

## OPTIMIZING THE USE OF A JOHN DEERE BUNDLING UNIT IN A SOUTHERN U.S. LOGGING SYSTEM

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**Keywords:** Forest residue, Biomass harvesting, Biomass feedstock.

**Abstract:** *With the current energy crisis and with petroleum prices skyrocketing, all sources of alternative fuels need to be explored. John Deere's Biomass Bundler unit is an effective machine for harvesting forest residues, which can be used as a source of fuel wood and/or a feedstock for ethanol based fuel production. This project aims to explore an avenue that could supply a very promising source of readily available energy in Southeastern forested lands. Typical, southern harvesting operations consist of whole tree harvesting in which trees are felled, then skidded to a landing. Limbs and tops are usually either deposited over the landscape or piled in wind rows. The biomass bundler will serve to capture the otherwise non merchantable material and maximize 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 will test a prototype harvesting system. The objectives of this venture are to: a) adapt the John Deere 530B bundler unit to a motorized trailer; b) design the optimum deck configuration; c) conduct a productivity study of the bundler unit.*

### Introduction

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

According to the United States 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 one billion gallons by 2015 (Morris 2006). One of the most prevalent sources of cellulose for ethanol production are forest residues (Perez-Verdin 2008). Such ambitious national energy goals require a vast supply of renewable feedstocks.

In order to fully utilize forest resources, all available material must be captured. Typically, southern harvesting operations consist of whole tree harvesting in which trees are felled, then skidded to a landing. Limbs and tops are removed from the tree and either deposited over the landscape or piled in wind rows. The biomass bundler will serve to capture this otherwise non-merchantable material and maximize the marketability of the entire tree. The bundler unit is utilized by feeding slash into a set of four compression feed rollers. Two compression arms then further compress the slash while sliding the bundle 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 (CRL) (Martin 2008).

The John Deere biomass bundler is commonly used in applications with cut-to-length harvesting systems that require it to travel within a stand. John Deere currently manufactures the 1490D which consists of a B380 biomass bundling unit mounted on a forwarder chassis (Figures 1 and 2). In order to reduce costs, maximize efficiency, and implement the bundler in a tree length harvesting operation, this project will test a prototype harvesting system. The objectives of this venture are to: a) adapt the John Deere B380 bundler unit to a motorized trailer; b) design the optimum deck configuration; c) conduct a productivity study of the bundler unit.



**Figure 1.** John Deere 1490D Slash Bundler



**Figure 2.** John Deere B380 Bundler unit

*Courtesy of John Deere*

Current forest harvesting practices in the southern United States are very proficient in harvesting timber; however, the harvest of forest residues are economically inefficient or nonexistent in most of the conventional harvesting configurations in the region. Most logging crews in the South that capture the forest residues do so using a drum 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.



**Figure 3.** Pile of wood chips



**Figure 4.** Slash bundle

Outputs of the two operations differ as well. Wood chip piles in storage pose a moisture content issue. Although the top and outer portions of chip piles can be dried to much lower moisture contents, the insides of chip piles remain much more saturated. With many of the biomass consuming plants desiring low moisture contents, any low energy process to dry biomass could prove to be a huge asset to the industry. Bundles have much more air space and air dry much better than chip piles. Within one month, bundles lost between 10 and 25% moisture content (Patterson 2008). The loss of moisture content through evaporation in the bundles cause a 12-28% increase in energy content per unit volume (Karha 2006).

The configuration of the forwarder mounted slash bundler is an unreasonable application for use in the whole tree harvesting operations. With all of the stems being transported to the deck, the bundler is just as functional in a stationary configuration as it would be mounted on a prime mover. The John Deere B380 will be mounted on a trailer for transport and will be fed by the loader at the deck. The exclusion of the forwarder will result in far less overhead. Currently, 1490D slash bundling units list for around \$600,000, and the proposed unit will be marketed for significantly less.

## **Materials and Methods**

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

The motor for the motorized trailer was based on the flow demands of the John Deere bundling unit. The maximum flow demand for the unit's functionality is 24 megapascals (Mpa)/3480psi (John 2008). Sizing of the engine was based on the horsepower demands of the hydraulic pump that powers the bundler. A 102 HP engine and a 200 liters/minute pump provided the power and flow rate needed for the bundler to perform. A 120 liter reservoir to house the hydraulic oil was also mounted on the trailer. The tank for the hydraulic oil was equipped with a cooling unit in order to regulate the temperature of the oil in the Alabama summer heat.

