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DEVELOPMENT OF A SMALL-SCALE HARVESTER FOR BIOMASS OPERATIONS

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Abstract: *Concerns about population growth and the availability of conventional non-renewable sources of energy have sparked lots of emphasis for studies about renewable energies. Biomass is an alternative source of energy that can be very successful in the United States where there is a surplus of growing stock of forests. While very promising, new development in the USA about how to improve this market has been slow to occur. Our objective is to develop a small-scale machine that can be used as a feller-buncher for biomass harvesting. As it is known that most woody biomass availability is in small diameter material, we are going to use a mini hydraulic excavator as a basis for this study, making modifications to its boom, and adding an auxiliary motor that will make the machine more productive and economically feasible while aiming for Timber Stand Improvements (TSI).*

Keywords: biomass, small-scale harvesting, TSI

1. Introduction

For many years our society has relied on the use of fossil fuels such as petroleum to supply its energy demands. Although these fossil fuels can be used in many ways, their use is limited by scarcity, the impossibility of production during a human lifespan, and their negative impacts on the environment. During the last few decades the adoption of renewable energy sources has been discussed and implemented as a clean and continuous alternative to fossil fuels. In the United States, many different types of renewable energies could be adopted, woody biomass is one type which presents high chances of success. Woody biomass presents a lot of potential in the USA because it has an impressive 310 million hectares covered by forest lands and a surplus in the growing stock of forests (United States, 2019).

Plant biomass as a source of energy is currently directly associated with the use of residues or forest by-products such as bark, black liquor, sawdust and shavings. The addition of non-commercial roundwood as material for biomass production could bring biomass importance to higher levels (Thiffault et al 2016). Two main advantages of the use of woody biomass are fewer environmental concerns, as well as better opportunity cost especially because the non-commercial trees usually do not have high value. Estimations, however, show that by 2022 the potential of forestry resources to produce biomass will be underused by approximately 42% (Langholtz et al., 2016).

For woody biomass production to be efficient, there is a high need of small-scale machinery for the harvesting of the trees, especially because biomass availability is higher in small tracts of forests, and/or in the trees with smaller DBH (diameter at breast height). Out of the commonly utilized forest harvesting systems in the United States, however, whole-tree systems are the most common. This system is fully mechanized and most of the times composed by large machinery (Conrad et al. 2018). Current harvesting systems can be very impactful for the environment and a lot of the times their use is physically challenging. Therefore, current harvesting systems are not fully adequate for the type of operations required for biomass.

Unlike many other parts of the world, most of the forest land in the United States is privately-owned. The South itself is a very unique region with a higher percentage of privately-owned forests in the US, as much as 87%. There are approximately 11 million individuals and families who possess forest lands in the USA and from those, around 61% of the landowners own 10 or fewer acres (Butler 2014, MacDicken et al. 2016). While industrialization and the need for continuous growth keep pushing the boundaries for the development of higher-end machines and large-scale development, that portion of individuals and families who own small areas of forests is most of the time forgotten or not targeted. The smaller forest areas that are maintained for beauty, heritage or recreational reasons can become profitable (or add different sources of income) if the right tools are provided (Parron et al. 2015, Luederitz et al. 2015).

There are few investments being made on the development of equipment for the harvesting of small-diameter trees. Based on this evidence, we propose to develop, test, and if successful promote a cost-effective harvesting method to produce biomass feedstock for the bioenergy market. We aim to achieve an environmentally friendly system, that has low capital and operational costs, and with high fuel efficiency.

2. Methodology

2.1 Study Area

The study will take place at the surroundings of Auburn University, Auburn – AL, USA. The harvesting operations will occur mainly in softwood (pine) stands as this forest type is prevalent in the region, but if possible, we plan on also harvesting hardwood stands. We will harvest during the first thinning season when the stand is around 10 years old. Additionally, when time and transportation allow, we intend to operate in the urban interface. The forest stands will be submitted to a series of timber stand improvement treatments. We plan on harvesting a couple hundred trees according to availability until we achieve a volume that is statistically significant.

