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COMPARISON OF FOUR HARVESTING SYSTEMS IN A LOBLOLLY PINE PLANTATION

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Abstract

Felling and skidding operations were monitored while clearcut harvesting a 12-acre area of a 14-year old loblolly pine (*Pinus taeda*) plantation. The study area contained 465 trees per acre for trees 2.0 inches Diameter at Breast Height (DBH) and larger with a Quadratic Mean Diameter (QMD) of 7.26 inches. Two feller-bunchers (tracked and rubber-tired) and two skidders (conventional and large capacity) were paired to create four different harvesting systems which were randomly assigned to 3-acre units for evaluation of production rates and costs. Each system was balanced to determine the number of machines needed to minimize the cost of producing each ton of wood. Cost from woods to landing ranged from $1.92/ton to $3.16/ton. The two systems that incorporated the large capacity skidder performed better, and at a lower cost per ton, than the systems that used the conventional skidder.

Keywords: Productivity, Cost, Felling, Skidding, Biomass Harvesting

Introduction

Forests of the southeastern US accounted for 63% of the total timber volume harvested in the US in 2011 (Oswalt et al., 2014). Similarly, primary wood-processing plants in the South produced 45% of the saw-log products; 63% of veneer products; 74% of the pulpwood, and 64% of all composite products in 2011 (Oswalt et al., 2014). Major products that are produced from this resource include lumber, plywood, pulp and paper, pellets, Oriented Strand Board (OSB), Medium Density Fiberboard (MDF), and High Density Fiberboard (HDF). Getting this resource from the stump to a mill or processing facility basically involves four steps: felling, skidding, loading/chipping, and transporting. Of course, each step has a cost associated with it, so efficient harvest systems are important for minimizing these costs.

Although growing volumes are continuously increasing for the South, so is the harvest volume, which results in greater demand on the resource and leads to trees being harvested earlier at a smaller size (Stokes and Klepac,1998). Harvesting and handling these smaller size trees results in lower system productivity and higher costs. As demand for bioenergy and bio-products grows, so does the interest in harvesting smaller and smaller diameter stems. Research is needed to continue to explore the impact of small diameter stems on harvesting costs.

In response to the interest in harvesting small diameter stems, Rummer et al. (2010) proposed a pine energywood system that could be established with 1,000 trees per acre and harvested at age 12. When felling trees for energywood. Watson and Stokes (1989) reported the cost of felling is significantly reduced when the feller-buncher does not need to move around standing trees. Rummer et al. (2010) proposed that felling a pine energywood stand would be optimized using clearcut harvesting and a swing-to-tree machine that can access multiple rows with less trafficking than a traditional drive-to-tree feller-buncher. Move-to-tree time would be dependent on swing performance rather than driving performance which may be more efficient in small evenly-spaced trees.

The focus of this study was to evaluate and compare the performance and cost of four harvesting systems while operating in a young loblolly pine (*Pinus taeda*) plantation. This study provided a unique opportunity to pair different machines (feller-bunchers and skidders) to create four different harvest systems for comparing production rates and costs when harvesting young, small diameter material. The four systems evaluated included: (1) a tracked feller-buncher with a conventional skidder (TFB/CS); (2) a rubber-tired feller-buncher with a large capacity skidder (RTFB/LS); (3) a tracked feller-buncher with a large capacity skidder (TFB/LS), and (4) a rubber-tired feller-buncher with a conventional skidder (RTFB/CS).

Literature Review

Time and motion studies are often used in analyzing harvesting systems. The purpose of a time and motion study is to break the individual machine movements into elements. By analyzing the amount of time a machine operator takes to perform an element, researchers can delve deeper into machine comparisons or identify elements to examine for efficiency improvements. A range of harvest functions have been studied to determine productivity while harvesting planted southern pine (Cubbage, 1983).

A variety of factors have been found to impact productivity of feller-bunchers. Ashmore et al. (1983) determined that feller-buncher elements were affected by DBH, brush conditions, the number of trees per cycle, and stand density. Wang and Greene (1997) concluded that felling productivity was affected by mean DBH removed, harvest intensity, and harvest method. Visser and Stampfer (2003) found that felling productivity was dependent on piece size and the number of trees per bunch.

