IMPLEMENTING RESIDUE CHIPPERS ON HARVESTING OPERATIONS FOR BIOMASS RECOVERY

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IMPLEMENTING RESIDUE CHIPPERS ON HARVESTING OPERATIONS FOR BIOMASS RECOVERY

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IMPLEMENTING RESIDUE CHIPPERS ON HARVESTING OPERATIONS FOR BIOMASS RECOVERY

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Jaspreet Aulakh, daughter of S. Ranjit Singh (India), was born in 1982 in the small town of Khanna in India. She completed high school in 2000, and joined Punjab Agricultural University In 2001. She earned a Bachelor's of Agriculture, and graduated with honors in 2005. The same year she received admission to Auburn University to pursue a Master's of Science degree in Forestry. She moved to the US with a lot of dreams.

THESIS ABSTRACT

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Three operations that implemented a small residue chipper on their conventional logging operations were studied in 2006. Two of the jobs were thinning operations, the remaining operation conducted clearcuts. All three implemented the chipper in a different way: the first operation fed the chipper using the same loader that handled roundwood sorting and loading; the second operation used a separate loader with the chipper; and the third operation used a small Bell Logger for feeding the chipper. All three operations used set-out trucking as their method of transportation.

Production was recorded from several months of data for Operations 1 and 2. Equipment costs for were estimated using an after-tax cash flow method, and trucking costs were also included. No cost was added for stumpage or profit. Operation 1 averaged 1.4 loads per day at an estimated cost of $11.81/ton of fuel chips. Operation 2 averaged 2.2 loads per day with a cost of $12.18/ton; and Operation 3 managed 4 loads per day at $10.66/ton. The fuel chips produced generally contained about 80% wood, with the remaining material being evenly divided between bark, needles and twigs. Operation 2 eventually shut down because the production of fuel chips was interfering with his roundwood production.

Implementing a residue chipper on a conventional operation has the potential to produce fuel chips for a biomass consuming facility, provided it does not interfere with roundwood production. Set-out trucking aids the operation by minimizing the delay time for trucks.

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1. INTRODUCTION

The demand for fuel continues to escalate with the increasing size of our population creating a demand for research in the field of energy alternatives. The Biomass R&D Advisory Committee has envisioned that 25 percent of the petroleum needs might be replaced with alternate fuels such as biomass by 2025 (Perlack et al, 2005). Biomass is available in the form of urban residues, logging residues, mill residues, and small-wood for energy production. Perlack et al (2005) estimated that 70 million tons of logging residue can be obtained currently with timber harvesting operations. Biofuels produced from biomass will reduce both our greenhouse gas emissions and our dependence on foreign countries for fuel needs. Therefore, research on biomass and biofuels is necessary to meet these objectives.

Utilizing biomass in any available form will help in meeting the objectives mentioned above. It has already been proven that this biomass resource exists in our agricultural and forest land resources (Perlack et al, 2005). But we need economical and socially acceptable methods to extract the biomass. Biomass has long been a source of renewable energy, but it has only recently surpassed hydropower as the largest source of renewable energy. This shows that efforts are being made to utilize this form of energy.

Additional benefits can be derived from increasing biomass consumption. Forest health can be improved by timber stand improvements in stagnant stands. Additional jobs could be created in rural areas. Also, new biomass markets will strengthen the forest products industry by providing new markets (Borgman et al, 2007). However, using conventional harvesting systems for fuel wood thinning is inefficient and expensive because of the small diameter of trees and the lower productivity of the system.

More research is needed to identify economically and ecosystem-friendly methods to extract biomass. This study examines the use of small residue chippers an conventional harvesting systems as a source of biomass feedstock and additional income. The case studies from this project will provide estimates of cost and productivity for harvesting woody biomass which can be used to determine the feasibility of the system.

In-woods chipping of the residues is a possible method of recovering biomass left on the site after harvesting. According to Stokes and Sirios (1986), chipping is the most commonly used processing alternative to reduce the material to a form that will allow easy and economically feasible removal, transport, and handling (Stokes and Sirois, 1986). Chipping will also help by reducing potential fire hazards and as a source of additional income through the sale of the chips. In addition, site preparation costs may be reduced because of increased recovery of biomass from the tract.

There are a number of possible techniques to remove fuel during harvesting operations. Tree-length removal has been used traditionally for clear-cutting, but research has shown that whole-tree systems are more appropriate for harvesting a higher percentage of biomass. These are high production methods, and utilization of residues in the form of biomass requires the use of chippers. Large chippers are expensive and require higher set-up and moving costs. They cannot be utilized only for chipping small wood quantities because the costs incurred don't justify their use.

A smaller and less expensive chipper with lower ownership and operating costs is a possible solution that allows the operations to stay small. The simplest method of removing biomass from the stand is to move the full length trees with the limbs and tops still attached, (Walbridge and Stuart, 1984) and chipping the unused portions of the trees at the deck. Therefore, there is need for a specially designed chipper, which may be termed a residue chipper, for the collection and utilization of residue from these small-scale operations. It may prove an economical and environmentally friendly option for the recovery of residue at the landing which can be successfully incorporated into other types of harvesting systems.

Bundling of fuelwood is another system for biomass recovery. Bundling may be more feasible in some instances because it would allow economically feasible transport of residue materials to a remote site for chipping. That wood increase the utilization of the chipper, reducing the per-ton cost of utilizing residues. But, it has not been shown that the additional costs of bundlers on multiple sites would justify the increased utilization and reduced number of chippers.

Several loggers have small portable chippers, such as the Bandit 1850, which are being used on harvesting operations in the southeastern region of the U.S. A recently completed study has demonstrated their feasibility on smaller tracts for integrated harvest of both merchantable and unmerchantable materials (Westbrook, Jr., et al, 2007). In another study, the residue chipper helped reduce stocking densities through removal of small stems in thinnings, and removed standing biomass after clear-cuts. The study demonstrated that portable in-woods chippers with conventional equipment can be the solution to utilize biomass to a much greater extent (Bolding, 2002).

Previous research efforts have concentrated only on chippers in controlled conditions. This study examined three operations which used a chipper along with conventional harvesting equipment to produce biomass for a fuel market. The case studies were used to document the problems faced by these loggers, and how they are managing their integrated system.

2. OBJECTIVES

The objectives of this project were to:

- Determine production estimates of the residue chipper in thinning and harvesting operations,
- Develop estimates of quantity and quality of fuel chips produced by this chipper, and
- Develop models to estimate the cost associated with incorporating these residue chippers into the traditional conventional systems.

3. LITERATURE REVIEW

The Billion Ton Vision estimates that 368 million dry tons of biomass can be removed from our nation's forests on an annual basis (Perlack et al, 2005). Biomass currently accounts for 3 percent of the total energy consumption of the United States, and it has recently surpassed hydropower as the largest source of renewable energy. It is mainly used for industrial heat and steam production, but the general outlook for additional biomass consumption looks quite promising. The primary mission of the U.S Department of Energy (DOE) is to increase energy security by reducing the country's dependence on foreign petroleum. Utilizing biomass will help accomplish this as well as improve environmental quality. The Biomass Research and Development Advisory Committee formed after the 2000 Biomass Research and Development Act was passed has a vision that 5% of U.S power, 20% of transportation fuels, and 25% of chemicals will be provided by biomass by 2030. This equals 30% of current petroleum consumption and will require the consumption of one billion dry tons of biomass (Perlack et al, 2005), which will be supplied by both agricultural and forest lands. As part of that plan, forestlands in the U.S will produce 368 million dry tons annually. This projection includes the supply of biomass from fuel wood harvested from forests (52 million dry tons), residues from wood mills (144 million dry tons), urban wood residues (47 million tons), logging and site clearing operations, and wood removed to reduce fire hazards (60 million tons) (Perlack et al, 2005).

The research on biomass and other forms of energy alternatives was intense during the 1970's due to the oil embargo. But by the 1990's, research on alternative fuels in USA had curtailed because of historically low oil prices. Recent increases in the demand for oil and the subsequent oil price increases have increased interest in harnessing alternative sources of energy. Biomass in the form of logging residues, crop residues, urban residues, and short-rotation forest crops have again been recognized as important potential resources. This has lead to more research on new engineered equipment and harvesting systems to obtain the biomass forms mentioned above.

3.1. BIOMASS INVENTORY

The Southeast United States is one of the most important wood basins in the country. Vast amounts of timber exist in these planted and natural forests, with an estimated 7.56 billion cubic meters (Smith et al, 2002). The hardwood species, such as oak, sweet gum, and hickory, and softwood species, such as loblolly pine, are the most important trees of this region. For many years emphasis has been on research and development of new techniques and methods of extraction and replenishment of timber resources from these forests. The conventional operations, which mainly aim at the removal of the bole wood that is suitable for pulp, chip-n-saw logs, plylogs, and saw logs, are responsible for removal of only 60% of the above ground biomass available (Stokes and Watson, 1989). Thus, many tons of usable biomass are left unused and have to be disposed of during site preparation.

The U.S. has a forest base of 206 million hectares classified as timberland, from which 105 million cubic meters of pulpwood, 106 million cubic meters of sawlogs, and 84 million cubic meters of energy wood are harvested in the South annually (Smith et al, 2002). Out of the 85 million hectares of forest land in the south, 45.4 million hectares consist of hardwoods, 0.64 million hectares are planted hardwoods, 26.3 million hectares of natural pines and 12.8 million hectares of planted pines(Forest Resources of The US, 2002).

There are 85 million hectares in the South; 8.6 million hectares are under public ownership, with 14.5 million hectares under industrial ownership. The remaining 58.9 million hectares are owned by non-industrial private owners (Source:-Forest Resources of The US, 2002). On the industry owned forest lands, two-thirds of woody biomass is removed during the harvest, while the rest is left unused (Hughes and McCollum, 1982). This removal of biomass occurs much less frequently on private non-industrial land.

The understory biomass could become an essential source of industrial energywood. Research has shown that up to 98 tons per hectare of above-ground biomass may be present in southern pine stands (Franchi et al, 1984). The above ground biomass is the only part of the tree which can be harvested economically for fuel.

3.2. BIOMASS HARVESTING SYSTEMS

Twaddle et al (1989) reported at the meeting of the American Society of Agricultural Engineers that countries like Canada, Denmark, Finland, New-Zealand, Norway, Sweden, the U.K, and the U.S. are considering new incentives to harness biomass as a form of renewable energy. The ideas of 1980's are being reconsidered again now with the increased fuels prices and diminishing fossil fuel resources. The importance of biomass has recently been recognized more than ever, not only in the U.S., but all of the developed and developing nations of the world (Adegbidi et. al. 2001). The demand is increasing for biomass in many countries, which is either driven by the government incentives, increasing oil prices, or by the quest of making harvesting operations more efficient. The development of a market to utilize non-merchantable material depends on the ability to harvest the material in a socially acceptable and economically feasible manner. There exists a great opportunity of revitalizing the forest products industry in the USA which concentrates mainly on extraction of merchantable bole wood (Perlack et al, 2005). Moreover, with the increasing research on biofuels, and the fact that one green ton of biomass is equal to one barrel of bunker 'C' oil, forest residues form an important raw material that may be utilized in the future.

Kluender reported that the pulp and paper industry in 1980 depended on fossil fuels for 52% of their energy needs. This amount was reduced to 25% in 1986 because low costs of other fuels (Watson et al. 1986a). The trend of non-dependence is still considered a great option, and most pulp and paper mills are trying to obtain energy for their boilers from residues of all kinds, such as mill residues, urban residues, energy wood, and harvesting or logging residues. Moreover, a metric green ton of slash at 45% moisture content is equal to 8750 millijoules (mj) of energy content (approx.), and assuming 65% of energy conversion, it will produce around 5687mj in the boiler furnace (Bolding and Lanford, 2001). The conversion factors which define fuel wood as potential sources of energy were mentioned in a paper by Stokes in 1997 (Table 1). So, we see that logging residues have long been recognized as a potential source of energy, but the high costs of harvesting them have restricted their utilization.

TABLE 1.-“Useful Conversion factors for bioenergy” (Stokes 1997) (Bolding 2002).

1 BTU =1.055056 joules (J)
1 QUAD =1 quadrillion Btu of energy
=1×10^{15} Btu of energy
=40.82 million metric tons of coal
=54.43 million metric tons of oven-dried hardwood
= 27.2 million cubic meters of crude oil

Machines have been developed and are continually being tested for their feasibility for capturing these forms of residues (Watson et al. 1986a). Examples of this are the Bandit 1850 residue chipper and Conehead chipper.