Deck configuration is very important element in a logger's productivity. "Good landings are important for a safe, efficient operation" (Stenzel 1985). If a deck is cramped and congested, the mobility of the workers and machines could be limited. The bundling operation cannot interfere with the travel of the skidder or the merchandizing or delimiting of stems by the loader; however, the trailer mounted B380 must be close enough to the knuckle-boom loader that it can feed the bundler the forest residue. Our objective was to find the ideal deck configuration for the implementation of the bundling unit through testing different arrangements.

Preliminary stand data was gathered before the harvest. The type of harvest, approximate stand age, and the species composition of the stand was collected. The harvesting operation was monitored for two complete eight hour shifts to determine skidder productivity. Student workers were tasked with the collection of elemental time study data for the bundler operation. Production rates for the bundler were calculated based on the time and output of the B380.

According to a May 2004 release from the Forest Service, 300 centimeter bundles work well in transportation (Rummer 2004). For this study, the bundler software was configured to output 250 and 350 centimeter bundles. Elements for the bundler time study are feeding slash, cutting, and a delay element. The number of turns for the knuckleboom loader to feed the biomass material were recorded as well as the number of cuts needed to sever the bundle. Delay elements represented any delays the bundling process might encounter. Production rates were reported in time/bundle, bundles/productive machine hour(PMH), bundles/scheduled machine hour(SMH), and tons/PMH.

## Results

The completed unit is shown in Figure 5. While the initial plans called for a remote control, proprietary software made such a connection too difficult. A tethered line was used to operate the bundler, though in the finished product the loader operator will control the bundler via a remote control.



**Figure 5:** Trailer mounted B380

After testing the unit on several locations to understand machine capabilities and familiarize the operator with machine performance, a study site was selected. The Roanoke, Alabama site, a 36 hectare clearcut, consisted of a large loblolly pine component with a small number of hardwood trees. Bundling productivity data was collected for one week on a 10 hectare portion of the tract. The gently sloping stand was a naturally regenerated loblolly pine stand. It contained 305 tons per hectare of total merchantable timber with the vast majority being pine sawtimber.

The following volume table shows the breakdown by species and product class. Sixteen, 0.04 hectare plots were measured to provide an estimate of standing inventory. The residue availability estimates and merchantable weights are based on *Georgia Forest Research Paper 60 and 79*.

**Table 1.** Roanoke site stand inventory

	Tons per Hectacre
Pine Sawtimber	217
Pine Pulpwood	55
Hardwood Sawtimber	5
Hardwood Pulpwood	28
Residue Available	82
Residue Harvested	57

The tree-length logging operation, Sanders Logging, consisted of two loaders, two skidders, and one feller-buncher. Typically, the feller-buncher would maintain a one half to a full day buffer ahead of the skidders. Before bundling commenced, skidders would delimb the trees using a gate on approach to the logging deck. By delimiting in this manner, the skidders would have to clean slash from both the gate and the pull through delimiters on the deck and return the forest residues back to the woods.

During bundling operations, delimiting was performed strictly on the deck with pull through delimiters. This alteration in the operation produced a higher concentration of slash at the deck and potentially affected the skidders' productivity. In order to quantify the change in productivity caused by bundling and the adjustments in the delimiting process, a work study was performed on the skidders.

The study's work sampling noted the skidder's operation every 4 minutes. Four days of skidder data was collected while the operation was using the gate to delimb trees. On average, gate delimiting consumed about 7% of total productive skidding time. The pre-bundler data also showed that slash movement away from the deck consumed an average of 11% of total productive time. On the other hand, during the bundling operation when gate delimiting was not utilized, slash movement only consumed approximately 7% of total productive skidding time. This indicates that bundling should not interfere with skidder productivity and may even enhance it.

Bundler productivity was collected over a one week timeframe. 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.

Measured production levels to make 250 centimeter bundles showed the prototype unit was capable of producing an average of 33.4 bundles per hour (15.9 tons/hr) 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 (14.6 tons/hr). A string repair occurred every 2.6 hours of run time with an average repair time of 12 minutes. To maintain proper functionality, saw chains were changed every 2.2 hours with a standard repair time of 14 minutes.

A limited number of 350 centimeter bundles were produced during the study. Without any delay considerations, 25.5 bundles per hour (17.2 tons/hr) were produced. Minor delays slightly decreased production to 24.2 bundles per hour (16.4 tons/hr). String and saw chain repair delays were estimated to be equivalent to those that occurred during 250 centimeter bundle production.

Of the two lengths, the 350 centimeter bundles proved to be the most conducive to a production bundling operation in the study conditions. These bundles generated between 5 and 10 percent more tons per hour in production. The longer bundles also traveled better for safe transportation. Based on our observed average

bundle weight, three bunks of 350 centimeter bundles at fifty percent moisture content would weigh approximately 27 tons.

