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INNOVATIONS IN THE FORESTRY SECTOR TO OPTIMIZE AND ENHANCE THE FOREST WOOD SUPPLY CHAIN IN THE CALABRIA REGION

(S.S.D AGR/09)

Ph.D. Thesis

Ph.D. Candidate:
Dr. Maria Francesca CATALDO

Thesis Supervisor:
Prof. Giuseppe ZIMBALATTI

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Abstract

The forest-wood supply chain is a chain made up by activities that cover the entire forest organization, with forest uses, logging and transport of timber, and the forest processing industry up to the final use. Each phase can make independent decisions, often generating entails a series of inefficiencies that could be filled thanks to scientific research that offers techniques useful for improving the performance of the individual activities in the supply chain, but also for improving the interconnection between them.

This Ph.D. research aimed to provide information on the current reality that characterizes the forest sector of the Calabria Region, focusing on the different aspects of the forest-wood supply chain, with the aim of support the supply chain through a progressive process dissemination, among forestry entrepreneurs, of the knowledge of the most modern and rational techniques and technologies of forest use. The results can contribute to suggest decision support tools useful to forestry workers, who can operate with greater economy and respect for the environment as well as strengthening the level of innovation of companies to make them more competitive on the market without compromising the functionality of the forest.

In this Ph.D. thesis, a five-step experimental procedure was set up by performing the following activities:

(i) Determine productivity by different kinds of machines comparing specialised and non-specialised in the forestry mechanization (with greater attention paid to the situation in Calabria and Romania where the research period abroad was carried out);

(ii) Evaluate environmental impacts of forest utilization focusing on soil compaction during skidding operation;

(iii) Develop of Non-Destructive Technologies (NDT) that can predict intrinsic wood proprieties of individual standing trees and assessing wood quality;

(iv) Study of a Calabrian forest company from the point of view of suitability and gaps for obtaining forest certification;

(v) ValoriseCalabrian wood.

The first activity revealed that the use of specialized forestry machines, compared to adapted farm tractors, were more efficient. However, it would be advisable to

make improvements in the organization of construction sites, such as intensifying the road network, training skilled operators in the use of particular machines, coordinating the team more effectively.

Although the impacts of forest uses on the soil are unavoidable, the study conducted in the second activity has shown that, however, it is possible to mitigate the effects by choosing the appropriate machines for the case, increasing the contact surfaces with the ground, reducing the transported load.

The results obtained with the third activity, from the NDT survey conducted on standing chestnut trees, have shown that sonic tomography is able to identify various defects in a tree trunk, including the ring shake, without affecting its biological activity, overcoming the difficulty due only to a visual inspection.

The fourth activity conducted on forest certification highlighted that the company under consideration, interested in adhering to the FSC® principles and criteria, is potentially suitable, since it has characteristics of forest management that meet specific environmental protection and equity requirements, social and economic efficiency, as defined by the chosen national reference standard.

With the fifth activity, tests were conducted on traditionally seasoned and heat-treated wood of three different forest species from Calabrian woods to specify the variation of some characteristics due to heat-treatment. The results obtained demonstrated that the strength performance in response to screw withdrawal and the resistance to surface abrasion are lower in the heat-treated samples. Furthermore, the heat-treated wood has undergone colour variations acquiring darker shades, and even greater surface roughness, compared to the original wood.

Keywords: forest mechanization; soil disturbance; non-destructive technology; forest certification; wood technology.

Riassunto

La filiera foresta-legno è una filiera composta da attività che coprono l'intera organizzazione forestale, con le utilizzazioni boschive, l'esbosco e il trasporto del legname, e l'industria di trasformazione forestale fino ad arrivare all'uso finale. Ogni anello della filiera può prendere decisioni autonome generando spesso una serie di inefficienze che potrebbero essere colmate grazie alla ricerca scientifica che offre tecniche utili per migliorare le prestazioni delle singole attività nella filiera, ma anche per migliorare l'interconnessione tra di esse.

Questo dottorato di ricerca si propone di fornire informazioni sulla realtà attuale che caratterizza il comparto forestale della Regione Calabria, concentrandosi sui diversi aspetti che la filiera foresta-legno abbraccia, con l'obiettivo di valorizzare detta filiera attraverso un processo di diffusione progressiva, tra gli imprenditori forestali, della conoscenza delle più moderne e razionali tecniche e tecnologie di utilizzo forestale, affinché i lavoratori possano operare con maggiore economia e rispetto per l'ambiente, nonché rafforzare il livello di innovazione delle aziende, strettamente legate alle risorse forestali locali, per renderle più competitive sul mercato senza compromettere la funzionalità del bosco.

In questa tesi di dottorato di ricerca, è stata sviluppata una procedura sperimentale suddividendo le attività in cinque fasi:

(i) Determinare la produttività mediante diverse tipologie di macchine, confrontando specializzate e non specializzate nella meccanizzazione forestale (con maggiore attenzione alla situazione in Calabria e Romania dove si è svolto il periodo di ricerca all'estero);

(ii) Valutare gli impatti ambientali delle utilizzazioni forestali concentrandosi sulla compattazione del suolo durante le operazioni di esbosco;

(iii) Sviluppo di tecnologie non distruttive (NDT) in grado di prevedere le proprietà intrinseche del legno dei singoli alberi in piedi e di valutare la qualità del legno;

(iv) Studio di un'azienda forestale calabrese dal punto di vista dell'idoneità e delle lacune per l'ottenimento della certificazione forestale;

(v) Valorizzazione del legno calabrese.

La prima attività ha rivelato che l'uso di macchine specializzate, rispetto a trattori agricoli adattati, era più efficiente. Tuttavia, sarebbe opportuno apportare miglioramenti nell'organizzazione dei cantieri, come l'intensificazione della rete stradale, la formazione di lavoratori qualificati all'uso di particolari macchine, il coordinamento più efficace della squadra ed in generale delle attività del cantiere.

Nonostante gli impatti delle utilizzazioni forestali sul suolo siano inevitabili, lo studio condotto nella seconda attività ha dimostrato che è possibile mitigarne gli effetti scegliendo le macchine adatte al caso, aumentando le superfici di contatto con il suolo, riducendo il carico trasportato.

I risultati ottenuti con la terza attività, dall'indagine NDT condotta su alberi in piedi di castagno, hanno dimostrato che la tomografia sonora è in grado di identificare vari difetti in un tronco d'albero, compresa la cipollatura, senza intaccarne l'attività biologica, superando le difficoltà di previsione legate alla solo ispezione visiva.
La quarta attività svolta sulla certificazione forestale ha evidenziato che l'azienda oggetto di studio, interessata ad aderire ai principi e criteri FSC, è potenzialmente idonea, in quanto presenta caratteristiche di gestione forestale che rispondono a specifici requisiti di tutela ambientale ed equità sociale ed economica, così come definiti dalla certificazione forestale scelta.
Con la quinta attività sono state condotte prove su legni tradizionalmente stagionati e termotrattati di tre diverse specie forestali provenienti da boschi calabresi per determinare la variazione di alcune caratteristiche dovuta al trattamento termico. I risultati ottenuti hanno dimostrato che le prestazioni di resistenza in risposta all'estrazione di una vite e la resistenza all'abrasione superficiale sono inferiori nei campioni trattati termicamente. Inoltre, il legno termotrattato ha subito variazioni di colore acquisendo tonalità più scure, e anche maggiore rugosità superficiale, rispetto al legno originale.

Parole chiave: meccanizzazione forestale; disturbo del suolo; tecnologia non distruttiva; certificazione forestale; tecnologia del legno.

STATE OF THE ART

Forests and logging operation in Calabria Region

Calabria is one of the most interesting Italian regions in terms of forest for the potential and diversification of wood production and also for the Mediterranean specificity of some natural heritage. The third Italian national forest inventory (INFC, 2015) is currently being drawn up, which will update the forest statistics by providing detailed information on regional realities, but based on the data published in the second Italian national forest inventory (INFC, 2005), the Calabria region, compared to a territorial area of 1,511,000 hectares (Iovino et al. 2017), has a forest area of 612,934 hectares and a woodiness index of 40.6%. A considerable share (54%) of the regional forestry assets, equal to 332,829 hectares (22.03% of the total regional area), falls within protected areas. This surface characterized by multiple forest species and woods inserted in different geo-morphological contexts, different climatic conditions, characterized by the action and use of man over time, also according to local customs and traditions, is divided as follows (Calabria Region 2007):

• National Parks: 246,759 hectares;

• Regional parks: 17,687 hectares;

• State reserves: 1,896 hectares;

• Regional state-owned areas: 26,608 hectares;

• Regional reserves: 5,253 hectares;

• SIC, SIN and SIR: 34,626 hectares.

Considering the data provided by the Forest Plan of the Calabria Region 2007 - 2013, the wooded area in Calabria is divided by property categories into:

- Private, which owns 50.59% of the regional surface;
- Public, which owns 34.74% of the regional surface;
- Unclassified, which includes 14.68% of the regional surface.

By type of crop, the wooded areas are divided into:

• High forests, which make up 56% of the regional surface;

• Coppices, which make up 27% of the regional surface

• Mixed, which make up 2% of the regional surface;

• Unclassified which represent 12% of the regional surface;

• Not defined which represent 2% of the regional surface.

However, it emerged from some provisional data from the latest inventory (INFC, 2015) that the Calabrian forest area has been increased, bringing the forest index to 44.5%, exceeding the national average by 8%.

This heritage positively carries out various functions: from higher quality wood production to be used in construction and processing industries, to biomass and waste from forest uses for energy production, from non-wood forest products to the supply of a whole series of goods and services that have become increasingly important in a context of sustainable forest management (GFS), that is, forest management that maintains a whole plurality of characteristics and attributes such as biodiversity, productivity, capacity for renewal, vitality and potential to fulfil, now and in the future, to relevant ecological, economic and social functions at local, national and global levels.

From the data reported by the 2007-2013 Regional Forest Plan, they estimate the cormometric mass that can be used annually by the forests of the Region to be approximately 1-1.5 million m^3, compared to 2.5 million m^3 of current increase relating to tall forests only (INFC, 2007). According to data published by Iovino (2013) in the decade 2001-2010, the wood harvest was equal to only 25% of the annual increase. In the face of this immense patrimony, the enhancement of the woods is still low with a wood harvest far below the possibilities and with the use of wood not sufficiently anchored to artisanal and quality productions.

It should also be noted in this regard that in 2011 about 730 forest companies and about 1,840 processing companies were operating in Calabria (Proto et al. 2011). The gap existing between wood supply provided annually by forest companies and the needs of raw materials by processing companies is often bridged by imports of timber coming, above all, from Eastern European countries (Proto and Zimbalatti, 2008).

In order to make useful indications about the systems used for forest utilization, it is necessary to consider the main stationary characteristics in which companies are placed in Calabria. 52% of the wooded area is between the second and third gradient, while slope values of less than 20% are found in about 88,000 hectares of forest. As for the accident of the Calabrian forests, it is noted that 57% of wooded areas are not rough, while 43% of the surface varies between the rugged and the very rugged. Finally, according to the degree of accessibility of forest areas, i.e. physical access to the forest and easily reached, most of the surface is accessible (88%). The territory is characterized by a wide network of natural forest tracks, especially in areas where the land is prevalent and where in the past there have been repeating and forest reconstruction financed by the 1st and 2nd Calabrian Special Laws. Unfortunately, these road networks are not always easily accessible due to lack of maintenance (Barreca et al. 2008). In Calabria, climatic conditions, which are certainly not prohibitive during the winter season, encourage businesses not to do any forestry activities during that time of the year for only 2 or 3 weeks.

The three main wood harvesting methods are: full-tree (FT), tree-length (TL), and cut-to-length (CTL). Anyway, the choice of a harvesting method depends on the final product required and can be divided into the following groups, sorted to relevance and level of diffusion:

- motor-manual FT/TL harvesting: felling and processing with a chainsaw, and skidding with a farm tractor and winch or grapple;
- motor-manual CTL harvesting: felling and processing with a chainsaw, and skidding with a farm tractor and bin or trailer;
- partially mechanized FT/TL harvesting: felling and processing with a chainsaw, and skidding with a skidder or cable crane;
- partially mechanized CTL harvesting: felling and processing with a chainsaw, and skidding with a forwarder.

During the '90s the most common working system in Calabria was considered as traditional and at the beginning of an early stage of mechanization (Hippoliti, 1997). It was based mainly on agricultural tractors, sometimes with specific forest machines like winches, hydraulic cranes, log grapples but also, the use of animal for gathering and yarding was a widely used technique, due to the site features, the characteristics of the propriety, the small dimensions of many enterprises, scant knowledge of modern machinery, and the scarcity of studies related to the use of modern machinery.

Despite the motor-manual operations are still frequently applied in steep terrain and the agricultural tractor equipped with forestry winches, pliers, trailers or dumpsters are still today the most common machinery for cutting and extracting timber (Verani and Sperandio, 2003, Proto et al. 2020), currently, there are numerous highly specialized machines for forest utilisation and can be traced to the use of the skidder, forwarder, and cable crane where the orography of the Calabrian forests are well suited to their use. Skidders, cable cranes and forwarders are used where farm tractors are limited by terrain steepness and roughness and to guarantee more productivity and safety with respect to traditional extraction methods.

During the last years, the technological gap between means and methods applied in the Apennines and Alps areas is considerably shortened, thanks to the firms which want to be competitive in local markets, and also, thanks to the recent boost initiatives connected to the rural development politics (Moscatelli et al. 2007).

Environmental impact from forest operation

Environmental impact can be understood as changes to the environment which increase the risk of failure and permanently disturb its evolution and appearance. From this perspective, low environmental impact production systems are considered to be those that (Marchi and Piegai, 2013): do not involve, at least in the long term, significant risks for the stability of the soil and the vegetation; they do not irreversibly alter the natural evolution of the forest in particular of the vegetation, or at least, they do not orient it in a negative sense; they do not involve unwanted and permanent changes to the appearance of the landscape. There is no work system in uses intrinsically low environmental impact, valid indiscriminately in all situations there are different work systems, in particular different logging systems, which allow to contain and also to minimize the environmental impact and optimize the economic one. Silvicultural activities necessarily involve changes to the environment and to the appearance of the landscape, normally irrelevant, limited in time and in any case less significant than those that can naturally occur due to deterioration and aging of even significant parts of the stands. Using a forest means practicing silviculture concretely, not just exploiting the forest by taking the wood. Man demands numerous benefits from the forest: soil protection from erosion, water regulation, improvement of the environment and landscape and even the production of wood. To obtain the former it is necessary, or at least often appropriate, to remove part of the trees that grow in the woods, or at least the use of the trees may not be in contrast with the needs of the environment: It all depends on how the work is carried out.

Forest uses, as the application of silvicultural techniques, however, have a certain effect on forest systems on the territory in general, at least in the short term. They can also cause other impacts whose extent, severity and duration can be very variable. However, as usual, these are non-permanent changes in the state of the places or that can be resolved with simple application measures carried out at the end of the works. The main negative effects of cutting and logging work occur at ground level (d’Acqui et al. 2020). In particular, two processes of soil degradation occur during the concentration and clearing phases: compaction and mixing of the surface layers. Both phenomena occur due to the passage of mechanical means or the train of plants or trunks. The main consequence of the mixing or removal of the surface layers of the soil is manifested by phenomena affecting the mineral layer of the soil and its exposure to the beating and erosive action of water. In some cases, however, the mixing of the soil and the exposure of the mineral layer favour natural renewal. On the other hand, soil compaction leads to modifications of the physical properties of the soil with a reduction in macroporosity and infiltration capacity. In some cases, especially on tracks used with wet ground, tractor tires can create grooves that are trigger points for localized but intense erosive phenomena.

These events as a whole can modify the characteristics of the soil, in particular drainage and infiltration with consequent widespread and localized erosive phenomena. The onset of these erosive phenomena can have a negative impact on water courses with an increase in turbidity and consequent negative effects on the fish fauna. The presence of suspended materials and sedimentation phenomena can lead to different types of impact: a direct impact that manifests itself with an increase in the mortality of fish fauna due to the high level of suspended material, and an indirect impact that occurs manifests with an alteration of the reproductive habitats and an increase in the mortality of the eggs due to the high quantity of deposited sediments. The sedimentation phenomena in ditches and streams can also alter the normal water flow with serious consequences in periods of intense rainfall. The uses can also cause effects on wildlife which at least during the working period is obliged to leave the area. Damage to vegetation can also be of a certain extent, especially in thinning, in fact during all phases of the work skinning, breakages, damage to stumps and roots can occur, which can lead to theindividuals' death or damage that also affects the characteristics of wood due to subsequent parasitic attacks. In the use of coppices, both tracked and wheeled tractors can cause damage to the stumps which subsequently have a mortality rate of 4-5 times higher than those not damaged as well as reducing the ability to produce suckers. Finally, another no less negligible effect is of a landscape type. This effect is usually negative for a short period of time after use.

Non-destructive testing technique to determine wood quality

The estimate of the woody assortments that can be retraced from a specific stand represents an important moment in which the real productive value of a forest is quantified. The most common non-destructive analysis techniques are mainly based on the visual characterization of the assortments with the identification of some requirements required by the reference standards: minimum length, growth rate, presence and measurement of defects. The steps for standing classification include the measurement of the portion of the working stem, the observation of the characteristics of the stem that can favour or hinder the processing and finally the assignment of the drum to a quality class. Classifying the timber means dividing the roundwood into homogeneous classes of belonging, according to the characteristics detected (size, diameter) and in relation to defects and anomalies (knots, chives, cracks, etc.) It is therefore evident the need to demonstrate the product potential right from the standing trees in order to justify and plan the cultivation interventions during the shift. In particular, on valuable woody productions, valid support for the choice of plants to be used can be achieved through a series of portable scientific equipment.

Non-destructive testing can be divided in global techniques (ultrasound waves, stress waves, and resonance) and local techniques (probing, coring, and drilling). The former techniques are mainly focused on estimation of static modulus of elasticity (MOE) and bending strength (fm, formerly referred to as MOR) (Jayne, 1959; Auty and Achim, 2008; Íñiguez-González et al. 2019), and the latter on estimation of density (Llana et al. 2018; Fundova et al. 2019; Martínez et al. 2020). It is also common to combine different non-destructive techniques for better estimation results (Divós and Tanaka, 1997; Vössing and Niederleithinger, 2018). Currently, worldwide research and development efforts are underway to examine the potential use of a wide range of NDT technologies for evaluating wood and wood-based materials—from the assessment of standing trees to in place structures (Brayshaw et al. 2009). Non-destructive testing has the potential to provide low-cost timber quality assessment, which could be used in the forest to segregate logs into different end use categories. The estimation of mechanical properties of timber from standing trees or green logs has many benefits for growers and processors, as decisions taken at an early stage can result in cost savings (Llana et al. 2020).

The most common non-destructive testing technique used on standing trees for mechanical properties' estimation is based on measurement of stress wave velocity

(Wessels et al. 2011). In fact, among the parameters that express the quality of wood, the determination of the velocity is the easiest and quickest (Divos, 2010).

Main recent forest laws in Calabria Region and Forest Certification

With the regional law 12 October 2012 n. 45 entitled: "Management, protection and enhancement of the regional forest heritage", forest management in Calabria has adopted the sustainability criteria, realigning the Calabria region to other Italian regions on the issue of forestry and at the same time filling a legislative gap in this sector, by drafting a text of law which, respecting both the Community Directives and the National Regulations, aims to meet the new needs of society, following the principles of sustainable forest management as guidelines. In addition, the Region has tried to equip itself over time with legislative instruments aimed at directing the management of the forest heritage in a modern and planned way. Among these, the recent "Guidelines for the Preparation of Forest Management Plans" published in the Official Bulletin of the Calabria Region n. 13 of 6 February 2017 (Calabria Region 2017). Lines mainly aimed to define the standards for the drafting, approval, co-financing and implementation of the Forest Management Plans (PGF) envisaged by current regional legislation. The qualifying elements of forest planning are also indicated, generalities and objectives, definitions of land use categories, contents.

Furthermore, for the year 2019, the validity of the regional program for development activities in the forestry sector and for the management of regional forests already approved for the year 2017 (Calabria Region 2019) was extended where the activities carried out in 2017 and 2018 constitute the fundamental part of the protection and development policies of the regional forest system, and the activities not carried out, for various reasons, must be carried out without interruption as they are necessary to guarantee the durability of structural interventions over time. Specifically, the main objectives of the Program are the conservation and optimization of biodiversity, the improvement of the hydrogeological structure and soil conservation, the restoration of wooded areas damaged by fires, reforestation interventions and monitoring of the areas subjected to previous interventions, the prevention and containment of the risk of desertification, the monitoring of plant diseases, the management and improvement of public forests, and forests falling within protected areas, the development of environmental tourism, development and improvement of the wood supply chain. The objectives for 2020, on the other hand, include: contributing to balance the different functions of forests, satisfying demand and providing ecosystem services of fundamental importance; create the necessary foundations for forests and the entire value chain of the sector to be competitive and make a valuable contribution to the bio-economy.

Already with the Law 12 October 2012, n. 45 (Calabria Region 2012), subsequently implemented with Regional Regulation 9 April 2020 n.2 (Calabria Region 2020), the Calabria Region explained the necessary principles to be followed to encourage sustainable forest management, protect the territory of the region as a whole and contain climate change. To achieve these objectives, it was considered indispensable in the law itself to be able to strengthen the forestry chain from its production base, while at the same time guaranteeing the multifunctionality and diversity of forest resources in the long term (Proto, 2013). An important peculiarity of the aforementioned law lies in the will of the Department of Agriculture, Forests and Forestry to promote study and research activities in the forest sector, aimed at the innovation of the same, with particular regard to the various forestry activities and forest-wood supply chain. Furthermore, the introduction of wood-based arboriculture and the enhancement of secondary forest products was considered of great importance, but even more the introduction and maintenance of certification systems and the establishment of specific marks of origin and quality of regional timber in order to enhance the wood resource of our region in the best possible way (Proto, 2013).

During the 90s it became common for companies to implement environmental management systems. The basic goal of the implementation of these systems was to identify and manage impacts to the environment and to continually improve performance. By the end of the 90s, the International Organization for Standardization (ISO) 14000 series of standards had been developed, and large companies in all regions of the world were actively engaged in implementing ISO 14001 for both their production and forestry operations. Developments in forest certification went hand-in-hand with developments in environmental management. The practical objective of forest certification is to guide forest management in a market-led manner in an economically, ecologically, socially, and culturally sustainable direction. In order to achieve that objective, there must be a close link to marketing. Thus, certification may act as (Hansen and Juslin, 2018):

• A tool for promoting sustainable forest management– For example, government authorities may use certification to support their forest or environmental policies.

• A tool for satisfying the needs of customers – For customers, certification indicates that the product comes from a well-managed forest. Certification helps consumers make choices and supports the attainment of sustainable development regarding consumption.

• A tool for marketing – Marketing adapts the company to its business environment and turns prevailing trends and customer needs into business opportunities. If sustainable development is one of the values of an enterprise, it makes sense to integrate certification with marketing decisions.

Environmental labelling is a mechanism to allow consumers to make product choices based on the environmental impact of a product. The premise is that an ecolabel or environmental label will provide an incentive for producers to minimize environmental impact, because they will receive some form of marketplace benefit (Hansen and Juslin, 2018).

As regards forest certification and wood products, it is one of the most important marketing and improvement tools at the organizational and management level, thanks also to the presence of, since 2001, the national structures of the two most important and widespread forest certification systems, the Forest Stewardship Council® (FSC®) and the Program for Endorsement of Forest Certification schemes™ (PEFC™). These certification systems are nothing more than voluntary adhesion systems, specially formulated for the forest-wood sector, which allow certifying the forest areas managed according to the principles of environmental, social and economic sustainability. Compliance with the principles and criteria established by both systems is checked and assessed by independent and authorized third-party bodies (ASI - Accreditation Services International and ACCREDIA accredited certification bodies for FSC and PEFC respectively), subsequently, once the forest of origin has been certified, both systems require that the traceability of certified wood be ensured along the entire production chain (Secco and Brunori, 2005; ISPRA, 2019).

In Italy, any company in the forest-wood supply chain, engaged in forest management and/or in the processing and sale of wood-based products, can choose between different types of certification of its environmental management system, namely (Secco and Brunori, 2005):

• A process certification, based on the UNI EN ISO 14001 standard;

• Two specific schemes developed specifically for the forestry sector, in order to achieve a process certification with a performance criterion and which allow the use of a product brand (FSC® or PEFC™);

• A product certification, or a particular certification system that guarantees the consumer the sustainable forest management of the forest from which the wood product comes and consequently certifies the entire supply chain through a chain of custody (CoC).

