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APPLICATION OF SMALL-SCALE SYSTEMS: EVALUATION OF ALTERNATIVES

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Summary: **Large-scale mechanized systems are not well-suited for harvesting smaller tracts of privately owned forest land. New alternative small-scale harvesting systems are needed which utilize mechanized felling, have a low capital investment requirement, are small in physical size, and are based primarily on adaptations of current harvesting technology. This paper presents an analysis of harvesting functions and considers base machine and multi-function capabilities for this application. Several options for small-scale mechanized harvesting systems are proposed, and recommendations are made for conducting field-tests to help determine system harvesting costs.**

Keywords: **forest operations, mechanized harvesting, thinning, costs**

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INTRODUCTION

Low capital timber harvesting systems relying on manual felling with chainsaws used to predominate in the southern United States. Highly mechanized systems utilizing rubber-tired skidders, feller-bunchers, and knuckleboom loaders have almost completely replaced small-scale systems using manual felling. These systems, which handle the wood in tree-length form, are highly productive and very efficient, especially for large tracts of timber. However, high moving costs make large-scale mechanized systems less cost-effective for harvesting smaller tracts or tracts with low total volume, such as thinnings. Also, because of the size and number of machines, mechanized systems can result in considerable site impacts, an increasing concern to nonindustrial private forest **(NIPF)** landowners that own the majority of the forest land in the South. Lower capital systems are smaller in physical size and have lower overhead costs, making them better suited for low volume harvests on private land because moving costs and site impacts are reduced. However, manual felling is a safety concern, and it is not productive enough when tree size is small and product value is low, such as for plantation thinnings. Small-scale timber harvesting alternatives for current applications must utilize mechanized felling.

In this paper, we review harvesting requirements and available equipment for small-scale timber harvesting systems utilizing mechanized felling. Based on a consideration of issues such as cost, safety, and acceptability to landowners and loggers, different alternative systems are proposed and evaluated. Recommendations for specific systems that should be evaluated in field trials are made. We hope that this information can help spur the adoption of small-scale systems as an alternative for small tract and low volume harvesting applications in the South, especially pine plantation thinnings, thereby helping to meet the needs of landowners, loggers, and the forest industry.

LITERATURE REVIEW

In the South, nonindustrial private forest land accounted for 19 out of 31 million total hectares of forest land (60%) in 1993. Approximately 27% of the total forest land in the South was in ownership sizes of 40 hectares (99 acres) or less, and nearly 18% was in ownership sizes of 20 hectares (49 acres) or less (Birch, 1996). Forest Inventory and Analysis (FIA) data analyzed by Greene et al. (1997) showed that NIPF land accounted for 68% of the total area of timberland in the state of Georgia in 1989. The percentage of the total timberland area in Georgia in stands of 40 hectares (99 acres) or less went from 71% (6.8 out of 9.3 million hectares) in 1982 to 74% (7.1 out of 9.6 million hectares) in 1989. In the same time period, the percentage in stands of 40 hectares (49 acres) or less went from 53% to 56%. Stand size reported by FIA is an estimate of the forest stand observed in the field and not the ownership size, which accounts for the considerably higher percentages for small tract sizes in Georgia than for small ownership sizes for the South overall. However, both studies give a strong indication of the extent of the forest resource in the South which is privately owned and in small tracts. Additional evidence of the strong trend toward smaller ownerships was given by DeCoster (1998). For the U.S. overall, 21.6%

of the total forest land area was in ownership sizes of 40 hectares (99 acres) or less in 1978; it was up to 3 1.6% in 1994, and is projected to be 43.2% in 20 10. He concluded that owners become less likely to manage land for forestry as ownership size decreases, so society risks losing the economic and environmental benefits of a significant portion of the forest resource if efforts are not made to address the forest management needs of small parcels.

From 1986 through 1991, tree planting in the United States averaged nearly 1.2 million hectares per year, with a peak of 1.4 million hectares in 1988 when tree planting under the Conservation Reserve Program (CRP) was at its highest level. During that time period, the proportion of the total tree planting that was done in the South ranged from about 70 to 75% (Mangold et al., 1992; Forward et al., 1990). Since most of the trees that were planted were pine, these data give a good indication of the extent of plantation pine in the South that will be reaching thinning stage in the next several years - probably an average of over 800,000 hectares a year.

A survey by Clair and Stokes (1987) showed the negative attitude that many NIPF landowners have about mechanized thinning systems. Seventy-two percent of landowners chose mules as the type of equipment they preferred for thinning their pine plantations. Assuming that mules were not available for skidding, they still strongly preferred farm tractors (68%) to skidders (13%). Other studies have shown that small forest tract owners have strong management objectives besides just timber production, especially related to aesthetics, and are more concerned about levels of site disturbance on their land from harvesting operations than large forest tract, industrial owners (Bliss, 1993).