#### Discussion

These production rates are similar to rates found in other studies. One study was performed in Arkansas by members of the Forest Products Society. 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 slash bundler produced 22.3 bundles per hour with an average cycle time of 2.69 minutes. Site 2 was a twenty-six year old stand of pine plantation undergoing a second thinning by the same harvesting system. Limbs and tops were piled at the deck and the slash bundler was able to produce more than 31 bundles per hour. Site 3, a stand of eleven year old loblolly pine plantation, produced 36.1 bundles per hour (Patterson 2008).

The fourth site in the study was a thinning operation in seventeen year old loblolly pine plantation. Cut-to-length harvesting equipment was utilized on the site which meant that the 1490D had to travel in-woods to gather material.

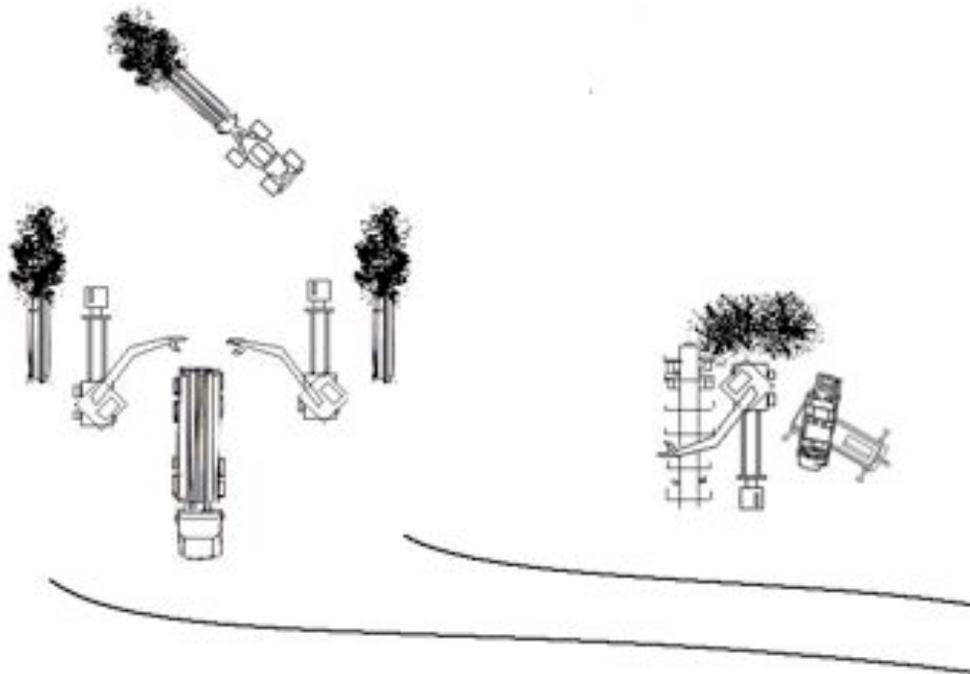
The resulting 13.8 bundles per hour reflect the operational differences. The average weight of the bundles for sites one through four are 883, 916, 950, and 957 lbs (Patterson 2008).

John Deere published numbers in a presentation of a study done in France showing 2006 production numbers. Study conditions are unknown, but the France study reported eighteen to twenty-five bundles per hour was feasible with the 1490D. An aside was made that these production rates could be achieved with an experienced operator and appropriate site planning (Martin 2008).

When the project was initially discussed, we considered integrating the trailer mounted bundler directly into a two loader system. After running the operation in the field, our initial presumptions have been altered. With the slash volumes we encountered during field tests, a separate loader needs to be allocated specifically for bundling. In this production study, we found the ratio of slash loads to roundwood loads to be around 1:5. For a 15 loads a day roundwood operation, producing 25-30 bundles/hr, an operator would be bundling for 6-7 hours per day.

The bundling operation should be within close proximity to the active logging deck 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 bundler from left to right so that the boom does not alter the operator's line of sight. Using set-out trucking and loading finished bundles directly onto a trailer would limit handling and increase production.

Figure 6 indicates the deck configuration utilized during the trial period. The bundler position enables smooth feeding, and extraction of bundles. Positioning the loader in this fashion allows the operator effective reach of all necessary elements.



**Figure 6.** Deck configuration used during the study.

An economic analysis was completed on the bundling operation. Capital investment, variable costs, and revenue streams are uncertain with this prototype. Reasonable estimates have been applied to a *DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS SPREADSHEET*, developed by Dr. Robert Tufts of Auburn University, to determine some of the economics surrounding a trailer mounted bundling operation (Tufts and Mills, 1982).

