High Tonnage Harvesting and Skidding for Loblolly Pine Energy Plantations

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Abstract:
The need for alternative and renewable energy sources is evident in the United States to ensure that the nation's energy appetite is fulfilled. The southeastern United States has a promising source for this renewable energy in the form of woody biomass. To meet the energy needs, energy plantations will likely be utilized. These plantations will contain a high density of small stem pine trees. Since the stems are relatively small when compared to traditional product removal, the harvesting costs will increase. The purpose of this research was to evaluate specialized harvesting and skidding equipment that would harvest these small stems cost efficiently. The feller-buncher utilized was a Tigercat 845D with a specialized biomass shear head. The skidder was a Tigercat 630D equipped with an oversized grapple. This equipment was evaluated in a stand with similar characteristics of a southern pine energy plantation. During the study, the feller-buncher achieved an average productivity rate of 52 green tons/PMH and the skidder had an average productivity rate of 123 green tons/PMH. A before tax cash flow model was used to determine a cost per ton for each machine. The feller-buncher costswere$3.48/ton over a 10 year lifespan while the skidder costs were $1.78/ton over the same 10 year life. The results proved that the current system working in a southern pine energy plantation could harvest and skid small stems for approximately $5.26 per ton.

Keywords: harvesting, biomass harvesting

1 Introduction

The topic of declining fossil fuels and the need for renewable energy sources is evident in today's society. Because of this necessity, researchers and politicians have assembled different ideas in which renewable fuels will be a major part of the United States energy portfolio. Some of the framed ideas include the Billion Ton Report (U.S. Billion Ton Update 2011), "25 by 25" (25x'25), and the Energy Independence and Security Act of 2007. The billion ton report (2011) illustrates how different areas of biomass feedstocks are allocated to the renewable fuel portfolio in a sustainable manner. Another policy that shows promise is the "25 by 25" idea. This states that 25% of our energy consumed must come from biomass by the year 2025. The one policy that has been enacted is the Energy Independence and Security Act of 2007 (EISA). Included in the act are standards in which bio-fuels will play a major role in ensuring national energy security and the reduction of green-house gases. One of the main goals of the Act is to have 36 billion gallons of bio-fuels produced annually by 2022. The common attributes of all of these ideas are that they require a tremendous amount of biomass in a relatively short time period. A great deal of this materialis expected to be sourced from woody biomass.

Woody biomass is available in such forms as urban residues, mill residues, dedicated energy crops, and logging residues. Currently, mill and logging residues supply the woody biomass market, but they are not sufficient to meet the large scale quantities set forth. Eventually, dedicated energy crops will likely be utilized by the United States to meet the requirements for biomass feedstocks. Short-rotation woody crop (SRWC) supply systems were first described in the late-1960s and early 1970s as a means of rapidly producing lignocellulosic fiber for use in the wood products industry and for energy (Tuskan 1998). Studies have been accomplished to determine optimum species, silvicultural techniques, fertilization, genetics, and irrigation to make the crop successful (Tuskan 1998). The barrier with short-rotation woody crops is the immense amount of inputs needed for high growth rates. This poses economic and environmental issues that may hinder the introduction of a biofuel market. These two issues happen to be important considerations when choosing a crop for biomass production. Another aspect that should be taken into account is the volatile risk associated with the biofuel market. The need for biomass feedstocks for energy has not been constant in the past. To mitigate risk, the biomass feedstock crop should be flexible in its ability to produce different products in order for the landowner to make a profit from his/her initial investment. Correspondingly, the crop should be well known in different areas such as management, nursery management, and disease/pest control.

Southern pine stands have the potential to provide significant feedstocks for the biomass energy market (Scott and Tiarks 2008). Pine plantations have played a major role in the success of the forest products industry in the United States but specifically in the southeast United States. The Southeast produces more industrial timber products than any other region in the world (Allen et al. 2005). This can be attributed to the Southeast climate and knowledge of intensive southern pine plantation management. The stands proposed for the energy plantations will predominately be composed of loblolly pine (*Pinus taeda*) planted at a density between 1000 and 1200 trees per acre (TPA). Stands would be grown for 10-15 years where they will be harvested by the clearcut method. Stands at this age are not merchantable in today's market because of the small stem dimensions at this young age. The shorter rotations will be attractive to landowners looking for a quick return on investment when compared to other timber product types that require much longer rotations.