Harvesting operations utilizing residue chippers have found a lot of advantages in recovering material left after harvesting (Watson et al, 1986a). This may be an additional source of income to the landowner in addition to regular products supplied to the mills. It has been proven that the harvesting of the residues along with the merchantable material helps in higher utilization (75-95%) of the above ground biomass (Stokes and Watson, 1989). Another advantage of removing the energywood will be reduction of site preparation cost. The sites which have energywood removed show site preparation cost reduction of $350 per hectare compared to tracts without energy wood harvest (Stokes and Watson, 1989). Dubois et al (2001) also supported the site preparation cost reductions by reporting that tracts with energywood harvests will benefit with savings of

$416.65 per hectare. The savings on the site preparation costs, roundwood cost savings, and future prospects of utilizing it for biofuels are persuasive for at least some people to continue harvesting for energywood (Stokes and Watson, 1989). This number should increase once the economic feasibility is proven.

Restoration of forest health has been the national priority of the Forest Service. One aspect of it is the reduction in the number of trees per acre and the removal of trees in poor health or with a high probability of dying in the future, which will result in improving the vigor of the remaining trees by reduction of competition (Hartsough et al, 1995). This will also help in the reduction of insects and diseases in such forests. Harvesting to reduce the fuel load and reduced mortality will help to lower the likelihood of wildfires. Hence, economical and environmentally sound methods are needed to restore forest health. There is a lot of opportunity and interest in employing pre-commercial, post commercial, and integrated energywood harvesting to these stands to alleviate the overstocking problem that tends to enhance the likelihood of catastrophic wildfires (Bolding et al, 2003). The small trees tightly spaced in the understory of mature forests act as a fire ladder, increasing the risk of fire leading to stand destruction and smoke problems (Bolding and Lanford, 2001)

There are a number of mechanical methods and approaches which exist to reduce forest fuels, harvest energywood, and utilize forest residues. A number of harvesting systems have been tested all over the U.S. and other parts of the world to utilize this form of energy. As has already been mentioned above, harvesting crews with a portable chipper have been used to recover material left after the harvest. Portable chippers have been studied with conventional systems and cut-to-length combinations in Southeast USA (Mitchell and Gallagher, 2007, Bolding, 2003). Other combinations of equipment such as mobile harvesters and chippers for fuel recovery are popular in some other parts of the world such as some European countries like Finland and Italy (Spinelli et al, 2007).

Most conventional operations leave a considerable amount of material on the site and landing to be dried and windrowed (Stokes et. al. 1985). When too much non-merchantable material is remaining on the site, a typical strategy after the clear cut has been mechanical site preparation and replanting (Stokes et. al. 1985). The trends today might be towards herbicide application due to low costs and easy application. But, the site conditions after the harvest define the type and extent of site preparation treatment required for successful regeneration. As an example, if plenty of small stems exist on a site, it will require mechanical shearing, raking and disking before herbicides can be used. Typically, pine stems less than 6 inches in dbh and hardwood stems less than 8 inches in dbh are left on the site to be disposed of at the time of site preparation. On the other hand, another option can be to economically harvest this material if possible and use it as energywood.

An oversupply of mill residues and lack of markets limit the recovery of logging residues (Johnson.1989, Stokes 1992). It is not economically possible with the conventional systems to harvest all the biomass, but they have great potential for improvement (Stokes et. al. 1985). Portable chippers have revolutionized the use of entire tree harvesting (Young 1980). The common practice is to fell the trees, transport them to the landing, utilize the on-site residues, chip them, and transport them in a chip van. The total output depends on the organization of the work (Seki et al, 1982). There are a number of factors which affect the efficiency of biomass harvesting systems, including the chipper, climate, chip van availability, the preparation of work, the movement of the chipper between sites, and the servicing and repairs. The use of the chipper has made the use of tops, defective, and small trees for energy fiber possible (Stokes et al, 1985).

Chippers have been studied in different types of harvesting systems and different lines of production. Stokes reported the use of chippers in 1985 for harvesting energywood along with merchantable wood, technically defined as the one-pass method, and the two-pass method, in which the energywood is harvested before the roundwood harvesting. But he mentioned that there might be some variations due to the stand type and composition. So, there is need for more studies to identify the optimal equipment mixture to improve these operations. The percent of biomass utilization was higher in the two-pass method (70-80%) than the conventional method (50-60%), and highest in the one-pass method (80-90 %) (Watson et al, 1986b). The author concludes that in the two-pass method the felling costs were significantly higher because only the small diameter trees were felled, and the feller-bencher had to maneuver much more between the other trees. The utilization in the conventional method was the least because only the roundwood was harvested. In the one-pass method it was highest because the feller-buncher was harvesting both energywood and roundwood simultaneously, and bunching them separately. The skidder costs were found to be least limiting with this type of operation.

Hartsough et al (1997b) studied three types of systems to harvest biomass along with roundwood. The three systems include: the use of a residue chipper in a conventional operation, which consists of a feller-buncher, skidder, stroke-processor, loader, and chipper; a system consisting of a harvester and forwarder (a cut-to-length (CTL) system) with a chipper; and a hybrid system consisting of a feller-buncher, processor, and chipper. All three systems were able to harvest a considerable amount of biomass, although there was variation among the systems. The CTL system was more productive than the hybrid system, but had high processing costs. The whole-tree system had high processing costs due to time spent decking the material. In the plantations, the hybrid system was least expensive, but in natural stands, the whole- tree system was more profitable.

In other studies, it has been identified that whole tree processing with a flail/chipper has more advantages than tree length (Stokes and Watson, 1988). The main advantage is greater biomass recovery in the form of tops, limbs, and bark over the tree length system. The residues from tree-length harvesting have been considered bulky and spread all over the site. As a result, 10 percent of the tree is left in the forest in the form of slash and debris in the tree length system. And on the other hand, it is feasible and economical to recover most of this material (14.7 percent of the total tree) ejected from a flail delimber-debarker for flail/chip option.

The availability of a wide variety of chipping equipment makes the task very viable (Christopherson et. al.1993), but the chipper selection depends upon a number of variables such as:

- Size of the trees
- Amount of chips required
- Rate of chip production required from the operation
- Importance of chip size consistency

The use of woody biomass for direct burning in boilers is usually in the form of chips. The two properties of the fuel chips that greatly affect the efficiency of burning the material in the boiler are moisture content and particle size. Smaller particle size is important for faster combustion, and more surface area is important for evaporation, oxygen exposure, and easy suspension in a suspended type boiler (Sirois and Stokes, 1985). Whole-tree chipping is the most common reduction process, but shredding, grinding, and chunking may be used.

Fuelwood producers are generally interested in small to medium sized residue chippers which can chip material up to 8 inches in diameter (Christopherson et al, 1993). There are a number of factors which influence chipper productivity, including moisture content, tree diameter, and possibly weather conditions. For instance, winter harvesting is most advantageous in the northern climes, but for large biomass operations it may be necessary throughout the year.

In his paper, Christopherson et al (1993) also mentioned that the size of the operation also affects the choice of the machines, and that small operations can consider the development of attachments for a farm tractor, with it being available for other operations.

3.3 Economic Analysis of Biomass Harvesting Systems

Several studies have been done to analyze the economic feasibility of biomass harvesting systems. The research has concentrated on the study of portable chippers in conventional systems. There are several other options available to obtain small wood, but the most widely studied has been portable chippers with a conventional system. This can be accredited to the widespread nature of conventional systems and the fact that other systems are still in the prototype stage in the U.S. Positive results are required to make the prototype systems a viable option and to convince landowners and loggers that they can be used profitably. The research so far has been concentrated around the removal of residue material in conventional systems, but in any harvesting system utilization of material is more economically feasible under the following conditions (Watson et al, 1987):

1. The value of material is high at the wood burning facility.
2. "A credit is applied to energywood for site preparation savings."
3. Large volumes of energywood are available per unit of land basis, and
4. The hauling distance is short.

Productivity and cost of conventional understory biomass harvesting systems have been studied over the years. The advantage of reduced site preparation costs have also been estimated through these studies.

The economics of the one-pass and two-pass methods mentioned previously also have been studied. In the one pass method both energywood and pulpwood are removed simultaneously in a conventional system. In the two-pass method, the energywood is harvested in the first pass, and pulpwood in the second pass (Miller et al, 1985). Stokes reported in 1985 that harvesting energywood with a one-pass method was more cost effective than the two-pass method. A conventional system is defined as one in which a feller-buncher is used to fell trees, a skidder is used to haul the felled wood, and a loader is used to load the skidded wood onto log-trucks. The log trucks are used to haul processed wood to the wood using facility. The energywood harvested in the one-pass or two-pass method in conventional systems is processed with a chipper on the landing. The chipping helps to reduce the size of material, making transportation more efficient.

Several studies were done in the same period to estimate the cost incurred in the extraction of energywood in the one-pass and two-pass methods. Site preparation savings have been credited to energywood removal in some of these studies. The one-pass harvesting method has been recognized to be less sensitive to the amount of energywood present (Miller et al, 1985, Watson et al, 1986b, Stokes and Watson, 1986b). In this study, productivity and costs were not significantly related to tract tonnages in the one-pass method (Miller et al, 1985). Also, chipper production was not affected by the tonnages per acre since the skidder was able to feed the chipper at a rate that was not significantly different on the range of energywood tested. It was reported that this was because of the additional volume of energywood can be obtained from the pulpwood operation. Therefore, the one pass method was most economical for all products because of better productivity. On the other hand, costs of the two-pass method depend upon the feller-buncher productivity which is significantly affected by the tonnage on tracts (Miller et al, 1985). The feller-buncher was the only machine affected by tonnages. The two-pass harvesting method for energywood production demonstrated higher costs of harvesting with low tonnages and moderate costs with low tonnages.

The chipper costs are higher in the one-pass method because of less utilization due to more delays (Watson et al, 1986b). The delays were the result of the interaction between different equipment such as skidder, loader, bucker, chipper, and process of removing tops of merchantable material. More intensive management or better synergy can help to reduce these delays and reduce chipping costs. Felling costs were highest for energywood, thus they have the greatest chances of improvement in the two-pass method. Watson et al estimated the costs of harvesting energywood in 1985 for the one-pass and two-pass method between \$7.60 and \$8.85 per green ton. The cost incurred in the production of fuel chips was well below the value of fuel at the mill.

The study regarding the integration of the one-pass and two-pass biomass harvesting methods and site preparation was reported by Stokes and Watson (1986). The site preparation methods tested were (1) shear-rake-pile, (2) single disk, (3) herbicide treatments, and (4) double disk. This study was done to identify the opportunities for reducing site preparation costs with intensive utilization of biomass. Most of the tracts with the energywood harvest did not require intensive site preparation methods. This was decided after testing the amount of residue material left on the sites after harvest. The conventional method required more site preparation methods to be done in order for the site to be suitable for regeneration. On the contrary, the one-pass and two-pass methods needed less site preparation for making the site favorable. Thus, integrating energywood harvest and site preparation can reduce overall site preparation costs (Watson et al, 1984, Stokes and Watson, 1986b). Savings ranged from $12 per acre for herbicide treatment to $92 per acre for disking. But even if these savings are not applied to biomass harvest methods, depending upon the haul distance, these systems can be economically feasible. These savings do allow some leeway in the hauling distance and in reducing site preparation cost. These studies indicate that conventional harvesting systems can be used to economically harvest the understory biomass when there is a good market for fuel.

3.4. IN-WOODS CHIPPING

The growing demand for biomass means that more wood will have to come from forest biomass and other industrial sources, such as mill residues (Sirois and Stokes, 1985). Forest residues in the form of unmerchantable cull logs, limbs, tops, and small low quality residue trees left after the harvesting form an important part of this resource. The supply of these varies from region to region because of forest type and market pressure. But the cost of extracting, processing, and transportation exceeded the dollar value offered in 80’s, compared to the costs of conventional fuels such as coal and oil.

Small trees in the range of 1-5 inches may be grown and harvested, or thinning may be planned only for harvesting energywood or a pre-commercial small wood removal.

There are two main types of in woods chippers: portable and mobile (Sirois and Stokes, 1985). Portable chippers are accessible and in use by some harvesting operations, but mobile chippers are still in the development and prototype stages. Portable chippers are confined to the deck. The material to be processed is brought to them by skidders in the form of residue or whole trees. The loader places the material into the infeed of the chipper and the chipping process throws the chips into a chip van for transport. They are generally high production, high cost machines, and thus require highly efficient systems to use them to full capacity (Sirois and Stokes, 1985). The mobile chipper on the other hand is mounted on its own carrier and is a self- loading chipper with mechanical infeed. Chips can be stored onboard in a container or on a second machine for forwarding. This machine is not confined to the deck. The processing systems should be composed of efficient and economical combinations of machines, and current technology and some small set-up changes can make a huge difference in their profitability (Ashmore and Stokes, 1987).

Most studies on mobile chippers ceased in USA after the 80's due to lack of interest and high costs. But in the other parts of the world, such as Sweden, Finland and other European countries, it still has its importance. Spinelli et al, 2007 reported that a mobile chipper is one of viable option along with others such as bundling and collection of loose material. And, these methods are applied in various countries. Mobile chippers have been popular in Italy and studies have shown they are economical in certain conditions (Spinelli and Spinelli, 1998). There may be future research projects on this type of machine depending upon the future market developments and utilization of biomass material.

