A New Slash Bundling Concept for Use in a Southern US Logging System

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Abstract

John Deere's biomass bundler unit is an effective machine for harvesting forest residues, which can be used as a source of fuelwood and/or a feedstock for biofuel production. This project explored an avenue that could supply a promising source of readily available energy in southeastern forested lands. Typical southern harvesting operations consist of whole-tree harvesting in which trees are felled and then skidded to a landing. Limbs and tops are usually either deposited over the landscape or piled in windrows. The biomass bundler captures the otherwise nonmerchantable material and maximizes the marketability of the entire tree. In order to reduce costs, maximize efficiency, and implement the bundler in a tree-length harvesting operation, this project tested a prototype harvesting system. This venture (1) adapted the John Deere B380 bundler unit to a motorized trailer, (2) designed an optimum landing configuration, and (3) conducted a productivity study of the bundler unit. The unit produced 13.2 tonnes per productive machine hour (PMH; 14.6 tons/PMH) of 250-cm bundles and 14.9 tonnes/PMH (16.4 tons/PMH) of 350-cm bundles, assuming minor delays at a cost of \$12.50 to \$14.20/tonne (\$11.25 to \$12.85/ton).

There are 368 million dry tons of biomass available annually on a sustainable basis from forest-derived resources in the United States (Perlack et al. 2005). This represents a huge potential resource for energy production (Rummer et al. 2004). With the current energy crisis and with high petroleum prices, all sources of alternative fuels need to be explored. John Deere's biomass bundler unit is an effective machine for processing forest residues, which can be used as a source of fuelwood and/or a feedstock for biofuel production. Although technologies and markets for such innovative practices have not yet matured, this project aimed to explore a system that could supply a promising source of readily available biomass from southeastern US forested lands.

According to the US Department of Energy's Comprehensive Energy Plan, one of the key goals for the nation is to diversify America's energy supply. The government aims to promote alternative and renewable sources of energy (Bodman 2005). The Energy Policy Act, part of the energy plan, sets goals of producing 250 million gallons of cellulosic ethanol by 2013 and 1 billion gallons by 2015 (Morris 2006). One of the most prevalent sources of cellulose for ethanol production is forest residues (Perez-Verdin et al. 2009). Such ambitious national energy goals require a vast supply of renewable feedstock.

In order to maximize the use of forest resources, available material must be efficiently captured. Current forest harvesting practices in the southern United States are proficient in harvesting timber; however, the harvest of forest residues is economically inefficient or nonexistent in most of the conventional harvesting configurations in the region. Typically, these operations consist of whole-tree harvesting in which trees are felled and then skidded to a landing. Limbs and tops are then removed from the tree and either deposited over the landscape or piled in windrows. Most logging crews in the South that capture the forest residues do so using a drum-type chipper. Chipping forest biomass is effective; however, it requires a large amount of capital investment to an already economically stressed industry. In-woods chipping operations require the purchase of a chipper as well as chip vans for transport.

A recently developed piece of equipment, the John Deere Slash Bundler, provides an alternative method to capture this otherwise nonmerchantable material and maximize the marketability and utilization of the entire tree. The bundler

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unit is operated by feeding slash into a set of four compression feed rollers. Two compression arms then further compress the slash while sliding the bundled material forward. A rotating twine magazine then fastens the bundles with bailing twine. At a predetermined length, the automated cutting saw severs the compressed slash, resulting in a slash bundle, sometimes referred to as a compressed residue log (bundle) (Martin 2008).

The machine has been tested in several trials. One study was performed in Arkansas using the original forwarder-mounted JD 1490D configuration (Patterson et al. 2008). The study consisted of four case studies performed on four different sites. Each of the sites underwent a different harvest regime. The first site consisted of a mature stand of loblolly pine clear-cut harvested by conventional logging equipment. Logging residue was piled along the roadside to increase accessibility. The JD 1490D produced 22.3 bundles per hour with an average cycle time of 2.69 minutes. Site 2 was a 26-year-old stand of pine plantation undergoing a second thinning by the same harvesting system. Limbs and tops were piled at the landing, and the JD 1490D was able to produce more than 31 bundles per hour. Site 3, a stand of 11-year-old loblolly pine plantation, produced 36.1 bundles per hour. Site 4 was a thinning operation in a 17-year-old loblolly pine plantation. Cut-to-length harvesting equipment was utilized on the site, meaning that the JD 1490D had to travel in woods to gather material. The resulting 13.8 bundles per hour reflect the operational differences. The average weight of the bundles for Sites 1 through 4 were 401, 415, 431, and 434 kg (883, 916, 950, and 957 lb), respectively.