Rubber-tired grapple skidders are the most common machine used in the southeastern US for transporting trees from woods to landing. Skidder productivity is dependent on a variety of factors. Greene and Stokes (1988) observed that skidder productivity was mainly dependent on skid distance. Visser and Stampfer (2003) determined that turn volume and extraction distance had the most significant effect on skidder productivity.

A wide range of harvesting systems operates in the US because of diversity of conditions (Stokes, 1992). Typically in the southeastern US, harvesting is accomplished using drive-to-tree feller-bunchers that utilize circular sawheads and rubber-tired grapple skidders. These machines perform well for most ground conditions encountered in the South. There are a limited number of studies that document production rates and costs of using this type of traditional equipment to harvest small diameter timber. A production rate of 48.8 merchantable green tons/Productive Machine Hour (gt/PMH) was observed for a drive-to-tree feller buncher performing a clearcut operation in a loblolly pine plantation with an average tree size of 7.1 inches (Klepac, 2001). A rubber-tired grapple skidder operating in a clearcut of a loblolly pine plantation with an average tree size of 6.2 inches achieved a productivity of 45.8 gt/PMH (Klepac and Rummer, 2000). The bioenergy and bio-products industries often do not want to compete against traditional forest products markets for raw material, so interest in harvesting even smaller stems grows. If smaller trees are to be used for fuel to replace oil, the price of oil must exceed the breakeven price for a system to be feasible (Hartsough and Stokes, 1990).

Harvesting small-diameter pine as a source for bioenergy could encourage the practice of clearcut harvesting stands at ages where first thinnings are typically implemented (Doruska and Nolen, 1999). Pine plantations in the southeastern US are commonly managed for harvest with a first thinning to remove pulpwood, and in many cases followed by a second thinning several years later. Larger diameter, higher value products are then harvested during the clearcut harvest at the end of the rotation.

Smidt and McDaniel (2012) evaluated thinning a 12-year old loblolly pine stand in south Alabama in terms of productivity and costs of harvesting roundwood, chipping whole-tree, and producing clean chips. Analysis showed that a two feller-buncher and one skidder system was the most cost effective. However, whole-tree chipping of this material could not compete economically with the other two methods described. Conrad et al. (2013) evaluated three harvest treatments using clearcut harvests in 22 and 26-year old stands. Treatments included a conventional roundwood harvest, an integrated harvest (roundwood with chipping of residues), and a chip harvest. Results showed that harvesting energywood reduced system productivity, thereby increasing costs as compared to the conventional roundwood harvest. The integrated chip treatment had a significant negative impact on skidding cost ($10.89/ton) as compared to the other treatments, which ranged from $2.74/ton to $3.79/ton for skidding. Baker et al. (2010) investigated a mechanized, tree-length harvesting system in a 28-year old clearcut, a 33-year old clearcut, and a 16-year old thinning. The addition of a small chipper to produce biomass chips from non-merchantable material was studied and found to have the most benefit operating in clearcut harvests as opposed to thinnings.

Literature shows that piece size significantly affects the performance of feller-bunchers and skidders. Handling of small-diameter material by these machines has a negative impact on productivity, which results in increased harvest costs. Implementing clearcut harvests enhances machine performance, but it is typically utilized in older stands consisting of larger diameter trees. The stand examined in this paper was a young, 14-year old pine plantation where trees averaged 7.26 inches in diameter.

Methods

Operation

Felling was accomplished using either a Tigercat 845D[1] tracked swing-to-tree feller-buncher or a TimberKing 340 rubber-tired drive-to-tree feller-buncher. The Tigercat 845D utilized a shear head and was powered by a 260-hp Tier 4 engine with a boom reach of 26.5 feet and was approximately two years old. The shear head was unique in that is was optimized for small diameter stem handling with a larger accumulation pocket and a faster open/close shear cycle. This machine is referenced in this paper as the tracked feller-buncher, or TFB. The TimberKing 340 was equipped with a 175-hp engine, a circular sawhead, and was approximately seven years old. This machine is referenced in this paper as the rubber-tired feller-buncher, or RTFB.