Studies have shown that skidding is cost effective if there is enough quantity of small stems available on a site (Stokes et al, 1984; Miller et al, 1985; Watson et al, 1986a, and Watson et al, 1986b). Felling economically is also possible if an ample quantity of biomass is available on the site (Watson et al, 1986a; and Watson et al, 1986b). The felling cost becomes limiting when there are less than 15 tons of material per acre (Miller et al, 1985; and Watson et al, 1986b). The skidding costs are larger when more time is spent collecting small material. When the material is moved to the deck, chipping is the most common method of handling material. Chipping helps in the reduction of particle size, which helps in its transport and burning. The power requirement for converting small material into chips is less than converting large stems into chips (Stokes and Sirios, 1989). Stokes et al (1987) proved in their study that the power requirements vary with diameter, and that dbh has a significant affect on the power requirement. "The average power requirements measured in this study for small and large chippers were 158 kW (212 hp) and 262 kW (352 hp), respectively." Also, the results show that power requirements for small diameter trees in the range of 4-8 inches, for all species (pine, softwood, and hardwood) are in the range of 156-414 kW, which includes both large and small chippers. This means that small chippers with less horsepower can be used for chipping small residue trees. Some industries are into transpiration drying, but processing dry material means that the knives need to be changed more often, which reduces productivity on a per hour basis (Watson et al, 1986a).

The improved utilization of biomass, with less wastage, can result in an increased fiber supply and yield from our forestlands. This means that everything possible should be utilized which has some economical value, including the forest residues which are not normally recovered in conventional operations. Harvesting the forest residues without chipping is not economical because the non-uniformity of material makes their handling and transport difficult. Chipping greatly helps in reducing transportation costs by reducing particle size and making handling easy. Whole-tree chipping has been considered an economical method of harvesting small stems since the 1970's in the southeastern United States because it helps in the recovery of more biomass than other systems.

The harvesting options can be framed as: (1) Post harvest, (2) Pre-harvest, and (3) Integral harvest (Stokes and Sirois, 1989). The first option is limited to harvest of downed stems, limbs, and the tops of processed trees. It is less cost effective because a smaller amount of organized material makes harvest difficult. The second one is limited to small equipment specializing in the harvest of small wood, and no tops and limbs can be recovered. The last option helps in the recovery of all small diameter stems, and has an added advantage of modification to include whole-tree chipping and flail delimbing and debarking to increase product value.

The in-woods flail delimber/debarker with a chipper has revolutionized the production of clean pulp chips with a greater recovery of fuel chips. Baughman et al

(1990) reported that data collected from Weyerhaeuser holdings using the flail system produced 57 green tons per PMH of clean chips, with 14-21 green tons per PMH of fuel chips. They also stated that fuel production is directly dependent upon the production of clean chips by the flail/chipper system, and upon available biomass. The whole trees are fed into the flail, which move the debarked stems into the chipper and the debris into a tub grinder, from which they are blown into their respective pulp chip vans and fuel vans for transportation. In 1994 Watson and Stokes compared a conventional thinning operation to removing roundwood with a flail/chipper operation. In this study they found that the flail operation resulted in an additional 4.2 tons per acre of pulpwood quality material was recovered and a higher volume of biomass was also removed from the site. The plantations in the southeast have initial stockings of 1,000-2,000 trees per hectare to minimize the opportunity of ingrowths of undesired species. These are thinned between the ages of 10 to 23 years, to a stocking of 200 to 500 stems per hectare. So, a large amount of small stems can be removed in this period, which can be used for both fuelwood and roundwood.

Stokes and Watson (1991) reported the recovery efficiencies for tree length, whole tree, and flail delimbing systems. The results showed that 21%, 14%, and 4% of the residue was available for energywood from the whole-tree, tree-length, and flail-chip options, respectively. All three methods left 15.6% of the trees on site in the form of felling and skidding loses. Another 8.5% was left because of gate delimbing in the tree-length harvesting system. In the flail/chip system, 12% of the material is recoverable, but needs further processing. A total of 44 metric tons/ha, 25 tons/ha and17 tons/ha of mill residues (energywood) are recoverable in whole-tree, flail/chipper, and tree-length harvesting systems, respectively. It is possible to recover some of this biomass by utilizing a small portable chipper with a conventional operation harvesting whole-trees, along with a delimber. Hartsough et al (2000) reported that the processing of whole trees with a delimber prior to feeding to the chain flail delimber/debarker/chipper is not cost effective. Although the delimber helped to separate 35 dry pounds of limbs per tree, there were fewer pulp quality chips in the delimber processed material, due mostly to breakages. But, it helped to make the delimber/debarker/chipper whole tree operation faster.

In 2001, Bolding and Lanford advocated a possible solution for reducing fuel in the forests by a cut-to-length (CTL) system with a small in woods chipper. They found that portable chippers with less horsepower are less expensive compared to other biomass processing machines. If the material can be sold in the form of energywood, the lower, operating costs to reduce forest fuel make the operation more feasible. So, in addition to reducing fuel, it can be used as an additional source of income. Further, Bolding's study reported that the unpopularity of the prescribed fire, due to increased liability concerns and state and federal regulations due to smoke management, further advocate the use of chippers. The landowners may be ready to accept lower stumpage prices if they are promised "cleanup" on their land from these types of operations. The chipped fuel wood can also be utilized in the form of mulch or organic matter.

4. METHODS

4.1. RATIONALE AND JUSTIFICATION

Although large chippers are available for the processing of pulp chips, there are few options to economically process small-wood and residue. The large size and high costs make large chippers inefficient for smaller tracts. A smaller chipper will be more efficient and an easily available option for the recovery of forest residues for fuel wood. While previously mentioned studies have discussed their added advantage of reduction in the site preparation costs to the landowner after the final cut, these costs have not been worked included in this study. The production and cost data collected from this study should provide the basis for a more relevant use of this chipper for residue recovery on harvesting operations in the Southeast U.S. A small, less expensive chipper, with reasonable operating and ownership costs and productivity matching the volume of conventional harvesting systems may be a useful processing alternative for deck cleanup purposes and the generation of additional income. The results of this study will assist loggers in deciding whether a small residue chipper (Figure 1) can be profitably integrated into a normal roundwood operation.

Figure 1. A Bandit Model 1850 chipper, similar to the residue chipper used by two of the loggers in this study.

4.2. Data Collection

The objective of this research was the collection of production numbers and estimating the machine costs for various loggers using a small chipper. The smaller chippers do not provide pulp quality chips because bark and other debris are included among them; but can be used for the production of chips for energy wood. Analysis of the chipping costs will determine if residue chippers can be a viable alternative for the production of fuel material.

4.2.1. Study Site

The operations were observed on three sites in Alabama, one near Union Springs, one near Dudley, and one near West Point. All sites were in the lower piedmont area of Southern Alabama stretching from Greenville to Lanett.

4.2.2. Non-merchantable Material Defined In the Research

Merchantable material is the total wood supplied to the mills. The non-merchantable material, or residue material, consists of all other material remaining from the harvesting (Bolding and Lanford, 2001). It is expected that the material will differ a little in the thinning and the clear-cut operations. In thinning operations, the non-merchantable material includes mostly tops, limbs, and foliage of pine, and only a few small hardwoods. Clear-cuts are likely to include smaller diameter trees cut during the harvest. Therefore, the residue material generated from clear-cuts is likely to be more varied than a thinning site. The small-diameter residue material trees differ with species and are defined as follows: for pine species, trees with less than a 6-inch diameter are non-merchantable, and for hardwood trees, trees with less than an 8 inch diameter are non-merchantable. It was assumed that all the non-merchantable material for both types of treatments would be chipped in the residue chipper for energy-wood.

4.2.3. Truckloads per Day

The residue chippers studied were portable chippers with no harvesting heads or loading heads attached. The chipped material was blown directly into the chip vans. The size of the van was generally enough for carrying 25 tons of wood. Loggers were visited on site to collect samples and review production. Historical records were also obtained from two of the three loggers which were used to verify production over a longer period of time.

4.2.4. Quality of the product

The product samples produced with the residue chipper were collected from loaded chip vans. The sampling was done from September 2006 to January 2007 on the first operation, May 2006 to August, 2006 on the second operation, and later in January 2007 on the third operation. The chip vans on the site were accessed to take samples, which were brought back to the laboratory to be studied. Material was collected from across the back of the vans and filled a small grocery bag. Two handfuls of samples were randomly obtained from each bag. The samples collected from the chippers were separated into five categories: wood, bark, foliage, twigs, and indistinguishable material and the percentage (green weight basis) of all types of material were recorded (Table 2). These samples were weighed after drying to determine their moisture content on wet basis. The moisture content is a defining factor for the quality of the product and determines how well the energy wood product will burn in the boiler when used for heat production.

Table 2. Five categories were used for sample separation

Component	Weight in grams (gm)
Wood	The weight of the wood out of the sample
Bark	The weight of the bark
Twigs	Weight of twigs
Foliage	Weight of foliage
Fines	Weight of material hard to distinguish in the above four categories

4.3. Statistical Analysis

Analysis of the Three Treatments on the Sample Components

The three operations were considered as three different treatments. The three systems had three different equipment mixes and also different silvicultural treatments. Also, their preferences of utilizing the non-marketable material varied. These were considered as three separate treatments and their effect on the components were statistically studied. The statistical tools used were an analysis of variance (ANOVA) test and Tukey's Studentized Range test.

Analysis of the Roundwood Production on Fuel Chip Production

The two operations discussed in the results for which past data were available were statistically analyzed to determine the relationship between roundwood production and fuelwood production. Historical weekly data collected for the past year or so were used for the analysis.

4.4. Cost Analysis

A cost analysis was completed for the residue chipper to estimate the cost, the economic life, and the cost incurred per productive and scheduled machine hour. These numbers were combined with the production numbers to get the cost per ton, and were used to calculate the cost of production of energy wood. They were summarized against the method of harvest to compare the cost differences among the different operations. Table 3 shows the components that were used for the machine rate analysis.

Hourly costs were calculated for the residue chipper and the loader using an after-tax cash flow method (Tufts et al 1989). The numbers were incorporated into a spread sheet developed by Tufts. The after-tax cash flow approach allows the impact of income tax effects, time value of money, and inflation, along with the usual operating and investment costs. Cost inputs consist of both fixed and operating costs. Fixed machine costs included machine payments, insurance, taxes, and depreciation with interest rate.

Operational costs for the machine included labor, fuel and lubrication, and maintenance and repair excluding the downtime costs. (Tufts and Mills, 1982)

Table 3. Elements for the Cost Analysis of the chipper.

Chipper Machine Elements	**Elements Defined**
Purchase price($)	Cost at which a machine is purchased
Estimated life (years)	The number of years it can work in good condition
Salvage Value ($)	The price at which the machine can be sold after use.
Utilization Rate (%)	The ratio of productive machine hours to the scheduled machine hours.
Fixed Cost ($/SMH)	Fixed cost includes depreciation, insurance, and interest and taxes.
Operating Cost($/ SMH)	Operating cost includes repair and maintenance and fuel and lubricants costs etc.
Labor Cost ($/SMH)	It includes wage per hr and the benefit costs.
Total Cost	Sum total of Fixed, Operating, and Labor cost.

(Source: Stokes et al, 1986)

Operating cost exclude labor. SMH = scheduled machine hours

4.4.1. Utilization Rate

Utilization is defined as:

$$\frac{\text{Productive hours}}{\text{Scheduled hours}} \times 100$$

Or the percentage of time the machine is actually working.

4.4.2. Fuel and Lube Costs

Fuel costs were estimated by first calculating the consumption of fuel per hour by multiplying the horsepower of the machine by a factor of 0.037 (Brinker et al, 2002). Then, the amount of fuel was multiplied by the price of diesel, assumed to be $2.75 per gallon, to get the total fuel cost.

Fuel Consumption = 0.037 x horsepower (hp) = gallons/PMH

Total fuel cost = gallons/PMH x $/gallon

Lube cost = $2/PMH

Total fuel and Lube cost = Total fuel cost + Lube cost

4.4.3. Maintenance and Repair Costs

Maintenance and repair costs = % of straight-line depreciation based on machine complexity

$$\text{Depreciation (D)} = \frac{(P - S)}{L \times H}$$

Where ‘P’ = Purchase price

‘S’ = Salvage Value

‘L’ = life in years, and

‘H’ = productive hours per years

The machine rate analysis method was used to calculate utilization rate, fuel cost, and maintenance and repair costs, using the formulas above. The utilization rates and the percentage of depreciation were taken from Brinker et al (2002). Maintenance & Repair (M&R) costs were calculated according to machine rate principals (Brinker et al, 2002). The straight line depreciation costs were calculated for productive hours. Then, percentage of depreciation was used to give the M&R costs. 150% of depreciation was chosen for the chipper in all the operations studied because this is harsh application for the chipper. For all the machines the utilization rates were used from the Forestry Handbook. The scheduled machine hours were assumed to be 2000 hrs per year. The utilization rates were used to calculate the productive machine hours (Brinker et al, 2002). These numbers were then used in the discounted cash flow analyses.