John Deere reported production rates from a 2006 study done in France (Martin 2008). Study conditions are unknown, but the French study reported that 18 to 25 bundles per hour was feasible with the JD 1490D. An aside was made that these production rates could be achieved with an experienced operator and appropriate site planning.

The John Deere Slash Bundler was originally designed to be used in applications with cut-to-length harvesting systems that require it to travel within a stand to collect the residues. John Deere currently manufactures the 1490D, which consists of a B380 biomass bundling unit mounted on a forwarder chassis (Figs. 1 and 2). This machine has a current list price of approximately $600,000. The standard configuration of the bundler unit mounted on a forwarder is

Figure 1.—John Deere 1490D Slash Bundler (courtesy of John Deere). The machine features a bundling unit with a forwarder for mobility.

Figure 2.—John Deere B380 Bundler unit, which makes a continuous compressed residue log (bundle).

unnecessary for use in southern, whole-tree harvesting operations. With whole trees being transported to the landing, the forest residues are readily available for a stationary bundler. A better application for the John Deere B380 would be for it to be mounted on a trailer and fed by the loader on the landing. The exclusion of the forwarder will result in far less capital and fewer operating costs.

Biomass chipping operations and bundling operations differ in final product characteristics. Figure 3 shows a wood chip pile, which can pose a moisture content issue during storage. Although the top and outer portions of chip piles can dry to much lower moisture contents, material farther inside chip piles retains the moisture. Many of the users of biomass specify low moisture contents because drier material has a much higher energy value. Bundles, like the one shown in Figure 4, have much more airspace throughout the bundle, leading to improved drying through evaporation. Within 1 month, bundles can lose between 10 and 25 percent moisture content (Patterson et al. 2008), resulting in a 12 to 28 percent increase in energy content per unit volume (Karha and Vartiamaki 2006).

To reduce costs, maximize efficiency, and implement a bundler in a tree-length harvesting operation, this project tested a prototype harvesting system. The objectives of this research project were to (1) adapt the John Deere B380 bundler unit to a motorized trailer, (2) design the optimum landing configuration, and (3) conduct a time-and-motion study of the bundler unit.

Figure 3.—Wood chip piles do not facilitate drying.

Figure 4.—A slash bundle produced by the 1490D Slash Bundler.

Figure 5.—Trailer-mounted B380 bundling unit.

Materials and Methods

In mounting the B380 bundler on a motorized trailer, safety and functionality were of utmost concern. The trailer-mounted bundler (TMB) must be able to perform all the designed swivel and tilt movements without risk of obstruction or instability. The slash must be able to enter and exit the TMB without impediment. Mounting connections must be designed to withstand the large amount of torque and forces associated with the cantilever setup of the TMB and the position of the slash bundles.

The TMB, with modifications, is shown in Figure 5. While the initial plans called for a wireless remote control, proprietary software made such a connection too complex. A tethered line was used to operate the TMB, although in a commercial unit the loader operator would control the TMB via a remote control. The size of the motor for the trailer was based on the hydraulic flow demands of the John Deere B380. The maximum flow demand for the unit's functionality is 24 MPA (3,480 psi; John Deere 2008). A 76-kW (102-HP) engine and a 200-liter/min (52.8-gal/min) pump provided the power and flow rate needed for TMB performance. A 120-liter (32-gal) reservoir to house the hydraulic oil was also mounted on the trailer. The hydraulic oil tank was equipped with a cooling unit in order to regulate the temperature of the oil in the hot summer operating conditions.

The tree-length logging operation consisted of two loaders with pull-through delimbers, two skidders, and one feller-buncher. Typically, the feller-buncher would maintain a one-half to a full-day buffer ahead of the skidders. When pulling trees to the landing, skidders would remove the limbs from the trees using a delimbing gate. Trees would then be cleaned up and topped on the landing by the pull-through delimbers. In this manner, the skidders had to maintain two areas: remove slash from the delimbing gate and also remove slash from the pull-through delimbers on the landing. All of this forest residue was returned to the woods. During bundling operations, delimbing was performed strictly on the landing with pull-through delimbers, and the skidders moved the slash and tops to the TMB. This alteration in the operation produced a higher concentration of slash at the landing and potentially affected the skidders' productivity. In order to quantify the change in production caused by bundling and the adjustments in the delimbing process, a work study was performed on the skidders prior to adding the TMB. The study's work sampling noted the skidder's operation every 4 minutes.