This particular process of traceability within the same supply chain involves the implementation of an accurate information system specifically documented and relating to the entire cycle of the production chain of a raw material/product in all the various stages of processing, handling and transport.

The substantial difference between the ISO 14001 certification system and the FSC and PEFC systems is basically represented by the type of approach adopted; in fact, in the case of the ISO 14001 standard, there is a system-based approach, while in the FSC and PEFC schemes there is a performance-based approach for the product. In detail, the system approach is based on the logic of continuous improvement of its production process (Secco and Brunori, 2005) progressively seeking to reduce the significant environmental impacts and pollution towards the environment that derive or may derive from the activities management and production itself; each individual organization internally establishes the appropriate actions aimed at achieving the objectives in a completely autonomous way, through the definition of a policy and tools for implementation and monitoring. The application of the UNI EN ISO 14001 standard does not provide to the possibility of labelling products with a specific brand (Secco and Brunori, 2005). The PEFC certification scheme, like FSC, differs from the previous one as it is fundamentally based on the achievement and/or compliance with certain predefined performance criteria, having general validity for all companies in the forest-wood sector. Use a "performance" approach, PEFC and FSC, present significant application differences compared to the system approach, in detail, through the performance approach it is necessary that several steps occur in the procedural process, which are one consequential to the next:

- the organization requires certification of conformity and applies the reference requirements;
- the certification body, ascertains the fulfillment of the requirements set by the reference scheme;
- the accreditation body checks the work of the certification body ensuring its competence and professionalism.

In fact, FSC is not a certification body but a legislative one that defines 10 Principles and 70 Criteria (P&C) to be used in order to achieve sustainable and responsible management of forests and plantations all over the world, since through it we intend to protect the natural environment in its entirety, bring real benefits to populations, local communities and workers, as well as ensure certain efficiency in economic terms.

The Mission of FSC (FSC Italy Statute, 2014) is to promote forest management that respects the environment at a global level, ensuring that the collection of woody and non-woody products from the forest preserves the biodiversity, productivity and ecological processes of the ecosystem, that it is also socially useful, helping local populations and society in general to enjoy long-term benefits, and finally that it is economically sustainable, ensuring that all forest operations are managed and structured in such a way as to be sufficiently profitable, without generating financial profit at the expense of forest resources, the ecosystem or the communities concerned. With reference to the national context, thanks to the participation of as many as 23 founding members, the FSC-Italia Group was born in 2001, today defined as the Italian Association for Responsible Forest Management (FSC Italy Statute, 2014); it, appropriately recognized by its international structure, basically sets itself the objectives of safeguarding and improving the environment and forest resources in Italy and around the world, through the application of the FSC certification scheme.

In relation to its Principles and Criteria, as well as its Mission, FSC issues three different types of certification, described below:

1. Forest Management Certification (Forest Management, FM) where the management of forests and arboriculture systems is assessed, from the initial planning phase, also considering all the silvicultural aspects that lead to the hammering intervention, up to the operations felling and logging;

2. The Certification of the traceability of forest products, also called Chain of Custody (CoC) which verifies the complete traceability of forest products from the forest to marketing, in all the various stages of their production;

3. Controlled Wood Certification (CW) where a material that can be mixed with other certified material during the production phase of the finished product, which will be labelled accordingly with the FSC Mixed brand.

It is particularly important to specify that in the CoC process, certification goes hand in hand with the transfer of ownership of the material from one organization to the next, and in order for the finished product to be sold under the FSC brand, the entire chain must necessarily be certified.

From the report of the 2020 Shareholders' Meeting (https://it.fsc.org/it-it/news/id/810), in Italy, the forest areas certified according to FSC standards are growing (about 66,000 ha), for a total of 19 properties and 278 owners involved. The Chain of Custody certifications registers 2,780 active certificates and almost 3,500 companies involved; numbers that firmly confirm Italy in first place in Europe.

Like FSC, PEFC is also an international non-governmental, independent and non-profit organization. It is very similar to FSC but with some differences. Its objectives include improving the image of silviculture and the forest-wood supply chain, effectively providing a market tool that allows the marketing of wood and forest products deriving from forests and plants managed in a sustainable way. The PEFC system, like FSC, allows to certify:

- the sustainability of forest management,

- the traceability of wood and paper products marketed and processed that come from PEFC certified forests.
But unlike FSC, the certification of controlled wood is not envisaged and furthermore, it does not currently provide for wood arboriculture, but in Italy the international PEFC poplar cultivation scheme is being developed.
As reported by the statistics of the official website of PEFC in Italy (https://www.pefc.it/scopri-il-pefc/il-pefc-italia/statistiche-pefc-in-italia), in 2019 the certified forest area is 865.943 ha, with 24.000 forest owners involved, while the companies with CoC certifications are another 1100.

Aspects of Wood Technology

Wood is a porous and fibrous structural tissue found in the stems and roots of trees and other woody plants. It is an organic material – a natural composite of cellulose fibers that are strong in tension and embedded in a matrix of lignin that resists compression. Wood is produced by the plant as a structural element, with excellent characteristics of strength and resistance, and is therefore used by man.
Wood is a natural material with good beauty aspects and superior formability which has been used as an engineering and construction material and also used for interior and exterior decoration (Hoseinzadeh et al. 2019). Moreover, wood has a good weight ratio and acoustic properties (Ateş et al. 2010). Despite of its great benefits, wood also suffers a number of disadvantages, for instance wood is damaged when exposed to environmental conditions as a function of sunlight, humidity, wind and microorganisms (Hoseinzadeh et al. 2019).
The industrial system draws technical, logistic and economic advantages in using raw materials of known and constant quality.
This condition, which normally occurs in many industrial sectors, is not the norm for the forest - wood chain since the raw material used, precisely wood, has a very high intrinsic variability due to biological origin.
In addition to the high variability between botanical genera and between woody species of commercial interest, there are significant differences in the characteristics of the wood linked to the production areas and management techniques.

Furthermore, even in the context of defined origins, a drift over time has become evident, causing changes in the characteristics of the wood and in the quality.
The contribution of research to increase and rationalize the correct and sustainable use of wood consists, among other things, in characterizing the raw material by enhancing the characteristics of the different species, origins and quality.
Wood modification (chemical, thermal, impregnation) represents an assortment of innovative processes adopted to improve the physical, mechanical, or aesthetic properties of sawn timber, veneer or wood particles used in the production of wood composites. This process produces a material that can be disposed at the end of a product's life cycle without presenting any environmental hazards greater than those associated with the disposal of unmodified wood (Jones and Sandberg, 2020). One of the different techniques used for the enhancement of wood is heat treatment which consists in subjecting the wood to a drying cycle at high temperatures, in a controlled, oxygen-poor atmosphere. An elevated temperature is an important component when wood is to be modified solely with the help of water or moisture, but a temperature above 300 °C is of limited practical value due to the risk of severe degradation of all the main wood constituents (Navi and Sandberg, 2012; Jones and Sandberg, 2020). The modification of wood by heat without chemical additives and with a limited supply of oxygen to prevent oxidative combustion, i.e., thermal modification, is a generally accepted and commercialised procedure for improving some characteristics of wood (Jones et al. 2019). The idea is to alter the internal chemical composition of the material by exploiting the internal reactivity of the material and the removal of some of its active sites instead of adding reagents capable of interacting with the reactive sites. The changes in the wood during thermal modification are fairly well understood, involving chemistry processes that occur to varying degrees depending on the wood species. According to the European Committee for Standardization (2008), thermally modified timber is wood in which the composition of the cell-wall material and its physical properties have been modified by exposure to a temperature higher than 160 °C with limited access to oxygen. At temperatures between 160 °C and 220 °C (European Committee for Standardization, 2008), the main purpose is to ameliorate material properties, such as to increase the biological durability, to enhance the dimension

stability, and also to control the colour changes. Thermal modification has also been applied to reduce resin bleed.

Thanks to this system the physical and mechanical properties of the wood are modified. In fact, the heat treatment causes the deterioration of hemicelluloses, substances that are palatable to insects and lignivorous fungi, reducing the woody part that is more reactive towards water, thus improving dimensional stability and reducing susceptibility to biotic attacks. Furthermore, temperatures up to 220 °C change the colour of the wood making it take on darker shades of brown. This treatment, therefore, allows the wood to improve in terms of stability and durability over time.

Once treated, however, the use of this material for load-bearing structures is not recommended, as it is more fragile and less resistant. Similarly, the obtained rigidity can lead to the occurrence of cracks during machining.

This is certainly not a novelty in the sector, as the first works related to heat treatment date back to the already in the early 19th Century (Tredgold, 1820). However, it remains an interesting tool that deserves further study, especially in its application on the wood of tree species that need to enhance and expand their uses.

GENERAL INTRODUCTION

Global forests and the current forest situation in Italy

In 2015 the world's forest cover was 3.99 billion hectares. Europe has the largest forest area (25%) as it includes the Russian Federation, which alone comprises 20% of the world's forest area, at nearly 900 million hectares. Because of its size, the Russian Federation dominates any analysis of forest resources. Brazil has the second-largest forest area globally with over 494 million hectares. Africa contributes significantly to the world's forest resource with 624 million hectares of forest. The 18.8% of world forest cover found in North and Central America, mainly in Canada and the U.S (Villavicencio, 2009; FAO 2018).

Although forests are important for the wood they supply, it is important to recognize the myriad products and services that forests provide beyond wood. Much of the world's biodiversity is associated with forests, especially tropical forests. Many people around the world rely on forests for a wide range of nonwood forest products such as foods and medicines. Energy from wood is critical for about 2.4 billion people around the world and forests provide 40% of global renewable energy (FAO 2018).

In recent years, forestry has undergone a significant evolution: there has obviously been an improvement in forestry knowledge and practices, but above all, a modern consideration of the forest has matured, not only as a collective asset to be protected but also as a resource to be exploited. The forest heritage is therefore precious for its landscape value, for the function it exercises in protecting the soil, for its countless uses. The Piedmont Region (2002) expressed the importance of the forest in a simple but effective way, stating that the managed forest is a resource for everyone because the forest is a natural system that can provide a wide range of benefits to society, both in the form of products and services. The forest improves air quality because trees retain dust and, thanks to the photosynthesis of chlorophyll, store atmospheric CO_2 (one of the gases believed to be responsible for the greenhouse effect), producing oxygen as "waste". In addition, the forest stores solar energy which is stored in the wood throughout the life of the trees. This energy is returned to the environment either with the decomposition of the organic substance or, more rapidly, through combustion. The energy supplied by wood is clean, renewable, and does not alter the carbon cycle. The forest influences the climate as it mitigates temperature variations, both daily and seasonal, slows the speed of the wind, and increases the atmospheric humidity, both inside and in the immediate vicinity. It also represents a sort of bank of natural genetic heritage. Each forest has its own biodiversity which determines its ability to react to external perturbations. The forest, especially in the mountains, performs important functions of protection of the territory such as reducing the risk of landslides, decreasing the possibility of avalanche triggering or slowing down their descent, limiting the beating action of rain, slowing the flow of rainwater that it is first absorbed by the soil, made more porous thanks to the presence of roots and organic substance, and then slowly released. This action, called "water regulation", also reduces the water flow rate and consequently surface erosion and the risk of floods. The tourist attraction of the forest areas has favoured the development of collateral activities (local crafts, production of gastronomic specialties, sports activities, etc.) sources of work and income for otherwise marginal areas. The forest produces wood, a renewable raw material of great value for the manufacturing industry and for crafts, from which many common objects are obtained.

The geographical, geomorphological, pedological and climatic characteristics of the Italian territory result in a high environmental heterogeneity.

The Italian forestry heritage is made up, overall, of 10,982,013 ha, of which 9,165,505 ha of forest and 1,816,508 ha of other wooded lands (provisional results of the National Inventory of Forests and Carbon Tanks (INFC, 2015)). The forest areas, therefore, cover 36.4% of the national territory. In some Regions and Autonomous Provinces, forests occupy about 50% or more of the regional surface (RAF, 2017-2018). The comparison of the surface estimates produced by the three national forest inventories made in Italy (1985, 2005, and 2015) indicates a significant increase in the forest area in the last century, with a slight slowdown in the last decade. The expansion of the forest was mainly caused by the abandonment of territories that have become marginal for agriculture and the reduction in the use of pastures for livestock activities, and occurred simultaneously with a gradual decrease in forest uses (RAF, 2017-2018; Marchetti et al. 2018; ISPRA, 2019; Gasparini and Marchetti, 2019). The annual increase in the total forest area (Forests

+ Other Wooded Lands) for the 1985-2005 and 2005-2015 intervals is respectively 0.3% and 0.2% of the national area. In particular, the annual increase in the forest was 77,960 ha in the period 1985-2005 and 52,856 ha in the period 2005-2015, and affects, with varying intensity, all the Italian regions (SFN, 2020).

The natural reconstitution and expansion of the forest have been accompanied in recent decades by particular attention to the conservation and enhancement of the naturalistic aspects. Italy is one of the European countries with the highest incidence of forests with naturalistic constraints; to date, over 27% of Italian forests are subject to particular protection regimes: from the integral reserves of national and regional parks to the areas included in the European Natura 2000 network (Maesano et al. 2014, European Commission 2015). Since 1923, most of the Italian forests (currently 86.7%) have been subject to the hydrogeological constraint which recognizes that forests have an important role in water management and therefore imposes regulations and all management methods. Furthermore, since 1985, 100% of forests (a unique case in Europe) are also subject to landscape restrictions (Marchetti et al. 2018).

Calabria is among the most forested Italian regions. In fact, it has a woodiness index of 44.5%, exceeding the national one by 8%.

Faced with this immense patrimony, which determines problems to be faced but above all opportunities to be seized, the enhancement of the woods is still low with a wood harvest far below the possibilities and with the use of wood not sufficiently anchored to artisanal and quality productions. Although in Italy forest resources represent an important productive and employment reality for the country and offer ample opportunities for growth and development, today the Italian wood industry is a leader in Europe, but with the supply of raw materials from abroad, in fact, most of the timber needs are covered by wood imports from other countries. This is due to the fact that, despite the increase in forest areas, there has not been an adequate increase in investments in management, use and production in the sector. The forest-wood supply chain presents numerous opportunities for growth, especially upstream of the supply chain itself, for companies that carry out silvicultural activities ensuring, in addition to wood production, the management and continuous maintenance of the territory (Plan of the wood supply chain 2012 - 14).

Italy is one of the most important producers and exporters of furniture and has a consolidated production capacity in the paper and packaging sector, all economic activities consistent with the guiding principles of the "circular bio-economy" (Hetemäki et al. 2017), which the European Union (EU) has fully adhered to for its development strategy to 2030. To these large-scale processes must be added the positive trend of the timber construction market. Italy has reached a record level on a European scale in the recycling of wood products at the end of the cycle, so much that it has become a net exporter of these products. In fact, the Italian industrial production of finished wood products uses more material from the final stages of the supply chain (recycling and reuse) than from national forests.

However, the production capacity of the industrial and craft sector, kept separate from the logic of a national "forest-wood system", has resulted in the growing dependence on the import of timber and semi-finished products from abroad. Italy has become the second net importer of wood products in Europe (after the United Kingdom) (Marchetti et al. 2018).

The forestry sector is often limited to the production of wood for energy purposes, while the management of forest stands hardly sees the implementation of targeted interventions towards the production of wood assortments most requested by the first and second transformation sectors of the forest-wood supply chain. This is also accompanied by a lack of knowledge of the vegetative state of stands, for many of which the silvicultural treatments and interventions prescribed by good government practice have not been foreseen for some time. It is for this reason that many of these stands, even if inserted in a highly valued stationary context, are in precarious management conditions and show the need for urgent interventions (Ventura and Romano, 2000).

The interventions of forest use represent the moment of synthesis of correct silvicultural management applied in a specific forest surface. The increase in complexity in forest systems and the improvement of retractable wood assortments are the main objectives of interventions in the woods where the production function is recognized. Only through correct and multifunctional management of the forest, can all the functions and components (economic, protective, environmental and recreational) that the forest heritage performs, also and above all for future generations, be guaranteed at the same time (Proto et al. 2014).

Forest Wood supply chain

Forestry as an industry is not intended for itself. It represents several parts in a complex forest-wood chain. Technologically speaking, the forestry part of the forest wood supply chain forms a series of production processes that transform natural resources from forests into products and services. The timber production process takes place through the production stages. Production processes vary in different environments and have evolved over time in different directions. Different equipment and machines are required in the process of carrying out technological procedures, which enable the implementation of a certain procedure. Production processes also vary by raw material (maybe products or semi-finished products) in which they take place.

The supply chain can be defined as the manufacturer and its suppliers, vendors, and costumers – that is, all links in the extended enterprise – working together to provide a common product or service to the marketplace that the customer is willing to pay for.

Forest-wood supply chain deals with processes within the chain, starting from the management of the new forest to the valorisation of the wood product; covering forest organization, logging and transport, and forest industry to end-use (Vötter, 2009), but each provider can take independent decisions. Entrepreneurs often have to decide which type of supply chain to employ for a certain operation. In recent years, new technologies and methods for the utilization of wood have been suggested and introduced to enhance the wood supply chain. Basically, innovations have been grouped into two main classes: radical innovations that change the operating principle of a system and lead to a technology leap, and incremental innovations that improve the existing systems by enhancing the efficiency of their resources or reducing their costs in gradual steps.

For decades, in fact, the wood products industry has been doing strenuous efforts to improve productivity, efficiency and cost-effectiveness of its operations, including forestry, harvesting, transportation, wood processing and the manufacturing of end wood products and building components. Intense efforts have focused on minimizing individual costs links (process steps or units) in the process chain (Hansen and Juslin, 2011), thus incrementally improving the productivity and efficiency of the units (Larsson et al. 2016). As the wood supply chain is a complex and highly dynamic network due to unpredictable simultaneous interactions, it hardly can be solved optimally. In practice, coordinated processes are applied to cope with this complexity, but fail frequently when unexpected risks occur, or changes that must be implemented. This leads to an inefficient supply chain. A fundamental supply chain management principle is to emphasize the overall performance of the supply chain in order to compete with other supply chains (Haartveit et al. 2004; Westlund and Furness-Lindén, 2010). Accordingly, the attention focuses on the wood supply chain connecting forest owners and forest-based industries.

Study's objectives

As can be seen from the title of this Ph.D. research, the main objective is to optimize and enhance the forest wood supply chain in Calabria region. Recently, a National Operative Programme (NOP – ALFORLAB) was conducted to aim more attention to Calabrian forest sector (Paletto et al. 2017; Proto et al. 2017, 2018; Iovino et al. 2017; Pastorella et al. 2017; Sperandio et al. 2017; Puletti et al. 2017; Scrinzi et al. 2017; Infusino et al. 2017). In particular, some researchers (Paletto et al. 2017, Proto et al. 2017) had placed their attention on the strategies for enhancing the forest-wood supply chain in Calabria but from the point of view of stakeholders. Among the seven objectives proposed through their questionnaires to stakeholders aimed to enhance the forest-wood chain at local level (economic exploitation of wood products; diffusion of forest certification; orientation of production to market demand; coordination of forest-wood-energy chain's actors; implementation of environmental and cultural forest values; improvement of the level of mechanization in wood processing; improvement of the efficiency of forestry workers), according to this study, for the interviewed stakeholders the main three objectives were: the implementation of environmental and cultural forest values, the improvement of the efficiency of forestry workers, and the diffusion of forest certification. In addition, the stakeholders highlighted the importance of the activities of environmental education for the citizens and the professional training courses for the forest operators.

Starting from these considerations, this research doctorate aims to provide information on the current reality that characterizes the forest sector of Calabria Region, focusing on the different aspects that the supply chain embraces, with the purpose of enhance of the forest-wood chain through a process of progressive divulgation and spreading, among the forest entrepreneurs, of knowledge about the most modern and rational techniques and technologies of forest utilization, so that workers can operate with greater economy and respect for the environment. A significant effort has been devoted to developing environmentally friendly forestry for future generations; in particular were conducted several studies to investigate on many rings of wood supply chain to determine:

- Productivity by different kinds of machines comparing specialised and non-specialised in the forestry mechanization;
- Environmental impacts of forest utilization focusing on soil disturbance during skidding operation;
- Develop of Non-Destructive Technologies that are capable of predicting intrinsic wood proprieties of individual standing trees and assessing wood quality by stands and forest;
- Study of a Calabrian forest company from the point of view of suitability and gaps for obtaining forest certification;
- Valorisation of Calabrian wood.

Organisation

In order to guarantee a logical flow of topics linked on forest wood supply chain, the thesis is developed following the thematic chapters:

- Forest Mechanization;
- Soil Disturbance;
- Use of Non-Destructive Technology;
- Forest Certification;
- Wood Technology.

Each chapter is composed by an introduction, materials and methods, results, discussion and conclusion. In particular, the forest mechanization chapter is structured by a short introduction, two scientific papers already published, one under publication and one under review. The chapter of the use of NDT also consists of a published scientific paper.

FOREST MECHANIZATION

Introduction

Various harvesting methods can be used depending on forest site-specific conditions and degrees of mechanization and appropriate mechanization levels depend on several factors. Although in recent times significant forestry use innovations have become available (Cavalli 2008), the majority of Italy's private and public forests are still being harvested with traditional methods, i.e., motor-manual felling (chainsaw) (Brachetti Montorselli et al. 2010) and low mechanized methods. They are based mainly on agricultural tractors, sometimes equipped with specific forest-related machines (winches, hydraulic cranes, log grapples, etc.); use of animals for gathering and yarding is also widespread (Picchio et al. 2011). This level of mechanization of forest resource extraction is due to the features of the forest sites, the characteristics of the forest properties, and the small dimensions of many forest enterprises (Proto et al. 2014). The level of mechanization in harvesting is low: the most common harvesting method can be described as being at an early stage of mechanization (Macrì et al. 2016). Furthermore, the current increasing dynamism of the wood market has led to the development and improvement of technologies able to extract logs more efficiently by reducing consistently the time and labour required for production (Cavalli et al. 2014; Moneti et al. 2015, Macrì et al. 2016). In this chapter are shown two different works on machines used during forest utilization that regard directly the Calabria region, and two studies conducted on different forest sites in Romanian country aiming to give information about new technologies that could be useful to the enhancement of forest-wood supply chain in Calabria.

In particular, three of the studies above mentioned are published as scientific papers on national and international journals and one is currently under review.

Papers details

- **Cataldo MF**, Proto AR, Macrì G, Zimbalatti G (2020). Evaluation of different wood harvesting systems in typical Mediterranean small-scale forests: a

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- Borz SA, Marcu MV, **Cataldo MF** (2021) Evaluation of an HSM 208F 14tone HVT-R2 Forwarder Prototype under Conditions of Steep-Terrain Low-Access Forests. Croatian Journal of Forest Engineering, 42(2): 16, doi: 10.5552/crojfe.2021.775.

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Maria Francesca Cataldo role and contribution in this paper: investigation, data acquisition, data validation, data curation, statistical data analysis, writing original draft.

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Research paper

Evaluation of different wood harvesting systems in typical Mediterranean small-scale forests: a Southern Italian case study

Maria Francesca Cataldo[1]*, Andrea Rosario Proto[1], Giorgio Macrì[1], Giuseppe Zimbalatti[1]

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ABSTRACT Use of small-scale harvesting equipment in forestry is increasing in many regions of the world and tractor-based systems are the most common type of small-scale forestry equipment. This equipment is smaller, less expensive and less productive than advanced forestry machines and the choice of method depends on forest site-specific conditions. In southern Italy the prevailing conditions are those characteristic of small-scale forestry: harvested areas and volume are limited and ground-based extraction is still the most common harvesting technique. Two harvesting systems conventionally adopted in Italian small-scale forestry are those using either winch or grapple fitted farm tractors for wood extraction. A continuous time study was adopted to determine productivity rates and wood extraction costs and develop skidding time prediction models for these two different wood harvesting systems as used in typical Mediterranean forests, in chestnut and silver fir thinning operations. Comparing winch and grapple extraction revealed considerable differences in productivity (2.91 and 5.92 $m^3 h^{-1}$ respectively). Factors significantly affecting productivity differences were extraction distance and payload per turn. The study concluded that farm tractors can be used for small scale harvesting operations and its results can be used to set piece rates, design and rationalize work and estimate costs. In order to sustain small-scale harvesting equipment effectiveness, skid trails should be planned in forests. The use of farm tractors needs to be encouraged as an alternative self-sufficient productivity method in small-scale forestry operations.

KEYWORDS: wood harvesting, time studies, productivity, farm tractors, mechanization.