Trees were skidded whole-tree using either a Tigercat 630D rubber-tired grapple skidder or a Caterpillar 525B rubber-tired grapple skidder. The Tigercat 630D referenced in this paper as the large capacity skidder, or LS, was powered by a 260-hp engine and utilized a large, 25 ft^2 grapple (Taylor et al., 2014). The machine was mounted on Firestone Forestry Special DH 35.5L-B32 tires and was approximately three years old. In addition to the large grapple on the Tigercat 630D, another unique feature included Tigercat's TURNaround^{TM} system that featured a two-position rotating seat. This rotating seat was equipped with all machine controls on the seat arms, which allowed the operator to comfortably back up the machine while facing rearward (Taylor et al., 2014). The Caterpillar 525B was powered by a Cat 3126 DITA 160-hp diesel engine and utilized a traditional 12.5 ft^2 bunching capacity grapple and was mounted on 30.5L x 32 Firestone tires. This machine is referenced in this paper as the conventional skidder, or CS. At the landing, a Tigercat 240 tracked loader processed trees into longwood using a Chambers Delimbinator and loaded them onto trailers.

Study Site

The study site was a 14-year old loblolly pine plantation located in Crenshaw County, Alabama. The study area consisted of approximately 12 acres of a 52-acre tract. The study area contained 465 trees per acre for trees measuring a minimum of 2.0 inches Diameter at Breast Height (DBH) with a Quadratic Mean Diameter (QMD) of 7.26 inches. Soil type consisted of an Arundel-Halso, which are gently sloping to moderately steep, well drained soils and deep, moderately well drained soils that have a loamy surface layer and a clayey subsoil (Mason, 2007).

A line-plot cruise (1/10 acre plots) over the 52-acre tract was used to determine stand density and volume per acre. A 12-acre contiguous area on the south side of the tract was divided into four units which measured approximately 3 acres each. This area was selected due to similar stand composition and tree size as revealed from cruise data. The web tool ArcGIS Explorer Online (http://www.arcgis.com/explorer) was used to locate waypoints and create boundaries for the four harvesting units. These waypoints were entered into a Garmin GPSmap 62s handheld device and located on the ground. Unit boundaries were identified using flagging. Harvesting treatments were randomly assigned to each unit without replication (Figure 1).

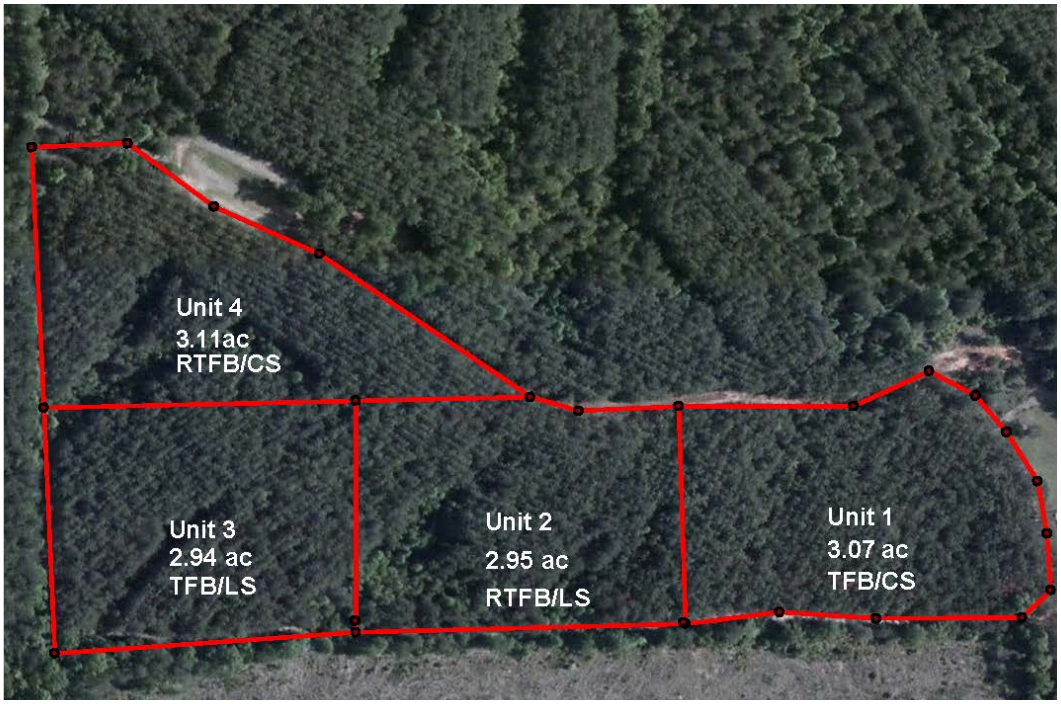

Figure 1. Layout of Unit Areas and Treatments

Felling

Within each unit, a felling plot was installed and every tree within the plot was color coded with paint based on 1-inch Diameter at Breast Height (DBH) classes so that trees could be identified by size as they were being cut. Only trees 3.6 inches DBH and larger were marked with paint. Feller-bunchers were recorded on digital video as they worked through each plot and the color code of each tree was recorded both visually and audibly on the video.