Preliminary stand data was gathered before the harvest. Estimates of residue availability and merchantable weights were calculated using methods developed by Clark et al. (1986) and Clark and Saucier (1990). The type of harvest, approximate stand age, and the species composition of the stand were documented. The harvesting operation was monitored for two complete 8-hour shifts to determine skidder operations prior to adding the bundling operation. Elemental time study data was collected during the TMB operation. Production rates were calculated on the basis of the time study and output from the TMB. Landing configuration is an important element in a logger's productivity. ''Good landings are important for a safe, efficient operation'' (Stenzel et al. 1985). If a landing is cramped and congested, the mobility of the workers and machines could be limited. The bundling operation cannot interfere with the travel path of the skidder or the merchandizing and delimbing by the loader; however, the knuckle-boom loader must be close enough to the TMB so that it can reach the in-feed. One of our objectives was to determine the appropriate landing configuration for the implementation of the TMB through field testing different arrangements.

The TMB makes a perpetual, composite 60-cm (24-in.)-diameter bundle that needs to be cut off for handling and transportation. A chainsaw mechanism is located on the outfeed of the TMB to sever bundles with a single cut. According to a May 2004 release from the Forest Service, 300-cm bundles work well in transportation (Rummer et al. 2004). For this study, the TMB software was configured to output 250- and 350-cm (8.2- and 11.5-ft) bundles.

TMB productivity was collected over a 1-week time frame. After observing the operation, elements for the TMB time study were identified as feeding slash, cutting, and a delay element. It was observed that during operation, it may take several cutting attempts to actually sever the bundle at the desired length, so the number of cuts needed to sever each bundle was recorded. The number of loader turns and saw bar cuts were collected as independent variables for cycle time equations. Delays were noted for data analysis and machine evaluation. Cycles were timed from the severing of one bundle until the severing of the next.

Production rates were reported in time per bundle, bundles per productive machine hour (PMH), bundles per scheduled machine hour (SMH), and tons per PMH.

An economic analysis was completed on the bundling operation. Capital investment, variable costs, and revenue streams are still uncertain with this prototype. Reasonable estimates have been applied to a discounted after-tax cash flow spreadsheet developed by Tufts and Mills (1982) to determine if incorporating a TMB in a southern harvesting operation is feasible for delivering a biomass product to a consuming facility.

Results

Being a prototype machine, the unit was operated in several locations to work out the bugs and understand machine capabilities. These tests involved working on various job sites with different loggers making bundles and familiarizing the operator with machine performance. After the TMB was determined to be operating adequately, a study site was selected. The Roanoke, Alabama, site, a 41-hectare (100-acre) clear-cut, consisted of loblolly pine (*Pinus taeda*) and a small number of hardwood trees. Bundling production data was collected for 1 week on a 10-hectare (25-acre) portion of the tract. The gently sloping stand was a naturally regenerated loblolly pine stand containing 277 tonnes/ha (121 tons/acre) of total merchantable timber with the vast majority being sawtimber-sized trees. Table 1 displays the standing timber weight by species and product class. Sixteen 0.04-hectare (0.10-acre) plots were measured to provide an estimate of standing inventory.

Four days of skidder data were collected while the operation was using the gate to delimb trees. On average, gate delimbing consumed about 7 percent of total productive skidding time. The pre-TMB data also showed that slash movement away from the landing consumed an average of 11 percent of total productive time. Therefore, a total 18 percent of skidder time was being consumed to remove or distribute slash. On the other hand, during the bundling operation when gate delimbing was not utilized, slash movement consumed only about 7 percent of total productive skidding time. This indicated that bundling should not interfere with skidder productivity and may even enhance it.