Introduction

Forests and wood products provide a basis for economic, environmental and social sustainability in rural areas and wood harvesting has long been one of the most important forms of forest management. Various harvesting methods can be used depending on forest site-specific conditions and degrees of mechanization and appropriate mechanization levels depend on several factors. In Italy, wherever terrain characteristics permit, chainsaws have been replaced with alternative highly mechanized systems, especially for specialized forest plantation harvesting, such as poplar (Spinelli and Magagnotti 2011) and eucalyptus (Picchio et al. 2012). But in mountainous areas, and where numerous environmental protection restrictions exist, conventional and traditional mechanization is used (Baraldi and Cavalli 2008, Zimbalatti and Proto 2009, Picchio et al. 2016, Proto et al. 2017, Iranparast Bodaghi et al. 2018). Although in recent times significant forestry use innovations have become available (Cavalli 2008), the majority of Italy's private and public forests are still being harvested with traditional methods, i.e., motor-manual felling (chainsaw) (Brachetti Montorselli et al. 2010) and low mechanized extraction methods (mules and/or agricultural tractors) (Picchio et al. 2011).

The choice of machinery and methods used depends on factors such as harvest type, environmental constraints, slope and roughness terrain classification, machine availability and harvesting costs. This is because each harvesting system has its limitations and each machine has technical characteristics which rule out its use in certain circumstances. In southern Italy limited harvested area volume prevails in small-scale forestry and ground-based extraction is still the most common harvesting technique. Specifically, 60% of southern Italy's forests are located on 20-60% gradients, restricting harvesting systems to small-scale forestry action (Nakahata et al. 2014, Proto et al. 2018b) such as motor-manual harvesting and low-cost equipment (Johansson 1997, Ozturk and Senturk 2010, Jourgholami 2014, Proto et al. 2016a, Koutsianitis and Tsioras 2017). In such conditions, chainsaws are the most common tools used for tree felling and processing (Zimbalatti and Proto 2010) while wood extraction uses farm tractors equipped with winches for bunching and skidding (Heinrich 1999, Cosola et al. 2016, Enache et al. 2016, Koutsianitis and Tsioras 2017, Proto et al. 2018b). In southern Italy, in particular, the most widely used timber extraction method is farm tractors equipped with winches and only a small proportion of wood is extracted with skidders, tractors with trailers or bins, cable cranes, forwarders, chutes and animals (horses, mules and oxen) (Macrì et al. 2016, Proto et al. 2018b).

Farm tractors have proved to be efficient and manoeuvrable ways of extracting logs in low gradient conditions (Gilanipoor et al. 2012, Proto et al. 2016b) and are often used as base machines in forest activities, especially where this is small scale (Johansson 1997). When properly equipped, farm tractors are capable of carrying out a wide range of forestry operations from skidding and forwarding to loading

1 Department of AGRARIA, Mediterranean University of Reggio Calabria, 89122 - Italy
*Corresponding author: maria.cataldo@unirc.it

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Table 1 - Description of study sites.

Characteristics	Unit	Site A	Site B
Location	-	Brognaturo	Brognaturo
Harvesting method	-	Cut-to-length	Cut-to-length
Dominant species	-	Chestnut	Silver fir
Forest type	-	High forest	Natural forest
Felling equipment	-	Chainsaw	Chainsaw
Extraction equipment	-	Farm tractor + Winch	Farm tractor + Grapple
Average altitude	m a.s.l.	1,050	1,100
Stand density	treesh^{-1}	870	570
Stock volume	m^3h^{-1}	948	889
Number of trees felled	treesh^{-1}	261	86
Average DBH	cm	35	39
Average height	m	24	25
Average volume per tree	m^3	1.09	1.53
Average slope	%	30	29
Roughness	-	I	I
Total area	ha	8	16
Extraction intensity	m^3h^{-1}	284	134
Total volume extracted	m^3	2,276	2,147

and processing (Russell and Mortimer 2005). European manufacturers have developed several forestry attachments for farm tractors such as winches, wire cranes, grapple loaders and processor and harvester heads. In small scale forestry, the use of farm tractors equipped with appropriate forestry equipment can be a valid solution because configurations of this sort are versatile and cost effective (Spinelli and Baldini 1992). Modified farm tractors are one of the most widely used means of timber extraction not only in Italy but also in the Balkans and the Carpathians (Zimbalatti and Proto 2009, Savelli et al. 2010, Stankić et al. 2012, Bîrda 2013, Borz et al. 2013, Borz et al. 2015, Leszczynski and Stanczykiewicz 2015, Moskalik et al. 2017, Proto et al. 2018b, Munteanu et al. 2019) and small-scale harvesting equipment use for forestry is increasing in many regions of the world (Melemez et al. 2014).

Most previous studies have focused on specialist forest tractors while farm tractors have previously received scant attention from researchers (Gullberg 1995, Gilanipoor et al. 2012, Spinelli and Magagnotti 2012, Gumus 2016). Many countries keep using traditional machines or animals to harvest and extract timber on the grounds that specialist forestry machinery can be very expensive to purchase and maintain (Akay 2005). The aims of the present study were *(i)* to determine productivity rates and wood extraction costs using conventional mechanization in Italian small-scale forestry, and *(ii)* to develop skidding time prediction models for two different wood harvesting systems in typical Mediterranean forests.

Materials and methods

Study sites

The studies were based in Brognaturo in the Serre Massif forest (in Vibo Valentia province), in the Calabria Region of Southern Italy (Fig. 1). Site A was a natural high chestnut forest and site B a natural silver fir forest, distinguishing high forests from coppices and natural forests from plantations or artificial stands. The main characteristics of the two sites are shown in Table 1. The area's forests have a good main road network (28 m ha^{-1}) and trails opened up during felling were used as a secondary road network, facilitating machine transit where a forest road network was lacking. Selective thinning cut was applied at both sites.

Figure 1 - Two study sites in Southern Italy (Calabria Region).

Table 2 - General characteristics of wood extraction with winches and grapple.

Characteristics	Unit
Winch	Use a cable and choker to pull one or more trees to a tractor. The skidding winch is normally attached to the 3-point hitch and takes its power from the tractor PTO. Advantages: Low to medium cost. Suited to a wide range of tractors and sites. When using winches in difficult "terrain the" load can be dropped and tractor can move to more favourable terrain and winch the log from a distance. Disadvantages: Limited application in thinnings for high density of trees and low accessibility with consequent difficulty of logs motion especially long logs. Skidding often produces dirty logs, which can cause difficulties at the processing stage. Can contribute to both soil and residual tree damage.
Grapple	Large hydraulic grapples mounted on the 3-point hitch can be used equally well for transporting cut-to-length logs or tree-length logs. The operator reverses up to the logs or timber stack and 'grapples' the load, which can then be hydraulically lifted for transportation. Advantages: Relatively inexpensive. Shortwood can be extracted clean. Operator does not need to leave the cab. Disadvantages: Requires good presentation of material and does not have the flexibility and versatility of typical winch skidders. Needs good sites, detailed planning and site layout is required especially in thinnings.

Table 3 - Specifications of the machinery used in the two study sites.

Parameters	Unit	Chainsaw	Tractor	Winch	Grapple
Producer	-	Husqvarna	Same	Schwarz	Krpan
Model	-	560 XP	Silver 110	EGV 105 AHK	KL 2200
Power	kW	3.5	81	-	-
Weight	kg	5.9	4,700	-	-
Displacement	cm^3	59.8	6,000	-	-
Overall length/ width	mm	-	4,250/2,735	-	-
Bar length	cm	40	-	-	-
Minimum power required	kW	-	-	74	40-90
Diameter	mm	-	-	13	-
Drum capacity	m	-	-	180	-
Nominal pulling force of winch	kN	-	-	100	-
Closing force	kN	-	-	-	70
Min / max opening width	cm	-	-	-	10/220
Rotation angle on both sides	degrees	-	-	-	± 40
Load capacity	kg	-	-	-	3,000

Description of harvesting systems and machinery used

The harvesting method observed in this study was cut-to-length (CTL) using chainsaws. Accordingly, trees were felled, delimbed, topped and processed (Kellogg et al. 1993, Pulkki 1997) and timber extraction was via farm tractor. Trees were cross-cut to obtain 4.10 m long roundwood assortments. The same farm tractor (Same Silver 110) was equipped with a winch (EGV 105 AHK Schwarz) in site A and a grapple (Krpan KL 2200) in site B. The main characteristics of the machines used in this study are shown in table 3. The most common farm tractor forestry accessories are winches and grapples whose principal characteristics are shown in table 2 (Russell and Mortimer 2005)

Tree felling was done by two qualified workers: a chainsaw operator (CHO) and an assistant (AS) on both sites with AS tasks being clearing undergrowth for emergency use escape routes and at the base of the trees to be cut down, as well as activities associated with tree felling (e.g. pushing trees in the right direction or hang-up tree releasing in the event of obstacles) and piling, moving and arranging cutting residues. In site A skidding work a farm tractor equipped with a winch was used as there was no tractor access to the felled timber.

The site A working team consisted of a tractor driver operator and two qualified choker setters. The former drove the tractor from the roadside to the felling site and released the cable for hooking. Loads were attached to the cable by the choker setters, winched to the skid trails and extracted to the landing area with the tractor. On site B, the crew consisted only of two workers: a tractor operator (the same person as site A) who used a skidding grapple to drag the trees to the landing area and a landing operator who drove a forest loader to facilitate wood piling beside the road.

Time study and data processing

The time study data consisted in monitoring about 350 felling (261 at site A and 86 in site B) and 80 skidding (40 at each site) cycles. Skidding operations were monitored constantly and the time required for the completion of each task was measured by digital chronometer (1 min = 100 unit, Tag-Heuer MicrosplitTM). The continuous chronometry method at elemental level was used to determine elemental time consumption (Harstela 1993). Mechanical and human delays were also recorded for each cycle. Work cycle times were divided up into multiple elements (Liepiņš et al. 2015) as Table 4 shows. For each cycle the following were measured as operational variables: extraction distances measured with a laser rangefinder, total number of trees transported and the volume of each log in the load, calculated using Huber's formula (Philip 1994):

$$V_i = \frac{\pi}{40000} d_i^2 L_i$$

V_i = volume of the log i (m^3)

d_i = mean diameter of the log i (cm)

L_i = length of the log i (m)

Data collected during winching and skidding for each cycle allowed hourly machine productivity computed via total time and log volume to be calculated (Borz and Ciobanu 2013, Gülci et al. 2018).

$$p = \frac{v}{t} 60$$

v = total log volume (m^3)

t = cycle time (min)

Table 4 - Elements of work time.

	ACTION	DESCRIPTION
Felling and processing with chainsaw	Moving	Begins when the chainsaw operator (CHO) or assistant (AS) starts walking toward the working place and ends when the worker reaches the working place
	Felling	Begins when the CHO reaches the tree and ends after the tree is felled on the ground.
	Supporting felling	Begins when the AS reaches the tree and ends after the tree is felled on the ground.
	Clearing	Cutting and crosscutting the undergrowth
	Delimbing	Cutting the branches from the felled tree
	Refuel and sharpening	The chain is sharpened every time the fuel chainsaw is filled
Extraction with cable winch or grapple	Travel unloaded (similar for cable winch and grapple)	Begins when the skidder leaves the landing area and ends when the skidder stops in the stump area
	Release and hooking (cable winch)	Begins when the worker has just grabbed the cable and sets the choker on the tree about 0.5–1.0 m away from the tree end, and ends when the skidder operator starts winching
	Winching (cable winch)	Begins when the driver starts to winch and ends when the tree has arrived at the rear part of the skidder
	Grappling (grapple)	Begins when the grapple of the skidder opens and takes the trees and ends when the grapple is closed
	Travel loaded (similar for cable winch and grapple)	Begins when the machine moves to the landing and ends when it reaches the landing
	Unhooking (similar for cable winch and grapple)	Begins when the machine reaches the landing and ends when the load is unhooked
Delay Time	In both phases (felling and extraction) was considered also miscellaneous time that is not related to productive work time (phone calls, etc.).	

Cost calculations

For the purposes of calculating hourly costs tree felling and extraction costs, Olsen and Kellogg's parameters (1983) were used together with methodology of Ackerman et al. (2014) developed within COST Action FP0902. Cost analysis was based on the following parameters: operator numbers, hourly operator costs, hourly machinery costs, the volume of wood extracted and productive machine hours. This method includes fixed costs, variable costs and labour costs (Tab. 5). The variable costs comprise fuel, lube and maintenance and repair. These variable costs are solely related to machine use and as such charged on a PMH. Hourly machine costs are shown as scheduled machine hours (SMHs) (Tab. 5). Capital costs related to chainsaws and tractors are shown separately because their expected financial lifespans are very different. The purchase prices and operator wages required for the cost calculations were obtained from catalogues and accounting records. Labour

Table 5 - Specifications of the machinery used in the two study sites.

		Value		
Parameters	**Unit**	**Chainsaw + 2 operators**	**Tractor +winch + 3 operators**	**Tractor + grapple + 2 operators**
Purchase price	€	980	60,000	60,000
Salvage value	€	0	12,000	12,000
Estimated life	year	1.2	10	10
Scheduled machine hour	h	1,680	1,050	980
Fuel and lubricant	€ h^{-1}	3.05	14.95	16.08
Annual depreciation	€ $year^{-1}$	817	4,800	4,800
Interest	€ $year^{-1}$	36	1152	1152
Total fixed cost	€ h^{-1}	0.51	8.59	9.21
Total variable cost	€ h^{-1}	3.54	18.15	19.51
Total labor cost	€ h^{-1}	42	63	42
Total hourly cost	€ h^{-1}	46.05	89.74	70.72

costs were set at 21 for scheduled machine hours (SMH) including indirect salary costs. Diesel fuel consumption was measured by evaluating the volume of fuel required to fill the fuel tank to the brim and recording fuel amounts used that day. A salvage value of 20% of the purchase price was assumed and value added tax (VAT) was excluded. Cost calculations were based on the assumption that companies worked year round with the exception of the rainy season, when southern Italy's harvest areas are not normally accessible. In general, a total of 1,680 hours per year were scheduled for felling work operations using chainsaws (210 days per year, 8 scheduled working hours per day). For extraction work this amounts to 130–150 working days per year (20-21 working days per month), at an average of 6-7 scheduled working hours per day (assuming one to two hours spent on lunch, rest and other breaks). This yielded annual working times of 910–1050 SMHs with a 70% use coefficient (Spinelli and Magagnotti 2011, Spinelli et al. 2014, Proto et al. 2018a).

Data Analysis

Operations examined in this study included observing 3,464 felled trees (2,088 in site A and 1,376 in site B). SPSS software version 20.0 (IBM Corp., Amonk, NY, USA) was used for the statistical analysis of the data. In line with other studies estimating operational performance (e.g. Proto et al. 2018a, 2018b, 2018c), two regression models (felling and skidding operations) were developed. The null hypotheses were that productivity remains similar across the various types of wood extraction. Initially, a 95% significance level was chosen to test the null hypothesis. A global significance test (F-test) was conducted to examine the suitability of the regression models and each coefficient was tested separately using a t-test to test the relevance of the variables. If the test results indicated p-values lower than 0.05 the null hypothesis was rejected (i.e. Proto et al. 2018b and 2018c). Two different models for predicting total times were evaluated using linear regression and selecting independent variables via a step-by-step regression. Regression analysis was used to model skidding by explaining the total cycle time variation as a function of operational variables that were considered independent variables in the model (number of trees, average volume, skidding distance, winching distance and number of trees). An additional variable was inserted to differentiate technical configuration of the tractor from the two work sites: site A = 0 for winch extraction and site B = 1 for grapple extraction. $R^2_{adjusted}$ was used as a measure of the predictive capacity of the equations.

Results

On site A, 2088 chestnut trees were felled on 8 hectares (261 trees ha^{-1}) amounting to a total wood volume of 2,276 m^3. On site B, 1376 silver fir trees were felled on 16 hectares (86 trees ha^{-1}) accounting for a total wood volume of 2,147 m^3. The total work time monitored during felling was 2235 minutes on site A and 854 minutes on site B. Hourly manual chainsaw felling and processing productivity was 7.63 m^3 h^{-1} on site A and 9.36 m^3 h^{-1} on site B. Chainsaw productivity using the predicting method was satisfactory ($R^2_{adjusted}$ = 0.697) (Tab. 6).

Table 6 - Productivity equation for sites A and B with manual chainsaw felling and processing.

Site	Model	Equation	F	P	$R^2_{adjusted}$
A+B	Productivity	P (m^3 h^{-1}) = - 11.427 + 0.369 × DBH (cm) + 0.262 × H (m)	595.828	0.00	0.697

DBH = diameter at breast height, H = height.

Table 7 - Basic descriptive statistics of operational variables and performance metrics.

Average parameter	Value		
	Unit	Site A	Site B
Productive machine hour (PMH)	m^3	2.91	5.92
Scheduled machine hour (SMH)	m^3	2.87	5.73
Logs extracted per cycle	n	3	2
Skidding distance	m	276	105
Bunching distance	m	33	-
Volume extracted per cycle	m^3	0.70	0.59
Extraction cost (PMH)	€ m^{-3}	30.80	11.90

Table 8 - Time consumption (mean value and standard deviation (SD)) for working cycle elements

	Work phase	Unit	Site A		Site B		Percent of total time (%)	
			Mean	(SD)	Mean	(SD)	Site A	Site B
Felling	Moving	min	0.40	0.17	0.52	0.19	4	5
	Felling	min	0.61	0.25	0.78	0.29	7	8
	Delimbing	min	6.59	0.91	7.63	0.97	77	77
	Refuel/Sharpening	min	0.49	0.19	0.52	0.21	6	5
	Delay time	min	0.47	0.18	0.49	0.20	6	5
	Cycle time	min	8.56	0.88	9.93	0.94	100	100
Extraction	Travel unloaded	min	2.59	0.37	2.86	1.15	19	39
	Hooking/Grappling	min	1.93	0.32	0.16	0.04	14	2
	Winching	min	2.22	0.23	-	-	16	-
	Travel loaded	min	5.76	0.41	3.05	1.11	42	42
	Unhooking	min	1.10	0.06	1.08	0.04	8	15
	Delay time	min	0.21	0.06	0.16	0.03	1	2
	Cycle time	min	13.81	0.84	7.31	2.28	100	100

Table 9 - Cycle time and productivity equations for sites A (cable winch) and B (grapple).

Site	Model	Equation	F	P	$R^2_{adjusted}$
A	Cycle time	Equation (1) Ct (min) = 5.817 + 0.039 × Wd (m) + 0.019 × Sd (m) + 0.461 × Nl (n)	49.327	0.00	0.788
B	Cycle time	Equation (2) Ct (min) = - 4.233 + 0.110 × Sd (m)	1,028.965	0.00	0.963
A+B	Productivity	Equation (3) P (m^3 h^{-1}) = 12.669 – 0.055 × Sd (m) + 8.024 × V (m^3) – 5.771 × St	28.178	0.00	0.508

Wd = Winching distance, Sd = Skidding Distance, Nl = number of logs, V = Volume, St = Skidding type (0 = winch; 1 = grapple)

Total hourly manual chainsaw felling costs with 2 operators were estimated to be € 46.05. Combining hourly costs with a productivity of 7.63 and 9.36 m^3 h^{-1} provided an estimated average unit cost of €6 and 5 m^3 respectively for sites A and B.

As Table 7 shows, at site A average skidding farm tractor equipped with winch productivity was 2.91 m^3 per productive machine hour (PMH). The average number of logs extracted per cycle was 3 and the average volume extracted per turn was 0.7 m^3. At site B, the average hourly productivity of the farm tractor with grapple was 50% higher than the winch (5.92 m^3/PMH^{-1}). The average number of logs extracted per turn was 2 with an average volume per cycle of 0.59 m^3.

Extraction costs related to using a winch with 3 operators were calculated at € 30.8 m^3 (PMH) and € 31.3 m^3 (SMH). On site A time delays marginally increased operating costs but low productivity primarily related to logging costs. On site B, higher productivity generated by use of a farm tractor equipped with a grapple and the labour of 2 operators led to lower extraction costs of € 11.9 m^3 (PMH) and € 12.3 (SMH). Loaded and unloaded travel were the two main time elements and winching only occurred at site A. On average, the extraction cycle time at site A where the winch was used was 13.81 min (±0.84 standard deviation (SD)), while at site B the grapple extraction cycle timeframe was 7.31 min (±2.28 SD), with the individual elements shown in Table 8. One confusing effect was unloaded and loaded travel time.

The volume of valid observations collected during the tests was sufficient to develop a reliable time cycle model forecast. Statistical analysis shows that the models presented for the work sites are significant ($p < 0.05$). The time cycle equations, calculated for skidding operations in the two different systems (cable winch versus grapple), were correlated with several parameters (Tab. 9).

There was no significant difference in productivity in terms of numbers of logs extracted (p-value: 0.28), but skidding distance and volume extracted per work cycle had a significant influence.

Discussion

Tree felling using chainsaws followed by farm tractors is commonplace in many countries. Several studies have shown that time consumption is mainly influenced by tree breast height diameter in felling operations (DBH) (Lortz et al. 1997, Ciubotaru and Maria 2012, Borz and Ciobanu 2013, Jourgholami et al. 2013, Câmpu and Ciubotaru 2017). Ghaffarian (2007) and Uotila (2014) determined a linear relation between felling time and tree breast height diameter. In line with these studies, this research confirmed that breast height diameter significantly affected tree felling productivity. Motor-manual felling with chainsaws is technically possible where ground-based heavy forest machinery cannot be used and alternative methods are not available (Borz et al. 2015). Power chainsaws are still important in tree felling. Jourgholami et al. (2013) reported the limits to its usefulness in Hyrcanian hardwood forests while in Romanian resinous forests, Câmpu and Ciubotaru (2017) monitored time consumption and productivity in manual tree felling with a chainsaw. In fact, in Romania, chainsaws and skidders are the most frequently used harvesting system (Sbera 2007) especially when dealing with increased log volume. In many countries, small-scale timber harvesting generally implies the use of inexpensive machinery operated on a part-time basis (Russell and Mortimer 2005). The benefits of small-scale forestry equipment are, in fact, lower capital expenditure and operating costs, the potential for multiple uses and ease of transport (Masson and Greek 2006, Borz et al. 2019). But, to our knowledge, few studies have addressed skidding performance using a farm tractor equipped with a grapple or cable winch in central and southern Italy in typical small-scale Mediterranean forests (Spinelli and Baldini 1992, Calafatello et al. 2005, Spinelli and Magagnotti 2012). This makes comparing the results reported here with those available in the international literature difficult. Nurminen et al. (2006) reported that traveling time (loading and unloading) was largely dependent on driving speed and distance but also timber volume per load. Menemencioglu and Acar (2004) found a value to be 6.35 m3 PMH^{-1} while Spinelli and Magagnotti (2012) calculated a productivity value of 4.7 m3 PMH^{-1} for thinning using a farm tractor (116 kW). Gilanipoor et al. (2012) found an average productivity rate of 2.50 m^3 PMH^{-1} and Calafatello et al. (2005) measured a lower productivity value of 6 m^3 PMH^{-1} using a farm tractor equipped with a winch in high forests. Comparing the two systems revealed that winches are suitable when logs cannot be directly accessed by tractor. However, winch productivity was strongly influenced by winching distance and log volume increasing total working times. Moreover, winch use required more operations, longer cable release and log hooking times. These factors impact costs; in fact, in this study winch extraction costs were more than double grapple extraction costs (31 m^3 and 12 m^3 respectively). Winch use requires an additional worker due to difficulties in hooking the logs, especially where volume is average-high, while two workers are sufficient for grapple extraction (a tractor driver and a worker) in skidding. In addition, using a farm tractor with grapple generates greater productivity than the former system because direct extraction from the tree felling point makes it faster. In addition, the smaller contact surface between the logs and the soil in grapple as opposed to winch use reduces soil surface structure changes.

Statistical analysis confirmed that skidding productivity depends on distance as well as transported log volume. In fact, extraction distance had a marked effect on total work timeframes, reducing productivity. This concerned all winch wood extraction, above all because it required longer cable release and winching operation time frames. Log volume also affected productivity because greater volumes corresponded to greater log hooking and handling problems. Productivity rates for delay-free skidding time and skidding time delays showed the limited impact of delay times on total cycles, also reported in other studies (Calafatello et al. 2005, Gilanipoor et al. 2012, Liepiņš et al. 2015).

The productivity equation models indicate extraction distance and volume extracted per turn as the most important factors affecting skidding productivity. In total operating cycle times using the two methods, 60% of both was accounted for by unloaded and loaded turns and this confirmed that skidding distance significantly affected cycle times and productivity as reported by Liu and Corcoran (1993) but, as compared to previous research indicating that skidding productivity is affected by the number of logs per cycle, in this study we found evidence that productivity was influenced by transported log volume per cycle. These findings are consistent with the results of studies by Gilanipoor et al. (2012) and Spinelli and Magagnotti (2012).