Many studies have looked at the effects of tract size on timber harvesting costs. In an early study, Thienpont et al. (1976) found that the degree of mechanization increased with the size of the tract and the volume of timber on the tract, from bobtail truck systems predominating on small tracts (below 20 ha), to small skidder systems on medium size tracts (20 to 80 ha), to fully mechanized systems on tracts larger than that. Cubbage (1983) used computer simulation to estimate harvesting costs for southern pines as a function of tract size for a range of harvest system mechanization levels. Harvesting costs per unit production for highly mechanized systems on tracts larger than 8 to 12 hectares (20 to 30 acres) were lower than for less mechanized shortwood (bobtail truck) or chainsaw tree-length operations, but they increased rapidly on tracts under 8 hectares. Tract size had a greater effect on harvesting costs for more mechanized, and therefore more capital-intensive, systems. In a more recent simulation study by Cubbage et al. (1989), total tract volume affected harvesting costs more for highly mechanized systems than for less mechanized systems. The less mechanized systems were cheaper than the highly mechanized systems for harvesting lower volume hardwood stands, probably because of the need to manually delimb the hardwoods.

The primary reason that tract size affects harvesting costs so much for large mechanized systems is that move and setup costs are much higher than for smaller systems, and therefore larger tracts are required to spread out overhead costs. Move costs include costs for moving equipment from one site to another, employee wages during the move, fixed costs (depreciation, interest, insurance, taxes) for equipment during the move, and other overhead costs during the move (Cubbage, 1983). Foregone production during the time lost to moving is another cost associated with moving (Cubbage, 1982). In a survey of Georgia loggers that used predominately highly mechanized systems, the time required to move averaged 5.8 hours, at an average distance of 48 km (30 miles) (Greene et al., 1988). Moving costs ranged from $244 for a small cable skidder system, to $890 for a large-scale mechanized grapple skidder operation, to $1772 for a whole tree chipper system (Cubbage et al., 1989). For very small systems such as a bobtail truck or an animal logging operation, loggers typically drive equipment home from the work site every evening, and moving costs are often considered negligible (Cubbage, 1982; Toms et al., 1999).

Over the years, as mechanized systems have come to dominate harvesting operations, efforts have been made to investigate and promote smaller scale harvesting technology to fill the void left by the demise of traditional low-capital systems such as bobtail trucks. Much of the effort has focused on the use of agricultural or industrial base machines. In Scandinavia, where farm tractors and other small-scale equipment apparently fill an important niche in woodlot management because of ownership patterns, farm tractor attachments such as harvesting heads and grapple loader trailers have been developed and evaluated extensively (Nordstrom, 1987; Sennbald, 1995; Gullberg, 1997). Logging trailers and other attachments for use with farm tractors have also been evaluated in the United States and Canada (Wilhoit et al., 1995; Folkema, 1987; Stokes and Clair, 1988), but they have never caught on to much extent as they have in Scandinavia. Farm tractors with logging trailers have also been evaluated as a lower cost forwarding alternative in Brazilian forest plantations (Hakkila et al., 1992). Other base machines that have been evaluated for small-scale forest operations include backhoes, wheel loaders, and excavators (Rummer, 1982; Johansson, 1996; Johansson, 1995).

Inter-changeable attachments are another approach to reducing the capital required for a harvesting system by using a single base machine for different functions. Gruelich (1996) examined the concept of a single base machine, a track-type excavator with boom and stick, equipped with harvester head and grapple attachments for use in shovel logging operations for thinning in the Northwest. A small-scale tracked machine, the Makeri Harvester, has been offered with a number of different attachments such as a feller-buncher head, a grapple loader, and a trailer (Besse, 1992). This machine, in the form of a drive-to-tree harvester (without any attachments for intermediate transport or loading), was evaluated in a pine plantation thinning operation in Louisiana (Stokes and Sirois, 1983). A similar approach is to have a single base machine that accomplishes multiple functions. The Koehring feller-forwarder, the best known machine of this type, was reported to have high productivity per man/day (Kurelek, 1984). Wasterlund and Hassan (1994), in an analysis of present and future harvesting machines that would be environmentally "friendly" for selective cutting, considered the feller-forwarder and a similar feller-harvester to be an advantage in reducing traffic on a site, but pointed out the problem of low utilization rate for felling or harvesting heads during forwarding .

FUNCTIONAL ANALYSIS

There are two primary objectives for small-scale mechanized timber harvesting alternatives: 1) that they have a low capital investment requirement, and 2) that they be small in physical size. A low-capital system will have reduced overhead costs, making it more cost-competitive on smaller, lower volume tracts. An additional benefit of a low-capital system is enhanced opportunities for loggers because of the reduced financial risk for getting started, and staying, in the logging business. Small physical size pertains to both the number of machines in the system and the size of the individual machines. A smaller system means less time and cost required to move between tracts, making systems more cost effective for harvesting smaller, lower volume tracts. It also helps minimize site impacts, making timber harvesting more acceptable to private landowners. There are many possible combinations of equipment and people for systems to meet these objectives. Which combinations will be the most promising depends on factors such as system balance, costs, safety, and the availability and acceptability of the technology. This last factor is an important one that is often overlooked. Because development costs for completely new technology would be prohibitively expensive, and contractors are more likely to adopt harvesting equipment that has evolved from proven technology, we believe that small-scale mechanized timber harvesting systems should be based primarily on adaptations of current harvesting technology.

