Harvesting Understory Biomass with a Baler

by

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Abstract: A model WB-55 Biobaler[1] was evaluated while operating in a pine plantation to remove understory biomass. The harvested material was formed into round bales which averaged 1004 lbs. Mean heat content was approximately 8560 Btu/lb oven-dry. Time-study data revealed a productivity of 14.7 bales/PMH with a mean travel distance of 752 feet between bales. In-woods cost was between $17 to $18/gt (green ton). Size classification of unprocessed baled material and material processed thru a chipper and a haybuster resulted in an increase in the 4.75 mm size class from 29 percent of total weight to over 45 percent for both the chipper and haybuster. The intended purpose for baling understory biomass is to utilize the material as an alternative fuel source.

INTRODUCTION

Recent rises in oil prices have prompted new innovations in developing alternative fuel sources. Significant progress has been made in converting wood to bio-oil and bio-diesel. Transforming woody biomass into pellets for use as a fuel source is being accomplished by Green Circle, a company in Florida. Range Fuels, a Colorado company, focuses on producing low carbon biofuels and clean renewable energy using material such as harvesting residues, sawdust, corn stover, and switchgrass. Recognizing the potential these resources possess as a fuel source has resulted in the development of new technologies to harvest some of them.

One method of harvesting forest residues and biomass is with a round-bale hay baler. Baling of forest residues left from harvesting operations has some advantages when compared to chipping the material. Baling offers a means of compacting a loose or bulky material into unitized packages which can be easily handled. In addition, harvesting forest biomass using large round bales has the potential for having low energy costs compared to other harvesting and handling schemes, such as chipping (Fridley and Burkhardt, 1984). The concept of baling forest residues is not a new one. Fridley and Burkhardt (1984) evaluated a modified Vermeer 605F round-bale hay baler operating on a landing while baling prickly-ash, a hardwood/conifer mix, and red pine. Bale densities obtained ranged from 8.8 lb/ft^3 to 21 lb/ft^3. Stokes and others evaluated a Claas Rollant 62 round hay baler to bale small-diameter crushed trees. Oven-dry density was 113.7 kg/m3 with a moisture content of 38 percent green weight basis.

Other advantages to baling residues relate to storage and heat value. The increased density decreases storage area requirements. In addition, bales could be left in the field to dry. By hauling a product which is lower in water content, each legal limit load would transport a larger amount of energy (Schiess and Yonaka, 1983). Furthermore, baling is not rigidly linked to the

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement of any product or service by the U.S. Department of Agriculture or other organizations represented here.

transport phase as with chipping, which would increase machine utilization (Schiess and Yonaka, 1983).

A more recent innovation in baling technology for forestry applications includes using a round baler to harvest standing understory biomass. This method has the potential to be a very effective tool for treating stands with an overly dense understory which would be hazardous to treat with fire. Similarly, areas near a WUI or adjacent to an Interstate where burning would be too risky would benefit from understory harvesting. The removal of the excessive fuel loading would reduce the risk of catastrophic wildfire, facilitate the reintroduction of prescribed fire, and improve wildlife habitat (Canto et.al., 2008). Two baling systems were evaluated while operating in three different stand conditions on the Osceola NF. One system incorporated a mulch-and-bale technique. Standing understory biomass was mulched using a Supertrak SK-140 and then baled using an off-the-shelf Claas Rollant 250 powered by a CAT Challenger MT545B tractor. The second system was a modified New Holland BR740 (Bio-baler) and was also powered by a CAT Challenger MT545B tractor. The baler was equipped with a cutter-head which enabled it to cut, shred, and bale material in one pass. Canto and Rummer (2008) reported production rates of 2.6 gt/PMH for the Bio-baler and 5.5 gt/PMH for the Claas. Bale density averaged 20 lb/ft^3 for the Bio-baler and 23 lb/ft^3 for the Claas.

Another baler designed to harvest understory biomass has recently entered the market. The FLD WB-55 Bio-baler, produced by the Anderson Group, is capable of cutting and baling material up to 5 inches in diameter. This paper reports the performance and cost of the baler along with bale characteristics which include weight, density, moisture content, heat value, ash content, and size classification.