An after tax analysis was completed to estimate the cost of running a residue chipper system. This method approximates the cost of keeping a machine for a desired number of years and considers the effects of income tax and time value of money on costs. So, if we know the revenues from the system, and the costs, the net profit can be calculated by keeping the machine in a system. It can then be stated whether or not the machine has been profitable in a system.

4.5. Productivity Analysis

A time summary was also performed for the chipper by recording the productive times for chipping activities. For this survey, Yellow Boxes, manufactured by Kinetic Electronic Designs CC (Figure 2), were installed on two of the chippers used in the study.

They are devices which record vibrations during the use of a machine and were used to collect the duration of time the chipper was actually working. The Yellow Box software can also be used to create detailed individual time graphs**.** These graphs are analyzed to get the actual time the machine was used or was in motion. From this we estimated the productive time of the chipper.

Figure 2. Yellow Box connected to computer for data uploading

5. RESULTS

5.1. OPERATION 1

5.1.1. Study Site

Operation 1 was a site located near West Point, Georgia. The harvesting operation was observed from mid August 2006 to December 2006. The study site consisted of a young pine plantation on private land on which the stumpage was bought by the logger himself.

5.1.2. Equipment

The logger was working on the site with a conventional thinning operation. Equipment used by this logger consisted of a feller-buncher (Hydro-Ax 321), a skidder (John Deere 548), a loader with a pull-through delimber (Timberjack) and a residue chipper (Bandit 1850).

This Bandit 1850 portable chipper has 275 horsepower with an 18 inch-diameter capacity. The chipper weighs 12,000 pounds and has a 5.5 foot conveyor belt for speed feeding, which allows easy loading of large material and limbs. This chipper was designed for land clearers and land services which specialize in light land clearing. It is compact so it can be easily maneuvered from one landing or tract to the next. There exist a number of ways to equip this chipper, depending on the setup of the operation. The equipment layout of the machines on his landing is shown in Figure 3.

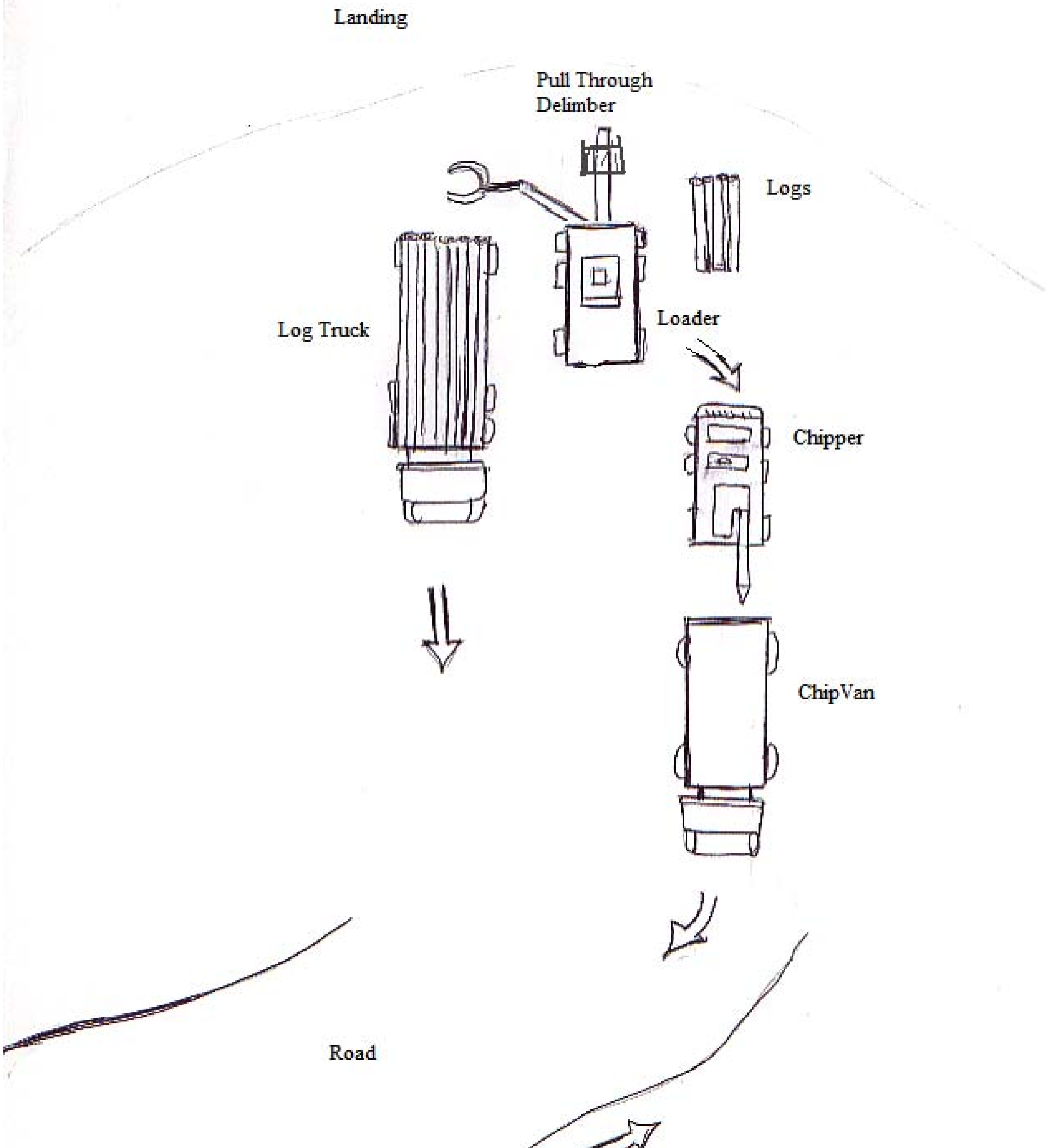

Fig 3. Chipping Layout for Operation 1

5.1.3. Residue Chipper Set-Up

This logger chose to set up his residue chipper integrated into his roundwood operation. This was a thinning operation in which only rows and selected trees were being harvested and brought to the landing in tree-length form by the skidder. Trees were gate delimbed, and then processed by a knuckleboom loader which was delimbing, sorting and hot loading the roundwood. The same loader used in the conventional system for roundwood processing was used for feeding the wood to the small residue chipper. No extra operator was hired for running the chipper which saved labor costs. When the residue material accumulated, the same loader was used to feed the residue into the chipper. The chips were blown into chip vans. This logger has been using this set-up for the past 2 years.

Trees were backed through a gate delimber before being topped with a pull-through delimber. The limbs removed at the gate were being spread back on the site and not chipped. Therefore, he was mainly feeding small diameter trees and the tops and very little foliage. This resulted in fuel chips with a higher percentage of wood compared with other material.

The plan of this logger was to generate one load of fuel chips per day. When production data from the previous year and a half were analyzed, it showed that on average he produced 30.43 loads of roundwood to 5.40 loads of fuel chips per week. But, when the data was broken into two sections it showed that he produced 3.6 loads / week for the first nine months and almost 7 loads per week in the later nine months of the operation. Graphical description of the historical data is given in Figure 4. The logger was quite satisfied with the results of the operation and residue chipper use. He was probably one of the first loggers in Alabama to start using this machine, and was very content with its performance and planned to continue to use the combination.

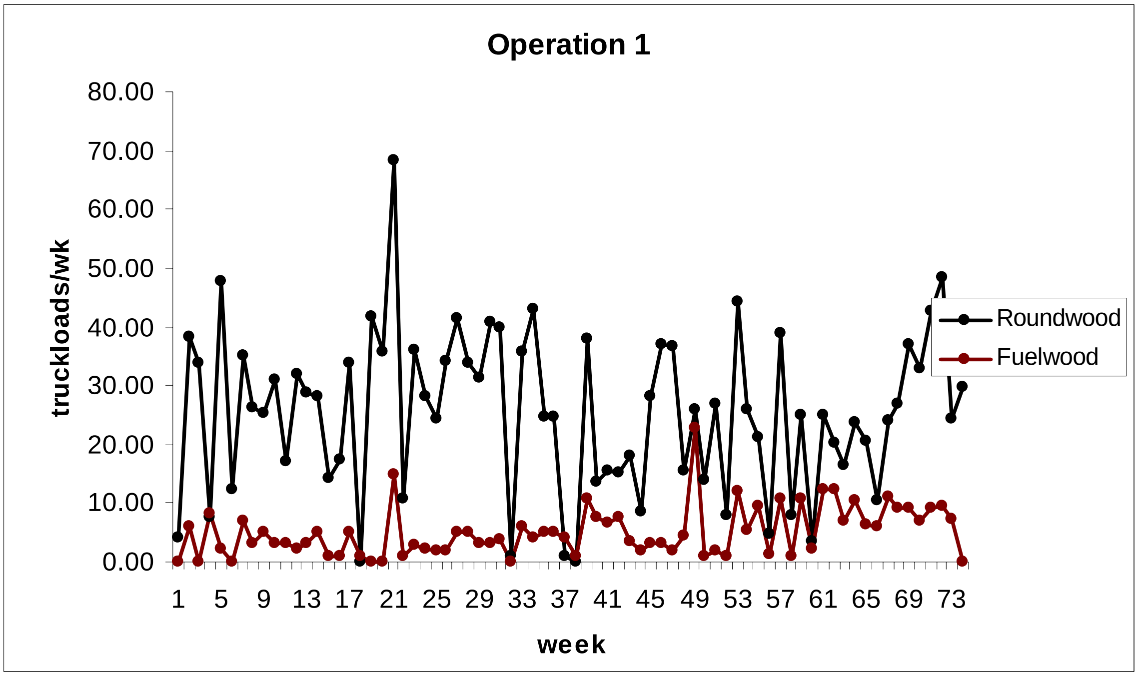

Figure 4. Truckloads of roundwood and fuel chips per week for Operation 1.

5.1.4. Product Sampling Results

Eight samples of chipped residue material were collected from Operation 1. The percentages (wet basis) for each type are presented in a Table 4.

Table 4. Breakdown of sample material - Operation 1 (%wet weight)

OPERATION 1						
Sample	Wood	Bark	Twigs	Foliage	Fines	Moisture%
1	84.08	7.79	1.06	0.03	3.32	47.63
2	85.89	8.09	4.80	0.09	1.13	49.92
3	80.31	11.11	4.63	0.95	3.00	44.73
4	85.18	9.56	2.27	1.81	1.08	57.26
5	80.13	9.83	3.08	1.13	5.83	56.46
6	87.02	10.85	0.00	0.02	2.11	52.70
7	73.51	10.05	0.42	3.03	2.66	56.67
8	84.25	9.51	3.81	0.07	2.36	54.58
Average	84.08	9.65	2.67	0.91	2.69	52.48

The samples from Operation 1 had the most wood content among all the operations studied. Most chip samples contained at least 80% wood with a range of 73 to 87 percent. Bark and wood accounted for 94 percent of material on average with bark content ranging from 8 to 11 percent. The fine content was very low in most of the samples. The fines were in range of 1%-3 %. The twigs were in the range of 0-5% and in one of the samples no twigs were observed. This can be attributed to the manner in which this operation was performed. The emphasis was to return the limbs to the skid trails to minimize site impact and chip only the tops and small diameter trees. The foliage content ranged from 0.02 to 3.03 % in the eight samples. The samples were oven-dried to estimate the moisture content. The average moisture content was found to be 52.48 percent on a wet basis.

5.1.5. Yellow Box Findings

The Yellow Box was used on the Bandit chipper to estimate the average number of hours a day that it worked. Data were collected over five months for this operation, and the run time per day and average run time for each month is shown in Table 5. The overall average time over the five months was calculated to be 1.87 hrs per day. Because this logger was using a set-out trucking system, we could not directly tie deliveries to production data. The overall delivery data for Operation 1indicated he was producing 7 loads per week or 1.4 loads per day during the 5 month period Yellow Box data was recorded. The average load for operation 1 was found to be 25 tons; therefore 1.4 loads per day would mean he was producing 35 tons per day. This gives the production rate of 18.71 tons per hour for this chipper. This rate was used in the Discounted Cash Flow spreadsheet to calculate the cost of running the chipper.