The problem lies in the logistics of felling the small diameter stems and delivering them to the mill in a form that is economically feasible (Spinelli et al. 2006). Harvesting systems must be balanced for the characteristics of the forest, machine types and intensity of the harvest to reflect the equipment's productivity (Akay et al. 2004). The main issue in the logistics process is the production costs associated with harvesting and handling the smaller stems.

In the Southeast, conventional whole-tree harvesting systems incorporate a feller-buncher to fell and bunch the trees while a rubber-tired grapple skidder drags the bundle of trees to the loading deck (Soloman and Luzadis 2009, Wilkerson et al. 2008). These two machines are essential to the operation and must be productive for profitability. The stems are processed at the loading deck into logs, tree-length material (de-limbed and bucked), or chips. In full tree systems, the residues such as foliage, limbs, bark, and tops are typically left on the loading deck or the skidder distributes the slash back into the harvested stand. These residues, along with the main bole of the tree, provide a large amount of low-cost biomass and potentially hinder future operations such as site preparation (Visser et al. 2009). In an energy plantation setting, the conventional whole-tree harvesting system configuration will follow traditional harvesting techniques and the whole-tree will be chipped. It is essential that the harvesting system be composed of as few machines as possible to save money in maintenance and labor costs, moving costs, and reduced interference delays (Klepac and Rummer 2000). When chipping, the equipment should be utilized to maintain woodflow for the highly productive chipping application. Using a whole-tree chipping system aids the harvesting process in several areas.

Investment in biomass harvesting productivity research studies have been minimal since the late 1980's because of the low interest in biomass feedstocks, resulting in a gap in the understanding of production potential of modern harvesting machines. Based on an unpublished benchmarking study of a current harvesting system operating in south Alabama, the USDA Forest Service found that current felling and skidding costs range from $6.00 to $9.05 per green ton. The use of more specialized and technologically advanced equipment could lower the cost per unit. These systems do not need to be capital intensive to lower costs, but must have the flexibility and capability to be used for conventional round wood production in case of a biomass market collapse. Because of the high volume and low product value, a highly productive operation must be developed to mitigate the low value of the material. High production rates lower the fixed costs by spreading the costs over more units harvested. The system designed for this study is a high-speed, high-accumulation feller-buncher and a modified high capacity rubber tired skidder. Field studies were performed on this new equipment to analyze productivity and costs associated with owning/operating the machines.

2 Methods

2.1 Study site

Corley Land Services purchased a 10.8 acre stand of 11 year-old timber on a site outside Monroeville, AL to demonstrate the system and implement a production study. The standused for the study should represent an energy plantation and have the following characteristics: planted pine plantation, minimum of 600 trees per acre, age class between 10 and 15 years, and greater than 100 acres. The stumpage acquired had a 10% cruise implemented to get an accurate estimate of the timber inventory on the property. Trees per acre, volume per acre, total volume, average height, and species composition were determined from the cruise.

2.2 Production study

To investigate the feller-buncher engineered by TigerCat, a time study was implemented to understand utilization and production capabilities.Several methods were used to collect data including using a stopwatch, a video recorder, and a MultiDat field recorder.

The productivity of the skidder was evaluated using the same three methods as the feller-buncher time study. First, a stopwatch was used to gather the cycle time for the skidder to leave the loading deck and return with a bundle of felled biomass. These cycle times wereanalyzed along with the distance traveled per cycle which was obtained by the GPS function of the MultiDat recorder placed in the skidder.Lastly, video was taken to analyze grapple functions and estimate bundle size.

Fuel usage was another variable investigated. The machines were filled in the morning before the operation began. The machines productive hours were measured throughout the day along with the scheduled hours set forth by Corley Land Services. At the end of the day, the machines were filled with a pump equipped with a fuel meter to determine consumption levels.

3 Results

Based on the cruise data, the average total pine biomass was 87.29 tons/acre. Stand density was measured by trees per acre (TPA) and basal area. Average trees per acre was 576 while the basal area was 120.31 ft^2/acre. Other key descriptive stand statistics can be seen in Table 1.

Table 1: Study site density and weight statistics

	Max	Min	Mean	Standard Deviation	95% lower	95% upper
Basal Area/acre*	133.84	95.55	120.32	11.63	111.99	128.64
Trees/acre	660	480	576	54.81	536.79	615.21
Weight/acre**	98.15	66.92	87.29	10.15	80.03	94.55

*BA/acre=measured in ft^2. **Weight/acre=measured in tons

From TPA and tons per acre, average tree size was formulated. Based on the data, average size resulted in 303lbs or 0.15 tons per tree. This value was utilized in productivity calculations for both the feller-buncher and grapple skidder.