METHODS

Equipment

The FLD WB-55 baler contained a 48-tooth rotor with a 7.5-ft cutting width and was mounted on Carlisle Trac Chief 14-17.5 NHS tires. Power to the baler was provided thru PTO by a Fendt 818 tractor. The Fendt 818 was mounted on Nokia 16.9-28 TR tires on the front and Nokia 20.8-38 tires on the rear. Minimum power requirement to operate the baler was 180 PTO hp. Power from the tractor PTO to the baler was split using a gear box which distributed power to two drive shafts. One shaft powered the mulching head while the other shaft powered the baler and rotofeeder. The chamber had a 4-ft x 4-ft capacity with chain driven tailgate rollers.

Stand Descriptions

The FLD WB-55 was observed in March 2009 while operating in a 28-year old loblolly pine (Pinus taeda) plantation which had been thinned using a fifth-row removal in 2007. The site was located approximately 20 miles east of Valdosta, GA in Echols County on land owned by The Langdale Company, a forest products company located in Valdosta, GA. Terrain was flat with a Mascotte soil series. The Mascotte series consists of poorly drained soils with a fine sand making up the A horizon (NRCS, 2009). A previous trial on the baler took place in October

2008 in a similar stand a few miles from where the March 2009 trial was conducted. However, this paper mainly focuses on data from the March 2009 trial.

Understory Biomass

Assessment of understory biomass loading was accomplished by installing 1 m^2 plots. Plot areas were measured and corners were marked with pin flags. All biomass inside the plot boundary was cut and placed in a large plastic bag. Material standing inside the plot but extended outside the plot boundary was severed at the plot's vertical plane and only the portion within the boundary was retained. In contrast, material that originated outside the plot but extended inside the plot boundary was also severed at the vertical plane and the portion which fell within the boundary was retained. Bagged material was weighed using a Pelouze hanging scale.

Baling

The baler traversed the stand traveling between rows. Two passes were made down thinned corridors while one pass was made down un-thinned corridors. Productivity was measured using time-and-motion. Elements evaluated included travel, turn, and wrap/bale. Any delays encountered were also noted and recorded. Travel time began when forward motion started and ended when forward motion stopped. Turn time included the time required to travel from the end of a row to the beginning of another row. The element began when the baler reached the end of a row and ended when the baler entered the next row. The wrap/drop element included wrapping the bale with twine and dropping it from the chamber. The element began when forward motion ceased and ended after a bale was dropped and forward motion resumed (Klepac and Rummer, 2009). Distance traveled while making a bale was measured using a rolo-wheel.

Extraction

A John Deere 541 farm tractor utilizing a spike on the front was used to transport bales from the woods to a landing. The tractor could carry only one bale per trip, which made production very low for this method. Since these were only test bales and it was not critical to transport them to a processing facility, this was the best available method for extraction.

Other equipment for bale extraction such as forwarders and small in-woods log trailers are being considered for future studies so that extraction production and cost estimates can be made for a high production setting where transport of bales to a feedstock processing facility in a timely manner is critical. An Anderson R-Flex 612 HD log trailer with a M-160 boom was made available for a few days of operation in June 2009 on Langdale property.

Processing

Bales can be processed in-woods at a landing or at the mill or facility where they will be used, depending on the type of feedstock required. Some options for processing include tub grinders, chippers, and horizontal grinders.

Test bales from the October 2008 trial were transported to Langdale's mill and processed in a tub grinder for use as boiler fuel. In addition, 100 bales from the October 2008 trial were transported to Herty Advanced Materials Development Center in Savannah, Georgia for testing. There, sixty randomly selected bales, 3 groups of 20 bales each, were processed with a Peterson horizontal grinder. Grates used in the grinder for repetitions 1 and 2 were 2,2,4,4 and 4,4,4,4, for the third repetition. From each repetition, three 55-gallon fiber drums were filled with the ground material for analysis of bulk density, moisture content, and size distribution. One drum from each repetition was ground with a Meadows hammer mill which had a 3/16-inch outlet screen. This material was analyzed for heat value and ash content.