The winching phase at site A accounted for 16% of the total cycle time frame. Regression analysis conducted on winching time cycles revealed that both winching distance as well as log numbers had a significant effect on time frames.

Loaded travel was the most time-consuming element in skidding at both sites: 40% of total time cycles at site A and 41% at site B. In the same way as unloaded travel, loaded travel was strongly related to skidding distances and affected by tree numbers. These findings are consistent with the results of studies by Bìrda (2013) and Özturk (2010).

This study's skidding productivity is similar to, and sometimes higher than, other studies conducted using traditional methods. For example, Calafatello et al. (2005) estimated a lower productivity value of 6 m^3 SMH^{-1} using a farm tractor equipped with a winch; in high forest, Spinelli and Magagnotti (2012) found productivities ranging from 3.7 to 4.7 m^3 SMH^{-1} using four wheel drive farm tractors with a nominal power ranging from 48 to 116 kW. However, a more efficient road network would favour more productive use of farm tractors with winches or chutes in these areas.

Conclusion

The aim of this study was to evaluate two wood harvesting systems in Calabrian mountainous forests, in a typical small-scale Mediterranean forest. The results obtained accorded with available references regarding small-scale forests where harvesting costs were sufficiently low. Consequently, for the work sites examined, using farm tractors equipped with grapples was more convenient than using a winch. The results showed that farm tractors can be used for small-scale forest operations using adequate forestry equipment. These considerations may contribute to improved planning in small-scale forestry systems in private and publicly owned forests. This paper's results may be useful in production organization when dealing with similar work conditions. In particular, under difficult working conditions such as the study area (steep terrain, limited infrastructure, long forwarding distance), these results may be of great practical help in improving logging planning, reducing extraction costs in most timber harvesting operations and consequently for the purposes of wood supply chain cost competitiveness in small-scale Mediterranean forests.

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Research paper

Whole tree system evaluation of thinning a pine plantation in southern Italy

Andrea R. Proto[1*], Vincenzo Bernardini[2], Maria F. Cataldo[1], Giuseppe Zimbalatti[1]

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ABSTRACT In Italy, some silvicultural treatment as thinning could be carried out in an economic way adopting systems based on small-scale mechanization. This paper examines the productivity standards of wood biomass in coniferous plantation thinning in Southern Italy under the conditions of small-scale forestry. The objectives of the study were to evaluate the incidence of different silvicultural treatments on productivity and harvesting costs and create productivity models for typical harvesting system used for wood thinned from Calabrian pine. Three different sites were monitored on the Sila Massif forest, and the experimental plan included three area tests, subjected in the last thirty years to intermediate cuttings with different thinning grade: light thinning (A thesis), moderate thinning (B thesis), heavy thinning (C thesis). The authors developed a productivity model for motor-manual felling and skidding timber with wheeled farm tractors, equipped with winch using a time motion study. Whole tree extraction system in coniferous plantation applied with typical felling system traditional has guaranteed productivity standards at a reasonable cost reducing high operational cost per unit harvested. The results, therefore, underlined that it economic possible to wood biomass harvest relatively small-diameter from thinning stands favoring moderate and heavy thinning.

KEYWORDS: small-scale forestry, time studies, productivity, thinning, costs, mechanization.

Introduction

Calabria is a region in Southern Italy particularly rich in forests that are also often highly productive; indeed, every year, in Calabrian forests, the average increase in wood volume, which is equal to 6-8 m^3 ha^{-1}, exceeds and sometimes doubles the increase estimated in the other forests of Southern Italy (Ciancio, 1998). Making up 32% of the total are beech (*Fagus sylvatica* L.), chestnut (*Castanea sativa* Mill.), Calabrian pine (*Pinus nigra* Arnold subsp. *Calabrica* Delamare) and silver fir high forests (*Abies alba* Mill.). In particular, the current distribution of Calabrian pine in the Aspromonte mountain and, mainly, in the Sila plateau, covering about 114,000 ha, indicates what remains of the largest coating forest of southern Italy, the so-called *Silva brutia* (Avolio and Ciancio 1985, Bonavita et al. 2015) and more than 50% are pure stands of both natural regeneration and planted origin. The latter originated from extensive reforestation projects carried out between 1950 and 1970 following specific State laws (Iovino and Menguzzato 2002a and 2002b). In fact, Calabrian pine is endemic to southern Italy with a natural range extending from Calabria to Sicily (Nicolaci et al. 2014) and characterizes the forest landscape of Calabrian Region with an important role in the local forest economy. The structure of Calabrian pine stands on the Sila Plateau is the result of the management history, which depends on land ownership, as well as the economic and social changes that have taken place in the area (Ciancio et al. 2006). In public properties (townships and State forests), management of Calabrian pine has usually been based on various types of clear felling (strip or patch), whereas on private properties, pine stands have generally been managed according to traditional and locally developed forms of selection cutting, which have contributed to the maintenance of pure pine stands with complex structures (Ciancio et al. 2006). This type of management has preserved the typical forest landscape by maintaining a continuous forest cover. Among the various forest management practices, the thinning is widely conducted to produce more valuable and large-diameter timber. It reduces competition among the remaining trees, reduces the risk of fire (Corona et al. 2015), and helps to maintain a healthy forest (Kerr and Hauf 2011). Considering the role of Calabrian pine as colonizing in Calabria Region, from the last century the thinning treatment played a key role to produce more valuable and large-diameter timber for the proper management of softwood stands (Breda et al. 1995, Nishizono et al. 2008, Marchi et al. 2014). Thinning should be early and frequent, especially in artificial plantations, to be fully effective (Peltola et al. 2002, Rytter and Werner 2007) and prevent the occurrence of degradation, fire susceptibility and instability of stands (Savelli et al. 2010, Picchio et al. 2011) but it is time-consuming and expensive. Usually, thinnings generate poor financial returns due to the handling of small trees, which have relatively low financial value but have a relatively high operational cost per unit harvested (Kärhä et al. 2004, Spinelli and Magagnotti 2010). For this reason, in Calabrian pine stands the thinning procedure is not always adopted and the necessary treatments have not been applied regularly in Calabrian region as in Italy (Cantiani and

1 Department of AGRARIA, Mediterranean University of Reggio Calabria - Italy
2 CREA - Research Centre for Forestry and Wood
*Corresponding author: andrea.proto@unirc.it

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Chiavetta 2015) because seen as a costly silvicultural treatment. This explains the worrying tendency to avoid thinning, especially in artificial coniferous forests, and the consequent rise of degradation and instability problems in many forests (Bergström et al. 2007). The aim of this study was to determine the cost efficiency of typical harvesting system used for wood thinned from Calabrian pine forests used as biomass fuel for power plants installed in the region. The study was conducted in three Calabrian pine stands thinned with different intensity to evaluate the incidence of silvicultural treatments on productivity rates and wood harvesting costs.

Material and Method

Study sites and Working system

The studies were carried out in a Calabrian pine plantation, established in the sixties for protection purpose. The forestation was realized by planting on soils, mostly with 80-100 cm wide terraces and drawn according to the level curves. On the terraces, spaced between them of 3-4 m, were placed the seedlings in 40x40x40 cm pits with an interdistance of about 1 m, for an initial density of planting that ranged between 2,500 and 3,500 plants per hectare. The planting growth was particularly fast, and at 15-20 years of age the stand of 180-200 m^3 per hectare were found (Avolio and Ciancio 1979). Thinning treatments were planned in the following decades and the study areas were subject to several researches. Avolio et al. studied the effect of different thinning intensities on growth and yield (1997 and 2012) while Baldini and Spinelli (1995) reported the efficiency and productivity in first thinning. Specifically, the aim of this study has been to evaluate on the same plantation the incidence of thinning intensities on productivity rate during the last and third thinning. Three different plots were monitored sites at Varco S. Mauro, on the Sila Massif forest, in Calabria region of south Italy. The experimental plan included three randomized blocks consisting of three areas, subjected in the last thirty years to intermediate cuttings with different thinning grade: light thinning (A thesis), moderate thinning (B thesis), heavy thinning (C thesis) (Fig. 1). Each site is classified as I class for roughness, while the slope is between I and II class (UK Forestry Commission 1995); dendrometric data were recorded in order to attain the total volume extracted/yielded in each area using a volume table (double entry) and a plot sample. The stand density was 1,033, 875 and 704 trees per hectare for site A, B and C. The total volume per hectare was 665 m^3 at site A, 629 m^3 at site B and 572 m^3 at site C. The main characteristics of the three sites are reported in Table 1. The forest area has a good main road network (31 m ha^{-1}) and the trails opened during felling were used as a secondary road network. The Whole-tree harvesting method was adopted for each sites (A, B and C). This method is the most common harvesting method in Italy because include the possibility of removing the woody residues from the site. Whole-tree harvesting can be defined as the removal of most branches and needles from a harvesting site in addition to the stem wood that is removed in conventional harvesting (Nisbet et al. 1997, Proto et al. 2017a). In fact, when using wood for energy production, the final product is biomass ready to be transformed into energy, regardless of the part of the tree from which it originated.

Table 1 - Test sites characteristics.

	Total Trees					Removal Trees				
Thesis	N ha^{-1}	G ha^{-1} m^2	V ha^{-1} m^3	DBH cm	Hg m	N ha^{-1}	G ha^{-1} m^2	V ha^{-1} m^3	DBH cm	Hg m
A	1033	71.89	664.446	29.8	22.59	233	12.74	116.106	26.3	22.06
B	875	69.62	628.501	31.7	22.86	275	19.28	159.323	30.0	22.63
C	704	61.98	572.519	33.4	23.77	304	24.17	218.394	31.6	22.86

n: Stand density; G: basal area; V: stand volume; DBH: diameter at breast height.

Figure 1 - Study area: site A (left) and site C (right).

Therefore, extraction of not only stemwood but also branches, tops, needles and bark contributes to the total amount of forest biomass harvested (Sängstuvall 2010). A single team of workers was used for each of three sites to reduce the variability due to human factors. In fact, it is common knowledge in the literature in the field that, under the same work conditions, different work teams achieve a different productivity (Campu and Ciubotaru 2017). Also, it is well known that the operator has a large influence on productivity in most types of forest works (Gullberg 1955). The team consisted of one chainsaw (Stihl MS 390, 3.4 kW) operator, one farm tractor driver (Landini Landpower 145 TDI, 104 kW) equipped with forest cable winch (Bernard, BK700R, 70 kN, 100 m capability), and one chokers setter in the bunching phases. The workers evaluated had more than five years of experience. Both sites were thinned selectively, in order to create enough space around good quality crop trees, while removing the trees that were defective in some way, or direct competitors (Spinelli et al. 2014) releasing final crops consisting respectively of 800 (site A), 600 (site B) and 400 (site C) trees per hectare. Extraction distances and between felled trees were measured with a laser rangefinder. In each site, the operators felled the marked trees and extracted the undelimbed whole-tree sections to the roadside. The trees, after the felling, were split in two parts to facilitate the skidding operations.

Time motion study

In this study, time consumption was conducted. The time required for the completion of each phase was measured using a digital chronometer. Operational, technical and personal delay types were collected during the field study. A number of 180 work cycles (60 at each site) were measured for tree felling. In particular non-work time consisted mostly of delays whereas the supportive time consisted of chainsaw refueling, chain sharpening and chainsaw repairing. Skidding operations were studied monitoring 120 cycles (40 at each site). The study determined productive time including breaks less than 15 minutes in duration (PMH15). Data analysis was done according to the recommendations of IUFRO (Björheden et al. 1995) and the *Good Practice Guidelines For Biomass Production Studies* (Acuna et al. 2012). Similar to other studies, to determine the field performance, this study analyzed the time consumption data using concepts generally used in observational studies (Wang et al. 2004, Behjou et al. 2009, Balimunsi et al. 2012, Borz and Ciobanu, 2013, Jourgholami et al. 2013, Proto et al. 2017a), as shown in Table 2.

Table 2 - Description of work elements and independent variables.

Work and time elements	Definition	Independent variables
Felling		
Walk to tree - Wtt	Begins when the worker starts toward the tree to be cut and ends when he reaches to the tree.	Distance between trees - Dt Diameter at breast height - DBH
Cut - Ct	Begins when the worker starts to make a wedge-shaped notch in the base of the tree to ensure that it accurately faces the felling direction and ends when the worker starts backcut.	
Fell - Ft	Begins when the worker starts cutting the opposite side of the direction of fall and ends when the tree hits the ground.	
Cross-cutting - CRc	Begins when the worker moves to the felled tree and ends when the feller finishes the last of the cross-cutting and starts toward the next tree to be felled.	
Refuel and sharpening	-	
Extraction cycle with cable winch		
Travel unloaded – T U	Begins when the farm tractor leaves the landing area and ends when the farm tractor stops in the stump area.	Winching distance - Wd Skidding Distance – Sd Number of logs – Nl
Hooking - H	Begins when the worker has just grabbed the cable and sets the choker on the tree about 0.5–1.0 m away from the tree end, and ends when the farm tractor operator starts winching.	Volume - V
Winching - W	Begins when the driver starts to winch and ends when the tree has arrived at the rear part of the farm tractor.	
Travel loaded – T L	Begins when the farm tractor moves to the landing and ends when it reaches the landing.	
Unhooking - Un	Begins when the farm tractor reaches the landing and ends when the load is unhooked.	
Delays – D T	Personal delay, Technical delay, and Operational delay.	

Data Analyses and Cost Analysis

Time consumption estimation models were developed by the means of stepwise backward regression technique. Thus, in both cases were developed maximal models including all predictor variables collected in the field (Borz and Ciobanu 2013, Macrì et al. 2016, Proto et al. 2018). SPSS software version 20.0 (IBM Corp., Amonk, NY, USA) was used for the statistical analysis of the compiled data. Similar to other studies, to determine the performance, a regression model was thus developed. Harvesting costs were considered and the Miyata approach (1980) was applied including fixed costs, variable costs, and labor costs. The scheduled machine hour (SMH) was assumed considering a ten-year economic life for the tractor and only one year for the chainsaw. The purchase prices and operator wages required for the cost calculation were, however, obtained from catalogues and accounting records. Cost calculations were based on the assumptions similar adopted in recent economic studies (Spinelli and Magagnotti 2012, Proto et al. 2018).

Results

The main statistical indicators of work time variation according to phases in tree felling and of operational variables measured in the three sites are presented in Tables 3 and 4. In site A were removed 233 trees, 275 and 304 felled respectively in site B and C amounting to a total volume of 493.8 m^3. The total work time monitored during 180 work cycles necessary for felling trees in the three felling areas was of 1,579.70 minutes (463.30 minutes in A, 535.37 in B and 581.03 in C). Hourly productivity of manual chainsaw felling and cross-cutting was 4.85 $m^3\ h^{-1}$ (9.3 tree h^{-1}) in A, 5.71 $m^3\ h^{-1}$ (8.3 tree h^{-1}) and 5.85 $m^3\ h^{-1}$ (7.8 tree h^{-1}) in C. The data showed that the productivity is strongly influenced by diameter. In order to emphasize productivity dependence on DBH, the average work time corresponding to a complete cycle according to diameter classes and including delays was taken into consideration. Differences in work time cycle between the three sites occur mainly due to the time element W_{tt}, the moving time to and from the different trees marked to be cut. In fact, in site C the low density and the long distances between the trees have influenced (+11%) respect other two sites. As confirmed recent studies, walk to tree is directly related to initial stand density and harvesting intensity. Most time consuming work operation in applying the C_t and F_t phases, then follows cross-cutting with 27-32% respect the total cycle. The cross-cutting phase took more time in site B and C (11-13%) respect in site A. Personal, organizational and technical delays was similar for each site (4-5%) while supportive time (*refuel and sharpening*) varied from 4.7% (site C) to 6.5% (site A). The skidding cycle time varied hardly between the three sites; the cycle time averaged about 12.00 minutes for an average skidding distance of 223 m. Instead, statistically significant differences were evident in most of the examined work elements during the skidding phase. Hourly productivity of skidding was 3.04 $m^3\ h^{-1}$ (0.197 h m^{-3}) in A, 3.89 $m^3\ h^{-1}$ (0.154 h m^{-3}) and 4.11 $m^3\ h^{-1}$ (0.146 h m^{-3}) in C. According to the average values, the longest time among the work phases of skidding by farm tractor with winch was travel loaded (43-46%), with the breakdown of the individual elements shown in figure 2. Considerable differences were found with thinning treatments, starting from the load volume and the distances (bunching and skidding) which contribute to the total skidding cycle time. The farm tractor working at site A traversed a higher stand density and took considerably longer to travel similar distance in comparison to sites B and C. The average number of logs per turn was equivalent for each site but the different DBH influenced the average volume per load (0.56, 0.73 and 0.78). During extraction, justified delays consisted of around 5-6% of the studied work time in both treatments. Production rates also differed among the three sites. Mean productivity for A was found to be 26 % lower than that of the site C; in fact, the total distance for each cycle was higher (+ 10%) and the average volume per travel was lower (- 28%). The correlation analysis between the studied variables confirmed the degree of association of the variables of the work cycle. The independent variables were selected for the step-by-step regression analysis. The number of valid observations collected during the tests was large enough to develop a reliable model for predicting the productivity. Two different models for predicting the productivity were evaluated using linear regression and selecting the independent variables with a step-by-step regression (Tab. 5). According to the statistical analysis, the models presented for the worksites are valid (p < 0.05). There was no significant difference in skidding productivity respect the number of logs extracted (p-value: 0.15), but bunching distance, skidding distance and volume extracted for cycle influence significantly. The models of felling productivity equation indicate the diameter, distance between trees to cut and total cycle time the most important factors affecting felling productivity. The models of skidding productivity equation indicate bunching distance, extraction distance and volume extracted for cycle the most important factors affecting skidding productivity. The system productivity and cost were examined based on the manual harvesting system that consisted of one chainsaw, one farm tractor with winch, one chainsaw operator, one driver and two assistants. The system costs included felling (cross-cutting comprised), and skidding costs.

Table 3 - Descriptive statistics at site A, B and C for felling phase.

Parameter	Unit	Site A		Site B		Site C	
		Mean	SD	Mean	SD	Mean	SD
Walk to tree - Wtt	min	0.91	0.34	0.89	0.34	1.03	0.39
Cut - Ct	min	2.49	2.60	3.30	3.42	3.48	3.60
Fell - Ft	min	1.29	0.12	1.54	0.16	1.70	0.17
Cross-cutting - CRc	min	2.04	0.22	2.18	0.23	2.48	0.27
Refuel and sharpening – R & S	min	0.50	0.13	0.53	0.15	0.45	0.15
Delay T	min	0.45	0.15	0.52	0.14	0.40	0.09
Distance	m	42.98	14.78	40.83	14.04	45.87	15.77
Diameter	cm	26.25	1.39	30.03	1.44	31.60	1.44
Productivity	$m^3 h^{-1}$	4.85	1.28	5.71	1.61	5.85	1.62

Table 4 - Descriptive statistics at site A, B and C for skidding phase.

Parameter	Unit	Site A		Site B		Site C	
		Mean	SD	Mean	SD	Mean	SD
Total cycle time	min	11.01	0.91	11.30	0.68	11.42	0.84
Time travel unloaded – T U	min	1.65	0.47	1.48	0.41	1.33	0.37
Hooking - H	min	1.44	0.39	1.53	0.41	1.61	0.48
Winching - W	min	1.93	0.27	2.06	0.35	2.15	0.39
Time travel loaded – T L	min	4.68	0.47	5.14	0.55	5.20	0.59
Unhooking - Un	min	0.93	0.16	1.08	0.22	1.11	0.29
Delay Time – D T	min	0.38	0.21	0.50	0.19	0.53	0.26
Bunching distance	m	37.57	10.31	33.25	9.12	30.93	40.10
Skidding distance	m	223.16	22.61	203.87	20.66	201.12	20.38
Number of logs	-	4.63	0.49	4.55	0.50	4.58	0.50
Volume	m^3	0.56	0.06	0.73	0.08	0.78	0.09
Productivity	$m^3 h^{-1}$	3.04	0.42	3.89	0.54	4.11	0.52

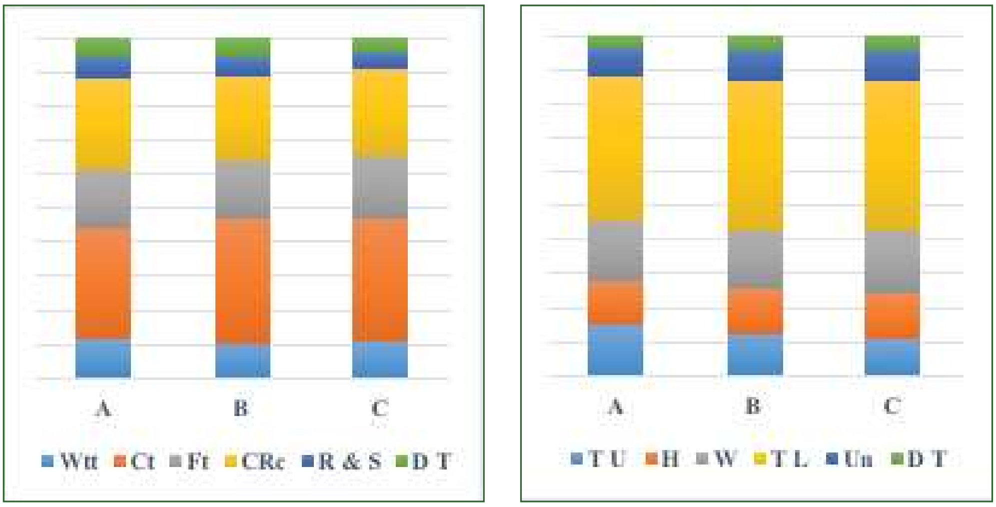

Figure 2 - Time distribution for felling operation (left) and skidding phase (right).

Table 5 - Productivity equation models for cutting and winching phases.

Model		Equation	F	P	$R^2_{adjusted}$
Productivity	Felling	P = 7.286 + 0.5 * Diam - 0.452 * TCT - 0.004 * Dist + 0.856 * SS	856.97	0.000	0.950
	Skidding	P = 1.932 - 0.003 * BDist - 0.008 * SDist + 5.339 * V - 0.162 * SS	342.371	0.000	0.920

P = Productivity; Diam = Diameter; TCT = Total Cycle Time; Dist = Distance; SS = Study Site (0 =A, 1 = B, 2 = C); BDist = Bunching Distance; SDist = Skidding Distance.

Estimates of hourly costs of chainsaw felling and farm tractor equipped with a winch were computed using the machine rate method (Miyata 1980). A total of 1,680 hours per year went scheduled for the operations (210 days per year for 8 scheduled working hours per day) and labor was € 15.00 per scheduled machine hour. Total hourly cost for manual chainsaw felling was estimated to be € 19.14. Combination of the hourly cost with an average productivity between 4.85 and 5.85 m^3h^{-1} provided an estimated average unit cost less than 4.00 € m^3 for manual chainsaw felling in all sites. Total hourly cost of farm tractor with winch, included two operators, was 53.18 € h^{-1} and the extraction costs were calculated varied from 17.5 € m^3 in site A, 13.7 € m^3 and 12.9 € m^3 for site B and C, respectively. The level of productivity analyzed on these different sites showed that different thinning intensity influenced the extraction costs. The wood biomass harvesting system amounted between 18 € t^{-1} (site C) and 24 € t^{-1} (site A) with a coefficient of conversion for Calabrian pine wood of 1 m^3 equal to 900 kg.

Discussion

The study had the objective to evaluate the influence of thinning treatments on whole-tree system in coniferous plantation. Tree felling using chainsaws followed by farm tractor is a practise conducted in many countries (Borz and Ciobanu 2013). In Italy, for example, this harvesting system is mostly applied in very dense stands where thinning operations are done and the development of assessing time consumption and productivity for similar work conditions was the aim of this study. Several studies showed the fact that in felling operations time consumption is mainly influenced by tree breast height diameter (dbh) (Sobhani 1984, Kluender and Stokes1996, Lortz et al. 1997, Ciubotaru and Maria 2012, Campu and Ciubotaru 2017). Samset (1990), Ghaffarian (2007) and Uotila et al.(2014) proved linear correlation between felling time on tree breast height diameter but the different and variegated tasks and operation with the chainsaw do not permit to assessment a unique time prediction model. For example in this study cross-cutting was included in the felling operation respect other researchers (Lortz et al. 1997, Wang et al. 2004) considered only delimbing phase. Similar to other studies (Kluender and Stokes 1996, Wang et al. 2004), this study confirmed that the distance between trees influence time consumption in tree felling operations. The economical and productivity analysis have demonstrated that the motor-manual felling with chainsaws with the use a farm tractor is especially when dealing with biomass production during thinning treatments where the ground-based heavy forest machinery cannot be used and different method cannot be adopted. In fact, power chainsaw is still an important equipment in tree felling (Jourgholami et al. 2013) and is still used even in Nordic countries, where it is favored by small-scale operators for wood energy demand (Laitila et al. 2007). In Romanian resinous forests, Câmpu and Ciubotaru (2017) monitored time consumption and productivity in manual tree felling with a chainsaw finding the limiting factors of this activity.