During the study period, a total of 186 feller-buncher cycles were measured and recorded which consisted of the harvest of 1,404 trees. Descriptive statistics for the feller-buncher cycle times are listed in Table 2.

Table 2: Key statistics for feller-buncher cycles

	N	Min	Max	Mean	Standard Deviation
Acc time*	186	0.22	3.48	1.36	0.33
Trees/acc**	186	1	15	7.55	2.19

*Acc = Accumulation. **Acctime = measured in minutes.

The mean estimate for time per accumulation was 1.36 minutes (95% confidence interval = 1.30 to 1.42). A scatterplot shows the relationship between the number of trees harvested per accumulation and cycle time (Figure 1). The figure illustrates a trend of increasing cycle time with the increase in trees harvested per accumulation. The average payload per accumulation was estimated at 1.13 tons.

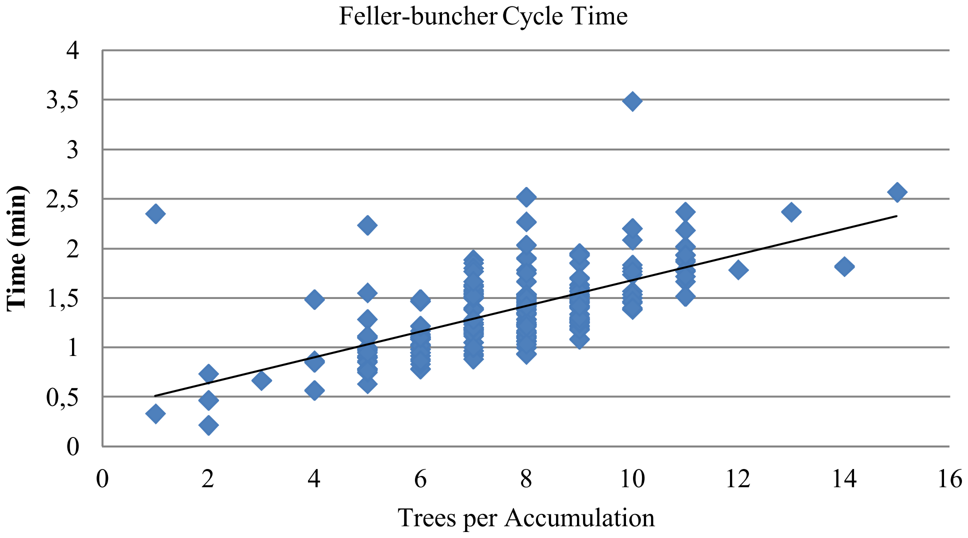

Figure 1: Scatterplot of feller-buncher cycle time versus trees per accumulation

The feller-buncher productivity was estimated by developing a linear regression model. The response variable was cycle time which was the time to harvest and release one accumulation of trees. The predictor variable was the number of trees harvested per accumulation. The ANOVA table (Table 3) shows that the variability in cycle time is significantly related to the number of trees per accumulation.

Table 3: Analysis of variance for feller-buncher cycle time

	df	SS	MS	F	Significance F
Regression	1	18.7861	18.7861	67.3571	3.76157E^{-14}
Residual	185	51.5971	0.2789		
Total	186	70.3833			

The number of trees per accumulation was proven to be significant using the t-test approach. The following table represents the regression equation details.

Table 4: Regression equation details for the feller-buncher cycle

	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	0.300	0.138	2.16	0.031	0.027
Trees	0.144	0.018	8.21	$3.8E^{-14}$	0.109

$$cycletime\ (mins) = 0.14447 trees/accumulation + 0.30044$$

From the table above, the p-value exhibited for the tree variability is statistically significant because it is less than the threshold of 0.05. This indicates that the number of trees harvested is statistically important and explains variability in the feller-buncher cycle time.

To determine skidder productivity, a stopwatch was used to record a total of 59 delay free cycles. The average payload for the delay free cycles was 7.55 tons. Further information concerning delay free cycles is illustrated in Table 5. The relationship between distance and cycle time is displayed in Figure 2 where the graph shows that there is a strong linear relationship between the two variables.

Table 5: Descriptive statistics for skidder delay free cycles

	N	Max	Min	Mean	Standard Deviation
Cycle Time*	59	9:15	1:06	3:55	1:53
Bunch #	59	3	1	1.68	0.502
Distance**	59	1096	103	459	251

*Cycle time in minutes, seconds. **Distance in meters.