2.2 Felling Using Excavator

Although a complete harvesting system includes processes from the laying of the trees to processing and delivering a product, this project will focus on the felling part of a harvesting system, this way economic and mechanical feasibility can be checked before extending investments to other areas. A small-excavator (Figure 1) model IHI 80 VX will be used as the basis for our studies with both a DFM saw (Dougherty Forestry Manufacturing) and Fecon shear head (Figure 2). The excavator chosen has a capacity of 41.98kW and weighs approximately 9 tons, that together with the rubber tracks will provide less soil compaction guaranteeing minimum impact on the environment.

Figure 1: Small excavator (IHI 80VX)

Figure 2: Fecon shear head and DFM saw head

To improve efficiency, two main modifications will be executed: 1) boom, 2) auxiliary hydraulic pump. The small excavator originally comes with a banana boom which allows for the machine to reach trees at certain distances without the operator having to drive from tree to tree; we believe, however, that by straightening this boom we will achieve faster movements which will count towards greater efficiency (Figure 3). Because this is a small excavator, we will improve its power by adding an auxiliary hydraulic pump (26.1kW motor - Briggs and Stratton #613477-2141). This new motor will be used exclusively to run the head. After those modifications have been completed, we will have a piece of equipment that will be similar to a small-scale feller-buncher. We believe that we can minimize soil disturbance and maximize productivity.

Figure 1: Small excavator with modified boom

2.3 Study Design

During the first weeks of the project, the felling crew will undergo a trial format for the operators to become familiarized with both the equipment and the expected silvicultural regime. This phase will serve as a way of minimizing the human variability on the final results of the harvester. This stage will be done taking into consideration the Occupational Safety and Health Administration (OSHA) instructions regarding safety.
After the period of familiarization is complete, the felling crew will start their field tests. Thinnings focusing on various basal areas will be the main silvicultural regimen selected with some other regimen, aiming for timber stand improvements (TSI). Each field test will take place at the selected experimental units with an area of 1 hectare.

2.4 Data Collection and Analyses

Before the felling crew can go to the field, it will be necessary to estimate the productivity of the experimental units. In the softwood stands, pine trees with DBHs between 3 and 14 inches will be cut, measured and weighed. The height and DBH from these trees will be compared to those found on the tables of Clark and Saucier (1990). If our results are consistent to those found by Clark and Saucier with no significant deviation, we will proceed using these tables for estimation of green weight of harvested trees. Other similar methods will be used for the estimation of green weight of hardwood trees.

Stands that share the same characteristics and are on the same age class will be inventoried prior to harvesting. To guarantee control over confounding factors, the matching of the silvicultural regimen to the stands will be done randomly. It is expected that the felling operator will determine what trees are harvested based on their experience, but there might be a need to mark the trees identifying to which regimen they belong. To detect how effectively the felling operations were conducted, some post-harvest inventories will be done which will determine the level of accuracy of the operator.

The time study method chosen will be elemental time studies as these tend to be more detailed and consider different sources of variability. Small HD video recorders will be the main piece of equipment for this data collection. These cameras will be attached to the exterior of the excavator cabin at an angle that best captures how the machine is operating. To estimate DBH, we will adapt a measuring system on the excavator, and, if not limited by time and/or cost, we will manually collect DBH measurements as a way of getting more accuracy in our data.

After the videos are shot on the field, the files will be meticulously reviewed in the office where we will assess how long it takes for each process to be completed. The processes that we are interested in are felling, selection of trees without bunching, selection of trees with bunching, laying bunch down, movement of the excavator without tree selection (no arm movement), reaching of the boom, stems per load or cycle, and various types of delays (mechanical {excavator or head}, operational, and others).

Additional information about the feller-buncher operation that can be important for identifying the characteristics of the system will also be collected. To measure the capabilities of the feller-buncher, we will combine the mean of trees per bunch and their respective DBH to cycle time which will give an idea of productivity; we will also analyze the number of trees our feller-buncher can reach before having to move the machine). Finally, topographic and ecological characteristics of the stand such as slope, terrain composition and roughness, understory, weather, and soil type will be used to compose our variables.

It is important to set minimum productivity that has to be achieved to evaluate the economic feasibility of this project. Previous studies using a similar system will be used as guidelines for the selection of the desired productivity. To determine a $/ton basis for each silvicultural regime, we will use machine costs calculations described by Tufts (1982 and 1985). Actual data which will be used for our calculations include the cost of the equipment which will be obtained by consulting the manufacturer and/or machine dealers; results of studies from renamed peers and publications; and data from field collection (cost of fuel, lube, repairs, and maintenance). The result of these analyses will be compared to those found by O'Neal and Gallagher (2007) and will be considered economically feasible if the productivity of the feller-buncher is increased by at least 50%.