The observed productivity differences during the skidding phases can be attributed to the volume per turn and the distances. In fact, several authors reported that in thinning treatments the time consumption for moving has been proved to decrease when the number of removed stems increases (Kuitto et al. 1994, Sirén 1998) or the stem size decreases (Ryynänen and Rönkkö 2001). Nurminen (2006) described that the time travel (unload and load) was largely dependent on driving speed, driving distance, but also timber volume per load. The results can compare favorably with those showed in other studies about farm tractor extraction under similar conditions (Zecic et al. 2005). Spinelli and Magagnotti (2012) calculated for thinning a value of productivity of 4.7 m^3 PMH^{-1} using a farm tractor (116 kW) and Menemencioglu and Acar (2004) found a value to be 6.35 m^3 PMh^{-1}. Acar (1997) reported an average productivity of 4.18 m^3 PMh^{-1} in a skidding distance of 100 m, while Gilanipoor et al. (2012) found that average productivity rate of 2.50 m^3 PMh^{-1}. Efthymiou and Karambatzakis (1992) reported a gross skidding production rate of 3.57 m^3 using a Unimog tractor. Similar to other studies, the cost analysis demonstrated that the cost of wood biomass harvesting from thinnings is higher than that from final cuttings (Kalio and Leinonen 2005). The gap is caused by the cost of cutting and piling of small-sized trees from precommercial fellings, whereas in the other phases of the procurement chain, cost differences are modest (Mizaraite et al. 2007). Considered the harvesting costs, the current dynamics of biomass prices in Southern Italy markets could favor thinning treatments in coniferous plantations of Calabria region considering simultaneously an opportunity to improve forest stand stability and timber wood quality (Proto et al. 2017b).

Conclusions

The present study examined all work phases from tree felling to the extraction of wood biomass to the landing under small-scale forestry conditions managed with different thinning treatments. Whole-tree system in coniferous plantation applied with typical harvesting system traditional has guaranteed productivity standards at a reasonable cost reducing high operational cost per unit harvested. In addition, given the high proportion of manual tasks, there is a need to evaluate the ergonomic conditions of the work because investing in occupational safety and health could provide improved productivity and working conditions (Proto and Zimbalatti 2010, 2015) and in particular during the use of chainsaw (Calcante et al. 2018) and farm tractor (Pessina and Facchinetti 2017). From the experience gained at the study area, a significant optimization potential can be identified, that could substantially improve the operational efficiency and reduce the production cost (Koutsianitis and Tsioras 2017). For example, alternative skidding equipment could be applied replacing the winch with a grapple considered the good accessibility of the stands. Another important improving could be the use of double-drum winch to reduce the number of skidding cycles. The study results, therefore, underlined that it economic possible to wood biomass harvest relatively small-diameter from thinning stands favoring moderate and heavy thinning and evaluated the role of biomass supply chain, the use of forest and wood-processing residues can appear as a circular economy approach in the bio-energy sector (González-García and Bacenetti 2019). In fact, considering the role and the important distribution of Calabrian pine and evaluated the valid growth response of this species, the effect of higher thinning intensity will influence productivity standards for wood biomass harvesting.

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Small-Scale Forestry (Under review)

Performance of forwarding operations in biomass recovery from dismantled apple orchards

Maria Francesca Cataldo[1], Marina Viorela Marcu[2], Giuseppe Zimbalatti[1], Andrea Rosario Proto[1]*, Eugen Iordache[2], Stelian Alexandru Borz[2]

[1] Department of AGRARIA, University of Reggio Calabria, Feo di Vito snc, 89122, Reggio Calabria, Italy.

[2]Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Brasov, Şirul Beethoven No. 1, 500123, Brasov, Romania.

*Corresponding author: andrea.proto@unirc.it; Tel.: +39 (0) 965.1694275

Abstract

Fruit orchards cover large areas and they require annual pruning which leaves abundant residues on the ground; when fruit production declines, the plants are dismantled to make place for new ones. In Europe, apple orchards are common, covering 35% of the area cultivated with fruit trees. Frequent renewal of this crop type requires a reduction of termination costs, which can be achieved by the utilization of biomass. This study evaluated the performance of biomass recovery from dismantled apple orchards by the means of a HSM 208F forwarder and a Jenz BA 725 chipper. Time studies were conducted to estimate the productivity and fuel consumption of forwarding operations. Data was collected by the means of a GPS unit, a video camera and an electric fuel pump, and 30 work cycles divided into elemental tasks were monitored. Models for time consumption and productivity as a function of extraction distance were developed by the means of least-square simple regression techniques, at different scales needed to characterize the forwarding operations. The average forwarding distance was of ca. 830 m and the net and gross forwarding production rates were of 21.79 and 15.35 loose m^3 h^{-1}. Operational speed was the highest in the empty turn and varied between 4 and 11 km h^{-1}, averaging ca. 7.4 km h^{-1}, while the hourly fuel consumption was of 11.82 l. The study provides reference data for forwarding operations deployed in apple orchards and demonstrates the successful use of forestry machines in the agricultural sector.

Keywords woodchips, forwarder, time and fuel consumption, productivity, functional models

Introduction

The energy report of the International Energy Outlook 2019 (IEO2019) published in September 2019 (Energy Information Administration 2019) reveals that the world energy consumption will rise by nearly 50% between 2018 and 2050. To respond to the global energy supply challenge, in recent years, public and political sensitivities to environmental issues and energy security have led to the promotion of renewable energy resources (Borz et al. 2019a; Cheng 2017; Mirza et al. 2008). In fact, according to the IEO2019 report (Energy Information Administration 2019), renewable energy will become the leading source of primary energy consumption by 2050 and renewables will displace petroleum as the most used energy source, since electricity use grows faster than any other end-use fuel. Biomass is one of the resources that play a substantial role in a more sustainable energy (Mirza et al. 2008; Moneti et al. 2015). The global energy potential of biomass is very large. It is estimated that the world's standing terrestrial biomass (i.e., the renewable, above-ground biomass that could be harvested and used as an energy resource) is approximately 100 times the world's total annual energy consumption (Klass 2004). The largest source of standing terrestrial biomass is the forest, which contains about 80 to 90% of the total biomass carbon (Klass 2004). Agriculture and forest industries provide a wide range of products and services such as food, feed, fiber, shelter, packaging, clothing and communications (Klass 2004; Chum and Overend 2001) and, conventionally, biomass and any waste that results from its processing or consumption is left in the growth areas where natural decomposition occurs. Yet, there are many other routes to use the biomass; for instance, the energy content of biomass could be diverted to direct heating applications by collection and combustion, or it could be converted into synthetic organic fuels if suitable conversion processes are available (Klass 2004). Nevertheless, several studies showed that traditional sources for bioenergy production would not be enough to meet future energy needs and to respond to the new targets set by the EU 2030 framework for climate and energy policies (European Parliament 2014; Stelte et al. 2012; Talagai et al. 2020; Toscano et al. 2018). This implies the need to find alternative and sustainable ways to obtain lignocellulosic material to be used. In this regard, an interesting option is given by the agricultural residues and, as a fact, the agricultural sector can contribute to support the biomass supply chain. Fruit orchards represent a global business and cover large areas, generating substantial income for many regions. During their management, they require annual pruning operations, which leave abundant residues on the ground, and when the plants get depleted and production declines, the orchards are dismantled and replanted (Nati et al. 2018).

The most common fruit tree in Europe is the apple tree, which covers 35% of the total orchard area (Eurostat 2015). At the European level, Romania produces significant amounts of apples and the area covered by apple tree plantations represents 12% of the total EU orchard area (Badiu et al. 2015; Eurostat 2020). This kind of crops require annual and cyclical operations (annual pruning and tree cutting at the end of the fruit production cycle) to achieve the targeted tree systems and to optimize the production of fruits. These activities output woody biomass materials such as branches, trunks, and rootstocks (Boschiero et al. 2016). The annual pruning itself generates a substantial quantity of residues which must be disposed (Magagnotti et al. 2013; Proto et al. 2019; Spinelli et al. 2010). In addition, frequent renewal of the plants requires a reduction of orchard termination costs in order to minimize the financial burden on orchard management (Badiu et al. 2015), and there is a strong interest in finding cost-effective termination techniques that may reduce the financial strain. In response, the last decades were characterized by some research carried out to estimate the productivity and cost of using agricultural pruning residues for energy applications (Brand and Jacinto 2020). The main findings agree that harvesting and transport costs, coupled with the low quality of biomass, are the typical challenges that stand for difficult obstacles to overcome. As a consequence, the biomass produced in fruit plantations is not currently used at its full potential to produce bioenergy. Part of this situation is the result of technical problems related to harvesting and to the lack of information on the quantity and quality of the residues (Dyjakon et al. 2016). For this reason, recent studies were conducted to evaluate the performance of harvesting complete fruit trees to see if this procedure guarantees the quality and quantity requirements of the biomass supply chain. This is important as the residues of permanent crops from Europe are a substantial reservoir of renewable biomass for energy and industrial use but they were poorly utilized until now for bioenergy purposes (Pari et al. 2017). Accordingly, the biomass yielded by orchards may be an attractive renewable source of energy for the local power market, offering additional revenues to farmers, too.

In the framework of a logistics chain, harvesting plays a pivotal role and, regardless of the crop type, the termination of permanent crops yields significant volumes of wood biomass, which can be used as a renewable fuel in bioenergy plants (Assirelli et al. 2019). However, handling of whole trees represents a delicate phase that can affect the costs and productivity. The most common solution to harvest the biomass from depleted orchards is the removal of the above-ground tree portion following tree felling and, in a second step, the extraction and collection of rootstocks. The phase of harvesting and transportation of whole trees is typically operationalized by the use of a farm tractor equipped with a trailer fed by a mechanical crane. However, the limited loading capacity and a slow movement velocity on the row, as characteristic of this option, affect negatively the productivity and cost-effectiveness of operations. An interesting alternative, that could have a great potential, is the use of purpose-built vehicles designed to transport roundwood in the forestry sector. As many studies describe (Cremer and Velázquez-Martí 2007; Kaleja et al. 2018; Nakahata et al. 2014; Proto et al 2018a; Spinelli et al. 2012; Tolosana et al. 2014), forwarders have been designed to carry out strictly forestry tasks such as the extraction of logs or logging residues. However, the use of these machines in the agroforestry sector can enable the collection and removal from the fields of wood biomass produced by orchard pruning or dismantling (Velázquez-Martí et al. 2012). Meanwhile, finding some use for orchard pruning residues would allow converting a disposal problem into a collateral production, with a potential for revenues or reduced management cost (Emer et al. 2011).

In the above-described context, the aim of this study was to evaluate the performance of biomass recovery from dismantled apple orchards by the means of a forwarder machine. In particular, the objectives were set to i) evaluating the time consumption and productivity in forwarding operations, ii) evaluating the fuel consumption in forwarding operations and iii) developing models of time consumption and productivity as a function of extraction distance.

Materials and Methods

Study Site

The area of study was located at approximately at 380 m above the sea level (N 46° 57’ 59’’ - E 24° 25’ 21’’ E), near the Dipşa village, Bistriţa-Năsăud county, Romania (Figure 1). The landscape in the area is characterized by the presence of many intensively-cultivated apple orchards characterized by different age and management states. As some of them have reached their economic life, their owners have decided to restock them, and they were scheduled for the extraction of old trees. At the harvesting time, the apple orchard taken into study was 20-years old and had a spacing of 2 by 4 m between the trees. Observations made by this study on the forwarding operations covered ca. 53% (ca. 3.6 ha) of the orchard’s area, involving a total of 979 trees, and were based on the free will of the forwarder’s driver to approach the operations.

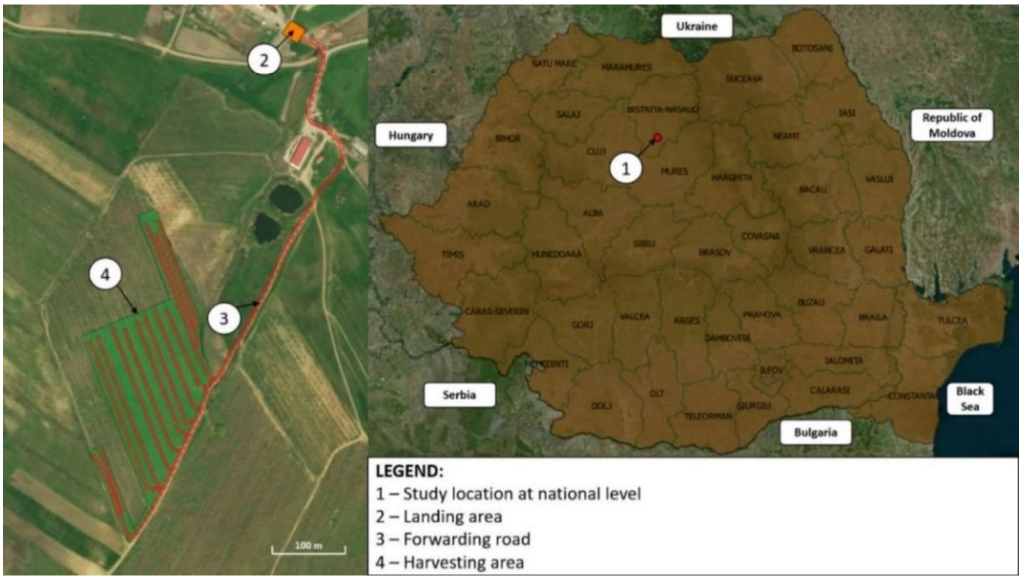

Figure 1 - Study location. Source: constructed in QGis based on collected locations and freely available GIS data.

Harvesting System Description and Work Organization

Harvesting operations were implemented under the so-called complete tree harvesting method, which supposes removal of trees including their stumps and major roots (Pulkki 2014). Compared to the traditional harvesting methods, the complete tree method requires the use of equipment able to uproot the trees by some sort of mechanical pushing (Oprea 2008), and to enable this type of operations, a telehandler Manitou MLT 845-120 (74.4 kW of engine power), equipped with an agricultural bucket with a capacity of 2000 L, was used. These operations were carried out in advance (ca. 6 months) of the extraction and chipping operations, therefore the trees to be extracted were already available as small bunches of felled trees at the field study time. Then, a HSM 208F series machine forwarder (Table 1) was used to load and transports the trees to a landing area where a chipper (Jenz BA 725) with power rating of 375 kW was used to convert them into woodchips.

As the chipping tasks were stationary, the same telehandler used for the felling operations was used to move and load the woodchips into a Schwarzmuller truck (Model s1 j02vln3) having 90 m^3 of capacity, propelled by a MAN trailer (Model L.2007.46.001 06X04 ZBBAAAE2AA TGX) equipped with a 324-kW diesel engine. This truck transported the chips from the site to a biomass terminal located in Toplița, Romania. The chipper, however, was not equipped itself with a crane for biomass handling and feeding, therefore this operational task was fulfilled by the forwarder.

The division of work on elemental tasks and categories of time consumption was based on the typical functions and work elements that a forwarder may carry on (Kaleja et al. 2018; Apăfăian et al. 2017; Cataldo et al. 2020; Proto et al. 2018b). Nevertheless, the division and documentation of work and time at elemental level was carried out in the office phase of the study based on data collected via GPS (Global Positioning System) and video recording. Table 2 is showing the main work elements, delay categories and elemental time consumption concepts used in this study, which were based on the time consumption structure used in forest operations (Björheden et al. 1995; Proto et al. 2020). Forwarding work was carried out by a driver having an extensive experience in such operations. As a fact, the company bases its operational portfolio to a great extent on the biomass recovery from dismantled apple orchards. Prior to data collection, the verbal consent of the company owner and workers engaged into operations was obtained in order to collect the data needed in the study and the workers were asked to carry on their jobs as usual. The time study data was collected during September of 2019.

Table 1 - Technical description of the HSM 208F forwarder.

Parameter	Unit	Value
Axles total	n°	4
Power	kW	185
Weight	t	18
Payload capability	t	14
Width	mm	2860
Length	mm	10920
Clearance	mm	661
Transmission	Type	Hydrostatic
Transmission	Gear	2
Fuel tank capacity	L	225
Crane type	-	Epsilon M70 F80
Crane range	m	8
Gripper type	-	FG43S
Speed at 1st gear	km h^{-1}	0 - 14

Table 2a - Concept of work organization observed and used in the study.

Work (time) element	Abbreviation	Description
Empty turn	*ET* - (*tET*)	Machine movement from the landing to the orchard (loading) area where either, return maneuvers or loading tasks were carried out as a consecutive task.
Moving to load	*ML* - (*tML*)	Any moving maneuvers between the locations in which the machine stopped to carry on loading tasks as well as returning maneuvers before engaging in loading tasks. Occurred several times per turn (work cycle).
Loading	*L* - (*tL*)	Maneuvers undertaken to load and arrange the trees into the bunk at each stop to do so in the orchard area. Occurred several times per turn (work cycle).
Loaded turn	*LT* - (*tLT*)	Machine movement from the last point of loading to the landing area.
Unloading	*U* - (*tU*)	Any maneuvers undertaken to unload the trees from the bunk and to place them on the ground, including small movements to do so. Includes the crane work and machine movement as well as a combination with chipper feeding in some work cycles.
Feeding the chipper	*FC* - (*tFC*)	Any maneuvers undertaken to unload the trees from the bunk and to feed them directly to the chipper, including small movements to do so. Includes the crane work and machine movement as well as a combination with unloading in some work cycles.
Moving at landing	*M* - (*tM*)	Any movements undertaken to return the machine for a new empty turn. Excludes any other moving maneuvers that had nothing to do with the work.
Moving	*MOV*-(*tMOV*)	The sum of time spent in empty and loaded turns, including the time spent in moving to load and moving at landing, computed on a work cycle basis.

Table 2b - Concept of work organization observed and used in the study.

Work (time) element	Abbreviation	Description
Miscellaneous	*MIS* - (*tMIS*)	Any other maneuvers, including machine movement, that had nothing to do with the work tasks observed. Observed, usually, at the end of a workday.
Undocumented	*UD* - (*tUD*)	Time in which no tasks were carried out in relation to the job and in which no video data coverage was available for interpretation.
Delays caused by study	*SD* - (*tSD*)	Time in which occurred events such as dataloggers setup and placement on the machine as well as their check.
Personal delays	*PD* - (*tPD*)	Delays caused by personal reasons in which the machine was not engaged in productive tasks.
Other delays	*OD* - (*tOD*)	Delays caused by organizational and other reasons in which the machine was not engaged in productive tasks.
Observation time	*TO*	Total time, including all the events documented above.
Workplace time	*TW*	Total time, excluding time consumption categories such as the miscellaneous, undocumented and delays caused by study.
Work cycle time	*CT*	Productive time (delay-free cycle time) including only the time spent to carry on the production. Includes loaded and empty turns, moving to load, loading, unloading and chipper feeding as well as moving at the landing. Excludes all the delays, miscellaneous and undocumented time.

Data Collection

Field data collection was designed to capture mainly information on time, fuel consumption and productivity. Time consumption data was collected by the means of a Garmin GPSMAP 64 STC unit which was placed on the machine's cab and set to collect locations at one second sampling rate. The resulted data was later used to document the time consumption and operational speed and to map the forwarding operations using the QGIS software (QGIS 3.4.12 LTR Madeira version, www.qgis.org). Since the GPS data alone may have its own limitations in accurately separating the time consumption on specific tasks (Talagai et al. 2020; Proto et al. 2020; Borz et al. 2019b), a small video camera was used to further document the operational behavior during the observed time. The camera was placed inside the cab with the field of view oriented towards the forwarder's bunk, in a location that enabled a good view on the bunk and the crane. As the video camera used in this study is capable to collect video data on extended periods of time and it has a battery life covering more than 8 hours, it was set to continuously collect video files having an approximate duration of 20 minutes each. The resulted video files were organized on days of operation and they were used to document the data by a coding procedure.

In what regards the estimation of productivity, and by taking into consideration that the forwarded biomass (Figure 2) consisted of small parts of trees and many branches for which it was virtually impossible to estimate the volume, as a supplementary measure, the total loose (or bulk) volume of forwarded woodchips was estimated based on the recommendations provided in Acuna et al. (2012).

To do this, the volume estimation was based on the truck dimensions which were measured in advance and the number of loaded trucks (N = 6) counted during the field observation time. Then, an estimate of the cyclical production was made based on the total volume of woodchips produced. Given the approach used to load and chip the whole trees (stump and major roots), the homogeneity in size of the apple trees at harvesting stage (they have the same age and quite the same dimensions) permitted to overtake the individual trees characterization. The average tree volume was estimated from the total woodchips volume divided by the total number of forwarded trees. Based on a similar study (Hildt et al. 2020), the volume of each load was estimated by multiplying the average tree volume by the number of trees extracted per load counted through the videos recorded during the forwarder loading activity. This data was used to model the productivity behavior as a function of the extraction distance.

Fuel consumption (liters, l) was estimated on daily basis using an electric pump connected to an external 400-L fuel tank. For this, the refilling to full method has been used each day (Acuna eta al. 2012; Proto et al. 2018c). At the beginning of a work day, the machine was fueled at full after placing it on a location characterized by a completely flat land. After the completion of operations from a day, the machine was replaced on the same location and refiled to full. Fuel consumption at daily level was computed as the difference of readings at an accuracy of 0.01 l.

Figure 2 - A loaded forwarder on the left; the telehandler loading woodchips into the lorry on the right.

Data Processing and Statistical Analysis

The files collected via GPS were pre-processed using the Garmin BaseCamp® (Version 4.7.0) software using procedures similar to those described by Borz et al. (2019b, 2018). GPX files collected in the four days taken into study were merged into a common database developed into Microsoft Excel® (Microsoft Office 365 ProPlus®) and then, based on the time and date labels contained into it, the video files were analyzed in detail and two new attribute fields were created to document the engine state and the task type. By a stepwise approach and also based on the GPS speed contained into the database, each one-second sample was documented based on the video files using the relevant codes given in Table 2. Engine state was coded by a binary approach to document the time spent with engine on and off respectively. Then, logical functions were used to categorize and allocate each 1-second sample on tasks and a reorganization of the database was implemented to summarize the time consumption on work elements at work cycle level. In this database, the time consumption categories of unloading, feeding the chipper and unloading and feeding the chipper were merged together because many of the work cycles contained combinations of these tasks. Nevertheless, each cycle was supplementary codded by a string attribute to document the type of tasks undertaken at the landing. Besides the payloads per turn, the operational variables taken into study were the moving distances. As the terrain inclination was very low in the area (less than 5%) the effect of slope was omitted in this study. Operational distances (empty turn - *ETD*, moving to load - *MLD*, loaded turn - *LTD* and moving at landing - *MD*) were estimated based on the map of locations collected in the field via GPS.

Each category of distance was extracted, cycle-wise, using the measurement functionalities of Garmin BaseCamp®. Then, the estimated distances were included in the database developed at work cycle level. Based on these figures, two additional categories of distances were computed: total moving distance (*TMD*, m) and the average forwarding distance (*AFD*, m), with the latter computed by dividing *TMD* by 2. Finally, the database was complemented by the payload per turn, based on the above descriptions.

A separate data processing workflow consisted of categorizing the operational speed per work tasks that supposed the machine movement. The tasks under question were the empty turn, moving to load, loaded turn and moving to landing, therefore the small movements during the unloading and chipper feeding tasks were excluded. The workflow used logical functions similar to those of extracting the data on time consumption with the difference resting in the fact that the data on speed was prepared in advance by conversion from strings to numbers. Statistical analysis was designed to describe the data and to develop relational models for the prediction of time consumption and productivity as a function of operational distance. The general workflow and the used statistical approaches were those specific to similar forest productivity studies (Proto et al. 2020; Borz et al. 2019b). A first step consisted of a normality check that used the Shapiro-Wilk test to see what kind of descriptive statistics could be used to characterize the data and as a prerequisite for modeling approaches. Then, the main descriptive statistics were used to characterize the data on time consumption, operational speed and operational variables. Time consumption and productivity models were developed by the means of least-square simple regression techniques, at different scales needed to characterize the forwarding operations. The significance of the developed models was judged based on the p-values and the values of the determination coefficients (Acuna et al. 2012), using a confidence threshold set at $\alpha = 0.05$. Data analysis was carried using Microsoft Excel® fitted with RealStatistics® freeware add-in.