Each feller-buncher had its own experienced operator throughout the study. Operators worked within each marked felling plot and placed trees in bunches for skidding. Bunch size was determined by skidder assignment, so operators built large bunches for the large capacity skidder and smaller bunches for the conventional skidder. Each bunch containing trees from within the felling plot was numbered so the size of each tree within a bunch would be known for calculating green tons per bunch. For bunches that contained trees from within the unit but were outside of the felling plot, a stem count was made and bunches numbered consecutively. Tree weights were calculated using a regression equation developed from trees from the study site and other tree measurements from nearby counties. Sampled trees were felled, measured for DBH, height to a 2-inch top, and total height. Whole-tree weights, in addition to total stem and weight to a 2-inch top, were obtained using a field scale. For trees in the 11-inch class and larger weights were calculated using an equation for planted pine in the Southeast (Clark and Saucier, 1990).

Video of the feller-bunchers was reviewed and analyzed using the time and motion study analysis software program TimerPro (Applied Computer Services, 2014). Elements for the Tigercat 845D feller-buncher included move-to-first tree, accumulate, move between trees, move-to-dump, and dump. A complete felling cycle was the time it took for the TFB to move-to-first tree through the time it took to dump. For the TimberKing 340 elements included move-to-first-tree, accumulate, move-to-dump, and dump. A felling cycle for the RTFB began with the move-to-first tree and ended when the dump element was completed.

Move-to-first tree included travel time from the point where trees were dumped from the head to the first tree to be cut in a cycle. The element started at the end of dumping and ended when the sawhead made contact with the tree or the machine stopped moving.

Accumulate was the time required to cut and gather trees into the head. For the Tigercat 845D this included reaching to and cutting trees, including extending the boom to the first tree of a cycle. For the TimberKing 340, accumulate time included traveling to trees, intermediate travel between trees, and cutting. The element for both machines started when the boom or head reached the first tree and ended when the last tree was cut.

Move between trees was associated with the Tigercat 845D and included time required to travel during a cycle to reach additional trees to cut. The element began after a tree was cut during accumulating and the tracks started moving and ended when the tracks stopped.

Move-to-dump was the time required to travel to the location where trees were being placed to create a bunch. The element began when the last tree in a cycle was cut and the tracks or tires started moving and ended when the tracks or tires stopped.

Dump was the time required to release trees accumulated in the head onto the ground or bunch being built. For the Tigercat 845D the element began when the last tree was cut and rotation of the cab toward the dumping location began and ended when all trees were out of the head. For the TimberKing 340 the element began with forward rotation of the head and ended when all trees were released from the head.

Skidding

An elemental time and motion study was performed on each skidder using stopwatches as they worked in each assigned study unit. Individual cycle elements during a skidding cycle are long enough that the time and motion information can be adequately collected in the field using a split timer stop watch with 1/1000 minute graduations. Machine elements evaluated included landing empty, travel empty, position, grapple, intermediate travel, travel loaded, landing loaded, and ungrapple. Total weight of bunches built from trees cut from felling plots was determined using felling data. Bunches created from unmarked trees within a unit, but outside the felling plot, were estimated using a stem count and an average tree weight of 520 lbs.

The landing empty element included travel across the landing to a common point at the landing boundary after ungrappling a load. The element started at the end of ungrappling and ended when the skidder reached the intersection of the landing boundary and the primary skid trail.

Travel empty included travel to the woods to obtain a load and included all travel after landing empty to the point in the woods where the skidder made its initial stop. The element began at the end of landing empty and ended when the skidder stopped to prepare for positioning.

Position time included travel while the skidder backed up to grapple a bunch. The element began at the end of travel empty and ended when the skidder stopped at a bunch to prepare for grappling. Occasionally, this element did not occur with the Tigercat 630D, since it sometimes traveled to the woods grapple first and stopped at a bunch.

Grapple time included lowering the grapple, closing the grapple around a bunch, and lifting the grappled bunch in preparation for travel to another bunch location or to the landing. The element began at the end of positioning, or in some cases with the Tigercat 630D, at the end of travel empty, and ended when the load was secured in the grapple and forward travel began.