One of our objectives is that our machine is environmentally friendly or that the damages from it are minimum. To identify if this objective will be met, we will study the damages to the remaining stand immediately after the feller-buncher is used. Line transects will be established to evaluate soil disturbance and damage to residual trees. We will use scales like those proposed by McMahon (1995) and Turcotte et al. (1991) to categorize soil disturbance; along our line transects, a few plots will be created where we will measure the extent of the damage to residual trees, these plots will be of 30m each and will be spread in a way that it is representative of the stands.

3. Justification

Although we understand that for biomass operations to occur a whole harvesting system including chipping and transportation should be developed, we see the importance of starting this project with the felling section as the success of this phase is mandatory for the execution of other phases of the system.

3.1. Lack of Investments in Small-Scale Machinery

The effectiveness of mechanization for logging operations has made this sector evolve towards bigger machines over time, but there is no consensus on whether this necessarily means innovation. Some studies have shown that loggers in the United States and Canada are conservative when it comes to investing in innovations and tend to focus on short term problems such as fuel prices, insurance costs, stumpage prices, and mill quotas, while problems such as machinery efficiency are barely considered (Baker and Greene 2008, Blinn et al. 2014).

3.2. Current Small-Scale Logging Constraints

Manual harvesting in the United States can be an option for smaller areas when the objectives of the forest stands are for family use or without commercial intents. When some level of efficiency is expected from the forest operations, manual harvesting using chainsaws can be more expensive in the long run because of the cost associated with the many operators *vs*. single-operated machines, less productive and less safe. The final required product can also prevent the use of manual harvesting (Schweier et al. 2015; Vanbeveren et al. 2015). In terms of safety, forest operations are not known for being the safest and most ergonomic activities in the world. Exposure to frequent and excessive noise, such as the noise from chainsaws, for example, can cause Noise-Induced Hearing Loss (NIHL), a permanent loss that can lead to social and health problems. Excessive heat is also another major work problem, it can cause fatigue, loss of attention, and greatly improve the chances of accidents (Smith & Thomas 1993, Minette et al. 2007). Many of these ergonomic issues that are enhanced in manual operations can be reduced when in a small-scale machine (e.g. cabins with air conditioners and sound isolation).

3.3. Advantages of Small-Scale Harvesting

Motivations behind the adoption of small-scale harvesting systems may vary from case to case or can be the only feasible option for an area. One of the biggest determining factors of the adoption of small-scale harvesting is the reduction of costs and environmental impacts. Due to their sizes, smaller forest machines tend to have their retail price and operation costs reduced when compared to large-scale machines. Their size also reflects on how impacted an area is, small-scale technologies allow better flexibility and adaptability, resulting in potentially fewer damages to the environment (Updegraff & Blinn 2000; Bliss & Kelly 2008).

4. Expected Outcomes

We strongly believe that many benefits can be accomplished with the success of this project. We expect that by demonstrating the economic feasibility of our feller-buncher we can show the importance of developing small-scale harvesting systems to operate in large thinnings and TSI operations, as well as in smaller tracts of urban forests. Besides the economic benefits, there will also be a value to be added to the residual trees, which will be a reflection of an environment with less competition for nutrients and resources. This reduction in the competition can also improve forests' health. By removing the less desirable tree and utilizing them into a marketable product we will be getting the most out of the opportunity cost of those trees. Finally, the weight and size of this smaller feller-buncher should limit ground disturbance and be much less impactful when compared to common sized feller-bunchers, those characteristics will help to minimize sedimentation into surrounding streams.

We anticipate that this feller-buncher can be available for implementation as soon as production and profitability are shown. This equipment can be directed to tree-care companies, it can add to current logging contractors, it can be niche market for new contractors, or even be used by small-scale landowners for an extra source of income. The adoption of our feller-buncher also has the potential to increase local development by providing employment opportunities for the skilled local workforce in rural areas. Finally, future expansion of supplementary plants in rural areas will improve the scope of opportunity by providing near and stable markets for biomass and bioenergy.

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