Two delays became evident during operation of the TMB: twine breakage and problems with severing the bundle. A twine repair occurred every 2.6 hours of run time with an average repair time of 12 minutes. Some were very minor (5 min) and were corrected by retying the dangling piece of twine to a new starting point. Longer delays occurred when the twine broke inside the cartridges and covers had to be removed to reroute the twine (20 min). The delay in severing the bundle occurred as the chain became dull and would not cut efficiently through a bundle. To minimize this delay and maintain proper functionality, saw chains were changed every 2.2 hours with a standard repair time of 14 minutes.

Table 1.—Roanoke site stand inventory.

Product	Tonnes/ha (tons/acre)
Pine sawtimber	197 (86)
Pine pulpwood	50 (22)
Hardwood sawtimber	5 (2)
Hardwood pulpwood	25 (11)
Residue available	74 (32)
Residue harvested	36 (16)

Measured production levels for 250-cm (8.2-ft) bundles showed that the prototype unit was capable of producing an average of 33.4 bundles per hour, or 14.4 tonnes/h (15.9 tons/h) with no delays. Accounting for minor operational delays that were observed during the production study (such as extra saw cuts and feeding delays), the average production for the bundling operation was 30.8 bundles per hour, or 13.2 tonnes/PMH (14.6 tons/PMH). A limited number of 350-cm bundles were produced during the study. Without any delay considerations, 25.5 bundles per hour, or 15.6 tonnes/h (17.2 tons/h), were produced. Minor delays slightly decreased production to 24.2 bundles per PMH. Twine and saw chain repair delays were estimated to be equivalent to those that occurred during 250-cm bundle production.

Discussion

Of the two lengths, the 350-cm (11.5-ft) bundles proved to be the most conducive to a production bundling operation under the study conditions. These bundles generated between 5 and 10 percent more production per hour. The longer bundles made for easier loading and safer on-road transportation than did the shorter bundles. Based on our observed average bundle weight, three bunks of 350-cm bundles at 50 percent moisture content would weigh approximately 27 tons.

When the project was initially discussed, we considered integrating the TMB directly into a two-loader system. After running the operation in the field, our initial plans were altered. With the slash volumes we encountered during field tests, we determined that a separate loader needed to be allocated specifically for bundling and that the system should be run as a satellite operation. We found the ratio of slash loads to roundwood loads to be approximately 1:5. For a 15-load-per-day roundwood operation, producing 25 to 30 bundles per hour, a loader operator would be bundling for 6 to 7 h/d. Figure 6 displays the landing configuration utilized

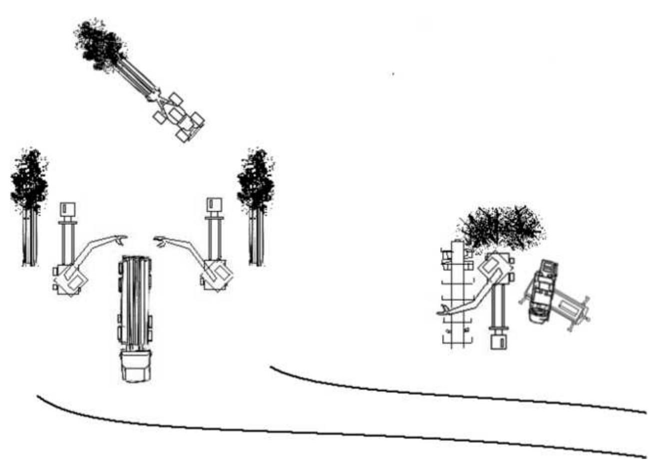

Figure 6.—Landing configuration used during the study. The bundling operation is stationed at a satellite deck adjacent to the live landing. The residue material from the knuckle-boom loaders handling roundwood is brought over to the bundling operation by the skidders.

Table 2.—Ownership and operating costs for the trailer-mounted bundler (TMB) and knuckle-boom loader.[a]

	TMB		Knuckle-boom loader	
	Ownership (SMH)	Operating (PMH)	Ownership (SMH)	Operating (PMH)
Purchase price ($)	250,000		150,000	
Interest, insurance, and taxes (%)	16		16	
Maintenance and repairs ($/h)		50		10
Fuel and lube ($/h)		10		10
Labor				$15.00 + 30% fringe

[a] SMH = scheduled machine hour; PMH = productive machine hour.

during the trial period. The TMB position enables smooth feeding and extraction of completed bundles. Positioning the loader in this fashion allows the operator to efficiently reach all the necessary elements.