Intermediate travel included travel between bunches when the skidder picked up more than one bunch for a load. The element began at the end of the grapple element and ended when the skidder stopped to prepare to grapple an additional bunch.

Travel loaded included travel from the woods once the skidder obtained a full load to the landing boundary. The element began at the end of the grapple element once a full load was obtained and ended at the intersection of the primary skid trail and the landing boundary.

Landing loaded included travel from the landing boundary across the landing to the point where the load was dropped near the loader. The element began at the end of travel loaded and ended when the skidder stopped to prepare to ungrapple.

Ungrapple included the time required to drop the load on the landing near the loader. The element started at the end of landing loaded and ended when the load was dropped and the skidder began landing empty travel.

A Garmin GPSmap 62s was mounted in each skidder during the time study period to obtain skid distances. Distances obtained included landing empty travel, travel empty, intermediate travel, travel loaded and landing loaded.

System Productivity and Costs

A machine rate is a method used to compare costs associated with different machines. It does not include all of the costs associated with operating equipment, such as profit, loss, or risk. Productivity and costs for each of the four systems was determined using the machine rate method (Miyata, 1980). Some costs are based on a Scheduled Machine Hour (SMH) basis, which are the number of hours that a machine is scheduled to work in a year. Other costs are reported on a Productive Machine Hour (PMH) basis, which are the hours that a machine actually performs work. When a machine breaks down, or is receiving scheduled maintenance, it is not performing work. Some costs, such as fuel, are typically incurred only when the machine is performing work. This type of cost is a variable cost and is reported on a PMH basis. The ratio of PMH to SMH is the utilization rate and reflects the percentage of scheduled time that the machine actually performs work.

General assumptions used for machine rate calculations included 2000 SMH/yr, a 10% interest rate, $1.85/gal off-road diesel fuel cost, and 85% utilization rate. Fixed costs were based on the purchase price of a new machine, 1% insurance rate, 0.1% property tax rate, a 5-year life, and salvage values of 20% for the rubber-tired feller-buncher, 50% for the tracked feller-buncher, and 25% for the skidders (Brinker et al., 2002). Variable costs were based on horsepower, a fuel consumption rate of 0.028 gal/hp-hr, a lube cost equivalent to 36.8% of fuel cost, and a repair and maintenance cost equivalent to 90% of depreciation for all machines except the rubber-tired feller-buncher, which was based on 100% of depreciation (Brinker et al., 2002). For the rubber-tired feller-buncher and conventional skidder a replacement cost of $12,000 for tires was included. For the tracked feller-buncher a replacement cost of $3000 for tracks was used; and a tire cost of $22,000 was used for the large skidder. A tire/track life of 4000 hours was assumed for all machines. A cost of $1,000/set for saw teeth with a 425 hour life and an $8,500 disk cost with a 5,100 hour life were used for the rubber-tired feller-buncher. A labor cost of $15.00/SMH plus 30% benefits was assumed (Brinker et al., 2002).

Statistical Analysis

To test for significant differences in total cycle times between plots by machine, Duncan’s Multiple Range Test ($\alpha=0.05$) was performed using SAS (2011). Duncan’s Multiple Range Test (SAS, 2011) was used to test for significant differences in standardized cycle time and standardized productivity for skidding among the four systems.

Results and Discussion

Felling

As the feller-bunchers severed stems, they accumulated multiple stems in the ‘pockets’ of the cutting heads before they began the move-to-dump cycle element. Depending on which machines were paired for the tested systems, two or more accumulations were needed to build a bunch. Each complete cycle (from move-to-first tree to dump) resulted in a single observation. The Tigercat 845D feller-buncher cut 575 trees which resulted in a total of 72 observations while building bunches for the conventional skidder (TFB/CS system). The Tigercat 845D feller-buncher cut 387 trees, which resulted in a total of 52 observations while building bunches for the large skidder (TFB/LS system). The TimberKing 340 feller-buncher cut 385 trees, which resulted in a total of 85 observations while building bunches for the large skidder (RTFB/LS system). The TimberKing 340 feller-buncher cut 343 trees, which resulted in 101 observations while building bunches for the conventional skidder (RTFB/CS system).

