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Research paper

Labor-intensive techniques for recovering energy biomass from forest tending operations

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ABSTRACT

The study investigated the collection of renewable energy feedstock from the early thinning of red pine (*Pinus brutia* Ten.) forests, using labor-intensive semi-mechanized work techniques especially suitable for developing economies. The production of energy biomass may improve the financial sustainability of early thinning operations, promoting better forest management. The study was conducted on 165 trees, distributed among 6 stands in order to obtain general representation. Each tree record included tree weight by product type and the time to fell, extract and process the tree into commercial products. The experiment showed that early thinning may offer between 1.3 and 4.9 t (dry) of log product per hectare (10000 m^2), but this amount can be doubled or tripled by changing to whole-tree chipping. Collection cost varied from 86 to 212 € t^{-1}. Over 80% of total collection cost was represented by processing into logs or chips. Whole-tree chipping allowed a ten-fold increase of processing productivity, but the additional cost of the chipper offset any productivity gains. Therefore, one should consider transporting whole trees to the user plant or to an engineered wood yard, for storage and centralized processing. Future research should explore this opportunity, and determine the maximum transportation distance for cost-effective whole-tree transportation.

1. Introduction

Increased reliance on renewable energy sources is a strategic goal for both industrialized and developing economies, in an attempt to mitigate the environmental pressure caused by rapid economic growth [1]. Among the many options for renewable energy generation, energy biomass is most promising because biomass fuel is available in large quantities almost everywhere. Furthermore, energy use promotes the clean management of agricultural residues and industrial byproducts, and the efficient exploitation of unutilized natural resources [2]. Finally, biomass systems enjoy the strategic advantage of small-scale decentralized generation, which may compensate for a generally weak distribution network, while supporting rural development and contrasting uncontrolled urbanization [3].

Within this wider context, forest biomass represents a special case, because of the crucial environmental role of woodlands. Concerns that the current drive to biomass may lead to overexploitation is balanced by the hope that biomass may support responsible forest management, especially when no other revenues can be accrued from forest tending. That is the very case of young forests, which contain a crop of small trees and are unable to offer any of the products demanded by conventional markets. Here, the lack of revenues prevents proper tending, which is crucial to stand growth [4] and stability [5]. As a result, forest managers look at the new biomass products as an opportunity to generate some revenues from small trees, with the purpose of increasing the financial sustainability of forest tending operations, and especially early thinning.

The main issue with early thinning is the negative effect of small-tree size on work productivity. As a general rule, work productivity is proportional to the size of the work object, as long as this falls within the capacity of the working unit [6]. That makes early thinning a problematic practice for most industrialized countries, where labor cost is very high in relation to the value of energy feedstock. Under such conditions, the only solution is to mechanize operations, in order to boost worker productivity and achieve financial sustainability. Even so, high cost is often incurred, and managers tend to delay the first thinning operation until trees have reached the minimum size compatible with cost-effective work.

However, the same conditions may not apply to developing economies, where labor cost is quite low and capital availability represents the main limiting factor. Under those conditions, advanced mechanization is often discouraged by the high investment cost of

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modern machinery, while semi-mechanized labor-intensive operations may be favored. In turn, reliance on labor-intensive techniques tends to remove the need for delaying intervention, because such work techniques are less sensitive to small piece size. In fact, delayed thinning implies the accumulation of excessive fuel loads, expanding the risk for wildfire [7], which is a main problem in the dry habitats that characterize many of the developing economies.

This is the very case of Turkey, which offers a classic example. Turkey is a rapidly developing economy, with one of the fastest growth rates in the Mediterranean basin. This generates an increasingly large energy demand, which the Government hopes to meet with renewable sources, at least in part. To this end, the Turkish Government has offered subsidized feed-in tariffs for green energy [8], and in response Turkish investors have already commissioned two large biomass-fuelled power plants [9]. Feeding these new plants (and those that will follow) requires efficient mobilization of existing biomass stocks, which are indeed abundant. In particular, very large amounts of wood biomass could be sourced from Turkish red pine (*Pinus brutia* Ten.) stands [10], which cover 5.9 million ha (1 ha = 10000 m^2) and represent the most common forest type in Turkey [11]. For this same reason, red pine plays a main role in the rural economy of the country, and offers a whole range of products and services, including soil protection and biodiversity - all of which make this new opportunity for timely tending the more welcome [12].

At present, much work has been devoted to quantifying the amounts of biomass that could be obtained from red pine stands [13]. Information is also available for the cost of recovery, as long as logging residues from final felling are concerned [14]. In contrast, no studies are available about the harvesting of wood biomass from early thinning. Therefore, managers face the paradoxical situation where they have accurate knowledge about the amount of biomass they could get from early thinning, while they have no idea about how much that would cost or what would be the most effective way to collect it. Such knowledge is crucial to planning a good product strategy at the time of harvest, because different products can be obtained from early thinning operations, but different product choices will impose different harvesting techniques and incur different cost [15].