There are four primary functions that any harvesting system must accomplish: felling, processing (delimbing, bucking, topping), intermediate transport (skidding or forwarding), and loading. The methods and technology used to accomplish these functions determine the combination of base machines, functional mechanisms, and people in the system. The following is an analysis of each of the primary harvesting functions considering the different types of machinery/technology available, costs, labor requirements, and safety. An evaluation of base machine and system options follows.

Felling

Related to felling, it is instructive to review small-scale systems currently meeting the requirements for certain timber harvesting niches. Bobtail trucks, the predominate pulpwood harvesting system in the South many years ago, can still be seen in use around towns and cities loading shortwood from tree removal or trimming operations to sell as pulpwood. Small-scale operations using manual chainsaw felling and either cable skidders or animals for skidding are often still used for sawtimber harvests, especially in situations where volume is low or aesthetics are more of a concern, such as at the urban-rural interface. What all three types of small-scale systems (bobtail truck, cable skidder, animal logging) have in common is manual felling and processing with chainsaws. Manual felling and processing is fairly productive with the large piece size from sawtimber harvests, but the productivity drops considerably with the small piece size typical from thinnings. The lack of bunching with manual felling also reduces the productivity of subsequent functions (manual processing, skidding) with small trees. Hang-ups, which are particularly troubling if felling manually in thinnings, can reduce productivity considerably more. Safety is also a big concern with manual felling, because of the hazards associated both with tree felling and chainsaw use. With manual processing, the chainsaw use is still a safety concern, but not as much as with felling. Based on both productivity and safety considerations, alternative small-scale harvesting systems must have mechanized felling, and preferably mechanized processing as well.

The three types of mechanisms appropriate for mechanized felling in a small-scale system are: hydraulic shears, chainsaw felling head, and harvesting head (with a chainsaw for felling and bucking plus feed rollers and delimbing knives). Small-scale feller-buncher heads using hydraulic shears are commercially available for small skid-steer machines. They even come as interchangeable attachments. These small skid-steer machines are a low-capital felling option that were used a considerable amount in the past for harvesting plantation pine (Cubbage, 1981). Chainsaw felling heads are most familiar on the small three-wheeled machines that have been very popular as a relatively low-capital feller-buncher. An advantage of this type of felling head is that it allows a small base machine to handle large trees. A disadvantage is that, because of the dangle mounting arrangement and problems with the chain coming off the bar, chainsaw felling heads typically cannot accumulate, making them less productive in small timber such as thinnings. Harvesting heads were previously only available from Scandinavian manufacturers, but more and more North American manufacturers are making harvesting heads as cut-to-length systems have increased in popularity. Harvesting heads have traditionally been boom-mounted for swing-to-tree harvesting, but recent applications have used less expensive drive-to-tree configurations. Smaller harvesting heads are available for small carriers such as farm tractors or small excavators, but the capital costs for the head alone are still quite high, $50,000 or more. Harvesting heads have not been available as interchangeable attachments, largely because of the complexity in hardware/hydraulics and controls for accomplishing both the felling and processing functions.

Of the three types of mechanisms, hydraulic shears are the most promising because of low cost, high productivity, and the potential for interchangeability. Chainsaw felling heads would be somewhat more expensive than a small hydraulic shear head, and they are less productive when tree size is very small because of the lack of accumulation capabilities. Another disadvantage is that chainsaw heads are not available as a standardized quick-disconnect attachment, but the flexibility of being able to harvest a wider range of tree sizes would be an advantage over hydraulic shears. Harvesting heads have the advantage over shears and chainsaw felling heads that the processing could be accomplished along with the felling. But harvesting heads are relatively expensive, and have never been adapted for interchangeability.

Processing and Intermediate Transport

Processing and intermediate transport are so interdependent that they will be considered together. Processing includes delimbing and topping if the trees are handled in tree-length form, or delimbing, bucking, and topping if the trees are handled in log-length form. The shortwood form used by bobtail truck systems would be too inefficient, so tree-length and log-length are the choices to consider for small-scale mechanized harvesting systems. The choice depends to a large extent on the form of intermediate transport used, with forwarding typically used with log-length wood and skidding with tree-length wood.

Log-length wood that is forwarded must be processed at the stump, which has several advantages in terms of site disturbance. The slash forms a mat on the forest floor which can help to reduce the effects of machine traffic, nutrients in the slash are distributed throughout the stand rather than concentrated at the landing, and it is generally considered more aesthetically pleasing, an important consideration from the standpoint of landowner acceptability. Another advantage is that the area required for trails and landings with cut-to-length (forwarder) systems is usually less than with tree-length (skidder) systems. Also, small saw logs can be merchandized if the wood is handled in log-length form. Processing choices with log-length wood include manual chainsaw processing, which is labor-intensive and a safety concern, or using harvester heads. Tree-length wood that is skidded would have to be manually processed with chainsaws.