Sample bales from the March 2009 trial were analyzed for moisture, heat, and ash content. A Woodsman horizontal drum chipper and a haybuster were both evaluated for in-woods processing of bales during June 2009. The number of bales required to fill a chip van was tallied for each machine and vans were weighed to determine payload. Also, samples were collected from each machine for moisture, heat, and ash content in addition to size classification. For size classification, dried material was processed thru 31.75 mm, 19 mm, 4.75 mm, 4 mm, 2 mm, and 0.84 mm screens. Material retained in each screen was weighed, along with material which passed thru the 0.84 mm screen and percent in each size class was calculated.

Bale Measurements

Weights of bales from the production study were weighed within 24 hours using a Dillon dynamometer. Bale width, horizontal diameter, and vertical diameter were measured to the nearest tenths of feet for estimating density.

Material was collected from a sub-sample of timed bales for moisture content and heat value determination. Samples were placed in plastic bags, sealed, and labeled. In the lab, they were weighed wet, placed in drying pans and dried in an oven at 105°C until a constant weight was obtained. Dried samples were then bagged and taken to the Biosystems Engineering Department at Auburn University for heat value and ash content analysis. There samples were processed thru a hammermill and then burned in a calorimeter for heat content determination.

RESULTS

Understory Biomass

Large amounts of woody biomass were prevalent throughout the understory. Species encountered consisted predominately of gallberry (*Ilex glabra L.*), with small components of waxmyrtle (*Morella cerifera L.*), blueberry (*Vaccinium elliottii*), saw palmetto (*Serenoa repens Bartr.*), sweetbay (*Magnolia virginiana L.*), eastern baccharis (*Baccharis halimifolia L.*), fetterbush lyonia (*Lyonia lucida Lam.*) and red maple (*Acer rubrum L.*).

Plot inventory data for the baler were expanded to reflect green tons per acre and are summarized in Table 1. Understory loading ranged from 4 gt/ac to 30 gt/ac, and averaged 11.29 gt/ac.

Table 1. Summary of understory woody biomass loading.

		Green tons/acre			
Machine	***N***	***Mean***	***SD***	***Min***	***Max***
Gallberry and other[1]	24	10.29	4.042	3.8	19.4
Red maple	24	0.25	1.229	0.0	6.0
Pine	24	0.75	3.495	0.0	17.2
Total	24	11.29	5.491	3.8	29.9

[1]Includes waxmyrtle, blueberry, saw palmetto, sweetbay, eastern baccharis and fetterbush lyonia.

Baling

Twenty-six observations of making bales were recorded for the FLD WB-55. Total cycle time averaged 4.3 minutes with a mean travel distance between bales of 752 feet and a production rate of 14.7 bales/hr. Combining bale weight and total time resulted in a productivity of 7.3 gt/PMH. Using the swath cutting width of 7.5 feet and combining it with total cycle time resulted in a mean of 2 ac/PMH.

Recovery efficiency was estimated using the ratio of baled tons per acre and mean biomass loading per acre. Data collected on the FLD WB-55 suggest a recovery efficiency of approximately 34 percent.

Table 2. Summary of elemental time study data for the FLD WB-55.

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
Travel (min)	26	3.4	0.86	2.1	5.6
Turn (min)	26	0.4	0.38	0.0	1.6
Wrap/drop (min)	26	0.5	0.14	0.2	0.9
Total time (min)	26	4.3	1.01	2.7	6.7
Travel dist. (ft)	26	752.0	136.38	508	975
Turn dist. (ft)	26	41.7	35.62	0.0	95.0
Trv. speed (mph)	26	2.6	0.51	1.6	3.5
Bales/hr	26	14.7	3.15	9.0	22.1
Swath acres/hr	26	2.0	0.55	0.098	3.14
Recovery (%)	26	33.8	6.47	25.0	48.7

Extraction

Data was not collected on the John Deere 541 farm tractor for estimating productivity and cost to transport bales from the woods to a landing, since that would not be a typical method of operation. However, two options to consider would be to either use a small log trailer or a full size forwarder.