The bundling operation should be within close proximity to the active landing in an effort to not affect skidder production during slash delivery. Forest residues should be deposited at the rear of the loader. Slash should be fed into the TMB from left to right so that the loader's boom does not impair the operator's line of sight. Set-out trailers would be ideal in these conditions. Instead of trucks sitting idle waiting to be loaded, they would simply pick up a full load of bundles and drop off an empty trailer to be loaded. Set-out trailers would also limit handling of the compressed residue logs, aiding in maintaining bundle integrity.

Field testing of the landing configuration determined that an additional loader was needed to feed the TMB. Therefore, two different options were considered for the knuckle-boom loader for the economic analysis. An older, used loader was evaluated with a lower initial price but higher fuel consumption and maintenance costs. The second option was a new, small loader with lower fuel consumption and maintenance costs. The two options produced similar costs, and purchasing a small new loader for bundling seemed the most logical decision. Labor costs were associated only with the knuckle-boom loader because the production TMB would have a remote control for operation.

In the economic analysis, a 75 percent utilization rate (1,500 PMH/2,000 SMH/y) was assumed for both the loader and the TMB. Fuel consumption for both the loader and the TMB averaged 10.0 liters/h each. For analysis purposes, we assumed a fuel cost of $0.75/liter and a lube cost of $2.50/h (total fuel and lube was $10/PMH). Maintenance and repair costs for the TMB were based on experiences during the field study. The operation consumed one roll of twine per 25 bundles. At a cost of $23 per roll, twine costs equated to roughly $2/ton. Chains for the chainsaw consumed another large portion of the maintenance costs. The chain needed to be changed roughly three times per day to effectively sever bundles. Assuming that a chain can be resharpened (in a shop) six times before being discarded, chain costs would total approximately $12,500/y, or $0.60/ton. Allowing for some repair costs, total maintenance and repair was estimated to be $50/PMH (Table 2).

The annual equivalent cost is the cost per year to own and operate the piece of machinery over its entire life-span. Assuming a life-span of 4 years, the 250-cm bundling operation cost estimates totaled $12.85/ton to produce bundles. The 350-cm bundles totaled $11.25/ton to operate the loader and trailer-mounted bundling unit. By adding $6/ton for trucking, $2/ton profit for the logger, and $1/ton for stumpage to the landowner, bundles could potentially be delivered to a facility within 50 miles for approximately $20 to $22/ton.

Because the purchase price of the TMB is unknown, a sensitivity analysis was performed at $200,000, $250,000, and $300,000. The impact of this purchase price sensitivity analysis on the cost per ton to produce 250-cm bundles was $7.44, $8.08, and $8.71, respectively. Bundling cost per ton for the 350-cm bundles was $6.51, $7.07, and $7.62, respectively. An increase in the purchase price by $50,000 would constitute a 50- to 60-cent increase in cost per ton for bundling.

Conclusions

Trailer mounting a John Deere B380 bundling unit provides a new configuration that uses innovative slash bundling technology, which easily integrates into southern US tree-length harvesting operations. The prototype design has proven that a self-contained motorized trailer can fully satisfy all hydraulic and electrical demands of the TMB. The tested prototype bundling operation did not negatively affect the skidding component of the roundwood operation and, according to the cooperating logger, had no effect on roundwood production. This conclusion is important to the success of any forest residue harvesting operation. Any decline in the logger's more lucrative roundwood production would lead to significant problems in the economics of introducing the new bundling operation.

The study's landing configuration, which incorporates a satellite bundling operation, is the ideal setup for similar harvesting operations and stand conditions. Well-coordinated slash flow from the roundwood operation would enable the bundling operation to maintain the rate of 13.2 to 14.9 tonnes/PMH (14.6 to 16.4 tons/PMH) observed during the production study. Assuming an average bundle weight for most green forest residue, a 25-ton trailer load of bundled material could be achieved in just over 1.5 hours. Using set-out trailers and loading finished bundles directly onto a trailer would limit handling and increase production.

The results of this production study and economic analysis indicate that a bundling operation could deliver green bundles for approximately $20 to $22/ton. Producing 350-cm bundle lengths had a higher production rate and lower costs than producing shorter, 250-cm bundles. With modifications to the prototype trailer-mounted bundling unit and operational improvements, bundling systems can economically be integrated into tree-length harvesting operations in the South as markets for such material become available.

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