Evaluation of the WB55 Bio-baler for Baling Woody Biomass in a Forest Application

John Klepac
USDA Forest Service, SRS
Auburn, Alabama
jklepac@fs.fed.us

Bob Rummer
USDA Forest Service, SRS
Auburn, Alabama
rrummer@fs.fed.us

ABSTRACT: A FLD model WB55 Bio-baler[1] was evaluated while working in a pine plantation in southeast Georgia. The baler was equipped with a fixed tooth rotor and had a 48 tooth capacity, a 7.5-foot cutting width, and was powered by a Fendt 818 tractor which provided 185 hp. Understory biomass removed consisted mainly of gall berry, wax myrtle and sawtooth palmetto. Inventory data revealed an understory biomass level of 10.7 green tons/ac in the area. Total productive time to bale averaged 4.3 minutes with a production rate of 14.7 bales/PMH (Productive Machine Hour). Travel distance averaged 752 ft/bale. Bale measurements revealed a mean bale weight of 1004 lbs and a mean bale density of 18.7 lb/ft^3. Field moisture content of sampled bales was 38.11 percent (wet-basis). Analysis of bale samples revealed a mean oven-dry heat of combustion of 8560 Btu's/lb (oven-dry). In-woods cost per unit for the two machines was $8.74/bale or $17.60/green ton.

Keywords**:** Biomass, baling, production, heat content, Btu.

[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.

Overview

In December 2007 the performance of two agricultural balers working in a forest environment on the Osceola National Forest in Florida was evaluated. This was a cooperative research project which merged expertise from a variety of areas and included the Department of Agriculture and Agri-Food Canada / University Laval, National Forests in Florida, the National Wild Turkey Federation, the Osceola National Forest, Langdale Company, the Southern Research Station, and Supertrak, Inc.

One of the balers studied was the Bio-baler, which was developed at the University Laval by graduate students and Dr. Philippe Savoie. The baler was a modification of a New Holland round baler equipped with a rotor head equipped with flail knives. Since that time, a new company was formed by two of the students who worked with the Bio-baler. This new company, named FLD Biomass Technology, designed and produced a new baler. This new baler, named the FLD WB55 Woody Baler, is a modification of a Claas machine with a roto-chopper attached to the front.

The FLD baler was observed twice while operating in loblolly pine plantations in southeast Georgia on land owned by the Langdale Company. The first production study was performed in October 2008. Afterwards, several modifications were made and in March 2009 the baler returned for a second trial. The objectives during both trials were to evaluate performance while baling understory biomass by measuring time to bale, distance traveled between bales, bale density, bale weight, moisture, heat, and ash content of the baled material and fuel consumption rate of the machine.

Introduction

New conversion technologies and national energy policy are creating potential biomass demand on a large scale. This creates new opportunities for land owners and forest contractors in addition to new challenges and concerns for harvesting and delivering biomass for use as heat, power, bio-based products, or bio-fuels. The form of the feedstock is important, depending on the biomass conversion facility that will use it. Some facilities will require the material to be chipped or ground up, while others will be capable of accepting whole bales or bundles.

Recovery of logging residues as a source of hog fuel has enhanced utilization of harvested stands. This material is generally processed thru a tub grinder and delivered. In Scandinavia, residues from Cut-to-Length (CTL) operations are bundled into the form of a log and delivered. Since trees are processed at the stump limbs and tops accumulate, which makes utilizing a bundling machine to collect this material very effective. Also, transport trucks and processing facilities there are designed to handle products in the form of a log or bundle, which makes biomass recovery an efficient process.

Harvesting standing biomass can be both beneficial and challenging. Baling material from a plantation into round bales has several benefits which include promotion of growth of residual trees, fire hazard reduction, decrease in herbicide application, and wildlife enhancement.

Stand Descriptions

Sites where the study was conducted were both approximately 28-year-old loblolly pine plantations located on flat terrain with Osier and Mascotte soil series. The Osier series consists of poorly drained soils with the A horizons consisting of a loamy fine sand and loamy sand (NRCS, 2009). The Mascotte series also consists of poorly drained soils with a fine sand making up the A horizon (NRCS, 2009). Each site was thinned using a fifth-row removal treatment in 2007.

Equipment Overview

Equipment observed included a FLD WB55 baler (Figure 1) equipped with a fixed tooth rotor with a 48 tooth capacity and a cutting width of 7.5 feet. The baler was mounted on Carlisle Trac Chief 14-17.5 NHS tires. Minimum horsepower requirement for the baler was 130 hp. Power to the baler was provided thru PTO by a Fendt 818 tractor that produced 185 hp. The Fendt 818 was mounted on Nokia 16.9-28 TR tires in the front and Nokia 20.8-38 tires on the rear. Bales were transported from woods to a landing with a John Deere 541 farm tractor with a spike mounted on the front.