A small log trailer would be one option for moving bales from the woods. This system would have a lower production rate and would incur costs for two additional pieces of equipment; the log trailer and a tractor for pulling the trailer. During June 2009 a Anderson R-Flex 612 HD log trailer with a M-160 boom (Figure 4) was on site for two days. The trailer had a hauling capacity of eight bales and was rated at 1100 lbs maximum lift capacity at full extension.

Another option would be to use a forwarder. Either a small 4-wheel machine or a medium size 6-wheel machine could be considered, depending on the size of the operation. This option would incur more capital cost, however, productivity would be enhanced.

Processing

At the landing bales can be loaded directly onto flatbed trailers for transport, or processed into a desirable size using a tub grinder, a chipper, a horizontal grinder, or a haybuster. During June 2009 processing bales at the landing was tested with a Woodsman model 334 chipper and also with a model H-1100 Haybuster tub grinder.

The Woodsman chipper was a 440 hp machine equipped with an in-feed conveyer and a 36-inch wide drum. The throat opening measured 22-inch high x 36-inch wide. A CAT 559B knuckleboom loader was used to feed the chipper. A total of thirty bales were required to fill a chip van which resulted in a payload of 13.42 tons. It was determined that the chipper is not the most feasible machine to use for this process. The throat size was a limiting factor which required bales to be broken up before they could be feed into the chipper. At the throat entrance, material tended to bridge, which slowed production.

Figure 1. Processing bales with a Woodsman 334 horizontal drum chipper.

A Model H-1100 tilt series II Haybuster tub grinder was also evaluated for processing bales. The tub grinder is powered by PTO and requires 150 hp minimum for operation. In a production operation, this would require an additional tractor on site to provide power to the grinder. Processed material was transferred from the tub to an inclined conveyor for top loading a chip van. This resulted in higher utilization of the chip van with a payload of 19.07 tons. Using 3-inch and 4-inch screens the Haybuster processed 40 bales per hour. Increasing screen size to 5-inch and 6-inch screens increased production to around 60 bales per hour. The 559B knuckleboom loader was used only because it was readily available. A smaller, less expensive loader would be capable of performing the feeding operation at a lower cost.

Processing of baled material into smaller sizes may be desirable by the facility using the material. Size classification of unprocessed baled material, material processed thru the chipper, and material processed thru the haybuster is displayed in Figure 2.

The amount of fine material (<0.84 mm) was similar for unprocessed bales and chipped material (11.46 and 10.61 percent of total weight, respectively), with the highest amount (19.81 percent) associated with material processed with the haybuster. Material retained in the 0.84 mm screen was lowest for bales (5.07 percent), followed by the chipper (7.22 percent), and then the haybuster (10.60 percent).
Material retained in the 2 mm size class ranged from 6.98 for the haybuster to 11.73 percent for the chipper. Unprocessed baled material averaged 8.78 percent for this size class.

For the 4 mm size class, material retained ranged from 4.62 for bales to 8.26 percent for the haybuster. Chipped material averaged 5.15 percent for this size class.

The highest percentages occurred in the 4.75 mm size class for all three material types. In addition, processing material thru a chipper or haybuster resulted in the largest increase in this size class as compared to unprocessed material. Unprocessed material averaged 28.97 percent, compared to 45.69 percent for the chipper and 45.55 percent for the haybuster.

Processing material significantly reduced percentages in the 19 mm and 31.75 mm size classes for both the chipper and haybuster, as compared to unprocessed bales. The haybuster produced the least amount of 19 mm material (4.67 percent), followed by the chipper (7.47 percent) and unprocessed bales (13.44 percent). This same trend also occurred for the 31.75 mm size class with the haybuster containing the least amount (4.13 percent), followed by the chipper (12.12 percent) and unprocessed bales (27.67 percent).

Results from samples collected from unprocessed baled material, the chipper, and the haybuster are shown in Table 3.

Table 3. Results from unprocessed and processed material.

		Mean		
Variable	***N***	***Bales***	***Chipper***	***Haybuster***
Moisture content (% wet-basis)	3	35.7	42.1	42.9
Oven-dry heat of combustion (Btu/lb)	3	8660	8689	8640
Ash content (%)	3	1.8	1.5	5.0

Testing of a 200 hp Doppstadt horizontal grinder is planned for the near future. This type of machine should prove to be more durable and have more longevity in a continuous grinding operation. In addition, instead of blowing material into a van as with a chipper, the grinder utilizes an inclined conveyer for top loading vans, which should improve payload efficiency.