Small-scale equipment designed for use with farm tractors is available for both forwarding and skidding. Several Scandinavian and Canadian manufacturers offer bogie axle trailers equipped with small hydraulic knuckleboom loaders. Tractor/trailer combinations are a relatively low-capital alternative to purpose-built forwarders for forwarding log-length wood. Also, they may offer an advantage from a moving standpoint if the trailer can be pulled on the road, because a farm tractor is a smaller piece of equipment to load and haul than a forwarder. Several North American manufacturers offer three-point hitch skidding attachments for tractors, both for cable and grapple skidding. For the small piece size coming out of a pine plantation thinning, grapple skidding should be much more productive, especially if it is used in conjunction with mechanized felling so the wood can be appropriately bunched. There are small purpose-built skidders available, but the use of tractors with skidding attachments may have advantages as far as multi-function capabilities, especially for loading.

Loading

Loading is also closely connected to intermediate transport, as a major factor in the loading function is whether the wood is forwarded or skidded. Forwarders have hydraulic log loaders for picking up the logs in the woods that can also be used to load trucks at the landing. This is a distinct advantage for a low-capital system since a separate piece of equipment for loading is not required. A separate loader in a small-scale thinning system would have a particularly low utilization rate.

Front-end loaders on tractors are another possible loading option for small-scale mechanized harvesting systems. They can have the same multi-function advantage as forwarders, as a tractor used for skidding could also be equipped with a front-end loader with log-loading forks. Also, log-loading forks should be less expensive than hydraulic knuckleboom log loaders, assuming a tractor is already equipped with a front-end loader. A drawback to this type of loading is the high degree of vehicle traffic involved with loading trucks, as the loader has to drive back and forth constantly to load a truck. Front-end loaders are more suited to handling log-length wood, but they should be able to handle small tree-length material, such as would come from most thinnings, efficiently and safely.

Base Machine and Multi-Function Canabilities

The use of a single base machine with inter-changeable attachments is attractive because it requires only one carrier, which is likely to be the most expensive component in the system. Having a single base machine should also reduce move costs. There are important limitations to the single machine system concept, however. The utilization rate for all of the attachments will necessarily be low, because each of the attachments used for the different harvesting functions will be idle while the other functions are underway. If the attachment is expensive, like a harvesting head, then the low utilization rate will significantly increase harvesting costs. The time and effort required to change attachments is another important consideration. For some functions, the weight and complexity of the attachment combine to make interchangeability impractical. We believe this to be the case for harvesting heads, and think that is why no harvesting heads with quick-disconnect capabilities have ever been developed. Even if attachments can be changed with relative ease, it is unrealistic to expect loggers to change between attachments too frequently, like for every forwarding cycle. Attachment changes would have to be relatively infrequent, perhaps once or twice in a day, for a system utilizing interchangeable attachments to be acceptable to loggers. Because of these limitations, we have concluded that a single machine system would have to be limited to using hydraulic shears (rather than a chainsaw felling head or a harvesting head) for felling. A system with two small base machines will probably be better balanced and more cost-efficient than any single machine system, and it allows for the possibility of using a chainsaw or harvester head for felling.

The choice of base machines involves consideration of factors such as traction, steering, and mounting configuration. Harvesting heads can be mounted either on the front of a base machine, in a drive-to-tree configuration, or, as has been more commonly done, on the end of a knuckleboom, in a swing-to-tree configuration. Hydraulic shear and chainsaw felling heads have usually been mounted in a drive-to-tree configuration, especially for small-scale harvesting applications. The swing-to-tree configuration is advantageous from the standpoint of site disturbance, because machine traffic on the site is reduced, but a heavier, more expensive base machine is required, and the hardware requirements for the knuckleboom significantly increase machine costs. For a small-scale mechanized harvesting system for applications in the southern U.S., we believe the drive-to-tree configuration will be the most practical, applicable for all three types of felling mechanisms.

Farm tractors are already well-accepted as base machines for small-scale harvesting operations, especially for pulling logging trailers (forwarding) or equipped with grapple skidding attachements, as shown in Figure 1. But for drive-to-tree harvesting applications, either skid or articulated steering is required to give the level of maneuverability needed to efficiently line up the cutting head with the tree. Small-scale articulated steering machines are not commonly available, but small, low cost rubber-tired skid steer machines are common, and they have often been used with shear head attachments for thinning, as shown in Figure 2. A newly available rubber-tracked skid steer machine may be even better suited to harvesting operations. The machine, the ASV Posi-track', is shown in Figure 3. It has a mass of approximately 3850 kg, considerably heavier than the typical skid-steer loader mass of approximately 2500 kg. Because of the extra weight and the large contact area provided by the tracks, stability and traction are improved, making this machine applicable for harvesting functions that the smaller skid-steer loader is not well-suited for, including pulling a trailer, skidding logs, and operating a harvester head. Yet it is still much smaller and lighter than available skidders or small crawler tractors, and considerably less expensive as well. Low ground pressure is another advantage of these machines. These machines come equipped with a front-end loader, similar to what is found on skid steer loaders, so they can be equipped to use quick-disconnect attachments in the same way. They also have capabilities for three-point hitch mounting and reversibility, although there are currently some limitations as to how the front-end loader can be configured when the three-point hitch set-up is in use.