Figure 1. FLD WB55 baler.

Methods

Understory Inventory

To assess the amount of understory woody biomass that existed in each area, 1 m^2 biomass inventory plots were installed. A total of twenty-seven plots were installed on Site 1 and twenty plots were installed on Site 2. 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

On Site 1 the baler began working around noon the first day and operated approximately 4.5 hours and made twelve bales. It was determined that the tooth design was not conducive for baling the small diameter material such as gallberry. Apparently the teeth were not efficiently pulling the material up into the baling chamber after it was cut. Therefore, Supertrak, Inc. provided new teeth the following day that were designed with more curvature to provide more of a scooping action.

All teeth were replaced during the morning of day two and work began around twelve-thirty. After about one hour of operation, it was concluded that the material was being cut too short, making it very difficult to bale. In addition, the material was thought to be too wet. A shear bar on front of the baler was removed and this significantly improved the baler's performance. After approximately 4.75 hours of operation five bales were produced.

On day three the crew decided that the rollers feeding the material into the baling chamber were too smooth. Therefore, steel nuts were welded along the length of the rollers to aid in moving material into the chamber. The baler began operating late that morning in an area adjacent to where it worked the previous day. After two bales were made, time-and-motion data collection began.

To estimate baler production an elemental time-and-motion study was performed. Elements for the study included travel, turn, and wrap/drop bale. Travel time included all travel of the equipment within a row. The baler made two passes within thinned rows (Figure 2) and one pass within unthinned rows. 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.

Figure 2. Baler making a second pass within a thinned row.

After a bale was dropped, it was flagged and numbered. A flag was also attached to a nearby limb or bush to mark the bale's location to aid in measuring travel distance in case the bale was removed from the stand prior to measuring the distance. Ends of rows were also flagged and numbered to aid in measuring turn distance.

In addition to the time-and-motion study, total machine hours and fuel consumption were also measured. An electronic activity recorder was placed in the tractor to monitor activity. The tractors fuel tank was topped off either at the end of the work day or the following morning prior to operating and total gallons used was measured with a fuel meter attached to a fuel supply tank.

After the Site 1 trial, several modifications were made to the baler to improve its performance. A gear box was installed to split the power from the tractor PTO to the baler and the mulching head instead of using a belt and pulley transmission. A second drive shaft with a clutch was added so that the torque provided to the baler and rotofeeder could be limited for protection during occurrences of jamming or clogging. The clutch inside the drive-shaft can be adjusted by loosening or tightening the springs. The baling chamber was also modified. Previously, rollers were used in the chamber to keep the material rotating, which is required for making a bale. The tailgate rollers were replaced with a chain-driven mechanism which is much more rigid and provides more grip on wet material.

The baler began work on Site 2 during March 2009 and was on site for eight days working in various stand conditions during this period. Production data were collected during a one day period in a plantation very similar to Site 1. A total of twenty-six bales were made in 2.1 hours. No mechanical delays were observed during the data collection period.

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.

Bale Measurements

Bales were weighed at the landing using chains and a hanging dial scale (Figure 3). Weights to the nearest 10 pounds were recorded. A John Deere 541 farm tractor with a spike attached to the front was used to lift the bales. To estimate bale density, horizontal diameter, vertical diameter, and width were measured to the nearest tenths of feet using a cloth tape.

Figure 3. Obtaining green weight of a bale using a hanging scale.

Heat Value and Moisture Content

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 Inventory

Large amounts of undesirable 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 from each site were expanded to reflect green tons per acre and are summarized in Table 1.

Table 1. Summary of understory woody biomass loading.

		Green tons/acre			
Site	***N***	**Mean**	**SD**	**Min**	**Max**
1	27	10.0	4.64	3.1	22.1
2	20	11.3	5.49	3.8	29.9

Baling

A total of twenty cycles were obtained from Site 1 and twenty-six cycles were collected from Site 2. However, three bales from Site 1 were not complete or did not bale properly, so they were not included in the summary. In addition, on Site 2, two bales fell apart during transport from woods to landing so they were not included in the summary of bale measurements. Total cycle time for Site 1 averaged 11.9 minutes compared to 4.3 minutes for Site 2. Travel distance required to make a bale averaged 1682 feet on Site 1 and 752 feet on Site 2. Baler productivity averaged 5.2 bales/PMH on Site 1 compared to 14.7 bales/PMH on Site 2. A summary of time study variables for both sites is shown in Table 2.