Table 5. The Yellow Box Time Recordings for Operation 1

YELLOW BOX FINDINGS- TOTAL WORK TIME									
Date-Sept (06)	Total Time (hrs)	Date-Oct (06)	Total Time (hrs)	Date-Nov (06)	Total Time (hrs)	Date-Dec (06)	Total Time (hrs)	Date-Jan (07)	Total Time (hrs)
14	3.17	2	1.05	1	1.11	1	1.14	2	2.16
15	1.44	3	2.38	2	3.39	4	4.41	3	1.23
18	1.10	4	2.38	3	2.04	6	1.02	4	1.25
20	1.17	5	1.06	4	1.01	7	1.53	9	1.58
21	1.08	6	1.32	6	3.09	8	2.09	10	2.11
22	1.2	9	7.16	7	0.51	11	2.31	11	3.45
23	1.43	10	3.04	8	2.01	12	1.08	12	1.11
26	1.03	11	1.22	9	0.54	13	3.30	15	1.56
28	3.51	12	1.51	22	1.13	14	1.43	17	2.44
29	1.21	13	1.40	27	2.21	18	1.13	18	2.2
		16	1.25	28	2.43	19	2.05	19	2.25
		18	2.07	29	2.12	20	1.30	20	2.03
		19	2.33	30	1.41	21	1.50		
		23	1.21			26	1.28		
		24	2.50			27	2.16		
		25	2.16			28	2.12		
		30	0.51			29	1.43		
		31	2.24						
Average Time/ Month	**1.63**		**2.04**		**1.77**		**1.84**		**1.95**

5.1.6. Utilization Rate

Scheduled machine hours per year were assumed to be 2000 hours for this operation. The chipper worked an average of 1.87 hours per day, or 467.5 productive hours per year. Therefore, the utilization rate for the chipper was 23.37%. The low utilization rate was the result of using only one loader, which spent most of its time merchandizing and loading roundwood. The main objective of the chipper on this job was to clean the site, though the logger had to have some profit while doing it.

5.1.7. Fuel and Lube Costs

Using an average price of diesel of $2.75/gallon, fuel costs for the Bandit chipper were estimated to be $27.98/PMH. Another $2 per PMH was added to cover lubrication costs. The loader fuel and lube costs were calculated in a similar manner and found to be $19.30/PMH.

5.1.8. Maintenance and Repair Costs

Maintenance and Repair costs were calculated according to machine rate principals (Brinker et al, 2002) and found to be $23.08 for the Bandit chipper. Over the 467 hours per year estimated for run time that would be approximately $10,800 per year for maintenance and repair expenses. After discussing this amount with the logger, he agreed this was a reasonable estimate. Chipper knife maintenance, rewelding of the chipper walls from wear and tear, repairing of the remote chipper controls and blower spout replacement were some of the costs incurred by the logger for this chipper.

Maintenance and repair costs for the loader were calculated to be $13.12/PMH. While the logger did not comment on this estimate, it was found by using long term accepted principals of machine rate calculations.

5.1.9. Cost Analysis

The costs analysis was completed for operation 1 using the Tufts spreadsheet. Cost inputs consisted of both fixed and operational cost.

5.1.9.1. Fixed Costs

The interest, discount and insurance rates were assumed to be 10%, 6% and 4 % respectively. The salvage value for the chipper was assumed to be zero in this case, as it is a new machine with an unclear future. The purchase price for the chipper was estimated at $100,000 (confirmed from Bandit Company). Because this was a harsh application for the chipper, machine life was only expected to be four years. No fixed costs were assumed for the loader on this operation because it was purchased and being used mostly for roundwood production.

5.1.9.2. Operational Costs

Variable costs were calculated as shown above. No labor costs were included on the chipper. The residue chipper was fed by the loader operator that processed and loaded roundwood. It generally supplied the chipper during the times between loading trucks. Since he was not a dedicated operator to the chipper only, only two hours of labor costs were used in this scenario. The labor rate for the loader operator was assumed to be $12.50. Since the spreadsheet was configured to allocate costs over a full 8 hour day, the labor rate for the loader operator was input as $3.13 (2 hours x $12.50/hr / 8 hours). Other variable costs for the loader such as fuel and repairs were included for the two 2 hours of chip production.

5.1.9.3. Hauling Costs

Hauling costs are also included in the total. The hauling cost was assumed to be $5/ton for this analysis, but will vary greatly with distance form the mill.

5.1.9.4. Cost Results

Using the system productivity calculated by the yellow box data of 18.71 tons/PMH and the utilization of 23%, the cost of producing fuel chips per ton for the residue chipper for four years were $4.67 (Table 6). The costs per ton per productive machine hour for the loader were $1.92 (Table 7). With the addition of hauling, the cost was raised to $11.59/ ton of fuel chips. Profit or any stumpage costs to the landowner are not included in this estimate.

Table 6. Discounted Cash-Flow Residue Chipper- Operation 1

DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS

Residue chipper- 1850 Bandit Chipper

Purchase price	$100,000		Discount rate		6.00%
Trade-in	$0		Finance APR		10.00%
BV of trade-in	$0		Marginal tax rate		28.00%
Down payment	$0		Amount financed		$100,000
Number of payments	48		Monthly payment		$2,536
Expense Option	$0		Adjusted basis		$100,000
Hours per day	8.00		Expected life, years		4
Days per year	250		Residual value end of life		20.00%
Fuel & Lube	$29.98		Inflate F&L		5.00%
Maint & Repair	$23.08		Inflate M&R		15.00%
Labor rate	$0.00		Inflate labor		5.00%
Fringe benefit %	30.00%		Utilization		23.37%
Insurance & taxes	4.00%		Production (tons/PMH)		18.71
AEC	($50,287)	($46,860)	($43,671)	($40,813)	#N/A
Cost per ton	($5.75)	($5.36)	($4.99)	($4.67)	#N/A
	Year 1	Year 2	Year 3	Year 4	Year 5
Salvage value	68,000	44,000	28,000	20,000	#N/A
ACRS Dep	20,000	32,000	19,200	11,520	#N/A
Book value	80,000	48,000	28,800	17,280	#N/A
Fuel & Lub	14,016	14,717	15,453	16,226	#N/A
Repair & Maint.	10,790	12,408	14,270	16,410	#N/A
Labor	0	0	0	0	0
Insurance	4,000	2,720	1,760	1,120	#N/A
Total Expenses	28,806	29,845	31,483	33,756	#N/A

Table 7. Discounted Cash-Flow Timberjack Loader- Operation 1

DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS

Timberjack Loader

Purchase price	$0		Discount rate		6.00%
Trade-in	$0		Finance APR		10.00%
BV of trade-in	$0		Marginal tax rate		28.00%
Down payment	$0		Amount financed		$0
Number of payments	48		Monthly payment		$0
Expense Option	$0		Adjusted basis		$0
Hours per day	8.00		Expected life, years		4
Days per year	250		Residual value end of life		20.00%
Fuel & Lube	$19.30		Inflate F&L		5.00%
Maint & Repair	$13.12		Inflate M&R		15.00%
Labor rate	$3.13		Inflate labor		5.00%
Fringe benefit %	30.00%		Utilization		23.37%
Insurance & taxes	4.00%		Production (tons/PMH)		18.71
AEC	($16,762)	($17,383)	($18,033)	($18,713)	#N/A
Cost per ton	($1.92)	($1.99)	($2.06)	($2.14)	#N/A
	Year 1	Year 2	Year 3	Year 4	Year 5
Salvage value	0	0	0	0	0
ACRS Dep	0	0	0	0	0.00
Book value	0	0	0	0	0
Fuel & Lub	9,022	9,473	9,946	10,444	#N/A
Repair & Maint.	6,134	7,054	8,112	9,328	#N/A
Labor	8,125	8,531	8,958	9,406	#N/A
Insurance	0	0	0	0	0
Total Expenses	23,280	25,058	27,016	29,178	#N/A

5.2. Operation 2

5.2.1. Study Site

Operation 2 was observed from mid May 2006 to August 2006. The study site consisted of a mature pine and hardwood stand on private land that was being clearcut. The site was located near Union Springs, Alabama.

5.2.2. Equipment

The logger was working on the above mentioned site with a conventional operation. His equipment spread consisted of one feller-buncher (Hydro Ax 511), two skidders (Caterpillar 525’s), and two loaders (Tigercat 240 B’s). Pull through delimbers on the loaders were used for delimbing and topping the stems. For residue chipping, he was using a small loader (Prentice 210 D) and a chipper (Bandit 1850). A loader may be attached directly to the chipper for self-feeding, but was not on this operation. The layout of the equipment on the landing is shown in Figure 5.

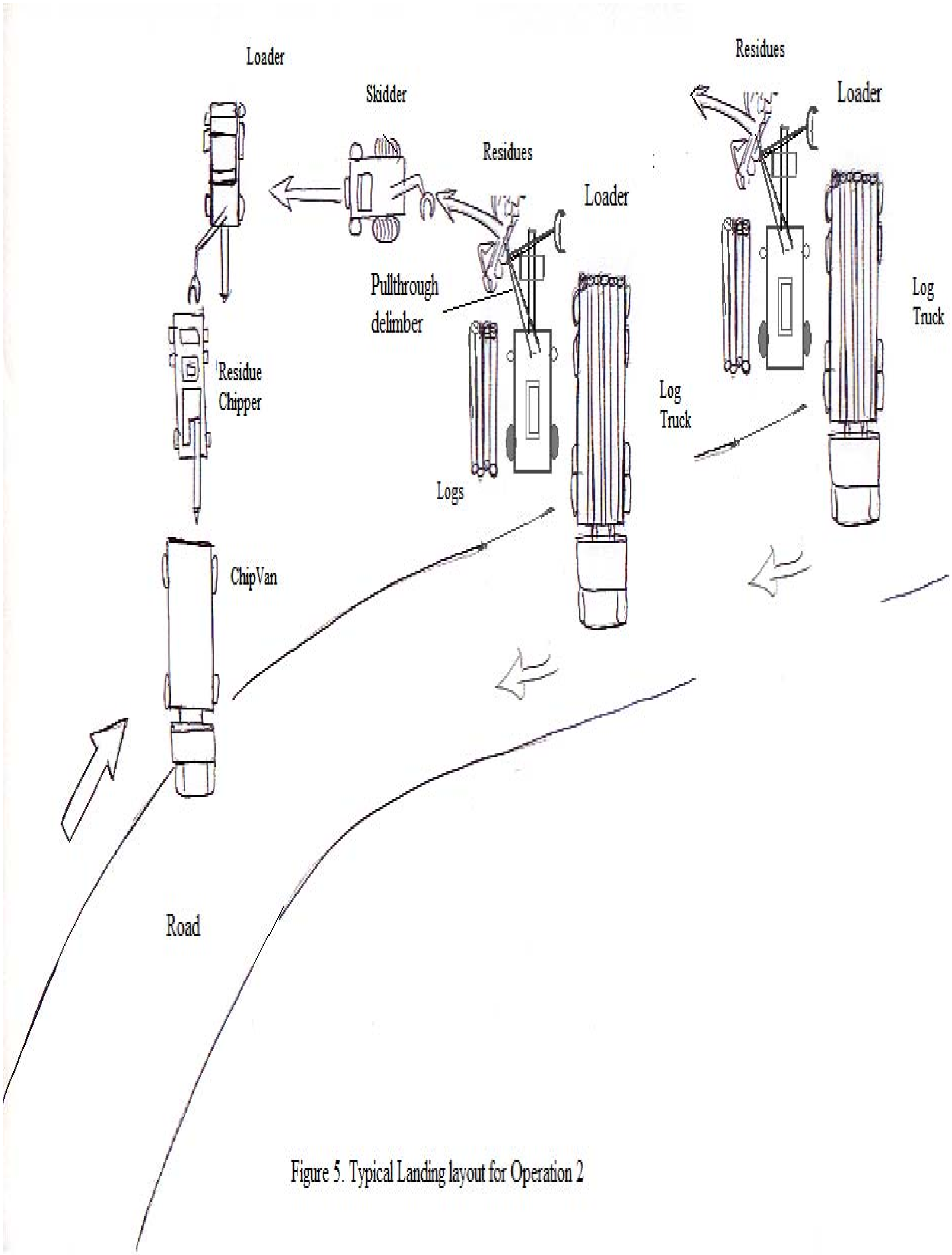

Figure 5. Typical Landing layout for Operation 2

5.2.3 Residue Chipper Set-up

This logger chose to set-up his residue chipper separately from his roundwood operation. This was a clearcut operation in which all above ground material was harvested and brought to the landing in whole tree form where two knuckleboom loaders were processing, sorting, and loading roundwood. These loader operators also pulled the small, unmerchantable material from the skidder load and put it aside for chipping. The chipping operation was set-up nearby so the skidders could take the material from the roundwood knuckleboom loaders and drop it off for processing. The full time operator for this part of the operation then took the residue material consisting of small stems, limbs and tops and fed them into the chipper. The chips were blown into the chip vans. The chips were then hauled to the nearby mills as fuel for wood boilers. This operation had been using this set up for the previous year or so.