Two different options were considered for the loader cost 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.

A 75% utilization rate (1500 PMH/2000 SMH/yr) is assumed for both the loader and the bundler. Fuel consumption for both the loader and the bundler averaged 9.5 liters per hour. For analysis purposes, we assumed 11 liters per hour, a fuel cost of \$0.66/liter, and a lube cost of \$2.50/ hr (total fuel and lube was \$10/PMH). Maintenance and repair costs for the bundler were based on conclusions from the field study. The operation consumed 1 roll of twine per 25 bundles. At a cost of \$23 per roll, twine costs equated to roughly \$2 per ton. Chains for the chainsaw consumed another large portion of the maintenance costs. Assuming 5 sharpenings per chain, and an effective chain cutting life of ½ day, chain costs total approximately \$12,500 per year or \$0.60 per ton. Allowing for some repair costs, total maintenance and repair was estimated to be \$50/PMH.

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

Because the purchase price of the trailer mounted bundler is unknown, sensitivity analysis was performed at \$200,000, \$250,000, and \$300,000. \$7.44, \$8.08, and \$8.71 were the respective cost per ton of 250 centimeter bundling. 350 centimeter bundling cost per ton was \$6.51, \$7.07, and \$7.62 respectively. An increase in the purchase price by \$50,000 would constitute a 50-60 cent increase in cost per ton for bundling.

## **Conclusion**

Trailer mounting a John Deere B380 bundling unit does provide a new configuration that employs innovative slash bundling technology which easily integrates into southern U.S. 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 slash bundler. Although the study's objective was to test the trailer-mounted bundler concept within a relatively short time frame and with relatively little monetary expenditure, a purpose-built trailer could potentially aid in the trailer-mounted bundler's success.

The study's optimal deck 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 14.6 - 16.4 tons/hr production rate observed during the production study. Assuming an average weight for most green forest residue, a 25 ton trailer load of bundled material could be achieved in just over 1.5 hours. Set-out trucking 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 trucking would also limit handling of the compressed residue logs which would aid in maintaining bundle integrity.

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 very important to the success of any forest residue harvesting operation. Any decline in the loggers more lucrative roundwood production would lead to significant problems in the economics of introducing the new bundling operation.

According to the study's production study and economic analysis, a similar trailer-mounted bundling operation could deliver green bundles for approximately \$18- \$20. 350 centimeter bundling seemed like the most conducive system for a bundle supply chain. With lower costs per ton to own and operate, the longer bundles were not only cheaper to produce, but they were also easier to transport.

## **References**

- Bodman, Samuel W. (2005). On the Road to Energy Security Implementing a Comprehensive Energy Plan: A Status Report. US Department of Energy. 12p.
- John Deere (2008). 1490D Slash Bundler. Brochure. USA.
- Karha, K. and Vartiamaaki T. (2006). Productivity and costs of slash bundling in Nordic conditions. Biomass and Bioenergy 30: 1043-1052.
- Martin S. (2008). Collection of Logging Residues: Spreading out the bundling method over Europe. Area Manager, Latin Europe, John Deere.

- Morris, D. (2006). Putting the Pieces Together: Commercializing Ethanol from Cellulose. Institute for Local Self-Reliance. Sept. 5p.
- Patterson, D. W., Pelkki M.H., and Steele P.H. (2008). Productivity of the John Deere slash bundler in removing in-forest residues from pine harvest sites in the mid-South: four case studies. *Forest Products Journal*. 2008. pp 31-36.
- Perez-Verdin G., Grebner D.L., Sun C., Munn I.A., Schultz E. B., Matney T. G.. (2008). Woody biomass availability for bioethanol conversion in Mississippi, *Biomass and Bioenergy*. Aug. 2008. 12p.
- Perlack, R.D., Wright L.L., Turhollow A.F., Graham R.L., Stokes B. J., and Erbach D. C. (2005). Biomass as a Feedstock for Bioenergy and Bioproducts Industry: The technical feasibility of a billion-ton annual supply. USDA/DOE joint report, April 2005. 59p.
- Rummer, B., Len D., and O'Brien O. (2004). Forest Residue Bundling Project – New technology for residue removal. Forest Operations Research Report, Southern Research Station, Auburn, AL. May 2004. 18p.
- Stenzel, G., Walbridge T.A. Jr. and Pearce J.K. (1985). *Logging and Pulpwood Production*. 2nd ed. Wiley, John & Sons, Inc.
- Tufts. R.A. and Mills W.L (1982). Jr. Financial analysis of equipment replacement.. *Forest Products Journal*. Vol. 32(10), pp. 45-52.