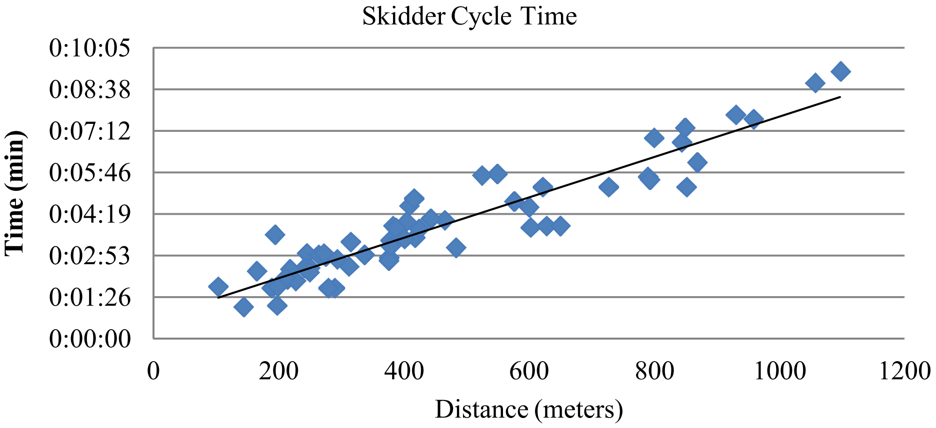

Figure 2: Scatterplot showing delay free cycle time and distance (n = 59 cycles)

From the 59 recorded cycles, a linear regression model was developed for the independent variable cycle time. The regression was proven to be statistically significant at the α = 0.05 level (F-value = 217.9, p-value = $3.8*10^{-27}$). The analysis revealed a high R^2 value of 0.886 and an adjusted R^2 value of 0.882. Thus, distance and the number of bundles explain 88% of variation in cycle time. The ANOVA returned a MSE of $2.04x10^{-7}$. Both independent variables were also proven to be statistically significant at the α = 0.05 level. Indicators for this conclusion are highlighted in red on Table 9. The distance variable was the more significant of the two as shown in the respective p-values calculated (Tab. 6) and therefore accounts for more of the variance.

Table 6: Regression coefficients and statistical information for the skidder cycle model

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept*	0.0001405	0.000198	0.71	0.4804	-0.00026	0.000537
Distance**	4.44437E^{-06}	2.97E^{-07}	14.97	3.13E^{-21}	3.85E^{-06}	5.04E^{-06}
Bunch #***	0.000317	0.000141	2.24	0.0286	3.43E-05	0.0006

*Cycle time decimal days. **Distance in meters. ***Bunch in number of bunches

$$cycletime = 0.000004444dist + 0.00032bunch + 0.00014$$

Productivity was calculated for each delay-free cycle. Average productivity for the skidder resulted in 123.73 green tons/PMH. The high productivity can be attributed to multiple factors in the study. First, the modified skidder has an oversized grapple which gives it the ability to grapple larger payloads. Since the skidder can acquire more tonnage with each skid without increasing cycle time, the productivity is increased. Also, the tract offered many short skids which minimize cycle time. This is confirmed by the regression developed which showed that distance was the most significant variable. The maximum productivities achieved were when the skidder grappled multiple bunches near the landing. In these cases, the skidder could produce 282 green tons/PMH. This unusually high productivity was not typical in the study. In other situations, long skid distances reduced the productivity to 55 green tons/PMH.

3.1 Economic Analysis

Each machine cost was estimated based on production rates found in this study. All costs were input into abefore-tax cash flow spreadsheet developed by Dr. Robert Tufts of Auburn University (Tufts and Mills 1982).

The MSRP for a new 845D feller-buncher was acquired from Tigercat. The initial expected capital investment for this specific machine is $495,080. This includes all extra components such as the biomass shear head ($65,945), upgrade on tracks($5,590), and the Cummins interim Teir IV engine($18,750). The 630D skidder MSRP was $330,000. For the purpose of this study, a $50,000 down payment was utilized on both pieces of equipment with the rest of the investment financed. Escambia County Bank was contacted for the finance rate and length of loan for the both machines. A typical annual percentage rate (APR) for each machine would be 7% for 60 months (Bill Cox, personal communication, May 2012).Insurance and property taxes were combined as a percentage for the analysis. The insurance (fire, theft, and vandalism) was set at 4% and the property tax rate used was 2%.