According to the logger, his plan was to generate about 3-4 loads of fuel chips per day. When the production data for the previous year were analyzed, they showed that he had produced on average 48 loads of roundwood to 11 loads (2.2 loads / day) of fuel chips per week. On average he was producing 4 loads of roundwood to one load of fuel chips. The historical data for logger 2 is shown in figure 6. Shortly after beginning measurement of chipper runtime with the Yellow Boxes, the contractor decided to discontinue its use. Very little production data were therefore available for this chipper. The major problems contributing to the decision to cease its operation were delays. The residue chipper was set-up far enough away that the skidders were required to bring all the material to be processed. The operation was observed waiting for material much of the time. The skidders were needed to move the material all the time, and any delay in moving the material meant the chipper was idle.

This operation was also experiencing a chipper problem. The knives had to be changed every 3-4 loads. This was costly in both time and knife sharpening expense. While there was not enough time to investigate the cause of the short knife life, a likely reason could be the amount of dirt found in the leaves and needles was accelerating knife wear.

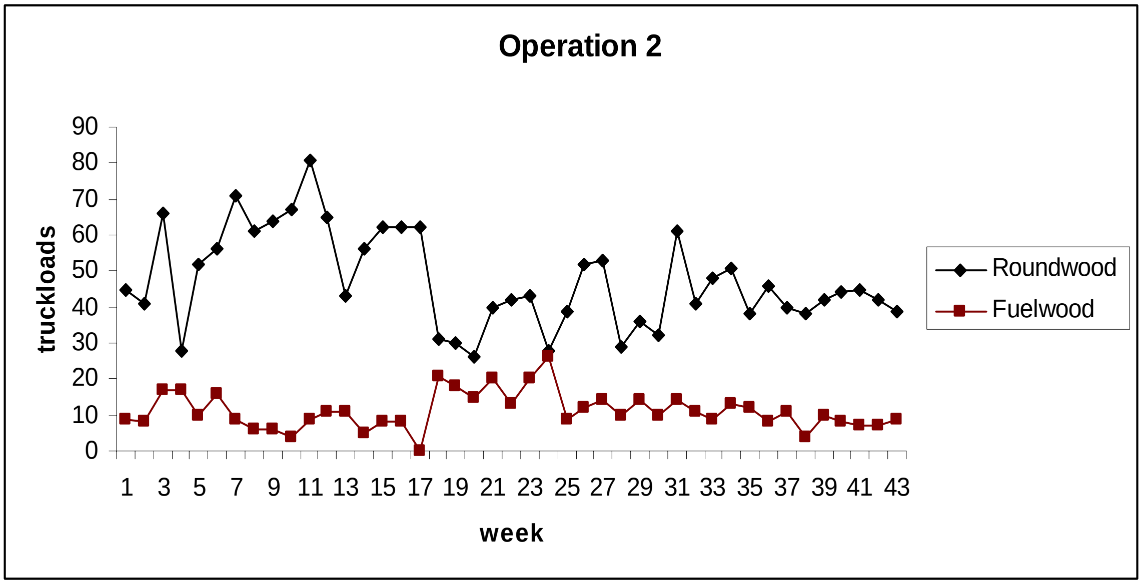

Figure 6. Truckloads of roundwood and fuel chips per week for Operation 2.

5.2.4. Product Samplings Results

Four samples of chipped residue material were collected from the Operation 2. The percentages (wet weight) for each types of material are presented in a Table 8.

Table 8. Component of residue material for samples taken at Operation 2 (% wet weight)

OPERATION 2						
Sample	Wood	Bark	Twigs	Foliage	Fines	Moisture%
1	78.34	7.06	7.01	5.50	2.10	44.57
2	77.93	8.79	3.70	5.16	4.32	48.33
3	71.45	11.27	4.75	7.14	5.40	38.26
4	47.40	13.06	11.38	15.37	12.79	55.17
Average	68.78	9.98	6.74	8.38	6.67	46.61

Most of the chip samples had a high volume of wood, generally around 75 percent of the material. The wood content of the samples showed a range of percentages from 47%-78% of the sample but generally stayed in the 75% range. Bark, twigs and foliage made up the remaining 25 percent and tended to be evenly distributed. The bark content increased from 7%-13% as the wood content decreased. The twigs percentages followed the same trends having a range of 7%-11% and foliage percentage between 5%-15%. The fine content also increased and had a wide range of 2%- 13%. The fourth sample was very different from the other three in its component percentages, with a smaller percentage of wood, and a higher percentage of all other components. This may have been caused by a higher percentage of tops being chipped prior to collection of this sample. The variability of the samples seems to suggest a need for more samples, but this was not possible, as the logger discontinued his chipping operation soon after the study was begun. While some dirt was evident, it was usually in very small quantities. These samples were oven dried for 6-7 days to estimate the amount of moisture content. The moisture content was 46.61 % on wet basis.

5.2.5. Production Rate

A Yellow Box was also used on Operation 2 to collect run time data for the chipper. However, the chipping operation was on the verge of being shutdown for this logger and the data was difficult to interpret, especially as it related to delivery data. There was very little observable correlation between chipper runtime and records of fuel chip deliveries. Therefore, the production numbers collected were not used, and the historical delivery volumes were substituted. Since Operation 1 and 2 were utilizing the same chipper, the same production rate was used for Operation 2 (18.71 tons/PMH).

5.2.6. Utilization Rate

It was assumed that the operation worked for 250 days a year, for eight hours each day, which equals 2000 scheduled machine hours per year. The logger produced 2.2 loads of chips/day, or about 55 tons/day. At the rate of 18.71 tons/PMH, the chipper worked an average of 2.94 hours/day, or 735 productive hours per year. Using these numbers and the formula above, it was calculated that the utilization rate for the chipper and loader was 36.75%.

5.2.7. Fuel and Lube Costs

Fuel and lube costs for the Bandit chipper were calculated similar to the previous operation, which amounted to \$29.98/PMH. For the Prentice loader, similar calculations netted a rate of \$16.15/PMH.

5.2.8. Maintenance and Repair Costs

Maintenance and repair costs were also calculated similar to the previous operation and amounted to \$23.07 and \$5.60/PMH for the chipper and loader, respectively. Again, the annualized estimate for chipper maintenance and repair (737 hours x \$23.07/PMH = \$17,000) was discussed with the logger. He was changing knives out on a daily basis and had to do a major rebuild of the chipper side walls after just one year of running and thought the cost estimate was justified.

5.1.9. Cost Analysis

Two machines were being used on site by this logger for the production of fuel chips. In addition to a residue chipper, a loader was also being used. No direct labor was being employed to run the residue chipper so labor rate was assumed to be zero. Instead a person was employed to run the loader. This loader was engaged in feeding the chipper.

5.2.9.1. Fixed Costs

The interest, discount, and insurance rates were assumed to be 10%, 6% and 4 % respectively. The salvage value for the chipper was assumed to be zero in this case, as it is a new machine with an unclear future. The salvage value for the small loader was assumed to be 20 % of the purchase price. Machine life was expected to be four years. Financing was assumed to be 100% for the chipper and the loader.

5.2.9.2. Operational Costs

Variable costs were calculated as shown above. Labor rate for the loader operator was assumed to be $12.50/hour, with 30% fringe added to that.

5.2.9.3. Results

System productivity was the same 18.71 tons/PMH as used in operation 1. The costs of producing fuel chips per ton for the residue chipper (Table 9) for four years were $3.82, and for the loader (Table 10) they were $3.36. The total cost per ton to put material in the van was $7.18 per ton. Costs for Operation 2 were found to be very similar to cots for Operation 1. So the additional volume produced on a daily basis was able to cover the cost of a dedicated employee and loader. With the addition of $5 of hauling costs, the costs were raised to $12.18 / ton of fuel chips.

Table 9. Discounted Cash flow Analysis- Residue Chipper Operation 2

DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS

Residue chipper –Bandit 1850

Purchase price	$100,000	Discount rate	6.00%
Trade-in	$0	Finance APR	10.00%
BV of trade-in	$0	Marginal tax rate	28.00%
Down payment	$0	Amount financed	$100,000
Number of payments	48	Monthly payment	$2,536
Expense Option	$0	Adjusted basis	$100,000
Hours per day	8.00	Expected life, years	4
Days per year	250	Residual value end of life	20.00%
Fuel & Lube	$29.98	Inflate F&L	5.00%
Maint & Repair	$23.08	Inflate M&R	15.00%
Labor rate	$0.00	Inflate labor	5.00%
Fringe benefit %	30.00%	Utilization	36.75%
Insurance & taxes	4.00%	Production (tons/PMH)	18.71

AEC	($60,503)	($57,539)	($54,841)	($52,502)	#N/A
Cost per ton	($4.40)	($4.19)	($3.99)	($3.82)	#N/A
	Year 1	Year 2	Year 3	Year 4	Year 5
Salvage value	68,000	44,000	28,000	20,000	#N/A
ACRS Dep	20,000	32,000	19,200	11,520	#N/A
Book value	80,000	48,000	28,800	17,280	#N/A
Fuel & Lub	22,036	23,138	24,295	25,510	#N/A
Repair & Maint.	16,964	19,508	22,435	25,800	#N/A
Labor	0	0	0	0	0
Insurance	4,000	2,720	1,760	1,120	#N/A
Total Expenses	43,000	45,366	48,490	52,429	#N/A

Table 10. Discounted Cash-flow of Prentice Loader- Operation 2

DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS

Prentice 210 D Loader

Purchase price	$40,000	Discount rate	6.00%
Trade-in	$0	Finance APR	10.00%
BV of trade-in	$0	Marginal tax rate	28.00%
Down payment	$0	Amount financed	$40,000
Number of payments	48	Monthly payment	$1,015
Expense Option	$0	Adjusted basis	$40,000
Hours per day	8.00	Expected life, years	4
Days per year	250	Residual value end of life	20.00%
Fuel & Lube	$16.25	Inflate F&L	5.00%
Maint & Repair	$5.60	Inflate M&R	15.00%
Labor rate	$12.50	Inflate labor	5.00%
Fringe benefit %	30.00%	Utilization	36.75%
Insurance & taxes	4.00%	Production (tons/PMH)	18.71

AEC	($47,929)	($47,227)	($46,627)	($46,167)	#N/A
Cost per ton	($3.49)	($3.44)	($3.39)	($3.36)	#N/A
	Year 1	Year 2	Year 3	Year 4	Year 5
Salvage value	27,200	17,600	11,200	8,000	#N/A
ACRS Dep	8,000	12,800	7,680	4,608	#N/A
Book value	32,000	19,200	11,520	6,912	#N/A
Fuel & Lub	11,940	12,537	13,164	13,822	#N/A
Repair & Maint.	4,116	4,733	5,443	6,260	#N/A
Labor	32,500	34,125	35,831	37,623	#N/A
Insurance	1,600	1,088	704	448	#N/A
Total Expenses	50,156	52,483	55,143	58,153	#N/A

5.3. OPERATION 3

5.3.1. Study Site

The third operation was studied in January 2007. The study site consisted of a young pine plantation being thinned. The operation utilized a residue chipper for fuelwood production along with conventional equipment. The site was located near Greenville, Alabama.

5.3.2. Equipment

The crew was a small thinning crew. A three wheel feller-buncher (Valmet 603), grapple skidder (John Deere), loader (Tiger Cat) with hydro gate, Bell Logger, and small chipper (Dynamic Conehead chipper) were used on site by this logger. The layout of the equipment is shown in Figure 7.