Any base machine converted for forest use must be appropriately modified to protect both the operator and the machine. Nilsson (1982) describes modifications for farm tractors including belly pans, radiator guarding, valve stem protection, engine guarding, and cab protection. Any machine used by a logging contractor in the United States must comply with safety requirements in the OSHA Logging Safety Standard (29 CFR 19 10.266). Some required modifications may be difficult to implement on certain types of base machines and can significantly raise the cost of the logging system.

LOW-CAPITAL THINNING SYSTEM OPTIONS

Based on the preceding analysis, we think that four-wheel drive farm tractors, small rubber-tired skid-steer machines, and larger rubber-tracked skid-steer machines are the three main types of base machines to be considered for small-scale mechanized harvesting systems. The following restrictions apply regarding the base machine type, harvesting function, and the form that the wood is handled in.

1. Felling only with small skid steer loader or larger rubber-tracked machine (not with a tractor).

2. Harvester head felling and processing possible only in a permanent mounting configuration (not as an interchangeable attachment).

3. Log-length wood to be forwarded by logging trailer, most likely pulled by farm tractor, possibly pulled by rubber-tracked machine.

'The use of trade names does not imply endorsement of products named nor criticism of similar products not named.

4. Tree-length wood to be skidded by grapple attachment, most likely using four-wheel drive tractor, possibly using rubber-tracked machine.

5. If harvester head used for felling and processing, a logging trailer would be used to forward the wood in log-length form, and it would also handle loading.

6. If hydraulic shear or chainsaw head used for felling, wood could either be forwarded and loaded in log-length form with a logging trailer (with manual processing at the stump), or it could be skidded in tree-length form (with manual processing at the landing).

These restrictions determine system options, which are outlined in Table 1 and illustrated in Figure 4. There are three combinations of base machines, and these break out into six possible system options. The only single machine system would use the rubber-tracked machine with a hydraulic shear felling head attachment, manual tree-length processing, and a logging trailer pulled by the rubber tracked machine for forwarding and loading. There are four possibilities utilizing a small rubber-tired skid steer machine for the felling function and a farm tractor for intermediate transport and loading functions. There are two felling options with this base machine configuration: using hydraulic shears, which would be more suitable for thinning operations, or using a chainsaw head, which would give more flexibility for harvesting a wider range of tree sizes. With either felling option, trees would be manually processed either in log-length form, with a logging trailer pulled by a farm tractor for forwarding and loading, or in tree length form, with a farm tractor with grapple attachment for skidding and front-end loader for loading. The only system option using a harvesting head would use the larger rubber-tracked machine with a harvesting head for felling and processing, and a farm tractor pulling a logging trailer for forwarding and loading. It should be noted that substitutions of different base machines make additional combinations possible. However, we ruled out some combinations that we did not consider practical, like using the more expensive rubber-tracked machine (in place of a tractor) for forwarding or skidding, or using the lighter skid-steer machine (in place of the rubber-tracked machine) with the harvesting head.

DISCUSSION

Included in Table 1 and Figure 4 is the anticipated number of workers required for each system. With the single machine system, two workers would be required, one to operate the machine and one to manually process the wood. The two machine systems utilizing manual processing require three workers, two for operating the machines and one for chainsaw processing, while the system with the harvesting head requires just two workers for operating the machines. Whether or not this would actually be the appropriate number of workers depends on system balance. According to old studies on productivity for small-scale equipment and manual chainsaw work, the skid-steer machine with shear felling head would be much more productive than one person manually delimbing and topping bunched wood for larger tree sizes, but the production is reasonably well matched when tree size is small, below 15 cm (6 in.) DBH (Cubbage, 1981). A chainsaw felling head would be considerably less productive than the shear felling head at the small tree size because of not being able to accumulate, but as tree size increases it would approach the productivity of the shear head because neither would be able to accumulate.

From a system balance standpoint, intermediate transport may be the limiting function. Productivity using a tractor and trailer for forwarding may be considerably less than that of the skid-steer machine with felling head, depending on conditions and tree size (Wilhoit, 1995; Folkema, 1987). The productivity for a tractor with grapple skidding attachment may be somewhat higher (than tractor/trailer forwarding) according to one early study (Blonsky, 1971), but it would be reduced considerably if the tractot were also used for loading. The productivity of the tractor/trailer forwarding may be fairly well matched to that of the rubber-tracked machine with a harvester head, assuming a productivity comparable to that of the small Makeri harvester in thinnings (Stokes and Sirois, 1983).