All variable costs associated with operating the feller-buncher and skidder were used in the cash flow model. Fuel use was determined based on the detailed records maintained by Corley Land Services. The feller-buncher used approximately 9.9 gallons of off-road diesel per productive/operating hour. The skidder consumed an averaged of 6 gallons per productive machine hour. Off-Road diesel was priced during the study at $3.80/gallon. Lube cost was determined as a percentage of fuel usage (Brinker et al. 2002). These costs were combined in the analysis for a resulting figure of $54.10/PMH for the feller-buncher and $39.16/PMH for the skidder. Repair and maintenance costs were formed using the Caterpillar Performance Handbook. Total repair and maintenance costs were estimated at $16.00/PMH for the feller-buncher. The maintenance and repair rate used for the skidder was $10.00/PMH. If the assumption error is 50%, the overall AEC of the machine had a minimal change (<1%). Major repairs or replacements were also included into the analysis. The two main components that would need to be replaced during the life of the feller-buncher would be the undercarriage and engine. According to Cummins, the feller-buncher engine would need to be rebuilt at year 5 at a cost of approximately $15,000. The undercarriage would have a low rebuild at ages 3 and 9. Also, it would have a major rebuild of the undercarriage at age 6. Both rebuilds include track replacement. Tires (at $8,000 every 3 years) would be the main component with a replacement schedule for the skidder. The labor rate was set at $15.00 per hour with 33% fringe benefits for the operator. An inflation rate of 3% was used on labor, maintenance, and fuel. A utilization rate of 75% was used for the analysis for the feller-buncher instead of the measured 86%. This is the maximum that could be seen for the machine due to expected operational delays. However, the skidder utilization rate of 32% was used because it was limited by the feller-buncher and deck delays.

The annual equivalent cost (AEC) is the cost to own and operate a piece of equipment over its entire lifespan while taking into account the time value of money (Tufts and Mills 1982). For the purpose of this study, the feller-buncher and skidder were placed on a 10 year or 20,000 SMH lifespan. Assuming this ten year span, the feller-buncher has an AEC of $275,066.94. By applying the 52 tons/PMH found in the study to the economic analysis, the feller-buncher could produce a ton of wood for $3.48/green ton. The skidder cost analysis model returned an AEC of $141,323 over the ten year lifespan. By applying the productivity of 123 tons/PMH and an utilization rate of 32% achieved by the skidder, the 630D can skid wood for $1.78/green ton. Thus, the two machines combined can harvest and skid wood for $5.26/green ton before tax in an energy plantation setting.

To better understand the system under government tax rates, an after tax analysis was performed while assuming the same parameters. The marginal tax rate used in the analysis was 25% which was for a married sole proprietor owner tax filing status and having a joint income of $70,700 to 142,700 (CCH 2011). This rate was used because the logger must net this amount of income to pay for the machinery. After applying the federal tax rate, the feller-buncher has an AEC of $206,984 and a cost per ton of $2.62. The skidder's AEC decreased to $106,559 and cost per ton to $1.34. The decrease in cost for both machines reflects a reduction in tax liability due to expenses. These deductions are applied to expenses and interest payments.

4 Conclusions

In this study, a Tigercat 845D feller-buncher equipped with a biomass shear head was used to harvest and a modified 630D skidder was used to skid the whole trees to the deck. The analysis of the machines took place on an 11 year old pine plantation near Monroeville, AL. The 10.8 acre tract took a total of 22.5 hours to harvest. Production and cost numbers were calculated for each machine working separately. These numbers were further analyzed for prospective system improvements.

The feller-buncher averaged 52 green tons/PMH during the study. Crooked trees, operator inconsistency and lack of experience hindered production. The before tax annual equivalent cost for the feller-buncher was determined to be $275,067 per year. By applying the productivity observed in this study, the cost per ton over a 10 year lifespan would be $3.48.Skidder production was determined to be 123 green tons/PMH. The annual equivalent cost for the skidder was determined to be $141,323. By applying the productivity rates observed in this study, the cost per ton over a 10 year lifespan would be $1.78.

The estimated felling and skidding cost for the two machines in an energy plantation setting is $5.26/ton with a production level of 78,975 tons/year. With improved feller-buncher productivity due to operator experience, production levels could be increased to 106,313 tons/year.This would decrease costs for felling and skidding by $1.08, which would have huge implications on the viability of the system.

This study indicates that the modified equipment met the need of a highly productive system for harvesting young southern pine energy plantations. In addition, the system is flexible in that it can operate in stands with traditional forest product removals to address market fluctuations.

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