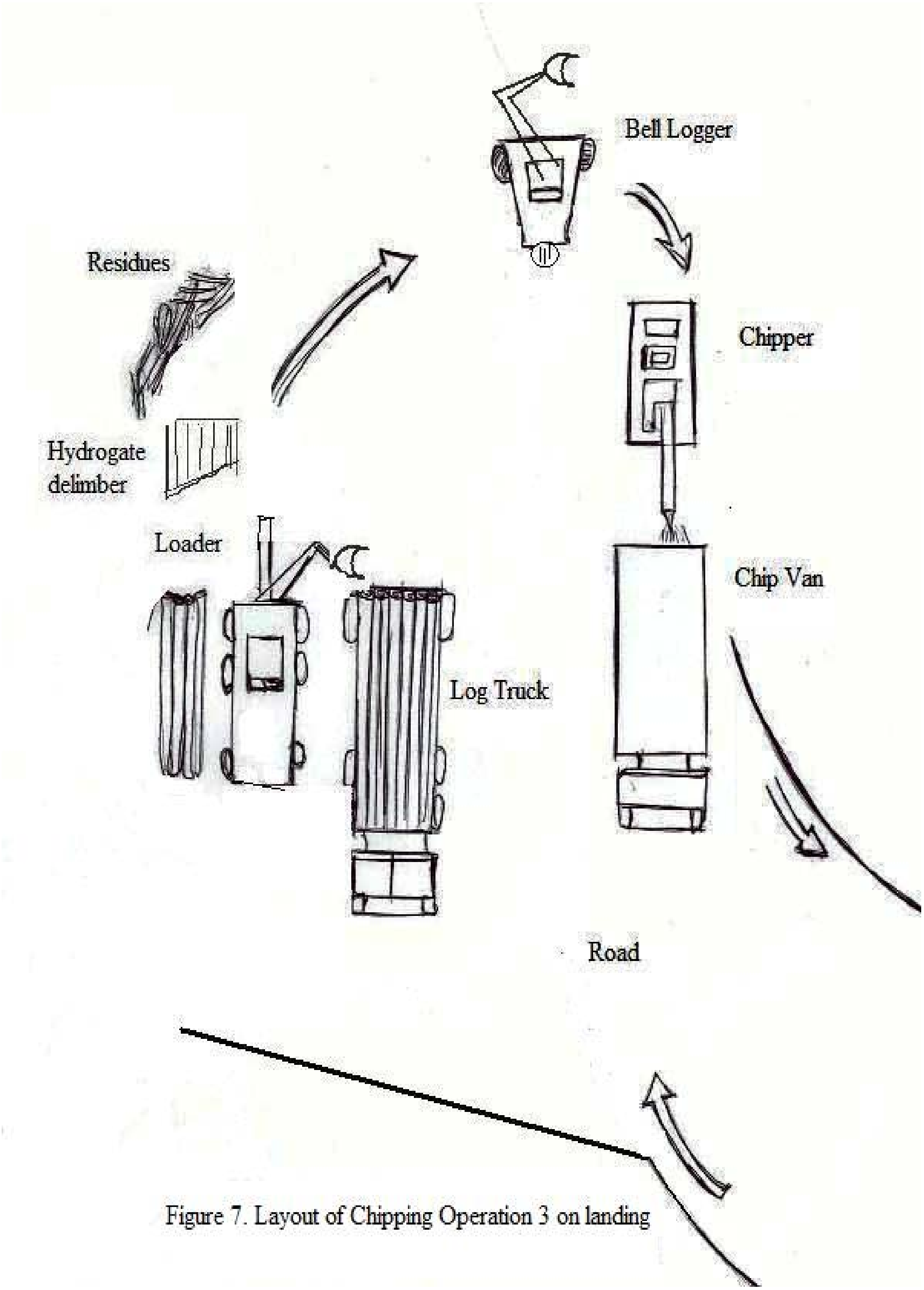

Figure 7. Layout of Chipping Operation 3 on landing

5.3.3. Residue Chipper Set-Up

This logger also chose to set-up his residue chipper separate from his roundwood operation. This was a thinning operation, similar to Operation 1. The thinned trees were skidded to the landing where a knuckleboom loader was used to process the trees and load roundwood. The loader was used to buck the trees at about 20 feet with minimal delimbing. The loader then loaded the random length material on a truck. Trees were cut to random length to assure a full payload from the small piece size.

The logger was using a hydrogate to delimb the trees and a Bell Logger to feed the chipper. The Bell Logger picked up the residue material consisting of small trees, limbs, and tops and fed them into the residue chipper. The fuel chips were blown into the chip vans. The chips were then hauled to the nearby mills as fuel for wood boilers.

Production was 4 loads of fuel chips / day on private land. He was getting the highest number of loads recorded for all the three loggers.

5.3.4. Product Sampling Results

Four samples of chipped residue material were collected from Operation 3. The samples were separated into five categories- wood, bark, foliage, twigs and fines as done previously for other samples. The percentages for each component are presented in Table 11.

Table 11. Component of residue material for samples at Operation 3 (% wet weight)

OPERATION 3						
Sample	Wood	Bark	Twigs	Foliage	Fines	Moisture%
1	72.77	8.09	1.40	4.09	13.65	53.39
2	67.96	5.98	5.70	1.39	18.96	45.61
3	64.98	5.08	3.90	0.85	25.10	33.54
4	58.67	10.50	9.66	5.16	16.00	35.99
Average	61.11	6.90	4.54	2.87	16.41	42.13

Most of the chip samples had a low volume of wood, generally around 65% of material. The wood content of the samples showed a range of percentages from 58%-72% of the sample. In the remaining material the bark content was in the range of 5%-10%; the twigs showed a wider range from 2%-10% and the foliage percentages were between 1%-5%. Fines (undistinguishable material) were much higher for this operation and were believed to be mostly needle material that was processed to very small piece size. The moisture content was 42.13% on wet basis.

5.3.5. Production Rate

This operation was visited near the end of the study. Lack of time and a long distance away allowed for a single day visit only. No Yellow Box was installed on this chipper. The Dynamic Conehead chipper is a larger chipper than the Bandit, and the logger was certain it could produce more volume. His experience with his crew was loading chip vans in about 1.25 hours. So, the production for this chipper was assumed to be 20 tons / PMH. A recent study done in Georgia (Westbrook, Jr., et al, 2007) found a production rate of 28.6 tons per PMH for a similar Dynamic chipper, so this estimate, if anything, is on the conservative side.

5.3.5. Utilization Rate

Scheduled machine hours per year were assumed to be 2000 hours, as calculated above. The logger produced 4 loads per day of fuel chips, or 100 tons/day. At the rate of 20 tons/hr, the chipper worked an average of 5 hours per day, or 1,250 productive hours per year. Therefore the utilization rate for the chipper was 62.5%.

5.3.6. Fuel and Lube Costs

Fuel and lube costs were calculated similar to the previous operations, using the higher horsepower rating for this chipper and the lower horsepower rating of the Bell Logger. Estimates for fuel and lube were $35.07 and $6.50 for the chipper and Bell, respectively.

5.3.7. Maintenance and Repair Costs

Maintenance and repair costs were calculated for the chipper and Bell Logger. Estimates were $25.00/PMh for the chipper and $11.43 for the Bell Logger. When the logger was asked about the maintenance costs, he did not comment on the value because he had not been running the machine very long.

5.3.8. Cost Analysis

Costs were calculated in a similar manner as the other operations. Cost inputs consisted of both fixed and operational costs.

5.3.8.1. Fixed Costs

The salvage value for the chipper was assumed to be zero in this case, as it is a new machine with an unclear future. The salvage value for the other machines was assumed to be 20 % of the purchase price. Machine life was expected to be four years.

5.3.8.2. Operational Costs

All these costs were estimated in similar fashion as the previous two operations. The scheduled machine hours were assumed to be 2000 hrs/year which gives 250 work days per year with 8 hr shift. The maximum utilization for the residue chipper and skidder for this logger was assumed to be 62.50 %. No direct labor was being employed to run the residue chipper, so labor rate was assumed to be zero. A person was employed to run the Bell Logger.

5.3.8.3. Results

The cost of producing fuel chips per ton for the residue chipper for four years were $3.49, and for the Bell Logger were $ 2.17 (Table 12 and 13). The total costs for the residue chipper and the Bell Logger were found to be $5.66. With the addition of hauling costs the costs were raised to $10.66/ ton of fuel chips. This estimate is understated. Even though we do not apply it here, for this operation a proportion of felling and skidding costs should be added to the total cost of fuel chips because the production of fuel material is one of the objectives of the harvesting system, whereas in the previous operations it was a by-product. How much costs should be added will depend on the ratio of roundwood to fuel chips.

Table 12. Discounted Cash-Flow Residue Chipper- Operation 3

DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS

Dynamic Cone Third Chipper

Purchase price	$125,000		Discount rate		6.00%
Trade-in	$0		Finance APR		10.00%
BV of trade-in	$0		Marginal tax rate		28.00%
Down payment	$0		Amount financed		$125,000
Number of payments	48		Monthly payment		$3,170
Expense Option	$0		Adjusted basis		$125,000
Hours per day	8.00		Expected life, years		4
Days per year	250		Residual value end of life		20.00%
Fuel & Lube	$35.07		Inflate F&L		5.00%
Maint & Repair	$25.00		Inflate M&R		15.00%
Labor rate	$0.00		Inflate labor		5.00%
Fringe benefit %	30.00%		Utilization		62.50%
Insurance & taxes	4.00%		Production (tons/PMH)		20.00
AEC	($94,595)	($91,703)	($89,185)	($87,164)	#N/A
Cost per ton	($3.78)	($3.67)	($3.57)	($3.49)	#N/A
	Year 1	Year 2	Year 3	Year 4	Year 5
Salvage value	85,000	55,000	35,000	25,000	#N/A
ACRS Dep	25,000	40,000	24,000	14,400	#N/A
Book value	100,000	60,000	36,000	21,600	#N/A
Fuel & Lub	43,836	46,028	48,329	50,746	#N/A
Repair & Maint.	31,250	35,938	41,328	47,527	#N/A
Labor	0	0	0	0	0
Insurance	5,000	3,400	2,200	1,400	#N/A
Total Expenses	80,086	85,365	91,857	99,673	#N/A

Table 13. Discounted Cash-flow Bell Logger- Operation 3

DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS

Bell Logger

Purchase price	$50,000		Discount rate		6.00%
Trade-in	$0		Finance APR		10.00%
BV of trade-in	$0		Marginal tax rate		28.00%
Down payment	$0		Amount financed		$50,000
Number of payments	48		Monthly payment		$1,268
Expense Option	$0		Adjusted basis		$50,000
Hours per day	8.00		Expected life, years		4
Days per year	250		Residual value end of life		20.00%
Fuel & Lube	$6.50		Inflate F&L		5.00%
Maint & Repair	$11.43		Inflate M&R		15.00%
Labor rate	$12.50		Inflate labor		5.00%
Fringe benefit %	30.00%		Utilization		62.50%
Insurance & taxes	4.00%		Production (tons/PMH)		20.00
AEC	($55,748)	($55,088)	($54,590)	($54,304)	($55,748)
Cost per ton	($2.23)	($2.20)	($2.18)	($2.17)	($2.23)
	Year 1	Year 2	Year 3	Year 4	Year 5
Salvage value	34,000	22,000	14,000	10,000	#N/A
ACRS Dep	10,000	16,000	9,600	5,760	#N/A
Book value	40,000	24,000	14,400	8,640	#N/A
Fuel & Lub	8,122	8,528	8,954	9,402	#N/A
Repair & Maint.	14,288	16,431	18,895	21,730	#N/A
Labor	32,500	34,125	35,831	37,623	#N/A
Insurance	2,000	1,360	880	560	#N/A
Total Expenses	56,909	60,443	64,561	69,314	#N/A

5.4. Statistical Analysis Results

ANOVA results showed that the three logging operations had a statistically significant effect on the percentage of wood in the samples (Table 14). Tukey's Studentized Range test showed that the percentage of wood was significantly different between the first and second logging operations and the first and third operations (Table 15). Similarly, the ANOVA results also showed that the percentage of foliage and fines were also significantly different, while bark and twigs were not (Table 14). Tukey's Studentized Range test showed that the percentage of foliage was significantly different between the first and second logging operations and the second and third operations (Table 15). The same test showed that the percentage of fines was significantly different between the first and third and the second and third operations (Table 15). The moisture content did not statistically show any significant difference between the three logger samples (Table 15).

Table 14. ANOVA test for logger sample, component comparison

Components	DF	ANOVA SS	Mean Square	F-value	Pr > F
Wood	2	928.9604599	464.4802300	6.86	0.0092
Bark	2	16.84557599	8.42278800	2.27	0.1428
Twigs	2	51.75489040	25.87744520	3.51	0.0603
Foliage	2	147.8221217	73.9110609	10.71	0.0018
Fines	2	672.4359206	336.2179603	28.19	<.0001

Table 15. Significant Differences in the Components by Logger

Components	Mean percentage*
Wood	Logger 1 = 84.08 b Logger 2 = 68.63 a Logger 3 = 61.11 a
Bark	Logger 1 = 9.65 a Logger 2 = 9.98 a Logger 3 = 6.90 a
Twigs	Logger 1 = 2.67 a Logger 2 = 6.74 a Logger 3 = 4.54 a
Foliage	Logger 1 = 0.91 b Logger 2 = 8.38 a Logger 3 = 11.03 a
Fines	Logger 1 = 2.69 a Logger 2 = 6.27 a Logger 3 = 16.41 b

*Same letter means no significant difference at 0.05 level of significance (Tukey's Studentized Range Test)

ANOVA test results for moisture:

Components	DF	ANOVA SS	Mean Square	F-value	Pr > F
Moisture	2	304.276	152.138	3.57	0.058

The three logging operations can be defined as three different treatments to the residue material consisting of tops, limbs, broken sections and small stems. The statistical analysis above was done to see how the different treatments affect the components of the sample. The statistical difference in the wood content which is the main portion of the samples was found to be different between the loggers. This was believed to be because the first logger was feeding mostly clean tops with no limbs. The other two logger samples were the same in the wood content since they were chipping the same kind of material. The second logger was feeding everything along with small stems into the chipper since it was a clear-cut operation. The third logger was bucking at 20 feet of length and was also chipping all residue material. High fine content was found in the third logger which was different from the other two operations. This was believed to be due to the fact the stand material was not clean and it was a young stand with vine problems. And, all this material was fed to the chipper after hydrogate delimbing.

5.5. Effects of Roundwood Production on Energywood

The first two operations discussed in the results were statistically analyzed to see the effect of fuel chip production on the roundwood production. The weeks with no production of either roundwood or fuel chips were removed to avoid biased results.