The Tigercat 845D accumulated approximately 7.35 stems per accumulation and the accumulation size was not significantly affected by skidder pairing. The TimberKing 340 operator accumulated 45% more stems per accumulation when building bunches for the large capacity skidder as compared to building bunches for the conventional skidder. Felling plots were designed to have a similar size distribution, so this difference in trees per accumulation is probably an operator effect rather than a pairing effect.

For the Tigercat 845D feller-buncher, there was no significant difference in mean total cycle time between building conventional size bunches (61.0 sec) and building large size bunches (59.6 sec). There was a significant difference in mean total cycle time for the TimberKing 340 feller-buncher between building conventional size bunches (41.9 sec) and large size bunches (46.8 sec). Mean elemental times for both feller-bunchers are summarized in Table 1.

Table 1. Comparison of Mean Time per Cycle Elements and Production Variables between a Rubber-Tired Feller-Buncher with a Sawhead (TimberKing 340) and a Tracked Feller-Buncher with a Shear (Tigercat 845D).

	TimberKing 340		**Tigercat 845D**	
Variable	**Conventional (smaller) bunches**	**Large bunches**	**Conventional (smaller) bunches**	**Large bunches**
Move to 1st tree (sec)	9.5	8.8	7.5	7.0
Accumulate (sec)	17.9[c]	24.1[b]	48.8[a]	47.5[a]
Move to dump (sec)	12.5	11.5	4.2	11.1
Dump (sec)	2.4	2.6	8.4	8.4
Total time (sec)	41.9[c]	46.8[b]	61.0[a]	59.6[a]
DBH/cycle (in)	6.9	6.7	6.5	6.9
Trees/cycle	3.4[c]	4.5[b]	7.5[a]	7.2[a]
Green tons/cycle	0.84	1.1	1.55	1.80
Green tons/hr	79.9[c]	89.2[bc]	94.6[b]	112.8[a]
Trees/bunch	14.3[c]	25.7[a]	16.9[bc]	19.7[b]
Accumulations/bunch	4.2[b]	5.7[a]	2.3[c]	2.7[c]

*Means with the same letter within a row are not significantly different ($\alpha=0.05$)

Comparing total cycle time between the two feller-bunchers revealed there was a significant difference between the two machines. The large accumulation pocket on the Tigercat 845D contributed to the longer total cycle times and more time spent in the accumulate cycle element.

The Tigercat 845D accumulated 2.2 times more trees per cycle, on average, than the TimberKing 340, which translated into 1.8 times more tons per cycle while building conventional bunches. On the contrary, the Tigercat 845D accumulated 1.6 times more trees per cycle, on average, compared to the TimberKing 340, which translated into 1.6 times more tons per cycle while building large bunches. This resulted in higher production rates observed for the Tigercat 845D feller-buncher.

The majority of cycle time for both machines was spent accumulating and moving between trees. For the Tigercat 845D, the time spent moving between trees was initially separated during the time and motion analysis. However, for the TimberKing 340, the move time between trees was a very short time. As a result of the latter, both motion accumulation times were combined. This made it easier to compare this element between the two machines. Duncan’s test showed there were significant differences ($\alpha=0.05$) in mean accumulation time between each machine. The statistical test also indicated that there was a significant difference ($\alpha=0.05$) in the accumulate cycle time for the TimberKing 340 to build each of the bunch sizes, but bunch size was not significant for accumulate cycle time for the Tigercat 845D. The Tigercat 845D averaged 48.8 sec while building conventional bunches compared to 17.9 sec for the TimberKing 340. The Tigercat 845D averaged 47.5 sec while building large bunches compared to 24.1 sec for the TimberKing 340 (Table 1).

Skidding

For the Tigercat 630D grapple skidder, a total of 33 observations were collected while skidding bunches built by the TimberKing 340, and a total of 37 observations were collected while skidding bunches built by the Tigercat 845D. Correspondingly, for the CAT 525B grapple skidder, a total of 37 observations were collected while skidding bunches built by the TimberKing 340, and a total of 32 observations were collected while skidding bunches built by the Tigercat 845D.

The unique rotating seat ergonomics on the Tigercat 630D may have contributed to faster position and grapple time. The time that it took for the Tigercat 630D to position and grapple was nearly half of the time that it took for the CAT 525B to perform the same functions.

Travel distances from the landing to each unit varied significantly. Both minimum and maximum total travel distance were observed for the CAT 525B skidder. A minimum total travel distance (woods plus landing) of 523 feet was observed while operating in unit 4, while a maximum of 2325 feet was observed while operating in unit 1.