If skid steer felling (with manual processing) is more productive than tractor/trailer forwarding or tractor/grapple skidding, then the skid-steer machine would be under-utilized in the proposed configuration. An additional forwarding or skidding unit could be added to give better system balance, but this would add to the cost and effort required for moving, counteracting the small tract advantage for a small-scale system. The single machine system would of course have a similar disadvantage as far as under-utilization of equipment, with both the felling head and the logging trailer being under-utilized, but the base machine itself would be maximally utilized. If felling productivity were approximately twice as high as intermediate transport productivity, the single machine system potentially could be as much as 67% as productive as the two machine systems, if the base machine was used one third of the time for felling and two thirds for forwarding. Actual productivity would probably be lower, due in part to the inconvenience of hooking up and unhooking the trailer. This task is made even more cumbersome by the hydraulic connections and controls that must be run from the tractor to the trailer.

System limitations are also included in Table I. Concern about safety for manual processing using chainsaws is an important limitation noted in the table. The option using a harvester head eliminates this safety concern. This option also has none of the other limitations related to interchangeable attachments or loading. The rubber-tracked machine has been tried on a limited basis with a small harvesting head, but it has not been thoroughly field-tested. The higher capital cost associated with the harvester head is the only significant drawback to this system option. It may be possible to put together this type of system at a cost of approximately $150,000 (excluding trucking and hauling equipment). The other systems might range in cost from $75,000 for the single machine system to $100,000 for the two machine system utilizing the tractor/trailer for forwarding and loading, with the cost of the tractor/grapple system falling somewhere in-between. The best choice will depend on cost per unit of wood produced, which is a function not only of capital (overhead) costs and productivity, but of other costs (labor and moving) as well. The two-machine systems may all have about the same production (if intermediate transport is the limiting function), probably in the 125 to 190 m^3 (50 to 75 cords) per week range. The harvester system would have a capital cost approximately 50% higher, but it would require one less worker than the two machine systems. The single-machine system would have considerably lower production at a somewhat lower capital cost (then the two machine systems using manual processing), but would have one less worker and lower moving costs since it has only one base machine.

Some equipment development work as well as field-testing is needed to assess actual system productivity before an accurate comparison of harvesting costs per unit production can be made. A limited amount of equipment development work will be required with the rubber-tracked machine. It is currently configured to have all attachments on the loader, but to use it in the single-machine system would require that the logging trailer attach to the other end. The rubber-tracked machine has been equipped with a harvesting head and tested to a limited extent, but no productivity data have been collected with it, and the base machine has not been thoroughly tested under rough forest work conditions. Also, proper guarding for operator and machine protection has not yet been standardized for this machine. Modifications would have to be made to the loader on the small skid steer machine to mount a chainsaw felling head on it. The skid-steer machine with shear felling head and the farm tractor with attachments for skidding or forwarding are all readily available and thoroughly tested in timber harvesting applications. But productivity data for tractor skidding in combination with loading using a front-end loader is not available that we know of.

SUMMARY AND CONCLUSIONS

A considerable amount of the vast forest resources in the southern United States is privately owned in smaller tracts, much of it plantation pine in need of thinning. Large-scale mechanized harvesting systems are not well suited for harvesting smaller, lower-volume tracts because of high moving costs and landowner concerns about site impacts. Traditional small-scale harvesting systems have relied on manual felling using chainsaws, but this is a safety concern, and productivity is too low when tree size is small and product value is low. New alternatives in small-scale harvesting systems are needed which utilize mechanized felling, have a low capital investment requirement, are small in physical size, and are based primarily on adaptations of current harvesting technology.

Based on an analysis of primary harvesting functions and base machines, and considering the different types of machinery/technology available, costs, labor requirements, and safety, several conclusions were drawn about potential small-scale mechanized systems for harvesting smaller tracts of privately owned forest land.

1. A drive-to-tree configuration is most practical for felling, using either a small rubber-tired or larger rubber-tracked skid steer machine.

2. Of the three types of felling mechanisms appropriate for this application, hydraulic shears are probably the most promising because of low cost, high productivity in thinning, and potential for interchangeability. A chainsaw head will be less productive with small piece size because of lack of accumulating capability, but has the flexibility of harvesting a wider range of tree sizes. A harvesting head would be the most expensive, but would handle both felling and processing.

3. Processing would have to be done manually using a chainsaw if felling was done using either the hydraulic shears or the chainsaw head.

4. Intermediate transport can be handled using either a four-wheel drive farm tractor and logging trailer for forwarding log-length wood, or a tractor with grapple attachment for skidding tree-length wood.

5. Loading would be handled by the knuckleboom loader on the trailer if logs were forwarded, or by a front-end loader on the tractor if the logs were skidded.

6. Three main combinations of base machines were proposed : a single machine system using the rubber-tracked machine with a logging trailer; a two machine system using the small skid-steer machine with either a shear or a chainsaw head for felling and a tractor with either a logging

trailer or a grapple skidding attachment; and a two machine system using the rubber-tracked machine with a harvesting head and a tractor with a logging trailer.

7. Intermediate transport is likely to be the limiting factor for system productivity. More information is needed to accurately estimate productivity, but it would probably range from 125 to 190 m^3 (50 to 75 cords) per week for the two machine systems, lower for the single machine system.

8. Capital requirements may range from $75,000 for the single machine system, to $100,000 for the two machine systems using shear or chainsaw felling, to $150,000 for the harvester system.