Twice during the time study on Site 1 a tooth on the roto-chopper became lodged in and bent the rake. This required the tractor to be driven to the shop to repair. The baler was down approximately 2.25 hours for each occurrence. There was also a weakness in a shear pin on the baler which broke three times during the course of the time study. Replacing the pin required an average of 5.8 minutes. However, when the shear pin failed this caused the rollers inside the baler chamber to not rotate. In order to start baling again, the chamber had to be cleaned out, which required removing material by hand. This resulted in additional delay time of 9.7 minutes on average.

In addition to making bales, there are other processes that must be considered to complete the system. Bales must be transported from the woods to a landing for further handling and processing. The type of feedstock required at the processing facility will determine the form the baled material must be in when transported for it to be usable. Some facilities might prefer bales to be delivered whole where they can be processed in a tub grinder to be used as hog fuel. In this case, bales could be loaded on flatbed trailers at the landing for transport. Other facilities may require the material to be processed into a particular size. This would require additional in-woods processing which may require utilization of a chipper or grinder.

Table 2. Summary of elemental time study data for both sites.

	Site 1					Site 2				
Variable	**N**	**Mean**	**SD**	**Min**	**Max**	**N**	**Mean**	**SD**	**Min**	**Max**
Travel (min)	17	10.2	2.29	8.0	16.7	26	3.4	0.86	2.1	5.6
Turn (min)	17	1.1	0.56	0.3	2.3	26	0.4	0.38	0.0	1.6
Wrap/drop (min)	17	0.6	0.39	0.1	1.5	26	0.5	0.14	0.2	0.9
Total time (min)	17	11.9	2.24	9.4	17.9	26	4.3	1.01	2.7	6.7
Travel dist. (ft)	17	1682.2	351.40	1154	2373	26	752.0	136.38	508	975
Turn dist. (ft)	17	151.6	82.60	45	315	26	41.7	35.62	0	95
Bales/hr	17	5.2	0.83	3.3	6.4	26	14.7	3.15	9.0	22.1

Fuel consumption was measured three times on Site 1 and once on Site 2. The lower cycle time per bale on Site 2 resulted in a lower fuel expenditure per bale as compared to Site 1. Using production rates for each site in bales per PMH resulted in a 53 percent reduction in gallons expended per bale (Table 3).

.

Table 3. Fuel consumption rate summary.

Site	***Total Hours***	***Fuel Consumption (gal)***	***Rate*** **gal/hr**	**gal/bale**
1	16.6	60.3	3.63	0.70
2	7.58	37.0	4.88	0.33

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 an Anderson R-Flex 612 HD log trailer with an M-160 boom 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 for transporting bales from woods to a landing 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. Using some assumptions, cost to forward bales using a 4-wheel and 6-wheel forwarder from woods to a landing were calculated and compared.

Bale Measurements

Bale size was very similar for both sites. Seventeen bales were measured on Site 1 and twenty-four bales were measured on Site 2. Data from both sites were combined to calculate means of measured parameters. Table 4 summarizes these results.

Table 4. Summary of bale measurements.

Variable	*N*	*Mean*	*SD*	*Min.*	*Max.*
D_H (ft)[1]	41	4.2	0.18	4.0	4.7
Dv (ft)[2]	41	4.0	0.20	3.5	4.3
Width (ft)	41	4.1	0.12	3.7	4.4
Weight (lb)	41	1004.2	89.33	763.5	1223.5
Volume (ft^3)	41	53.8	4.21	44.2	62.4
Density (lb/ft^3)	41	18.7	1.72	16.1	24.3
Circumference (ft)	41	12.9	0.46	11.8	13.8

[1]D_H is horizontal diameter.
[2]D_V is vertical diameter.

Heat Value and Moisture Content

Estimating recoverable heat energy for wood or bark fuel requires information regarding the temperature of air and fuel entering the furnace, temperature of stack gases beyond heat recovery devices, fuel moisture content, percent excess air, and the ovendry heat of combustion of the fuel (Ince, 1979). Heat of combustion is the total amount of heat obtainable from ovendry material, allowing no deductions for heat losses (Koch, 1972).

Samples were collected from thirteen bales on Site 1 and ten bales on Site 2 for moisture, heat, and ash content determination. A summary of elementary statistics for each of these variables is shown in Table 5. Heat content of a dry bale was based on the ovendry heat of combustion, which represents the highest heat potential of the material.

