# Performance of a Tracked Feller-Buncher with a Shear Head Operating in Small-Diameter Pine

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**Abstract:** A Tigercat[2] 845D tracked feller-buncher equipped with a shear head was evaluated while performing a clearcut in a 15-year old Loblolly pine (*Pinus taeda*) plantation and a 18-year old natural stand. Mean density of the plantation was 573 TPA (Trees per Acre) while the natural stand averaged 328 TPA, with a slightly higher density of 390 TPA in the study area. Total cycle time was not significantly different between the two stands and averaged 66.8 seconds. The feller-buncher harvested an average of 6.3 trees per min and 7.1 trees per accumulation. Productivity of the feller-buncher in the plantation averaged 77.9 green tons per PMH (Productive Machine Hour) with a mean tree size of 0.19 green tons. In the natural stand productivity averaged 118.7 green tons per PMH with a mean tree size of 0.49 green tons.

Keywords: biomass, feller-buncher, time-study, productivity, pine.

## Introduction

Reducing US imports of petroleum products and utilizing the nation's available sources of energy from forest and agricultural lands is a desirable, yet challenging, goal of both policymakers and the nation as a whole. In 2009, the United States imported about 51 percent of the petroleum consumed. This usage translates into a yearly total of 4.34 billion barrels imported (U.S. Energy Information Administration, 2011). The Energy Independence and Security Act of 2007 requires that 36 billion gallons of bio-fuels be produced annually by 2022 (EISA). To help meet these demands efficient and sustainable utilization of our nation's forest products will be necessary and will have to be implemented thru vital forest operations to get material from the woods to feedstock conversion facilities for bio-fuel production.

With the potential for increased demand for woody biomass in the future to help supplement current energy sources, high production, low cost harvesting methods will be essential for delivering a cost effective product. Merchantable trees are gathered and transported from stump to mill for processing into usable products thru the harvesting phase of forest operations. This consists of felling, skidding, loading and/or chipping and transport of trees. In-woods clean chipping removes bark, limbs, and tops from trees that are processed thru the chipper, which creates large amounts of residue

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[2] 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.

material. Total logging residue and other removals in the United States currently amount to nearly 93 million dry tons annually—68 million dry tons of logging residue and 25 million dry tons of other removal residue (Smith et al., 2009). Most of this residue is left onsite because its small piece size makes it unsuitable and uneconomical for the manufacturing of forest products (U.S. Dept. of Energy, 2011). However, as markets for bioenergy feedstocks develop, a significant fraction of this residue could become economically feasible to remove, most likely in conjunction with conventional harvest operations where the costs of extraction (i.e., felling and skidding) are borne by the conventional forest product (U.S. Dept. of Energy, 2011).

Dedicated southern pine energy plantations could provide significant feedstocks for U.S. bio-fuel and bio-power demands. Southern pine plantations of 1.5 million acres could produce an estimated 105 million dry tons per year (Taylor and Rummer, 2011). The stands proposed for the energy plantations would predominately be composed of loblolly pine (*Pinus taeda*) planted at a density between 1000 and 1200 trees per acre (TPA) and would be grown for 10-15 years where they would be harvested by the clearcut method (Jernigan et.al, 2012). Harvesting these smaller trees cost effectively is difficult to accomplish using current conventional logging systems. In the southeastern US, where the majority of the terrain is flat to gentle slopes, drive-to-tree rubber-tired feller-bunchers equipped with a circular saw head are the most common machines used.

One system that is currently being investigated for potential biomass harvesting is a recently developed tracked feller-buncher equipped with a shear head coupled with a large capacity rubber-tired skidder. This paper discusses the performance of the tracked feller-buncher operating in a plantation stand and a natural stand in south Alabama.

## Operation

This study was part of a larger project funded by the Department of Energy to evaluate new technologies for harvesting small-diameter trees for biomass. Data were collected on the harvest operation at two sites: a plantation stand and a natural stand. A clearcut prescription was implemented at both sites where trees were felled with a Tigercat 845D tracked feller-buncher equipped with a shear head and powered by a Tier 4 260-hp engine. A Tigercat 630D grapple skidder powered by a 260-hp engine transported tree bundles to a landing.

In the plantation trees were felled and bunched and left on the ground for about six weeks to dry. After the drying period trees were skidded to a landing and clean chipped. The purpose of chipping dried material was to evaluate actual payload of larger volume chip vans hauling dried chips. For the natural stand trees were felled and skidded to a landing where they were processed thru a Chambers Delimbinator and loaded onto trucks as longwood. Harvesting was accomplished during the last week of May 2012 for the plantation and October into November 2012 for the natural stand.