The best choice will depend on cost per unit of wood produced, which is a function of productivity and costs factors such as capital (overhead), labor, and moving. Some of the proposed machines/harvesting functions have been thoroughly tested in timber harvesting applications, but data must be collected for others before actual system productivity can be assessed and costs per unit production can be compared. We hope that the information presented in this paper can help spur the needed field-testing and the eventual adoption of small-scale mechanized timber harvesting alternatives which can help landowners, loggers, and the forest industry productively manage nonindustrial private forest land in the South.

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Table **1. Low-capital thinning system options**

# of Base Machines	# of people	Type of Machine	Felling	Processing	Intermediate Transport	loading	limitations
1	2	Rubbertracked machine	Shear head attachment	Manual, log-length	logging trailer	Logging trailer	1. Chainsaw for processing, safety concern. 2. Current configuration of rubber tracked machine requires all attachments on same end. 3. Reduced utilization rate for function not in use with single base machine.
2	3	Small skid steer machine/ 4WD	Shear-headon small skid-steer machine	Manual, Log length	Logging trailer wltractor	Logging trailer w/tractor	1. Chainsaw for processing, safety concern. 2. Processing must be done by one of machine operators, which reduces utilization rate for machine.
				Manual, tree-length	Skidding attachment wltractor	Front-end loader w/tractor	1. Chainsaw for processing, safety concern. 2. Processing must be done by one of machine operators, which reduces utilization rate for machine. 3. Front-end loaderfor handling tree-length wood.
			Chainsaw head on small skid steer machine	Manual, Log length	Logging trailer w/tractor	Logging trailer w/tractor	1. Chainsaw for processing, safety concern. 2. Processing must be done by one of machine operators, which reduces utilization te for machine.
				Manual, tree-length	Skidding attachment w/tractor	Front-end loader w/tractor	1. Chainsaw for processing, safety concern. 2. Processing must be done by one of machine operators, which reduces utilization rate for machine. 3. Front-end loader for handling tree-length wood.
	2	Rubber-tracked machine/ 4WD tractor	Harvester head with rubber-tracked machine	Harvester head	Logging trailer wltractor	Logging trailer wltractor	

Figure 1. Farm tractor with grapple skidder attachment.