Results

Time Consumption, Operational Variables, Production Estimates and Productivity Models

The data used in this study covered 30 full work cycles. In total, the covered distance by forwarding operations was close to 50 km (Table 3 and Table 4) and it varied, at work cycle level, between 1.25 and 2.14 km. A total production of ca. 530 loose m^3 of woodchips was estimated by this study, and the forwarder payload per turn varied quite widely in an amount of biomass corresponding to between 14.64 and 21.68 loose m^3 of woodchips, depending of the number of trees transported per load. Dominant within a work cycle were the empty and loaded turn distances which averaged close to 790 and 730 m, respectively. They varied, however, quite widely, in between ca. 540 and 980 m, a fact that enabled the development of time consumption and productivity models.

Table 3 - Descriptive statistics of time consumption.

Time consumption variable	Abbreviation (unit)	Descriptive statistics and normality check						
		Sum	Min.	Max.	Mean (median)	Standard deviation	Normality check	Diagnosis
Empty turn time	*tET* (s)	11499	249	515	383.30 (388.50)	±70.71	W=0.97305 *p*=0.6256	Yes
Moving to load time	*tML* (s)	5312	74	400	177.07 (158.50)	±87.35	W=0.86042 *p*=0.0010	No
Loading time	*tL* (s)	26627	410	1193	887.57 (915.50)	±172.42	W=0.95037 *p*=0.1730	Yes
Loaded turn time	*tLT* (s)	14098	270	855	469.93 (470.00)	±125.01	W=0.93772 *p*=0.0767	Yes
Unloading and chipper feeding time	*tUFC* (s)	29274	141	2276	975.80 (1047.00)	±520.30	W=0.93417 *p*=0.0634	Yes
Moving at landing time	*tM* (s)	889	-	183	29.63 (23.50)	±34.73	W=0.65000 *p*<0.0001	No
Moving time	*tMOV* (s)	31798	644	1517	1059.93 (1029.00)	±212.85	W=0.98621 *p*=0.9560	Yes
Miscellaneous time	*tMIS* (s)	3236	-	-	-	-	-	-
Undocumented time	*tUD* (s)	1578	-	-	-	-	-	-
Delays caused by study	*tSD* (s)	1293	-	-	-	-	-	-
Personal delays	*tPD* (s)	32436	-	-	-	-	-	-
Other delays	*tOD* (s)	4367	-	-	-	-	-	-
Observation time	*TO* (s)	103609	-	-	-	-	-	-
Workplace time	*TW* (s)	124502	-	-	-	-	-	-
Work cycle time	*TC* (s)	87699	1937	4130	2923.30 (3051.00)	610.95	W=0.95361 *p*=0.2111	Yes

In what regards the time consumption, in total, the study covered ca. 36.3 hours out of which, undocumented, miscellaneous and delays caused by the study itself amounted ca. 1.7 hours. The rest was the workplace time (34.58 hours). Of that, productive time accounted for ca. 70% while the personal and other delays accounted for the rest. In the workplace time, the greatest share was that of feeding the chipper and unloading (ca. 33.4%), tasks that were analyzed together in terms of time consumption and which were followed by loading tasks (30.36%), loaded (ca. 15.6%) and empty turns (ca. 13.5%). Moving to load and moving at landing accounted together for ca. 7.1% of the productive time. In what regards the operations at landing, it worth mentioning that predominant were those of feeding the chipper directly from the forwarder's bunk and in some cases from the pile (N = 23 cases), followed by unloading solely (N = 5 cases) and unloading and feeding the chipper (N = 2 cases). On average, unloading solely took far much less time (222.4±55.2 seconds) compared to unloading and feeding the chipper (1071.5±188.8 seconds) and to feeding the chipper solely (1131.3±446.7 seconds). Figure 3 shows the four basic models of time consumption during moving events recorded by the field study. The operational distance specific to each work element was found to be highly significant ($p<0.05$) in explaining the variation of time consumption (R^2 = 0.70 – 0.90). The highest dependence relation was found between time and distance for moving at landing. For the loaded turn task, time and distance had a standard deviation of 125.0 seconds and 107.4 meters, respectively, and the coefficient of determination metric characterizing their dependence relation was found to be the lowest ($R^2 = 0.70$).

Table 5 is giving an overview on the developed delay-free time consumption model at work cycle level. The average forwarding distance (AFD, m) explained the variation of time consumption at the work cycle level only to a limited extent (ca. 30%, $R^2 = 0.29$).

Nevertheless, it was found to be a significant predictor of the work cycle time (p = 0.002, α = 0.05). The rest of the variability may be the effect of other factors, including non-homogeneity of time consumption in tasks that involved unloading and feeding the chipper and which generated a great variation in time consumption at work cycle level. To this end, Figure 4 is showing a comparison between the time consumption at the work cycle level and the time consumption in moving tasks per work cycle. Based on the production output, which was estimated at 531 loose m^3, the gross productivity of operations was estimated to be of approximately 15.35 loose m^3 h^{-1}. This figure included in its estimation all the time spent as workplace time. By excluding the delays, the net productivity rate was estimated at ca. 21.80 loose m^3 h^{-1}. In the same conditions, the gross and net efficiency rates were estimated at ca. 0.065 and 0.046 h loose m^{-3}, respectively.

Table 4 - Descriptive statistics of operational variables and production.

Category & variable	Abbreviation (unit)	Descriptive statistics and normality check						
		Sum	Min.	Max.	Mean (median)	Standard deviation	Normality check	Diagnosis
Operational variables								
Empty turn distance	*ETD* (m)	23630	567	979	787.67 (778.50)	±121.97	W=0.9565 *p*=0.2510	Yes
Moving to load distance	*MLD* (m)	3565	47	319	118.83 (108.00)	±58.17	W=0.8827 *p*=0.0033	No
Loaded turn distance	*LTD* (m)	22011	537	977	733.70 (715.00)	±107.38	W=0.9779 *p*=0.7672	Yes
Moving at landing distance	*MD* (m)	740	-	169	24.67 (19.00)	±30.62	W=0.5953 *p*<0.0001	No
Total moving distance	*TMD* (m)	49946	1254	2140	1664.87 (1660.50)	±227.94	W=0.9492 *p*=0.1604	Yes
Average forwarding distance	*AFD* (m)	24973	627	1070	832.43 (830.25)	±113.97	W=0.9492 *p*=0.1604	Yes
Production								
Payload	*PL* (loose m^3)	531	14.64	21.68	17.69 (17.62)	±2.24	W=0.9359 *p*=0.0704	Yes

These figures apply for an average forwarding distance of ca. 830 m. While these figures can be used only as a reference, given the reasons explained above, the effect of the forwarding distance could have a significant effect on the productivity rates (Table 5 and Figure 5). As shown, moving tasks and moving distance have the greatest potential to significantly affect the productivity rate. For instance, by considering only the moving tasks, the average net production rate for a distance of ca. 830 m was found to be of ca. 63 loose m^3 h^{-1} which increased significantly to ca. 82 loose m^3 h^{-1} for a forwarding distance of ca. 630 m and decreased to ca. 43

loose m³ h⁻¹ for a distance of ca. 1030 m, indicating a productivity gain/loss of ca. 9.7 loose m³ h⁻¹ for every 100 m traveled in addition.

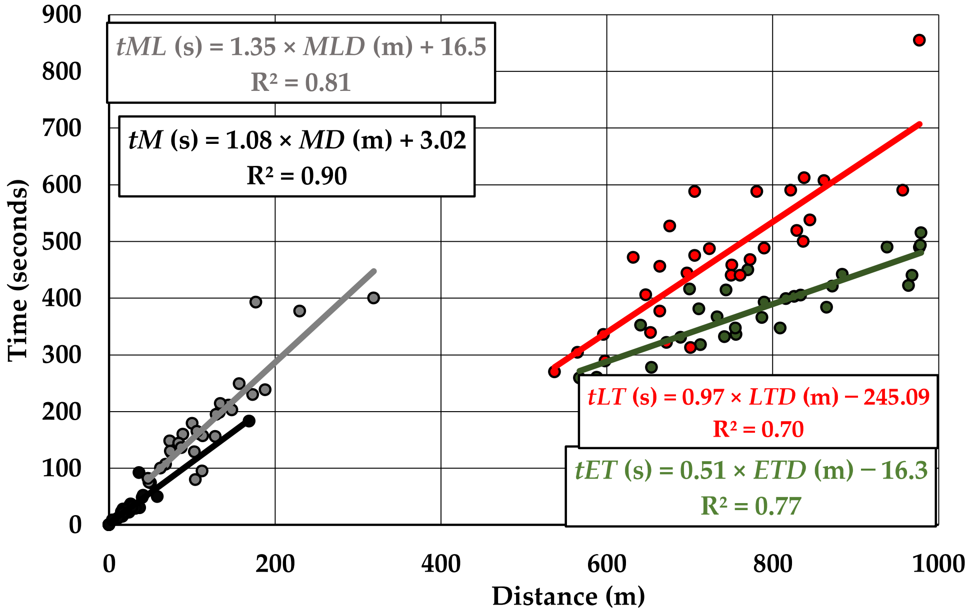

Figure 3 - Time consumption models of tasks that supposed machine moving.

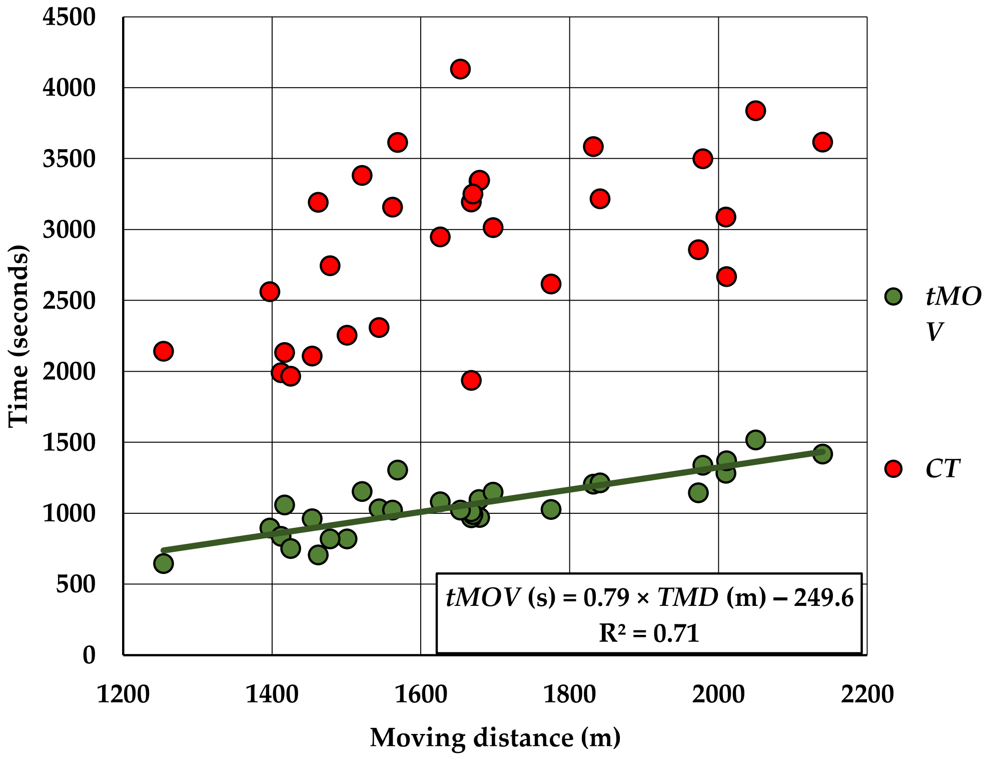

Figure 4 - Effects of loading, unloading and feeding the chipper on the work cycle time: a comparison between cycle time and moving time.

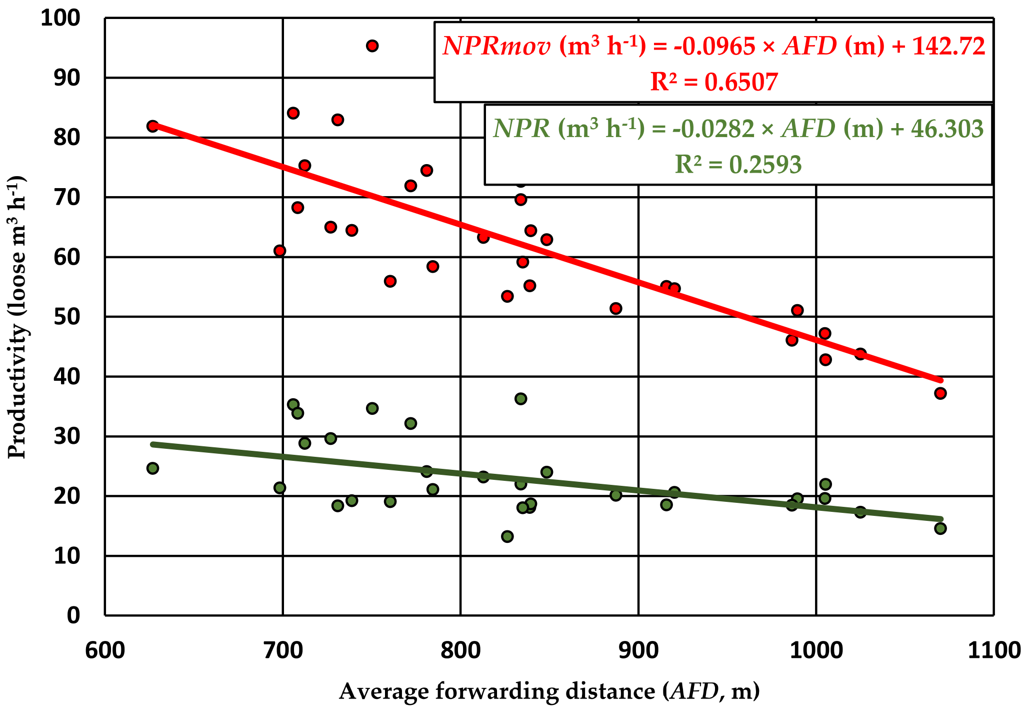

Figure 5 - Models of net productivity rates computed based on moving (red) and cycle time (green).

Table 5 - Cycle time consumption and productivity model.

Work cycle time and productivity model	N	R^2	*p* value	Predictor	Sig.
T_C (s) = 2.91 × *AFD* (m) + 497.04	30	0.29	0.002	*AFD*	yes
NPRmov[1] (loose m^3 h^{-1}) = -0.0965 × *AFD* (m) +142.62	30	0.65	0.000	*AFD*	yes

[1]Net productivity rate computed based on the moving distance

Operational Speed and Fuel Consumption

Figure 6 shows the main descriptive statistics of operational speed in those tasks that involved the machine movement. The data shown may be analyzed in conjunction with the results reported in Figure 3, indicating that the empty turn was done at the highest operational speed (SET, km h^{-1}), which varied in between 4 and 11 km h^{-1}, and averaging ca. 7.4 km h^{-1}.

Next in line was the loaded turn (SLT) that averaged ca. 5.6 km h^{-1}, moving at landing (SM = 3.2 km h^{-1}) and moving to load (SML = 2.5 km h^{-1}). Minimum values of zero for the last three categories of operational speeds are the effect of very short breaks that were unfeasible to separate from the data pools of each task.

The total fuel consumption measured during the field study amounted 313.18 l. At the same time, the machine's engine was found in a working state for ca. 26.5 hours, resulting in an hourly fuel consumption of 11.82 l. While it was virtually impossible to account for the fuel consumption only in productive tasks (the engine was found to be in the working state in some miscellaneous tasks and delays), the figure given herein stands rather for a gross figure, as the difference between the time spent with the engine on and the productive time was of ca. 2.1 hours. Nevertheless, miscellaneous tasks are not necessarily non-related to the productivity; therefore, the figure given may stand for a good approximation of the fuel consumption in the described operations. Altogether, the machine was found to have the engine working in 73% of the total observed time and the engine was off for the rest.

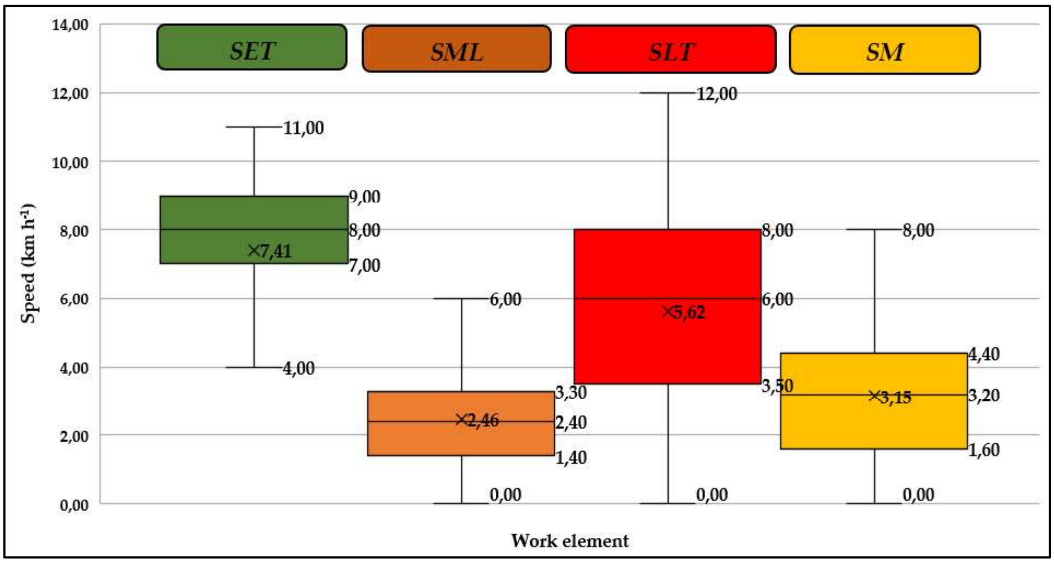

Figure 6 - Descriptive statistics of operational speed in different types of tasks involving the machine movement.

Discussion

Unfortunately, it is very difficult to compare the results of this study with general reference figures, because, to our knowledge, the topic of the present work is rather specific and very few works about complete-tree removal of terminated orchards can be found in the recent bibliography, especially in what regards the apple orchards. Nevertheless, the time consumption of work elements that involve machine moving depends on the operational distance (Apăfăian et al 2017; Proto et al. 2018a; Proto et al. 2018b) and speed, which in turn are mainly determined by geophysical factors. Given that the terrain was relatively flat in the study area and the fact that there were no evident obstructions by canopy or other factors, the speed recorded by the GPS approach could be interpreted as a good approximation of the real operational speed. In this regard, other studies have shown the utility of customer-grade GPS units in assisting time-and-motion studies (Borz et al. 2019a; Borz et al. 2019b; Talagai et al. 2020), including those carried out for forwarder machines (Apăfăian et al 2017).

From the analysis of time consumption, the highest dependence relation was found between time and distance of moving at landing, which was also the least time-consuming operation. However, the average operating speed of this task was 3.2 km h^{-1}. The results of this study about the operational speed in machine movement tasks were found higher than other studies. Hildt et al. (2020) studied the performance of some heavy, medium and light forwarder models tested in different working conditions, founding that the average speed of empty and loaded forwarder's turns were 4.3 and 4.5 km h^{-1} respectively, without any significant differences depending on the forwarder size. In Central Sweden, Berg et al. (2019) studied the performance of two heavy forwarders during final fellings in a forest with terrain conditions varying from easy to moderate. They found an average speed of 3.4 km h^{-1} for the empty turn and 2.9 km h^{-1} for the loaded turn. Similar to our results, Belbo and Talbot (2014) estimated a fuel consumption of 12.35 L h^{-1} for a traditional forwarder (130 kW) in conditions of a mean travel speed of 2.3 km h^{-1}.

The number of trees and the volume per load did not influence the cycle time which was probably an effect of lower masses transported in bulky loads per cycle and of the fact that several trees were loaded in the same work cycle of the crane. As such, the most important factor influencing the time consumption of forwarding operations was the extraction distance, which, as reported by several authors, is rather typical for forwarding operations (Proto et al. 2018a; Sever 1988). When chipping at the roadside, chips can be blown into a truck, a trailer, a container or directly on the ground to form a large heap. In this case, chips will be reloaded on the trucks. Some loggers prefer to reload the chips from a heap in all cases, in an effort to reduce truck waiting time. A loader can fill up a standard highway truck faster than the average professional chipper could (Laitila et al. 2015). Conversely, our results show that productivity of forwarding operation may be significantly affected by the option taken to feed the chipper as feeding the chipper directly from the forwarder bunk was five-fold more time consuming that unloading the biomass directly on the ground. We speculate here that significant reductions in time consumption, as well as significant increments in productivity of forwarding and of the all analysed system could be achieved by using a chipper equipped with self-feeding capabilities. On the other hand, costs of production in this configuration, could be increased compared to the studied system, a fact that still needs an additional check for validation. Accordingly, a comparison of the productivity results to those reported by other studies was difficult, mainly due to the measurement unit of the volume estimation, which used as a background the data of the amount (in loose m^3) of woodchips produced during the study. Concerning the productivity rate, Elmer et al. (2011) studied system for the energy-wood harvesting in the Austrian flat terrains by the means of a HSM208 forwarder and a Moipu 300ES feller-buncher, founding a net productivity of 5 m^3 h^{-1}. In Germany, other authors have tested a HSM208 forwarder, finding a net productivity which, according to Gaffariyan et al. (2017), was of 8 m^3 h^{-1}. Laina et al. (2013) monitored three whole tree chipping operations applied in oak thinning operations deployed in moderate to flat terrains (slope less than 30%). This operation included felling and bunching with a feller-buncher, extraction of full trees with a forwarder, chipping at landing with a mobile chipper, stacking in piles along the roadside, and loading in the truck with a telescopic crane. They found an average productivity of 38.4 oven-dried tons (odt) ha^{-1}.

Having in mind those from above, this study demonstrates the successful use of industrial machines brought from the forestry to the agricultural sector. This has been possible thanks to the characteristics of the machine such as the payload capability, the boom length of the crane, and the engine which, in addition to showing consistent fuel consumption levels to those reported by Spinelli et al. (2015), 11.5 l h^{-1}, and Holzleitner et al. (2011), 11.1 l h^{-1}, allowed an average operating speed during the empty turn of ca. 7.4 km h^{-1}, with peaks of up to 11 km h^{-1}. High operational speeds were also specific to loaded turn work tasks that were carried out, on average, at ca. 6 km h^{-1}. As such, an increased speed may compensate for the productivity loss due to the bulky payloads transported in operations and, given the gears used by the transmission system at high running speeds, it could also yield lower operational fuel consumptions, facts which, together, may validate this operational option in biomass recovery from apple orchards.

Last but not least, the flow of woodchips in terms of quantity and quality is important to sustain local, small-scale bioenergy facilities. For doing so, at least quality assessments need to be implemented in the future by studies conducted to examine the condition, type, shape, and thickness of the woodchips harvested from such orchards. As a fact, the quality of woodchips represents an important parameter to validate and use this kind of biofuel in different types and sizes of energy plants. Having in mind the great diffusion of small farms, the establishment of small-medium energy plants will be very likely and, consequently, the quality of the woodchips will have to assume a great importance. On the other hand, additional studies are needed to encourage the creation of a robust biomass supply chain network because a low economic value of biomass stock leaves no room for incorrect choices concerning trails, location of energy plants, and logistical transportation (Picchio et al. 2019).

Conclusion

This study monitored the performance of a forwarder-chipper system to harvest agricultural residues from dismantled apple orchards. The results have demonstrated that it is possible to recover this type of biomass residues while ensuring the economic and environmental sustainability of the wood-energy chain, proving, at the same time, the versatility of purpose-built forest machines which can be adapted to a wide range of operations, a fact than could substantially contribute to the machine utilization rate and, thereof, to investment recovery. While the productivity and fuel consumption were found to be in acceptable limits and they were affected by the forwarding distance, type of payload transported, and the specificity of unloading-chipping operations, the use of this system has to be evaluated also by considering some of the characteristics required by specific energy conversion plants, in particular those related to the woodchips quality.