To account for differences in travel distances and unit shapes, a standardized one-way distance of 685 feet (woods plus landing travel) was used for comparison of cycle times and production rates. Standardized cycle times were calculated based on travel speeds observed for each skidder and the standardized one-way distance. Time spent by each skidder operating within units positioning, grappling, and traveling between bunches (intermediate travel) were not adjusted since they represent the actual performance of each skidder and is independent of travel distance to the landing.

A summary of non-standardized time study variables is shown in Table 2 to provide actual observed performance of each skidder at the various distances from the landing and to illustrate the importance of using standardized times and distances for comparison purposes. Travel empty and travel loaded times were combined into woods travel time. Landing empty and landing loaded times were combined into landing travel time.

Using standardized productivities, the conventional CAT 525B grapple skidder averaged 72 gt/PMH while skidding bunches built by the Tigercat 845D, and averaged 1.1 bunches per cycle with a maximum of two bunches. The conventional skidder averaged 19.6 stems per cycle with a maximum of 32 stems. The large capacity grapple skidder averaged 141 gt/PMH while skidding bunches built by the TimberKing 340, and averaged 1.1 bunches per cycle with a maximum of two bunches. The skidder averaged 25.2 stems per cycle with a maximum of 43 stems. The large capacity grapple skidder averaged 128 gt/PMH while skidding bunches built by the Tigercat 845D, and averaged 1.2 bunches per cycle with a maximum of two bunches. The skidder averaged 27.2 stems per cycle with a maximum of 42 stems. The grapple skidder averaged 48 gt/PMH while skidding bunches built by the TimberKing 340, and averaged 1.1 bunches per cycle with a maximum of two bunches. The skidder averaged 19.6 stems per cycle with a maximum of 21 stems.

Table 2. Comparison of Mean Time per Cycle Elements and Production Variables between a Traditional Rubber-Tired Grapple Skidder (CAT 525B) and a Large Capacity Rubber-Tired Grapple Skidder (Tigercat 630D), as Observed, without Travel Distance Standardization.

	Means for Systems			
	CAT 525B		**Tigercat 630D**	
Variable	**RTFB**[1]	**TFB**[2]	**RTFB**	**TFB**
Woods travel (min)	1.54	3.32	1.83	2.32
Position & grapple (min)	0.62	0.79	0.33	0.40
Intermediate travel (min)	-	0.38	0.43	0.31
Landing travel (min)	0.65	0.37	0.40	0.44
Ungrapple (min)	0.14	0.11	0.15	0.17
Total time (min)	2.96	4.74	2.74	3.40
Bunches/cycle	1.0	1.1	1.1	1.2
Stems/cycle	14.3	19.6	25.2	27.2
Green tons/cycle	3.6	4.2	6.6	7.5
Productivity (green tons/PMH[3])	77.8	54.2	147.0	134.6
Woods travel distance (ft)	593	1825	1102	1145
Intermediate travel distance (ft)	-	124	126	113
Landing travel distance (ft)	197	168	187	168
Woods speed (mph)	4.4	6.3	6.9	5.6
Landing speed (mph)	3.7	5.1	5.5	4.3

[1] Rubber-Tired Feller-Buncher, TimberKing 340
[2] Tracked Feller-Buncher, Tigercat 630D
[3] Productive Machine Hour (PMH)

Total cycle times for the two skidders were not significantly different (α=0.05) when paired with the Tigercat 845D. However, there were significant differences in production rates among all skidder configurations, with the large skidder systems having the highest production rates and the conventional skidder systems having the lowest rates (Table 3).

Table 3. Comparison of Mean Cycle Times and Production Rates by System with Standardized Skid Distances.

	Standardized	
Skidder/Feller-Buncher	**Cycle time (min)**	**Production Rate (gt/PMH)**
Tigercat 630D/TimberKing 340	2.82[c]	141.2[a]
Tigercat 630D/Tigercat 845D	3.52[b]	127.9[b]
CAT 525B/Tigercat 845D	3.58[b]	71.8[c]
CAT 525B/TimberKing 340	4.62[a]	47.5[d]

*Means with the same letter within a column are not significantly different (α=0.05)

System Productivity and Cost

A machine rate analysis was performed for each machine studied. Productive machine hours were observed during the field study, and a utilization rate of 85% was applied to both machine types to calculate production in green tons/Scheduled Machine Hour (SMH). Production rates and costs for each of the four systems were then developed (Table 4). These costs are from woods to landing and do not include loading, transportation, profit, overhead, risk, or consideration of after-tax effects. When one machine in a system is substantially more productive than another, a system balance analysis is performed to determine how many of each machine is needed to balance production rates. The goal in balancing the systems was to maximize system production, not individual machine production, while minimizing cost.