## Methods

### Study Sites

The plantation consisted of 15-year old loblolly pine located in Covington County, Alabama. It had not been thinned and included a total area of 37 acres. The natural stand was approximately 18 years old and was located in Butler County, Alabama. This stand was predominately pine with a small component of hardwoods, mainly sweetgum, and contained a harvest area of 36 acres.

To characterize each stand a line-plot cruise was completed for each stand using 0.1-acre fixed radius plots. Within each plot, trees measuring over 1.5 inches Dbh (Diameter at Breast Height) were tallied. Total tree heights were measured on every fifth pine tree using a vertex hypsometer. A Trimble Ranger equipped with TCruise (Matney 1998) was used to record plot data. A PC version of TCruise was used to generate a cruise summary of each tract.

### Felling

The Tigercat 845D (Table 1) was observed while cutting trees which were marked with a number for identification and measured for Dbh. The same operator was observed on both sites. In the plantation the operator felled trees in a five row swath, centered on a row and felling two rows on each side. The machine was recorded on digital video while felling trees in the study area and each tree was identified as it was being cut.

The digital video file was reviewed using the software program Timer Pro (Timer Pro Professional), which is a program designed for time-and-motion study analysis. Machine elements that were evaluated and made a complete cycle included move to 1$^{st}$ tree, accumulate, move between trees, move to dump, and dump.

Move to 1$^{st}$ tree occurred when the machine traveled to cut the first tree in a cycle. The element began at the end of the dump element when the tracks started rolling. The element ended when track movement stopped.

Accumulate included both reaching to a tree and shearing for all trees in the cycle. The element began when track movement to the first tree stopped and extension of the boom started. The element ended when the last tree for the cycle was sheared. If the machine did not move to the first tree after dumping the head then accumulating time began after all trees were dumped and movement of the boom began.

Move between trees occurred when the machine traveled during the accumulating element in order to reach additional trees to shear. The element began after a tree was sheared and the tracks started rolling. The element ended when track movement stopped.

Move to dump occurred after all trees in the cycle were sheared and the machine traveled to a location to place the accumulated trees. The element started when the tracks began rolling after the last tree was sheared and ended when the tracks stopped rolling.

Dump included placing trees accumulated in the head either on the ground or in a bundle of previous placed trees. The element began when the tracks stopped rolling at the end of move to dump and ended when all trees were out of the head. If the machine did not move to dump then dump time started after the last tree was sheared.

Cycle volumes were determined by calculating individual tree weights using a regression equation developed from data collected from each site in addition to other sites in Butler, Covington, and Crenshaw Counties in Alabama (Klepac 2013). Some trees in the natural stand encountered by the feller-buncher were fairly large and outside the range of weight data collected for the site. These weights were estimated using published equations (Clark and Saucier, 1990).

**Table 1. Specifications of the Tigercat 845D feller-buncher (Tigercat 2013).**

| | |
|---|---|
| | Cummins 260 hp Tier 4 |
| | 26 ft 5 in |
| | 28 in |
| **Total width** | 129 in |
| **Total length w/o boom** | 193 in |
| | 57,100 lb |

## Results

### Study Sites

Cruise data from each site are summarized in Table 2 and reflect trees per acre and whole-tree green tons per acre for loblolly pine. The plantation stand had a very small component of sweetgum and oak in the 4 and 5-inch diameter classes that totaled only 3 trees per acre. The natural stand had a larger component of hardwood which totaled 28 trees per acre in the 4 to 9-inch diameter classes. Quadratic mean diameter for pine trees in the 4-inch and larger diameter classes was 6.0 inches for the plantation stand and 8.7 inches for the natural stand.

Fifty percent of the trees in the plantation stand were in the 5 and 6-inch Dbh classes. The largest Dbh class represented in the plantation was the 10-inch class which contained less than one percent of the total trees per acre. As a comparison, 25 percent of the total trees per acre in the natural stand were in the 5 and 6-inch Dbh classes while almost 9 percent were in 13 to 19-inch Dbh classes.