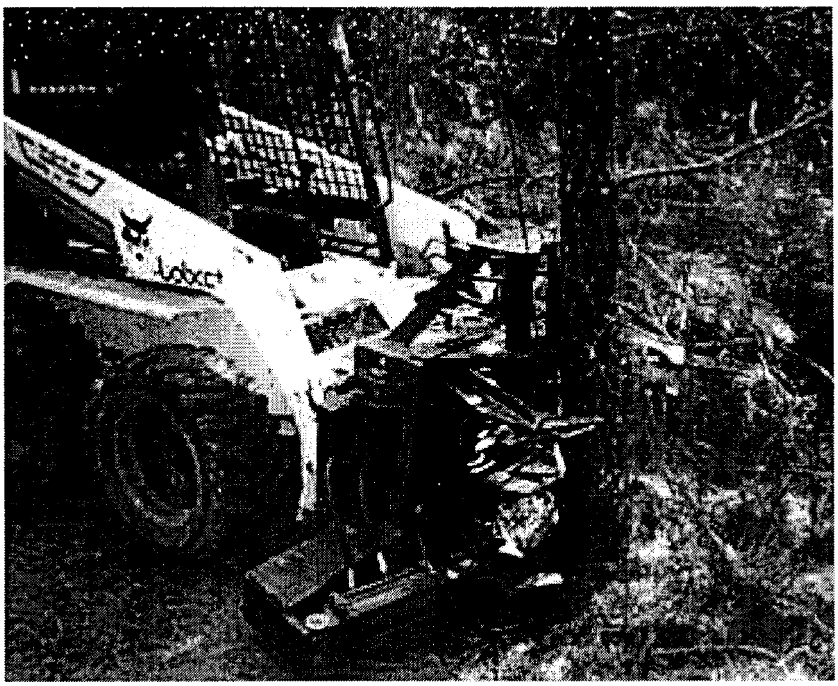

Figure 2. Shear head attachment on small skid-steer machine

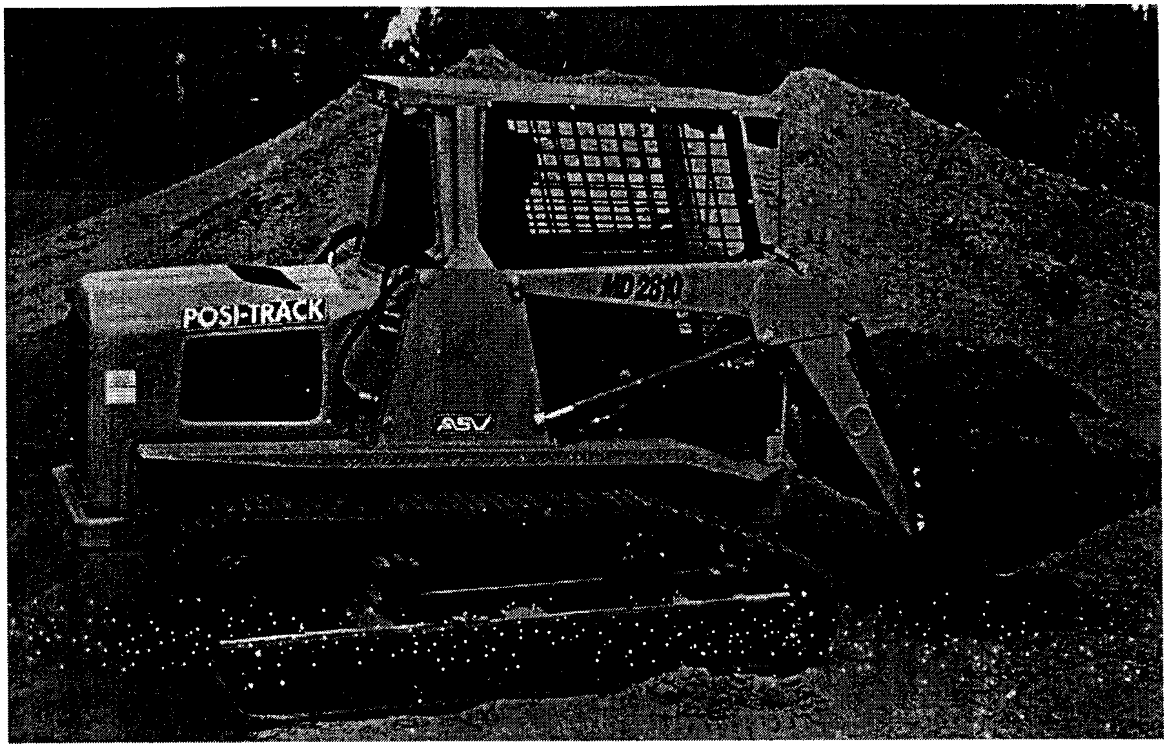

Figure 3. Rubber-tracked skid steer

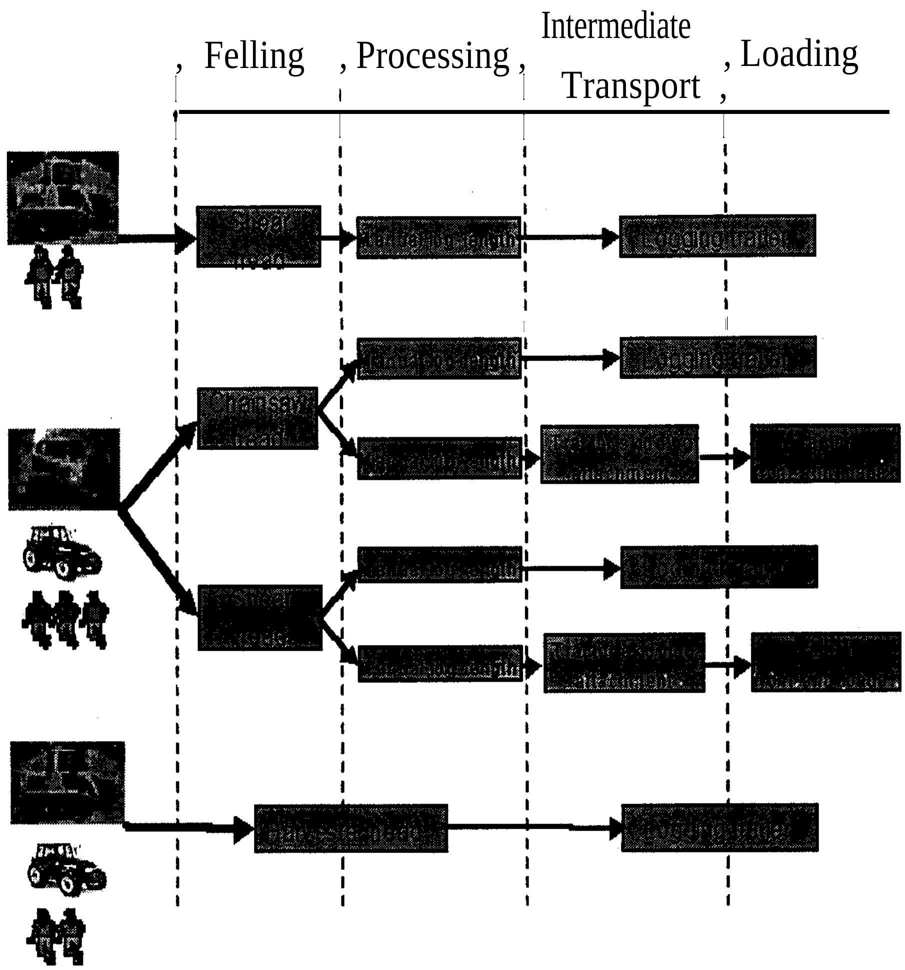

Figure 4. Illustration of small-scale mechanized harvesting system options.