5.5.1. Operation 1

Sixty-five weeks of data were analyzed for operation 1. To best fit the model, it was found from Box Cox test that the fuelwood (fw) required transformation. So, transformation of fw $^{1/4}$ was used to make the data normal. The regression model showed that the roundwood production had a significant influence on fuelwood production (p-value $\leq \alpha = .05$). To further explore what type of effect, a scatter plot was used. The scatter plot showed a positive effect of the explanatory variable (roundwood) on the response (Figure 8). This meant that as roundwood production increased, fuel chip production also increased, as would be expected.

Regression Model for Operation 1:

$[\text{Fuel chips (tons)}]^{1/4} = 2.852 + 0.0007\ \text{Roundwood (tons)}$

Analysis Of Variance:

	df	*SS*	*MS*	*F*	*Significance(f)*
Regression	1	2.854	2.854	8.380	0.0052
Residual	63	21.448	0.340		
Total	64	24.302			

Regression Equation Details:

Variable	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	2.85224	0.16887	16.89	< 0.0001
X Variable 1	0.0007	0.00023	2.90	0.0052

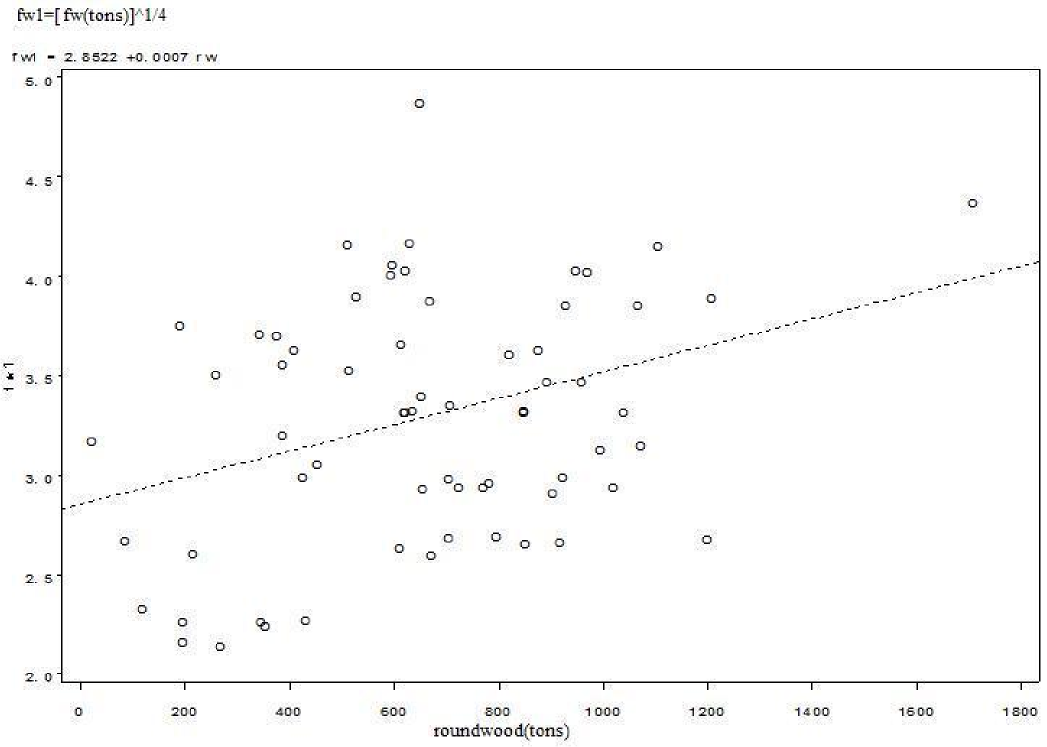

Figure 8. Graph showing the regression of fuel chips to roundwood

5.5.1 Operation 2

The data for Operation 2 contained 42 weeks of production and was analyzed similar to Operation 1. To best fit the model, transformation of fw $^{1/4}$ was used to make the data normal. The regression model also showed that the fuel chip production was significantly affected by roundwood production, but the scatter plot in this case showed a negative relationship between the two (Figure 9). This meant that as the roundwood production increased, fuel chip production decreased.

Regression Model for Operation 2:

$[\text{Fuel chips (tons)}]^{1/4} = 406.11 - 0.112 \text{ Roundwood (tons)}$

Analysis Of Variance:

	Df	*SS*	*MS*	*F*	*Significance(f)*
Regression	1	0.72602	0.72602	4.71	0.0360
Residual	40	6.16781	0.15420		
Total	41	6.89383			

Regression Equation Details:

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	6.02195	0.23409	25.72	<.0001
X Variable 1	-0.000413	0.0019041	-2.17	0.0360

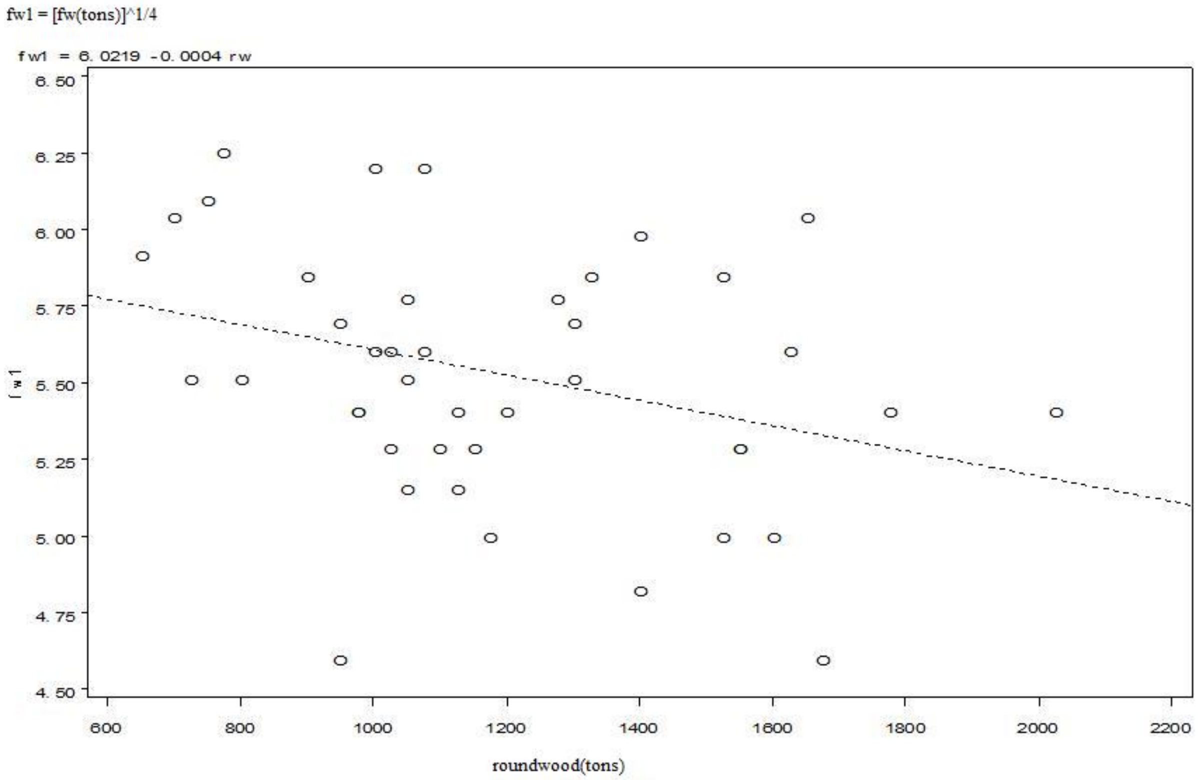

Figure 9. Graph showing roundwood on X-axis and fuel chips on Y-axis for Operation 2.

This negative relationship from the data supported the logger's decision to shut the operation down shortly after we started to monitor the operation. He believed the fuel chip production was preventing some roundwood production, and for the prices he was being paid, he could not afford to lose roundwood production. Roundwood must be the priority of the operation to cover logging costs. Fuel chips were considered an added opportunity for some additional income, but cannot be substituted for roundwood production.

6. SUMMARY

Conventional harvesting operations are the most popular method of harvesting in the Southeast US. The earlier feasibility study done by Bolding and Lanford (2001), with the combination of a small portable chipper with a CTL system seemed to be an efficient method to reduce forest fuel. No major emphasis has been given to the capability and capacity of conventional systems to serve the additional purpose of removing small biomass.

6.1. Logger System Discussion

Three loggers were studied to determine how they incorporated a residue chipper into their harvesting operations. They had three unique set-ups for obtaining fuel chips from their operations. The first logger elected to incorporate the residue chipper with a loader he used to process roundwood. He had been using the integrated set-up of the residue chipper with his roundwood operation for almost two years. As mentioned in the case discussion, the logger was getting 7 loads per week of fuel chips during the data collection period. According to him, he was using this operation as a means of extra income. He did not have the burden of additional labor. He was satisfied with the operation and wanted to continue to do it and set an example for other loggers.

The second logger used an independent set-up of a small loader and residue chipper with his conventional harvesting operation. The operation of the small loader required an extra laborer to run the system. He was not satisfied with the operation as he was getting fewer loads per day (2.2 truckloads) than he expected. While the cost estimates indicated he was still making money with this set-up, he elected to shut the operation down because he felt the fuel chip operation was hindering his production of roundwood. An analysis of his production data for the past year or so indicated his conclusion to be correct.

The third logger had a different perspective in undertaking the residue utilization operation. He added a Bell Logger and residue chipper into his original conventional thinning operation. He also had an extra laborer employed on the Bell Logger. This logger had a production goal of 4 loads per day, chipping more tops and limbs than the first operation. His higher production levels justified the additional operator.

All three harvesting systems justified the feasibility of using a residue chipper to recover fuel chips from their conventional operations, as long as roundwood production was not curtailed. Although these three loggers had different equipment mixes and system organization, they were still able to reach the goal of producing fuel chips. All three loggers were also using a set-out trucking system, and that helped with implementation of the residue chipper into the systems because a truck and driver did not have to wait for the chip van to be loaded.

6.2. Sample Analysis

The samples from all the loggers contained a considerable amount of wood content. The wood is the main component of the sample which defines the calorific value of the sample. The wood content in the samples of the first operation were higher than the first, with a range of 73- 87 percent. The samples were cleaner with higher wood content. The main reason for this was that this logger was putting only clean tops in the chipper. The samples from the second operation had a wood content in the range of 50- 78 percent. The wood samples from the third operation had more needles comparatively to the other loggers. He was gate delimbing trees, and all the material (limbs and tops) were processed in the chipper. The moisture content of all the samples was in the range of 40-50% (wet basis).

6.3. Cost Discussion

The costs were the lowest for the third operation. They were calculated to be $10.66/ton of fuel chips. The cost per ton incurred by this logger for residue chipping was considerably less than both of the other loggers, which can be attributed to his higher utilization. On the other hand, the way this operation was developed, logging cost should also be added to his fuel chip production costs since fuel chips were an important component of his daily production.

The costs for the first operation were $11.59/ton while producing the least amount of chips per week. He did not have any additional labor involved in the process. The costs were the highest in the second operation, which totaled $12.18/ton of fuel chips. While his costs seemed to indicate the operation was still profitable, he elected to cease running the chipper because the fuel chip production was interfering with his roundwood production.

7. CONCLUSIONS

This study was performed to observe several case studies of implementing a small chipper on a conventional operation to produce fuel chips for a biomass market. In addition to generating the fuel chips for a market, this type of operation brings about numerous opportunities for reducing forest fuel and reducing site preparation costs.

The conventional systems studied indicated that fuel chips can be produced from conventional operations with equipment currently available. All three systems were able to produce fuel chips and deliver to a market for around $12/ton, which included cost for chipping and trucking. No stumpage, logging costs or profit are included in that estimate. The market prices tend to vary with local supply and demand, but delivered prices of $11-$27.25 are common in the Southeast, with local prices averaging $20 (Timber Mart South 2007). The costs calculated for all three systems are less than the average delivered prices in this area, hence, the costs justify the expenses incurred by the addition of the extra equipment for fuel chip production.

8. RECOMMENDATIONS FOR FUTURE STUDIES

There are a number of issues that could be addressed with future studies of residue chippers. Collecting detailed production of chips with machine run times would have given a better indication of chipper production capabilities. The use of set-out trailers prevented this study from accurately determining those estimates.

Long term studies to determine if the smaller residue chipper, designed mostly to be used in a lower production landscape operation, will last over time in the higher production system of fuel chipping. One operation required some major repairs after a short period of time on their operation. Working more closely with a logger to track actual costs would have more accurately determined residue chipping cost.

Lastly, more detailed analysis of the fuel material to determine if the variation found in the fuel chips (amount of wood, bark, needles, etc.) had an effect on the use of that material in a biomass operation. Analyzing the samples to determine their exact energy value will help determine the feasibility of this operation.

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