**Table 2. Stand table for the plantation and natural stands.**

| **Dbh class** | **Trees/acre** | | **Green tons/acre** | |
|---|---|---|---|---|
| **(in)** | **Planted** | **Natural** | **Planted** | **Natural** |
| 4 | 93 | 29 | 7.3 | 2.3 |
| 5 | 125 | 46 | 15.2 | 5.7 |
| 6 | 162 | 37 | 27.3 | 6.5 |
| 7 | 125 | 43 | 27.7 | 10.7 |
| 8 | 50 | 38 | 14.4 | 12.5 |
| 9 | 14 | 32 | 5.1 | 13.3 |
| 10 | 4 | 30 | 1.9 | 15.5 |
| 11 | | 25 | | 15.9 |
| 12 | | 19 | | 14.0 |
| >12 | | 29 | | 60.4 |
| **Total** | **573** | **328** | **98.9** | **156.8** |

### Felling

The Tigercat 845D feller-buncher was observed while felling 712 trees (348 trees in the plantation and 364 trees in the natural stand). Of the 364 trees felled in the natural stand only 6.3 percent were hardwoods. Trees felled in the plantation ranged in Dbh from 2.6 inches to 10.0 inches, while trees felled in the natural stand ranged from 2.3 inches to 19.2 inches in Dbh.

Total cycle time was modeled using a General Linear Models Procedure in SAS (Statistical Analysis Software, 2011). The number of trees felled per cycle ($p<.00001$) and mean Dbh of trees felled per cycle ($p=0.0003$) were both significant independent variables for predicting total cycle time. Stand type (natural or plantation) was also tested but was not significant ($p=0.8766$), therefore, observations from both sites were combined.

An ANOVA (Analysis of Variance) for total cycle time is summarized in Table 3. The model had a sample size of 93, an $R^2 = 0.79$ and a coefficient of variation of 13.85. The equation for predicting total cycle time for the feller-buncher is listed below and is shown in Figure 1 along with a plot of measured time study data.

*Total cycle time (sec) = 7.883603*Trees + 1.713463*MDbh – 1.181092*

where: Trees = number of tree cut per cycle
MDBH = mean Dbh of trees cut per cycle

**Table 3. Analysis of Variance for total cycle time.**

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 2 | 29419.43896 | 14709.71948 | 172.05 | <.0001 |
| Error | 90 | 7694.91911 | 85.49910 | | |
| Corrected Total | 92 | 37114.35806 | | | |

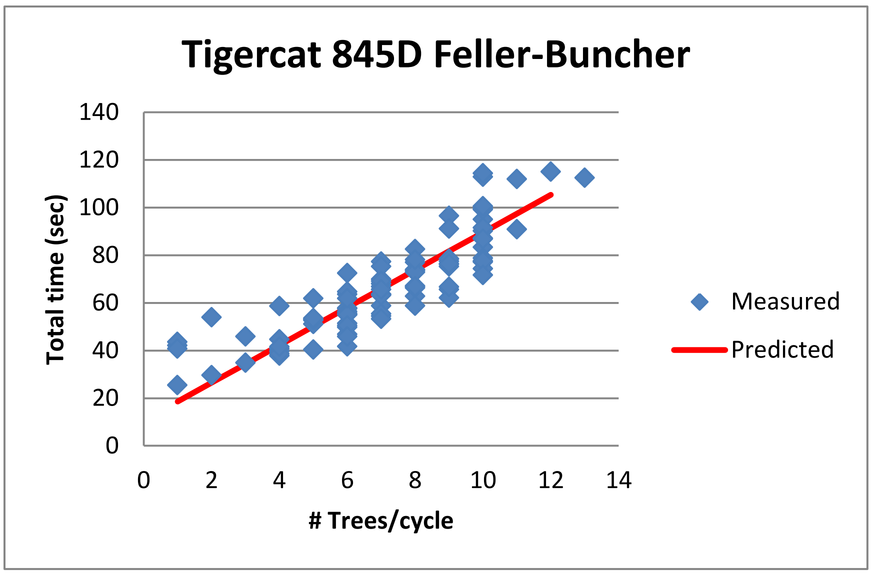


**Figure 1. Plot of time study data and regression equation for the feller-buncher.**

At the beginning of a cycle, which started after trees were dumped from the head, the feller-buncher was able to reach the first tree of a cycle 52 percent of the time without moving. In addition, the feller-buncher was required to move an average of 1.5 times during a cycle to reach additional trees to shear, with 41 percent of cycles with no moves between trees. The feller-buncher was required to move to dump only two percent of the time. A summary of time study data for the feller-buncher is shown in Table 4.