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

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
Field MC (% wet-basis)	23	38.11	5.345	30.52	49.13
Oven-dry heat of combustion (Btu/lb)	23	8559.7	228.03	8014	8858
MMBtu's/bale (field)[1]	23	3.34	0.620	2.48	4.48
MMBtu's/bale (dry)	23	5.42	0.523	4.45	6.57
Ash content (%)	23	1.84	0.574	1.02	3.42

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

Figure 4 shows how the heat content of baled material compares to other types of material such as resin, charcoal, and other woody products. Resin and charcoal have very high heat contents of about 15,000 and 12,000 Btu's/lb, respectively. Pine stumpwood, pine stemwood, pine tops, bales, and cones all have heat contents in the range of 8,000 to 8,600 Btu's/lb. This suggests that the heat content of baled understory vegetation is similar to that of stemwood, even though bales contain a significant amount of non-woody material.

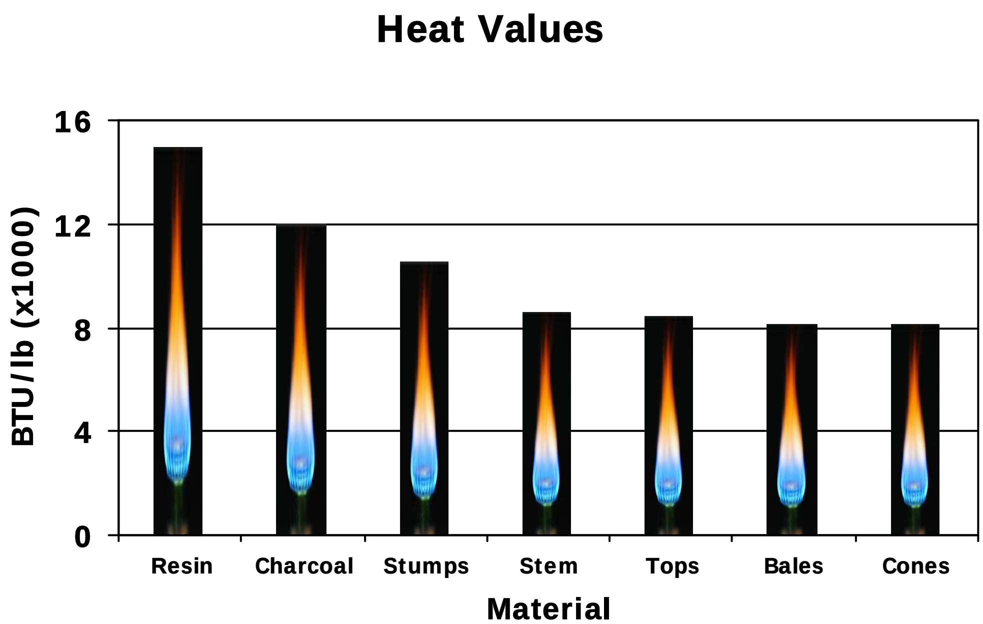

Figure 4. Heat values for various materials (Koch, 1972).

Costs

Machine rates were calculated using the retail price ($US) of a new machine and reflect the average cost over the life of the machine. A life of six years was assumed for the Fendt 818 tractor with a salvage value of 20 percent of the purchase price. In addition, a repair and maintenance rate of 100 percent of depreciation, an interest rate of 8 percent, 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 was assumed (Brinker, et.al., 2002). A fuel consumption rate of 0.019291 gal/hp-hr was used. For the FLD WB55 baler, a four-year life was used with a salvage value of 25 percent of the purchase price. A rate of 150 percent of depreciation for repair and maintenance and lube costs was assumed (Savoie, 2008). An insurance rate of 2.0 percent of the purchase price was used. These costs are summarized in Table 6 and do not include profit and overhead. Since the baler was only observed for one day during the March 2009 trial and was not in a full production mode, a utilization rate of 70 percent was used instead of a rate determined from the study.

Baling cost was $8.74/bale or $17.60/green ton. This was the cost for the tractor and baler to make a bale and drop it in the woods. Additional cost to transport bales from the woods to a landing was determined using a 4x4 and a 6x6 forwarder. As previously mentioned, once bales are at the landing they can either be loaded whole onto a trailer or processed further into a desirable type of feedstock by chipping or grinding the material.

Table 6. Machine rate summary.