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Evaluation of an HSM 208F 14tone HVT-R2 Forwarder Prototype under Conditions of Steep-Terrain Low-Access Forests

Stelian Alexandru Borz, Marina Viorela Marcu, Maria Francesca Cataldo

Abstract

Forwarding technology is well established in use around the world but, at the same time, forwarders are expensive machines that require a good planning to ensure the sustainability of operations. In addition, forwarder market is characterized by a limited pool of customers, therefore innovation attempts may be limited compared to other product development industries. Since the steps towards a full automation of operations are still at their beginning, improvements of forwarder machines may rest in developing and integrating components that could contribute to an increased effectiveness. To respond to such challenges, the Forwarder2020 project developed innovative components that were integrated in a number of forwarder prototypes based on a market pull approach that resulted in a flexible adaptation to customer requirements and work environments. Since one of the typical work environments was that of low access forests, some components (i.e. suspended cabin and transmission system) were engineered to enable faster and safer operations and to economize fuel. As a common validation step is that of bringing field evidence on the performance improvement, this study evaluated the operational speed, productivity and fuel consumption of a forwarder prototype in conditions of a steep-terrain low-access forest. The main findings were very promising as the prototype was able to operate at significantly increased speeds and the fuel savings were evident. For an average forwarding distance of about 1.5 km, net productivity and efficiency rates were estimated at 14.4 m^3/h and 0.07 h/m^3, respectively. They were related to the availability of wood, and further improvement of such figures is possible by a better organization of tree felling and processing. Operational speed was affected by the condition of skid roads used for forwarding, which were harsh. During the transportation tasks developed on roads typical for forwarding, the machine was able to sustain average speeds estimated at 8 km/h. As a matter of fact, in such tasks, the dominant operational speed (almost in 100% of the cases) was higher than 5 km/h irrespective of the road condition. Hourly fuel consumption was estimated based on the time in which the engine was working and it amounted to 17.1 l/h. More importantly, by considering the forwarded payload in terms of volume and mass, the unit fuel consumption was estimated to be 1.25 l/m^3 and 1.47 l/t, respectively. These results bring evidence on the performance improvement by modular innovation. In fact, such solutions could answer the challenges related to the sustainability of forest operations in low access forests.

Keywords: forwarder, prototype, innovation, effectivenes, module, evaluation

1. Introduction

Forwarders are among the most used ground-based machines to extract the wood around the world. They are defined as self-propelled vehicles that are built for use in the transport of trees or their parts into a bunk (ISO 6814 2009). Their original concept, which is still in use today, dates back to the 60s when the first fully-mechanized cut-to-length harvesting system was identified and framed by a Swedish group of researchers (Heinimann 2007), a system that is still considered to be the most technologically advanced in the world

(Lindroos et al. 2017). While the original system consisted of a harvester and a forwarder, for many reasons that affect the level of mechanization (Vusić et al. 2013), such as the regulatory system, forest type, acceptability of practices and intensity of extractions, in some parts of the world, forwarders are used today in partly mechanized systems that integrate motor-manual felling and processing of trees. A typical example is that of Eastern (Moskalik et al. 2017) and South Eastern (Proto et al. 2017, Stankić et al. 2012) European countries where the forwarder technology is either well established or under the introduction to operation.

The actual concept of forwarders has not been changed significantly compared to the original one, but a significant progress in the forwarding machines development was achieved in key areas such as the ergonomics, environmental impact and automation (Pandur et al. 2009, Stankić et al. 2012). To this direction, even the most advanced actual machines are seen to be partly automated to serve function-specific purposes, and a full automation is still out of reach on a short medium term (Lindroos et al. 2017). This leaves a lot of room for the improvement of machine components to be able to respond to pressing needs of the industry and, in fact, the relation between the two approaches – automation and improvement of components – is rather a synergistic and not a mutually exclusive one. In this regard, one of the key functions that may require improvement is the transportation function because other features, such as the productivity, environmental impact and costs, depend on its performance. The relevant features for this function are both empty and loaded turns, as their co-existence is mandatory to be able to access the wood. There are numerous factors that could affect the performance of the transportation function and, most often, its performance is associated with the forwarding distance (Apafaian et al. 2017, Proto et al. 2018), slope of skid roads (Ghaffaryian et al. 2007) and payload per turn, with the latter being used by some authors to categorize the machines in classes (Stankić et al. 2012). For instance, increment of operational distance was found by most of the studies to be among the critical factors that negatively affect the forwarding productivity. As such, it becomes an important factor, whose effects need to be bridged in many countries, because it can reach quite frequently to more than 1 km and it is often associated with an increased terrain slope (Borz et al. 2019a). Therefore, for the same machine class in terms of loading capacity, and for the same operational conditions in terms of distance and slope, enabling the transportation function to operate at higher speeds could be crucial to improve the productivity outcomes and to reduce the costs, especially in those conditions in which the access to forest is difficult and the forwarding distances are increased. While overcoming the effects of increased operational distance itself is an important problem to be approached, recent studies have identified several key performance areas to which modern forest operations, therefore the machines developed and used, need to be aligned to. The latest work in this regard has indicated several key performance areas framed around sustainability (Marchi et al. 2018) that need to be addressed by the science behind their corresponding disciplines (Heinimann 2007), with a great emphasis placed on the capabilities of the systems to deliver high-quality wood, in less time, at less costs and with less environmental burdens, while also balancing the system's capabilities with those of human operators – e.g. limitation of exposure to noise and vibration (Poje et al. 2019) – and of the institutional and practice setup in a given area.

Having in mind the above described, the Forwarder2020 project was framed around the operational requirements and preferences of users by a market pull approach (Borz et al. 2019a) to build innovative machines adapted to specific work environments. The project consortium developed innovative modules to be integrated in forwarders in such a way that enabled the flexibility in their purchasing and adaptation to special requirements of users, by approaching key issues such as the increased efficiency of operations, improved environmental protection and a better decision making. Of these, some modules were developed to increase the forwarding efficiency as a response to the high operational distances that are common in many European countries. Examples of modules developed for such environments are the suspended cabin and, in particular, the innovative transmission system that, together with the cabin, was designed to enable faster operations, contributing therefore to productivity increment and to fuel savings. While these capabilities were tested before releasing the prototypes, with excellent results after the development stage, a challenge was that related to testing the improvements in real operational conditions. In particular, the ability to drive at higher speeds compared to the conventional machines, as well as the effectiveness in fuel saving were the main key performance indicators to be demonstrated in real operations. In this regard, it is quite common to use specific techniques to emphasize the effect of technology development and integration into new machines (Visser and Spinelli 2012), therefore to validate their effectiveness.

The focus of this study was on evaluating the improvements brought by the innovations integrated into an HSM 208F 14tons HVT-R2 forwarder prototype in terms of productivity, efficiency, operational speed and fuel saving, as the machine was equipped with an innovative, power-split transmission and a hydraulically suspended cabin. The assumptions were that, in particular, the operations could be sustained at a higher speed and, by doing so, the capability of transmission system to save fuel would be enabled.

2. Materials and Methods

2.1 Field Test Location, Stand and Harvesting System Description

A forested area characterized by a low road density and accessibility was selected for the field test. It was located at N47°04'30.58" – E25°17'42.00" (1450 m a.s.l.), 25 km away from Topliţa city, Harghita county, Romania (Fig. 1); the harvested stand was located at about one km away in straight line from the nearest forest road. The land in the area is characterized by the presence of forests dominated by Norway spruce (*Picea abies* (Lam.) Link.) that are frequently bordered by alpine pastures. The wood harvested from the area is delivered to both small-sized lumber manufactures as well as to larger wood processing companies. Taking into account the access to the forest stand by a skidding road (Fig. 1), the average extraction distance, measured from the center of forest stand to the junction of skidding road to the forest road, was of roughly 1.6 km. The forest stand (Table 1) was harvested by a clear-cut implemented by motor-manual tree felling and processing and the manufactured logs were extracted using the forwarder prototype that has been tested for three days, from 26th to 28th of August 2019.

The main descriptive features of the forest, standing stock and system used to harvest the wood are given in Table 1. The mean slope of the terrain in the felling block was of approximately 26%. However, the mean slope of parts of the felling block in which the tests were carried out was much lower, accounting for up to 15%. In total (Table 1), 1105 trees were scheduled for extraction accounting for roughly 1120 m^3 over-bark (o.b.). About 10% of that wood was extracted prior the tests by a skidder and a farming tractor and about 20% was felled, processed and forwarded during the field tests.

Forwarding operations were carried out on an existing skidding road (Fig. 1c,d) that provided access from the forest road to the felling block and that was characterized by an evident heterogeneity in terms of longitudinal slope, surface roughness, surface type and width. Fig. 1d shows four segments that have been conceptually delimited based on the mentioned features:

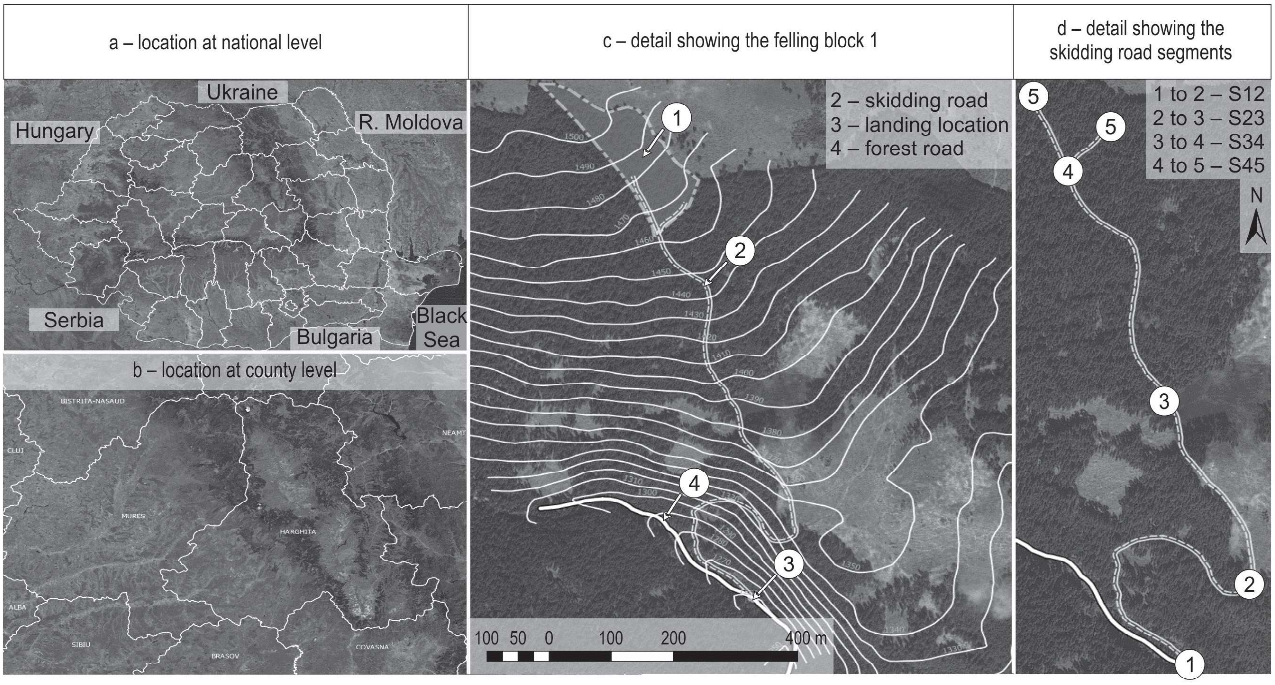

Fig. 1 Location of the field test –

Table 1 Description of forest stand and harvesting system

Parameter	Value
Stand composition, %	100 Norway spruce[a]
Age, years	120[a]
Mean DBH, cm	40[a]
Mean tree height, m	26[a]
Canopy closure, %	90[a]
Mean slope, %	26[a,b]
Area, ha	2.7[a]
Standing stock, m^3 over-bark	1117[a]
Standing stock, m^3 under-bark	1023[a]
Mean volume per tree, m^3 over-bark	1.11[a]
No. of harvestable trees	1005
Harvesting year	2019
Silvicultural system	Clear-cuts
Harvesting system	Motor-manual tree felling & processing + Forwarding[c]

[a] Figures based on the provisions of contractual documents
[b] Terrain slope was 5 to more than 15% in the area of test
[c] Refers only to the time of the field test

⇒ the segment located between points 1 and 2 (hereafter S12) was a bladed skidding road having an approximate width of 4 m, being characterized by a non-levelled condition, sharp turns and sharp changes in the longitudinal profile. Longitudinal terrain slope ranged from 10 to more than 40% and was non-evenly distributed on relatively short segments. The segment condition indicated a heavy traffic by skidding operations

⇒ the segment located between points 2 and 3 (hereafter S23) was a non-bladed skidding road running outside the forest, non-levelled, relatively straight, with many boulders surfacing the soil. Longitudinal slopes ranged from 10 to more than 20% and were evenly distributed on relatively long segments. It was trafficked by skidding operations and it was relatively compacted

⇒ the segment located between points 3 and 4 (hereafter S34) was a non-bladed skidding road running inside the forest, non-levelled, relatively straight, with boulders surfacing the soil and having a limited width. Longitudinal slopes ranged from 10 to more than 20% and were non-evenly distributed on relatively short segments. It was trafficked by skidding operations and it was relatively compacted

⇒ the segment located between points 4 and 5 (hereafter S45) was a natural soil, inside the forest, non-levelled, with some boulders surfacing the soil and stumps present at the surface. Longitudinal slopes ranged from 5 to more than 15% and were non-evenly distributed on relatively short segments. In general, the compaction was less than on the rest of road segments

Fig. 2 Forwarder prototype tested in the field during the demonstration events from May 2019 with the courtesy of Forwarder2020 consortium

The tested machine was a HSM 208F 14t HVT-R2 forwarder prototype (Fig. 2) that was developed in the framework of Forwarder 2020 innovation project, based on the concept of 208F series and integrating several innovations developed within the consortium such as the suspended cabin designed to improve the ergonomics, comfort and safety when operating at increased speed, a hybrid hydrostatic-mechanical power-split transmission (HVT-R2) designed to bridge some of the commonly known issues of the used transmissions such as those working solely on mechanical or hydrostatic concepts (HSM 2019), and an extended capacity of the bunk. The machine was equipped with a Volvo (Tier 4 8-l in-line 6 cylinder) engine and a Palfinger Epsilon S110F crane. Prior to the field tests under the real operational conditions, the performance of the prototype machine was compared to that of the series machine equipped with a standard transmission by tests on the roller bench, and then by some comparative field tests carried out in Romania, whose results have not been published yet. The main conclusion of the roller bench tests was that a significant performance improvement may be achieved at higher speeds (Schmidt 2019), which also contributes to fuel savings as high as 1.36 l/km (HSM 2019). During the field tests, the machine was operated by a worker who had an extensive work experience on the 208F series machine. He participated in the comparative supervised tests that were carried out using the same machine in May 2019, close to the location of this field test, and he was instructed to work by balancing his safety and comfort with the operation speed.

2.2 Performance Assessment

2.2.1 General Concept

The general concept used in the performance assessment was that of measuring, deriving and evaluating a set of key performance indicators in terms of both objective and subjective categories. The objective performance indicators were those generally described by the system engineering literature (Wasson 2006) and by the forestry operations concepts and terminology (Acuna et al. 2012, Björheden et al. 1995) such as the time and fuel consumption, operational speed, productivity and efficiency. Then, given the fact that driving at significantly increased speeds may affect the driver's perception of his/her own safety, in the subjective performance assessment, a face-to-face discussion approach was used to see if the driver felt comfortable to run the machine at different speeds and, on several occasions, a researcher joined the cab during the operations to personally evaluate such issues. The approach used was also market-oriented in the sense that the performance indicators selected for the evaluation were chosen to respond and clarify how and to what extent the innovative components integrated into the machine could satisfy, by their outputs in terms of performance, the preferences and operational needs of potential customers. For this, the work of Borz et al. (2019a) has served as both reference and guideline to first develop a set of indicators. As such, and given that many of these indicators are inter-related, for the purpose of this study, the following indicators were selected: the time consumption as a reference to build up figures on productivity and efficiency, fuel consumption and operational speed, with the later being related to both productivity and fuel consumption. The described approach was used to be able to show the differences, if any, compared to the existing results.

2.2.2 Time Consumption

The time consumption concept used in this study was agreed by the IUFRO (Björheden et al. 1995) and it was adapted to the main functions provided, in general, by the forwarders. The division of work on subsequent hierarchic levels was based on the recommendations of Spinelli et al. (2013), by limiting the number work elements (tasks) to those strictly needed to characterize the performance in terms of time consumption and operational speed and to account for the variability of these performance indicators given by the characteristics of delimited road segments. For reasons such as foreseeing that some of the work elements would develop at increased speeds, enabling a fast data collection, limiting the intrusion of observers in the way of doing work and being able to derive the operational speed as required by the study concept, the division of work place time into elemental time consumption categories was made in the office phase of the study based on the data collected via GPS and video recording. Similar techniques were previously documented and used with success in many fields, including those of forest engineering (Grigolato et al. 2016, Mologni et al. 2018). To this end, a customer-grade Garmin® GPSMAP 64st handheld unit was placed on the machine cab to avoid signal obstruction, then it was reinforced by adhesive tape and set to collect locations at one second rate (1 Hz). In parallel, a mini video camera was placed inside the cab at a height that allowed a good field of view on the bunk and crane during the operation and set to continuously collect video files. Among the capabilities of the used devices, attention is drawn to the high accuracy of GPS device that in some open conditions may be as high as 1 to 5 meters; under mature canopy, the accuracy stays in between 4 to 12 m (Keefe et al. 2019). Another feature is the extended battery life of the used camera (typically more than 10 hours), which enables it to record, label and store consecutive date and time stamped video files having a duration of 20 minutes each. In addition, time and motion studies carried out using a GPS approach have been proven to save important research resources and to automate, to some extent, data processing, while their outputs are of a great importance in mapping the observed events (e.g. Borz et al. 2018, Talagai et al. 2018, Borz et al. 2019b) and in inferring other parameters such as the operational speed. As such, the GPS approach was accepted and used in many forest operations productivity studies (e.g. Borz et al. 2015, McDonald and Fulton 2005, Strandgard and Mitchell 2015). Moreover, the video recording approach is one of the limited options available to accurately document the tasks (e.g. Borz et al. 2014) and it is particularly useful when the researcher presence in the field is either not possible or not advisable. For such an approach, however, the processing effort at the office has been proved to be resource intensive in some cases, depending on the complexity of the studied system, and therefore on the number of work elements within a work cycle (Musat et al. 2016).

Back at the office, the two collected datasets were analyzed together to extract the elemental time consumption and to derive other relevant indicators. First of all, the files collected via GPS, using a sampling rate of 1 Hz, were analyzed together in the framework of QGIS open source free software (version 2.14.0 Essen) after some refinements that aimed to exclude the locations characterizing non-work place time, since the forest road geometry was documented using the same device. Then, the field-recorded GPX files were converted into Microsoft® Excel® spreadsheets for further processing. Here, logical functions were used to convert strings into numbers or to extract numbers from strings where needed (e.g. speed data). Then, an initial database was built as a spreadsheet containing a set of parameters required for analysis such as the identification number, date and clock time, GPS speed and location. Video files were analyzed by playing them into the VLC media player open-source free software and a pen-and-paper approach was used to document the operations by coding the main tasks (Table 2) and by extracting the clock time for the beginning and ending breakpoints of each task.

Based on the codes noted on the paper and on the time-labels extracted at the break points, the initial database was further documented by adding the task (work element) codes for each 1-second observation, an approach that was enabled by the time attributes contained in the database.

2.2.3 Operational Speed

As one of the important goals of this study was to evaluate the improvements in terms of operational speed, the database developed for time consumption estimation was further documented to include the features related to this performance indicator. To do so, the skidding road was conceptually divided in segments according to the description provided above, and based on the geometry and locations collected by GPS. The database was further documented by including codes to describe the direction of movement and the bunk state in relation to speed for empty and loaded turns. The rest of the observed tasks were excluded from this analysis because there was less potential to show improvements in events such as, for instance,

Table 2 Description of work elements used in the study

Work and Time Consumption Category Scope of use and analysis	Abbreviation	Description and comments
Total Study Time Study level	TST	Total time recorded in the field as workplace time and delays caused by the study itself
Delays Caused by Study Study level	SD	Delays caused by the need to refuel the machine after completion of each work cycle as well as those caused by the need to make adjustments to the devices used to collect data
Work Place Time Study level	WPT	Total time observed and recorded in the field after the exclusion of delays caused by the study itself. Used for characterization at the study level
Empty Turn Time Study level, Cycle wise	ETT	Time consumed when driving empty from the landing to the felling block. Repeated at work cycle level and also used for characterization at the study level
Loading Time Study level, Cycle wise	LT	Time consumed when effectively loading and when moving to access the wood in the felling block or along a skid road. Repeated at work cycle level and also used for characterization at the study level
Assisting Time Study level, Cycle wise	AT	Time consumed when assisting the fellers by the crane to buck the trees, as well as the time spent to clear the ground using the crane and to make space for movement. Repeated only for few work cycles and also used for characterization at the study level
Loaded Turn Time Study level, Cycle wise	LTT	Time consumed when driving loaded from the felling block to landing. Repeated at work cycle level and also used for characterization at the study level
Unloading Time Study level, Cycle wise	UT	Time consumed to unload the logs at landing and to arrange them into the pile, including small movements for doing so. Repeated at work cycle level and also used for characterization at the study level
Maneuvering Time Study level, Cycle wise	MT	Time consumed to turn back the machine from the wood pile to the refueling place at the landing. Repeated at work cycle level and also used for characterization at the study level
Delays Study level	DT	Time consumed for personal reasons or to wait in the felling block for the fellers to process trees. Used for characterization at the study level
Productive (Delay Free) Time Study level, Cycle wise	DFT	Work place time after removing the delays. Used for characterization at the study level

moving when loading. This is because the speed that could be reached in such events depends largely on the location of log bunches and the distance between them. As the log bunches were grouped at relatively small distances among them, the speed in these movements was expected to be that which can be sustained also by the machines produced in series. Operational speed, on the other hand, was assumed to be the GPS speed and, given this aspect, the expectation was that the real ground speed be higher. This approach was helpful in determining the speed that could be sustained in relation to the condition of skidding road, therefore, in the estimation of operational speed behavior that could occur in different scenarios related to the quantitative and qualitative features of the forwarding infrastructure. In addition to these categories of conditions, data on operational speed was further used to characterize the performance of operations at the study level by categorization and mapping.

2.2.4 Fuel Consumption

Fuel consumption was measured using the direct method (Ignea et al. 2017) of refilling to full (Acuna et al. 2012). This approach was used to be able to compute the unit fuel consumption and to relate, to some extent, the fuel consumption to some of the operational variables. An electric pump attached to a 400 l external tank (resolution of 0.01 l, Fig. 3) was used to refill the tank to full after placing the machine in a flat location on the forest road, near the landing, after the completion of each work cycle (Table 2). Before refilling the fuel tank and for each work cycle, the board computer was checked to see the inclination of the machine. In cases in which it exceeded 3%, the machine was replaced to stay in that inclination limit. During each refill, measures were undertaken to eliminate the air possibly stored in the tank and a fixed mark was used each time to fill the tank to the same level. Nevertheless, one could assume a reasonable 0.5 l error per work cycle, a fact that would not significantly affect the results, given that the fuel consumption indicators derived in this study have used the total fuel consumption measured in the field tests. Visual periodic checks were also undertaken to see if the amount of the fuel used and measured corresponded to that missing from the tank.

2.2.5 Operational Variables

Only the most important operational variables were either measured or derived for this study. The distances covered during the empty turn (DET, m), loading (DL, m) and loaded turn (DLT, m) were measured in the QGIS software after joining the developed database to the files containing the geometry and location of GPS collected data. To correct these distance categories by slope and to estimate the real distance, a 10 m contour layer was constructed from the freely available imagery data under the QGIS web data repository and used to calculate the altitudinal differences needed to compute the slope. Distance covered by maneuvers at the landing was set to 20 m by a direct measurement. For a given work cycle, the operational distance (DO, m) was considered to be the sum of the above categories, while the average extraction distance (DA, m) was set conventionally by dividing DO by 2. Given the approach used to document the data on distance, a resolution of 10 m was set to describe the operational distance data.

