated Life: ____ years	
(SH)	Scheduled operating time: ___ hrs/yr	
(U)	Utilization: ___ %	
(H)	Productive time ____ hrs/yr	
(AVI)	Average value of yearly investment **AVI = [((P-S)(N+1))/2N]+S**	$_____/yr

I. Fixed cost:	
Depreciation= (P-S)/N	$_____/yr
Interest (____ %), Insurance (____ %), Taxes (____ %) Total ____ % x ($____/yr)	$_____/yr
(1) Fixed cost per year	$_____
(2) Fixed cost per H (1÷H)	$_____
II. Operating cost: (based on productive time)	
Maintenance and repair (_____% x ((P-S)/(N x H))	$_____
Fuel (____ L x $____/L)	$_____
Oil & lubricants	$_____
Tires (1.15 x (tire cost)/tire life in hrs.)	$_____
(3) Operating cost per H	$_____
III. Machine cost per H (without labor) (2+3)	$_____
IV. Labor cost ($_____/hr ÷U)	$_____
V. Machine cost per productive hr. with labor (III + IV)	$_____

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