	Machine			
Variable	**Fendt 818 tractor**	**FLD WB55 baler**	**4x4 Forwarder**	**6x6 Forwarder**
Purchase price ($)	150,000	125,000	200,000	240,000
Salvage value ($)	30,000	31,250	40,000	48,000
Depreciation ($/yr)	20,000	23,438	32,000	38,400
Interest ($/yr)	8,000	7,188	10,880	13,056
Insurance ($/yr)	3,500	1,797	4,760	5,712
Annual owning cost ($/yr)	31,500	32,422	47,640	57,168
Total Owning ($/SMH)	**15.75**	**16.21**	**23.82**	**28.58**
Fuel & Lube ($/PMH)	12.00	1.61	9.58	9.58
R & M ($/PMH)	14.29	25.11	22.86	27.43
Teeth ($/PMH)		4.00		
Bale twine ($/PMH)		3.53		
Total Operating ($/PMH)	**48.57**	**34.26**	**54.72**	**59.29**
Labor & Benefits ($/SMH)	15.60		15.60	15.60
Total Cost ($/SMH)	**49.75**	**40.19**	**62.12**	**70.08**

[1]Cost was calculated using a bale circumference of 12.9 feet, a production rate of 5.2 bales/PMH, and 17 wraps/bale.

Cost of forwarding of bales from woods to a landing was determined by making several assumptions. The 4x4 forwarder (9.6-ft bunk length) had an estimated payload of 10 bales, which consisted of bales stacked two wide, two long, and two high, with two on the top. Turn time was estimated at 20 minutes. 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. Since the 6x6 would pick up twice as many bales, a longer turn time of 30 minutes was assumed.

The tractor and baler were combined with a forwarder to make a complete system for making bales and transporting them to a landing. The number of machines was adjusted to determine cost and productivity of a balanced system (Table 7). From this analysis, an operation which used a small 4-wheel forwarder required two balers to balance the system. This resulted in a system rate of 10.22 tons/SMH (Scheduled Machine Hours) and a cost of $23.61/green ton from woods to landing. Using a 6-wheel forwarder required 2.7 balers to balance the system. Therefore, using three balers with a 6-wheel forwarder would result in a system rate of 14.06 tons/SMH and a cost of $24.22/green ton. Cost per bale and MMBtu would be $12.16 and $1.41, respectively.

Table 7. System balance summary.

System	*Machine*	*# of Machines*	*Machine (tons/SMH)*	*System* ($/SMH)	($/ton)	($/bale)	($/MMBtu)
Baler w/ 4-wheel Forwarder	Tractor/Baler	2.0	10.22	241.30	23.61	11.72	1.38
	Forwarder	1.0	10.54				
Baler w/ 6-wheel forwarder	Tractor/Baler	2.7	13.80	324.01	23.48	11.66	1.37
	Forwarder	1.0	14.06				

Conclusions

Baling is old technology that has been used in the agricultural realm for years. However, applying this technology in a forestry application is a fairly new innovation that will have to be refined to make it more feasible. Basically, this is a new product for the market and has the potential to serve as a new source of energy and reduce current demand for fossil fuel.

The Fendt/FLD baler system was successful in producing bales from understory biomass which consisted mainly of gall berry, wax myrtle, and palmetto. Modifications made to the baler after the October 2008 trial dramatically improved its performance, which resulted in a significant reduction in unit cost. Any additional modifications that can increase bale density and/or productivity will further improve the economic feasibility.

Several enhancements will be included in the production model which is scheduled to be available later this year. One enhancement involves the tires. The baler will be mounted on wider tires which will improve operability in forest conditions. Another enhancement involves modifications related to routine maintenance. Grease fittings and certain nuts and bolts will be re-located for easier accessibility.

The opportunity to collect detailed time-and-motion data on forwarding bales from the woods to a landing did not develop. An effort to obtain these data in the future will be made so that productivity and cost of this phase of the system can be more accurately determined.

Literature Cited

Brinker, R.W., Kinard, J., Rummer, B., and Lanford, B. 2002. Machine rates for selected forest harvesting machines. Alabama Agricultural Experiment Station, Circular 296 (revised). Auburn University, Auburn, AL. 29 p.

D'Amours, Luc and Lavoie, Frederic. 2009. Correspondence.

Ince, P.J. 1979. How to estimate recoverable heat energy in wood or bark fuels. USDA For. Serv., For. Prod. Lab. Gen. Tech. Rep. FPL 29. 5 p.

Koch, P. 1972. Utilization of the southern pines. USDA Agric. Handb. 420. USDA For. Serv., South. For. Exp. Sta.

NRCS, 2009. http://www2.ftw.nrcs.usda.gov.

Savoie, Philippe Dr. 2008. Correspondence.