Bale Measurements

Twenty-four bales were weighed and measured to determine circumference, volume, and density (Table 4).

Two bales fell apart during transport from the woods to the landing, so they were not included in the bale measurements summary. Samples were collected from ten bales to quantify moisture content, heat value, and ash content (Table 5). Means in parenthesis are for comparison and represent values calculated from three samples by Herty Advanced Material Development Center (Ali, O.F. 2008). Oven-dry heat of combustion was calculated using heat value and moisture content of the material after drying.

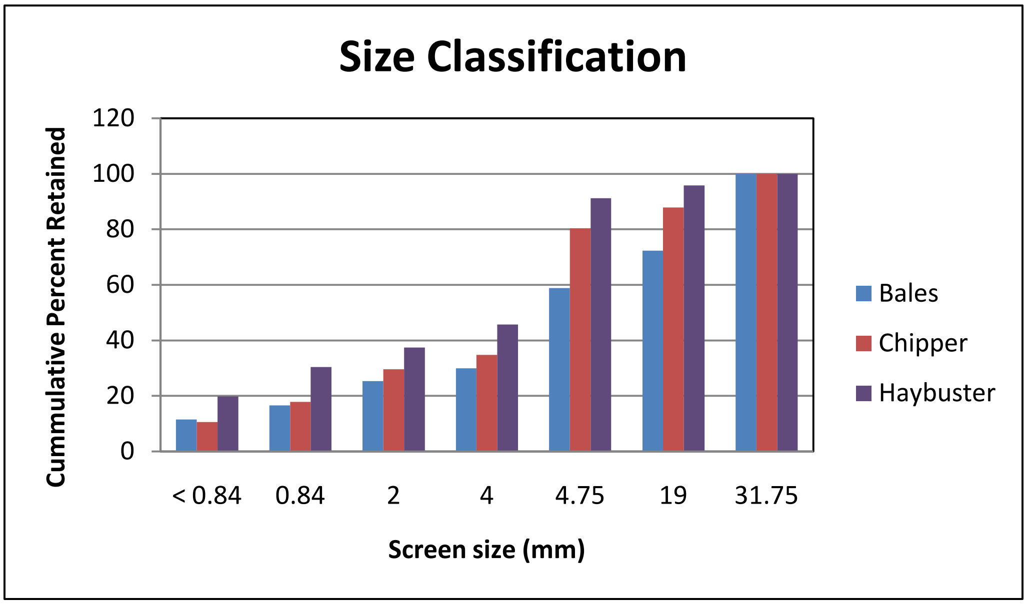

Figure 2. Size classification of material displayed as cumulative percent of total weight.

Table 4. Summary of bale measurements for the FLD WB-55.

Variable	***N***	***Mean***	***SD***	***Min***	***Max***
Horizontal diameter (ft)	24	4.2	0.15	4.0	4.6
Vertical diameter (ft)	24	4.0	0.19	3.6	4.3
Width (ft)	24	4.1	0.08	4.0	4.2
Weight (lb)	24	991.6	54.62	893.5	1063.5
Circumference (ft)	24	12.9	0.40	12.1	13.7
Volume (ft^3)	24	53.6	3.43	47.7	62.4
Density (lb/ft^3)	24	18.6	1.53	16.3	21.3

Oven-dry heat of combustion averaged 8629 Btu/lb from samples collected from ten bales. This value is comparable to the heat content of pine stemwood, tops, stumpwood, and cones, which have heat values in the range of 8,000 to 8,600 Btu's/lb (Koch, 1972). This suggests that the heat content of baled understory vegetation is similar to that of pine stemwood, even though bales contain a significant amount of non-woody material (Klepac and Rummer, 2009).

Table 5. Moisture content, heat value, and ash content summary.