**Table 4. Performance summary of the Tigercat 845D feller-buncher.**

| Variable | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Move to 1st tree (sec) | 45 | 8.4 | 4.77 | 3.0 | 29.1 |
| Accumulate (sec) | 93 | 52.2 | 16.65 | 13.3 | 92.0 |
| Move between trees (sec) | 56 | 8.2 | 6.85 | 2.0 | 42.5 |
| Move to dump (sec) | 2 | 8.5 | 6.86 | 3.6 | 13.3 |
| Dump (sec) | 93 | 8.2 | 2.35 | 4.1 | 16.2 |
| Total time (sec) | 93 | 66.8 | 20.08 | 25.3 | 115.0 |
| Trees/cycle | 93 | 7.1 | 2.60 | 1.0 | 13.0 |
| Trees/min | 93 | 6.3 | 1.45 | 1.4 | 8.7 |
| Moves/cycle | 93 | 1.5 | 1.36 | 0.0 | 7.0 |

Although total cycle time was not significantly different between the plantation and natural stands, there was a difference in mean tree size which resulted in a higher productivity in the natural stand. Mean tree size for the plantation was 0.19 tons per tree, which resulted in a mean of 1.51 green tons per cycle and a mean productivity of 77.9 green tons per PMH. The natural stand averaged 0.49 tons per tree, which resulted in a mean of 1.88 green tons per cycle and a mean productivity of 118.7 green tons per PMH. Figure 2 shows the distribution of the number of trees felled in each 2-inch Dbh class for both stand types.

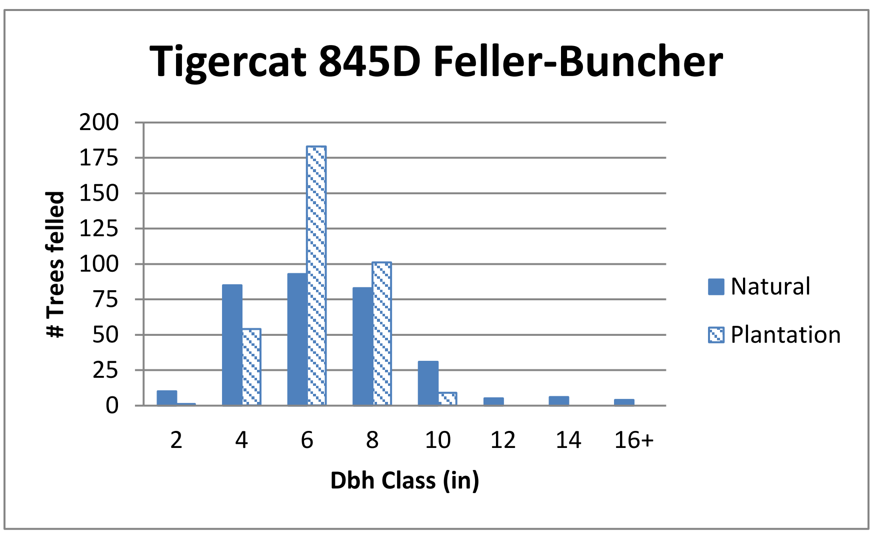


**Figure 2. Number of trees felled by diameter class for the feller-buncher.**

Fuel consumption was monitored using the machine's electronic fuel monitoring system while operating in the plantation study area. During this time the 260-hp feller-buncher consumed fuel at a rate of 6.5 gal per hour (0.025 gal per hp-hr). On a per unit basis the feller-buncher consumed 0.0972 gal per green ton felled, which resulted in a total of 10.29 green tons produced per gallon of fuel used.

## Conclusions

The Tigercat 845D tracked feller-buncher averaged 66.8 seconds per cycle with a mean accumulation size per cycle of 7.1 trees. The number of trees and the mean Dbh of trees felled per cycle were both significant independent variables for predicting total cycle time. Production rates reached 77.9 green tons per PMH in the plantation for a mean tree size of 0.19 green tons and 118.7 green tons per PMH in the natural stand for a mean tree size of 0.49 green tons.

The feller-buncher was evaluated in stands which consisted of larger trees and lower densities as compared to the proposed energy plantation stands (1000 to 1200 TPA). Mean Dbh of accumulated trees in the plantation was 6.2 inches. Assuming a higher density stand with a mean Dbh of 5 inches and 12 trees per accumulation would result in a predicted total cycle time of 102 seconds. From tree weight data collected in the area a 5-inch Dbh plantation tree would weigh around 208 lbs., resulting in a productivity of 44 green tons per PMH. At this production rate a system could potentially require at least two feller-bunchers to provide enough wood for sufficient utilization of the large capacity Tigercat 630D grapple skidder.

This study demonstrated that the feller-buncher is capable of operating productively in different stand types over a range of tree sizes. With the tracked machine less frequent travel within stands was required which resulted in less ground disturbance. Evaluation of machine performance in higher density stands with a smaller tree size would be beneficial since this would be more representative of the type of stands the feller-buncher would operate in for biomass harvesting.

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