Table 4. Production Rates and Costs for Four Tested Harvest Systems.

Harvest System	No. of Machines[2]	All (tons/SMH[1])	System (tons/SMH)	($/SMH)	($/ton)
Tigercat 845D	1	80.4	61.0	172.20	2.82
CAT 525B	1	61.0			
TimberKing 340	3	227.46	227.46	436.74	1.92
Tigercat 630D	2	240.04			
Tigercat 845D	1	95.9	95.9	198.21	2.07
Tigercat 630D	1	108.7			
TimberKing 340	2	135.83	121.13	383.01	3.16
CAT 525B	3	121.13			

[1] Scheduled Machine Hour (SMH).

[2] Number of machines required to balance a system to improve individual machine utilization.

Table 4 displays the results of the system balance and machine rate calculations for each of the tested harvesting systems. The conventional system (RTFB/CS) required two feller-bunchers and three skidders to balance the system and had the highest cost, $3.16/gt. Achieving a balanced system using the TFB/CS pairing required just one of each machine type, but at a cost of $2.82/gt. Balanced systems that used the large capacity skidder had the lowest overall system costs. The RTFB/LS and TFB/LS systems both had the lowest cost per ton at $1.92 and $2.07, respectively. However, the RTFB/LS system required three feller-bunchers and two skidders to balance the system, compared to one feller-buncher and one skidder for the TFB/LS system.

The systems that used the TimberKing 340 required multiple machines to reach a system balance for productivity. However, the systems that employed the Tigercat 845D balanced production by using just one of either type of skidder. In terms of cost, the least expensive system, on a cost/ton basis, was the system that incorporated the TimberKing 340 rubber-tired feller buncher and the Tigercat 630D large grapple skidder (RTFB/LS). However, this system required five machines to reach this low cost. Alternatively, the Tigercat 845D paired with the Tigercat 630D (TFB/LS) was the next lowest cost system and only required one of each machine type. Although the RTFB/LS system had the lowest cost per ton, a balanced system would require an additional $509,000 capital investment than the TFB/LS system.

Conclusion

Four machines were paired into four systems to compare production rates and costs while harvesting stems from a 12-year old pine plantation. Machines consisted of a conventional rubber-tired feller-buncher; a tracked feller buncher; a conventional grapple skidder, and a large capacity grapple skidder. The feller-bunchers operated differently based on the skidder pairing. Feller-buncher production rates were higher when building larger bunches for the large capacity grapple skidder. When the feller-bunchers were paired with the CAT 525B conventional skidder, smaller bunches were built and production rates were negatively affected.

Total cycle times for the two skidders were not significantly different (α=0.05) when paired with the Tigercat 845D tracked feller-buncher. However, paired systems that employed the conventional CAT 525B skidder resulted in lower production rates than those pairings that used the large capacity Tigercat 630D grapple skidder. The unique rotating seat ergonomics on the Tigercat 630D may have contributed to some of the production difference as it had a faster observed position and grapple time than the CAT 525B conventional skidder.

Balanced systems that used the large capacity skidder had the lowest overall system costs. The systems that employed the CAT 525B conventional skidder had the highest cost/ton of the four systems tested. Systems that included the Tigercat 630D large grapple skidder had the lowest cost/ton. While the system that employed the TimberKing 340 feller-buncher had the lowest cost, it also required five machines to balance the system and an additional capital investment of $509,000. The Tigercat 845D paired with the Tigercat 630D resulted in a system that balanced with just one of each machine type at a cost/ton of $0.15/ton more than the five machine RTFB/LS system.

The results of this study indicate that machine selection can impact the costs of wood sourced from young pine plantations. The most notable efficiency gained was in the skidding function. It was demonstrated that a large capacity grapple on a skidder can enhance production rates and reduce costs when harvesting small-diameter stems. This benefit is not dependent on the felling machine selection.

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Endnote

[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.

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