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
Moisture content (% wet-basis)	10	35.0 (41.2)	3.49	30.5	41.2
Oven-dry heat of combustion (Btu/lb)	10	8629 (8595)	90.4	8506	8751
MMBtu/bale (wet)[1]	10	3.0	0.29	2.6	3.5
MMBtu/bale (dry)	10	5.5	0.41	4.9	6.1
Ash content (%)	10	1.8 (2.5)	0.54	1.0	2.5

[1] MMBtu = $1x10^6$ Btu's.

System Costs

A machine rate, which reflects the average yearly cost over the useful life, was calculated for all equipment. These rates were then used to calculate a system balance and cost (Table 6). Assumptions used to calculate machine rates included a 6-year life for the Fendt 818 tractor, with a salvage value of 20 percent of the purchase price and a fuel consumption rate of 0.019291 gal/hp-hr (Klepac and Rummer, 2009). A repair and maintenance rate of 100 percent of depreciation, an 8 percent interest rate, an insurance rate of 3.5 percent of the purchase price, and a lube and oil rate of 36.8 percent of the fuel cost were used (Brinker, et.al., 2002). For the FLD WB-55 baler, a 4-year life, a 25 percent salvage value and an insurance rate of 2 percent of the purchase price were used (Brinker, et.al., 2002). A rate of 150 percent of depreciation for repair and maintenance and lube costs was assumed (Savoie, 2008).

The cost to forward bales from woods to landing was calculated for a 4-wheel and 6-wheel forwarder. For the 4x4 forwarder (9.6-ft bunk length) a payload of 10 bales was assumed, which consisted of bales stacked two wide, two long, and two high, with two on the top, with an estimated turn time of 20 minutes (Klepac and Rummer, 2009). The 6x6 forwarder (16-ft bunk length) had an estimated payload of 20 bales, which consisted of bales stacked two wide, four long, and two high, with four on the top, and an estimated turn time of 30 minutes ((Klepac and Rummer, 2009).

Table 6. System balance summary.

<table>
<tr><th rowspan="2">System</th><th rowspan="2">Machine</th><th rowspan="2"># of Machines</th><th rowspan="2">Machine (tons/SMH)</th><th colspan="4">System</th></tr>
<tr><th>($/SMH)</th><th>($/ton)</th><th>($/bale)</th><th>($/MMBtu)</th></tr>
<tr><td rowspan="2">Baler w/ 4-wheel forwarder</td><td>Tractor/Baler</td><td>2.0</td><td>10.22</td><td rowspan="2">241.30</td><td rowspan="2">23.61</td><td rowspan="2">11.72</td><td rowspan="2">1.38</td></tr>
<tr><td>Forwarder</td><td>1.0</td><td>10.54</td></tr>
<tr><td rowspan="2">Baler w/ 6-wheel forwarder</td><td>Tractor/Baler</td><td>2.7</td><td>13.80</td><td rowspan="2">324.01</td><td rowspan="2">23.48</td><td rowspan="2">11.66</td><td rowspan="2">1.37</td></tr>
<tr><td>Forwarder</td><td>1.0</td><td>14.06</td></tr>
</table>

CONCLUSIONS

The FLD WB-55 baler was successful in producing bales from understory biomass from a 28-year old pine plantation. Performance improved significantly after improvements were made following the October 2008 trial. Productivity increased from 5.2 bales/PMH to 14.7 bales/PMH, which reduced the in-woods cost from $43/gt to $17/gt.

Improvements to the baler were also made after March 2009. Included in these changes were the replacement of the tires with 500-22.3/60 sized tires, an increase in reliability, and improvements to make routine maintenance much easier. After these modifications were made, the baler was evaluated while working in willow and poplar plantations in Ontario during November 2009. Production at one site averaged 31 bales/hr for willow and 37 bales/hr for poplar (Savoie and others, 2010). Estimated yields were 14.7 gt/ac at the willow site and 19.1 gt/ac at the poplar site.

One issue to consider is the application of treatments over time. If re-baling is planned every 3 years to control growth, volume per acre cut in subsequent treatments may be less than in the initial pass, resulting in higher a cost per ton. However, if the mow-and-tow treatment is not employed periodically, re-growth will quickly overcome the effects of the treatment and there will be little benefit to wildlife, hunting, or fire. These sorts of questions are critical to understand what stand conditions are acceptable for baling treatments.

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