In particular, small pine trees from early thinning generally offer three types of product, namely: 1) merchantable pulpwood to a minimum top end diameter of 8 cm (only obtained from the largest individuals); 2) energy logs to a minimum top diameter of 2 cm and 3) whole tree chips, obtained by feeding whole trees to a chipper, without any other form of processing. Options 1 and 2 often coexist, while option 3 is exclusive. If managers choose options 1, 2 or their combination, then they need to invest considerable work time into manual tree processing in order to obtain a smaller amount of higher quality product, which is likely to fetch a better price than whole-tree chips. On the other hand, if they choose option 3, then they will get lower product quality and price, but obtain maximum volume recovery and quicker processing [8].

Other Authors have already compared the profitability of similar product strategies, but all previous studies have been conducted under the conditions of mechanized harvesting in industrialized countries [16,17]. In contrast, no studies have been conducted about the viability of early thinning with manual techniques, despite the very large potential for semi-mechanized labor-intensive methods in developing economies across the world, and the favorable conditions to manual work offered by the small trees derived from early thinning operations.

Again, Turkey represents an ideal case study because of the generalized implementation of semi-mechanized labor-intensive wood harvesting techniques. Turkish legislation requires that the State outsource all forestry work to resident families in the municipality where the stand is located, with the aim of supporting employment in rural communities. For that reason, all available forest jobs are divided into as many lots as the number of residents families entitled to it. Therefore, all resident families get their fair share of the available work, but none can accumulate a large enough workload to justify investment into specialized machinery. The result is the exclusive reliance on labor-intensive work techniques, which reflects the general case of developing economies - even though in Turkey the lack of specialized forest machinery is motivated more by a social concern than by an actual technology gap.

Against this background, the goals of this study were: 1) to determine work productivity and harvesting costs for a range of manual recovery techniques applied to the early thinning of young pine forests, 2) to compare harvesting cost under two different product strategies, i.e. production of a mix of conventional pulpwood and energy wood, or exclusive production of whole-tree chips and 3) to suggest possible solution to the cost-effective harvesting of early pine thinning material. This was a preliminary study meant to assess the techno-economic performance of semi-mechanized labor-intensive harvesting techniques in early thinning operations, with the ultimate objective of informing forest managers, energy investors, and all parties potentially interested in biomass recovery for energy generation. This study addresses Turkish red pine in particular, but it confronts a general issue that applies to other forest stands and countries, and as such it can be generalized to a large extent.

2. Materials and methods

The study was conducted in the state-owned forests managed by the Isparta Regional Directorate of Forestry, in the Mediterranean region of Turkey. The study sites represented natural Turkish pine (*Pinus brutia* Ten.) dominated stands, growing on mountainous karstic soils and managed according to multi-functional forestry practices. These stands are normally grown for the production of sawlogs and poles, and harvested according to 60–80 year rotations, depending on site quality. Six sites were randomly selected to represent different yield classes, in order to assemble a generally representative dataset. The study sites were found in the planning units of Isparta, Ağlasun, Aşağıgökdere and Çamlık, and consisted of young forests that were being thinned for the first time by removing between 58 and 72% of the total tree number. The driving criterion of the thinning operation was to create space around the best trees, in order to provide more space for growth and to slow down the spreading of an eventual fire event. To this end, operators took out small, weak and dominated trees. Removal trees had a mean diameter at breast height (DBH) between 1.8 and 7.6 cm and a total height between 2.1 and 7.4 m, depending on age and yield class (Table 1). Data collection was conducted on occasion of the prescribed thinning operations, which occurred between 2012 and 2015.

Trees were cut with a chainsaw (Fig. 1), extracted whole by manually dragging (downhill) or carrying (uphill) (Fig. 2) and then processed at the roadside with axes and chainsaws in order to obtain a mix of conventional pulpwood and energy wood. This procedure corresponded to integrated harvesting, aimed at obtaining quality products. Application of this procedure allowed the accurate measurement of all available product types, which explained its exclusive application. In contrast, whole tree harvesting was simulated by removing the work task “processing at roadside” from all calculations, and replacing the corresponding time consumption with that of whole tree chipping for each tree, which was estimated by simulation (Fig. 3). In most cases, crew size amounted to one worker, who operated independently of his colleagues. The chainsaw used for the work was a light type, with an engine displacement of 50 cm^3. The chipping productivity simulation was conducted for one of the smallest chipper models on the market, a disc type with a capacity of 20 cm. This machine was powered by an 52 kW farm tractor and fed manually by two workers. Chips were discharged into bin trailer, towed by a farm tractor.

All workers in the test were mesomorphic adult males, with an age between 30 and 45 years, and a work experience of at least 15 years. Although different workers were employed for different tasks and different stands, the skills and the built of the workers were very similar,