Production data was based on detailed measurements that were carried out, for each work cycle, at the

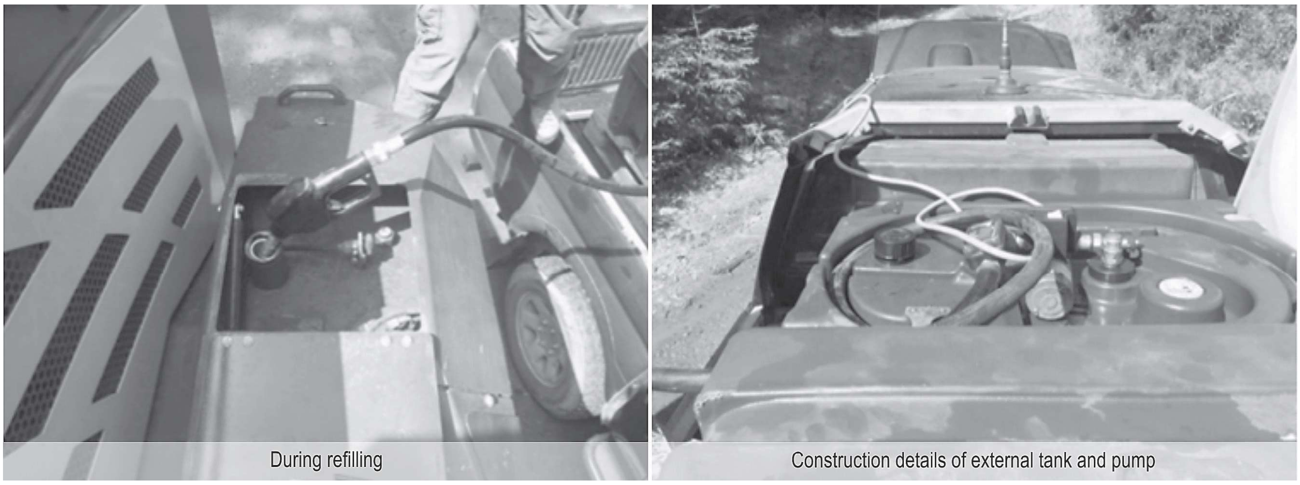

Fig. 3 Electric pump used to refill the tank

landing. Volume of each log (m^3 over bark, hereafter m^3 o.b.) was estimated using the conventional approach, based on the diameters at the ends measured to the nearest centimeter and the length of each log measured by a tape to the nearest 5 cm. Small parts of log, buttress ends and other parts of smashed wood were visually estimated and, for each turn, a volume of 0.1 m^3 o.b. was added to correct the production. A conversion factor of 0.85 t/m^3 o.b., as for fresh coniferous wood in the area, was used to estimate the forwarded mass per turn, and at the study level. Unfortunately, there was no literature available in relation to the conversion factors of fresh wood in the area, but still, the used factor was considered to be more than realistic given the season of harvesting. This is because the area is characterized by a colder climate in which the growth patterns of Norway spruce are different compared to the rest of the country, a fact that contributes to the differentiation of a particular anatomic structure of the spruce wood (Dinulică et al. 2019). Primary field data, such as the diameters and lengths of the logs, including the corrections, was collected in the time that the machine was engaged in operations in the felling block and it was noted, for each turn, on a paper field book. Production estimates were obtained at the office after transferring the data into Microsoft® Excel® sheets.

2.3 Data Analysis

Since the collected data set was limited in terms of number of work cycles, the data analysis was framed around descriptive statistics. While a modelling approach would have been very helpful in deducing more accurate functional relations between the input of resources and variation of operational variables, this approach was omitted due to the limited availability of the machine and the amount of resources needed to run an extensive modelling study, facts that constrained the data to a limited set. Nevertheless, the key performance indicators could be extracted by the approach of this study at a sufficient precision to be able to make comparisons and to emphasize the value added by innovative technology integrated into the prototype. Therefore, the following methods were used to analyze the data:

⇒ time consumption for tasks was structured as defined in the time concept used and both the absolute and relative values were computed as descriptive statistics

⇒ operational variables were computed and reported as descriptive statistics, then both the time consumption and those variables characterizing the production were used to estimate the relevant indicators of productive performance: gross and net productivity and efficiency rates

⇒ based on the statistics of operational variables and those characterizing the production, fuel consumption was reported using the main descriptive statistics. To this end, the concept of the study distinguished between three categories of unit fuel consumption (UFC), by reporting the inputs of fuel to the production expressed as volume and mass, respectively, by reporting the fuel consumption on an hourly basis. To enable other comparisons, part of the data was used to compute the unit fuel consumption as liters per kilometric ton (l/tkm), a metric that accounts for the mass moved over distance

⇒ a centerpiece of this study was that of evaluating if and to what extent the operational speed could be sustained at higher values compared to the existing machines. As the study site provided the conditions to evaluate such outcomes, the statistical approach used to evaluate the operational speed was that of deriving descriptive statistics in more detail that referred to both the study, in general, and to the typical skid road segments and bunk states in particular. Therefore, thematic mapping procedures were used with the support of QGIS to show the situation on operational speed in relation to the first two ranges of the transmission system (≤4 km/h and 5 to 18 km/h). Then, descriptive statistics were built and reported to characterize the empty and loaded turns at the study level and, finally, descriptive statistics were built and reported to show the differences in the operational speed sustained on different configurations of the skidding roads and bunk states

All the statistical work was carried out using the Microsoft® Excel® software. Part of the derived data, however, was analyzed by the means provided by QGIS software.

3. Results

3.1 Time Consumption, Operational Variables and Productivity

Following data analysis, the total study time (TST) amounted to almost 20 hours, out of which the work place time accounted for 82%. After the exclusion of delays, the delay free time (DFT) amounted to 15.5 hours representing 95% of the work place time (WPT). It means that the former category, loading time (LT)

Table 3 Descriptive statistics of operational variables and production

Category and Parameters Abbreviation	Descriptive Statistics				
	No. of observations	Sum	Minimum value	Maximum value	Mean Standard Deviation
Distance					
Operational Distance, m DO	15	44 150	–	–	–
Empty Turn Distance, m DET	15	21 760	960	1660	1451 (277)
Distance Covered when Loading, m DCL	15	720	10	150	48 (36)
Loaded Turn Distance, m DLT	15	21 370	720	1650	1425 (329)
Distance Covered in Landing Maneuvers, m DLM	15	300	–	–	20
Production					
# Logs NL	702	702	28	66	47 (10)
Payload, m^3 o.b. PL	15	221.3	8.6	19.4	14.8 (2.5)
Production, m^3 o.b. P	–	221.3	–	–	–
Production*, t P*	–	188.1	–	–	–
Corrected Production, m^3 o.b. CP	–	222.8	–	–	–
Corrected Production*, t CP*	–	189.4	–	–	–

was dominant (about 41%), being followed by empty (ETT) and loaded turns (LTT) that shared similar proportions (about 23.5%) and by the unloading time (UT) that accounted for almost 10%. However, the maneuvers between log bunches available in the forest were also included in the loading time. Maneuvering at landing (MT) and assisting into the felling block (AT) took less than 3% of the delay-free time.

The total distance covered by driving the forwarder prototype during the study (DO) was estimated at about 44 km (Table 3). Empty and loaded turns were deployed at relatively similar distances that accounted, on average, for about 1.4 km, and the average distance covered when loading was of about 50 m. Using the procedures described in the materials and methods section, the average extraction distance was estimated at about 1.5 km. A rough estimation on the speed of operations, including here only those tasks that involved movement of the machine, would be of 3.14 km/h, a figure that, given the operational conditions, may characterize a first improvement. In terms of production, a total of 702 logs were forwarded during the study, excluding here the short pieces for which the volume was estimated visually. In these conditions, the production at study level (P) was estimated at 221.3 m^3 o.b. and corrected at 222.8 m^3 o.b., standing for a total moved mass that was estimated at cca. 189 tons.

Based on the above figures, Table 4 shows the main indicators characterizing the productive performance. Under the assumption of no delays, productivity was rated at about 14.4 m^3 o.b./hour. Under the conditions of a perfect work organization in tree felling and processing operations, therefore by excluding the time spent in assisting operations, this figure would have reached about 14.6 m^3 o.b./hour, meaning that the contribution of a better work organization in this direction is expected to be rather small. Delays, on the other hand, affected the productivity rate by almost 5% (P_{gross} = 13.713 m^3 o.b./hour). As the delays were mostly personal, a supplementary improvement may rest in a better management of the work time. The value of both gross and net efficiency rate was rather similar, while the gross value of the effect of delays is slightly higher.

Payload per turn (PL), on the other hand, varied widely between about 9 and 19 m^3 o.b. Lower figures were related to a reduced availability, in some cases, of wood prepared as logs into the felling block, a fact that affected the productivity.

Table 4 Productivity and efficiency indicators

Operational Conditions	DFT hours	WPT hours	CP m^3 o.b.	P_{net} m^3 o.b./h	P_{gross} m^3 o.b./h	E_{net} h/m^3 o.b.	E_{gross} h/m^3 o.b.
Average extraction distance, DA = 1470 m Average operational distance, DO m = 2940 m Average payload, PL = 14.75 m^3 o.b. Average no. of logs per turn, NL = 46.80	15.50	16.25	222.78	14.373	13.713	0.070	0.073

3.2 Operational Speed

Fig. 4 shows an overview of operational speed at global level (Fig. 4a), as well as of the skidding road segments divided according to the concept of the study (S45 and S34 – Fig. 4b, S23 and S12 – Fig. 4c). For demonstration, two speed categories have been used, corresponding to the behavior of transmission system as described in the material and methods section. As shown, the dominant operational speed was that of more than 5 km/h that corresponds to the second, power-split range of the transmission, in which the machine behaves very well in terms of efficiency and fuel savings in off-road conditions.

The main goal of improvement was to be able to drive at higher speeds during the empty and loaded turns, which could result in increased productivity and significant fuel savings. In this regard, at study level, both median and mean values of empty and loaded turn speeds were quite similar. In fact, the median values computed based on the locations categorized as empty and loaded turns were 6 km/h. Average values for the same data were 5.9 and 5.8 km/h for the loaded and empty turns, respectively.

However, the data varied quite largely in relation to the skidding road condition. Fig. 5 shows the descriptive statistics of operational speed as a breakdown on the type of task and bunk state. On the S45 skidding road segment the average speed was about 3.8 km/h. Then, for the S34 road segment, the operational speed when driving unloaded in the uphill direction was about 5.9 km/h, being somehow higher than that of downhill uploaded driving (about 5.5 km/h). The highest average operational speed was that of a relatively straight road segment (S23). It was about

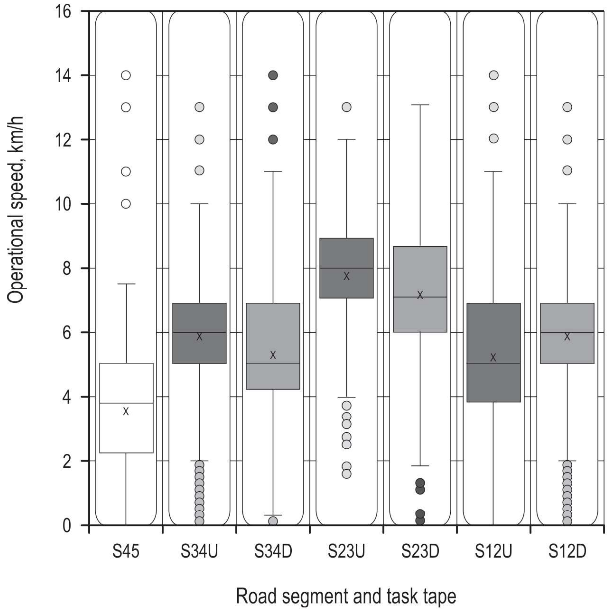

Fig. 5 Descriptive statistics of operational speed for uphill (unloaded, U) and downhill (loaded, D) turns on delimited skidding road segments (S)

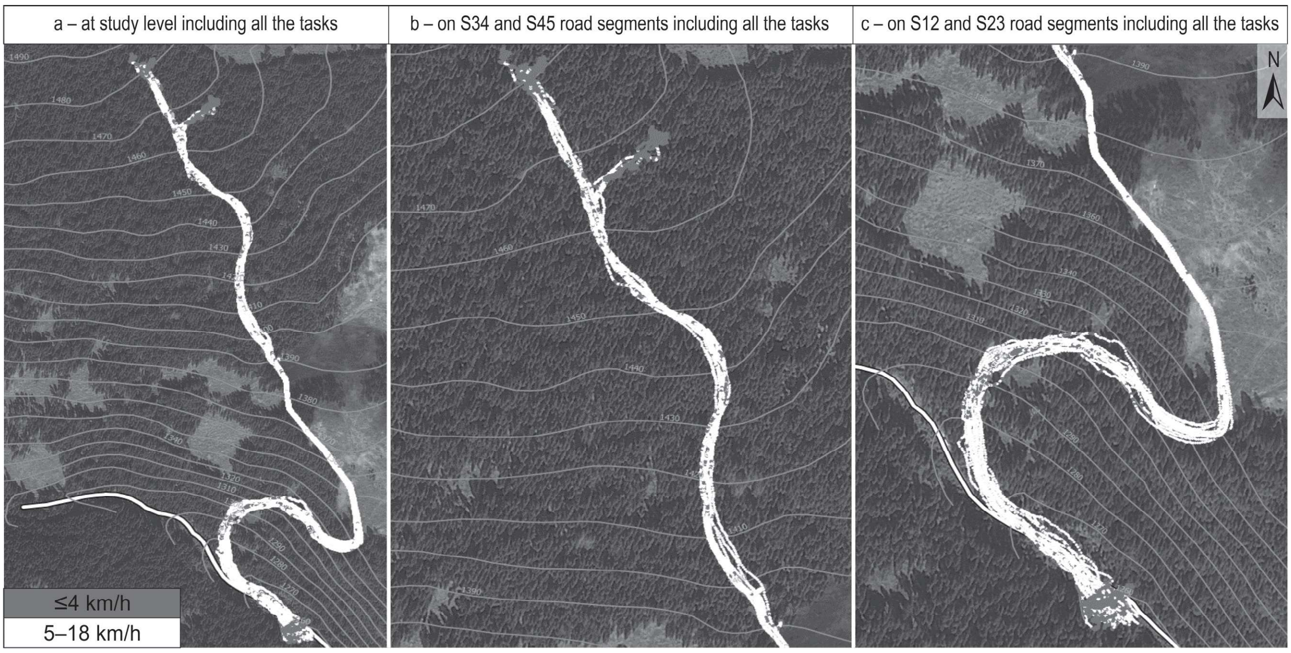

Fig. 4 Map of operational speed

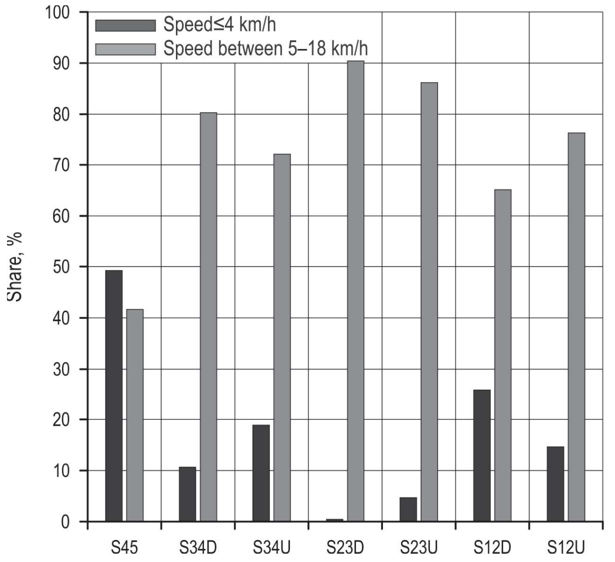

Fig. 6 Share of locations collected via GPS on operational speed categories, tasks and bunk states

7.7 km/h when driving unloaded in the uphill direction (S23U) and about 7.1 km/h when driving uploaded in the downhill direction (S23D). For S12, the average operational speed was about 5.3 km/h when driving uphill (S12U) and about 5.8 km/h when driving downhill (S12D). Speeds higher than 4 km/h were sustained as shown in Fig. 6. For S45, such speeds were only sustained in about 46% of cases, but here a differentiation in terms of bunk state and driving direction was not feasible given the ground conditions. Significant improvements were found, however, for the rest of roads segments, with the best results for S23, a case in which a speed higher than 4 km/h was sustained for more than 90% of the analyzed observations. For speeds sustained in the range of 10–18 km/h (not shown herein), the best results were found for S23U (12.6% of cases) and S23D (14.3% of cases).

Based on the above results, it could said that the prototype behaved very well as it was able to sustain high operational speeds. However, to be able to clearly differentiate the performance gains compared to conventional machines, comparative studies should be implemented in the future to evaluate the effectiveness of both machine types working under similar conditions. The forwarder driver was asked periodically how he felt about the speed of operation and a researcher joined the cab to see himself how the speed may affect the comfort and safety of operation. Indeed, the forwarder driver responded that if the conditions for all the road had been as those on the S23 road segment, he would have probably been able to drive even faster. Also, he stated that in the condition of the forest and limited space, the driving during the tests was close to the best he could manage (S34 and S45). This was also the case of the S12, where the road was characterized by sharp turns and very steep segments for which he stated that he had to control the speed when driving loaded in the downhill direction.

3.3 Fuel Consumption

Fuel consumption estimates, as they resulted from the field measurements and data analysis, are given in Table 5. There was an evident relation between the fuel consumption per turn and the operational distance but a model has not been developed given the small set of data used. The hourly rate was estimated based on all the time spent with engine working and all the fuel consumed during the tests, and it was about 17.1 l.

Based on the production statistics and the average operational conditions, the unit fuel consumption was estimated at cca. 1.25 l/m^3 o.b. Assuming the conversion factor used to estimate the moved mass, the unit fuel consumption was also estimated at cca. 1.5 l/t. This figure was translated in a unit fuel consumption of 0.499 l/tkm.

4. Discussion

In relation to productivity and efficiency, the results of this study have shown promising figures although it is quite difficult to make comparisons with other studies. This is because the reported results are affected by many factors, which are further affected by their variability. For instance, a known factor that affects the productivity is the availability of wood to

Table 5 Fuel Consumption Indicators

Operational Conditions	FC L	WPT hours	CP m^3 o.b.	CP* t	UFC l/h	UFC l/m^3 o.b.	UFC l/t
Average extraction distance, DA = 1470 m Average operational distance, DO = 2940 m Average payload, PL = 14.75 m^3 o.b. Average no. of logs per turn, NL = 46.80	277.87	16.25	222.78	189.4	17.104	1.247	1.467

be loaded per turn, which is dependent on the tree size and extraction intensity (Oprea 2008). Acknowledging the wide availability of studies reporting on forwarding performance, this part of discussion was built by referring to some studies that shared at least one common characteristic in terms of operational variables or technology used. For instance, a recent study of Proto et al. (2018) has indicated productivities in the range of 15 to 25 m^3/h, but these referred to extraction distances, which were half of those reported in this study. Accounting for the case study developed in Calabria (Italy), the same authors have indicated a productivity of cca. 15 m^3/h for a JD1110E machine, having a capacity of 12 t, that operated in selective cuts on a slope of 25%, which is comparable, to some extent, to that from this study, and for the conditions of an average extraction distance of about 700 m. As some of the features they described are comparable with those of this study, it could be inferred that a similar productivity was obtained for almost a double distance in this study. Nevertheless, it cannot be assumed that the difference in performance is purely the effect of distance since this study reports on clear cuts and the study of Proto et al. (2018) reports on selective cuts. In fact, their payload per turn was 10 m^3, indicating probably a lower availability of wood even if the average tree size was similar. In another case study, Proto et al. (2017) have found productivities of 14.4 and 15.7 m^3/h for extraction distances of approximately 300 and 600 m, respectively, for two John Deere machines (1110D and 1010D) operating on slopes of 26 and 29%, respectively. A rough comparison would emphasize the differences found, at least in terms of distance, which was much lower compared to this study as, in their study, the forwarded wood was bunched to the secondary roads (i.e. forwarding roads). Nevertheless, the payloads were much lower and the type of extraction was selective in their study. Similar findings apply when comparing to other international studies. For instance, in the study by Tiernan et al. (2004), clear felling was carried out on roughly half of the extraction distance and indicated a similar productivity, while Pandur et al. (2018) found a productivity of approximately 18 m^3/h on flat lands, but in their study the log size was higher and the extraction distance was less (about 1.1 km). For steep terrain and an extraction distance of 0.8 km, Dinev et al. (2015) found productivities of 44–53 m^3/day (probably 5–6 m^3/h assuming a work shift of 8 hours). Also, for an extraction distance of 1.1 km, a payload of 12–13 m^3 and clear-cut conditions, Slamka and Radocha (2010) found a productivity of cca. 11 m^3/h on gentle to moderate slopes. Therefore, it could be stated that the tested prototype improves the operations in terms of productivity as this figure was higher compared to the existing data, which spans, however, better extraction conditions, at least in terms of distance.

For both, empty and loaded turns, the average running speed in the field test was close to 6 km/h, under the argument that it refers to quite variable conditions of sampling, standing also for the GPS speed, which is known to be less than the real ground speed. Some examples coming from the literature indicate similar speeds that were only sustained for the empty turns and, in some cases, only for flat lands (Proto et al. 2017, Proto et al. 2018). For relatively similar conditions in terms of machine used, slope and payload, however, Slamka and Radocha (2010) found speeds of 2.5 and 4.0 km/h for the loaded and empty turns, speeds that were sustained and were higher even on natural soil as reported by this study. In fact, there are many studies that were developed in various conditions, showing the limits reached for empty and loaded turns in terms of speed. For empty turn, the reported speeds were in the range of 1.6–5 km/h, while for the loaded turn these were much lower, in the range of 2.2–3.7 km/h (Dinev et al. 2015, Ghaffaryian et al. 2007, Manner et al. 2016, Pandur et al. 2018, Stankić et al. 2012, Williams et al. 2016). From this point of view, both the cabin and the transmission system of the tested prototype worked synergistically and very well. On the one hand, the cabin provided the comfort and safety for the operator, which was also proven by the presence of the researcher in the cab. Based on this feature, the transmission system was enabled to work in the second, power-split range, that enabled a faster driving. These capabilities are particularly emphasized by the part of the skidding road that corresponded to the typical roads designed for forwarding, where the sustained speeds were, on average, close to 8 km/h. Under the assumption of providing well-maintained and levelled roads, speeds of 10 km/h or even higher could be sustained both during empty and loaded travel. This capability was tested (results not shown herein) during some supervised tests carried out in May 2019, aimed also to compare the performance of the prototype with that of a conventional machine made by the same producer. However, in conditions in which the skid roads are very steep, unmaintained and having sharp turns, operational speeds equal if not even higher, compared to those reported by the existing literature, can still be expected. This also applies to forest skidding roads, characterized by a limited width space. Nevertheless, it was impossible to measure other effects that could affect the ground speed such as slipping; therefore, the GPS speed was used as a reference to evaluate the performance in this aspect, and in order to improve the reliability of data, the study was conducted for several days and speed data coming from the same skidding road segments were averaged. As an overestimation of distance measured by GPS can be expected when sampling at high frequencies (Ranacher et al. 2016), the real ground speed would be in fact underestimated by the GPS speed.

Fuel consumption can also be compared, normally, for similar conditions. However, this is often quite difficult to make because it needs to be able to control many factors. For instance, Holzleitner et al. (2011) have shown that the hourly fuel consumption in forwarders may reach a wide variation depending purely on their engine output. While their mean hourly fuel consumption was 11 l, the data variation range was wider than 18 l/h and, even for the same engine output, it reached, in some cases, more than 12 l/h. This pinpoints the fact that other operational factors have an important effect on the fuel consumption given the fact that, for the same operational condition, it has been shown that there are no significant differences in fuel consumption in empty and loaded turns (Cosola et al. 2016). To this end, following the field test, the average extraction distance was estimated to be close to 1.5 km, while the average moving distance was close to 2.9 km. At the same time, the average payload per turn was close to 15 m^3. This resulted in an estimated fuel consumption of 17.1 l/h, 1.25 l/m^3 and 1.47 l/t. The study of Pandur et al. (2018) indicates, for similar conditions in terms of payload and log size, but for an extraction distance of 1.1 km, a fuel consumption of 15.6 l/h, 1.18 l/m^3 and 1.29 l/t reported for flat terrains. Similar figures were found by Danilovic et al. (2015) in flat terrain, reaching as much as 1.4 l/m^3. Also, for flat terrains, Pandur et al. (2018) reported a fuel consumption of 0.56 l/tkm. This last figure can be used as a reference for comparison as it reflects the effort as mass over distance and may emphasize the difference brought by innovative technology. In this regard, and by considering all the travelled distance irrespective of the bunk state (2.9 km), the unit fuel consumption reported by this study was estimated at about 0.50 l/kilometric tone. Since both the measurements of fuel consumption and production could be affected by errors, it makes sense to analyze some worse case scenarios. Assuming, even if highly unreasonable to think so, and error or 10% in the fuel consumption measurement (i.e. adding 30 l more) and a deviation of 10% in the estimated volume (i.e. excluding 20 m^3), which is also highly unreasonable, the unit fuel consumption would be cca. 1.5 l/m^3 and cca. 0.62 l/tkm, the last figure being close to that reported by Pandur et al. (2018) for flat terrains and much lower distances. Also, under the assumption of a conversion factor from m^3 o.b. to tons of 0.8, the above reported figures would be 1.56 l/t and 0.54 l/tkm, respectively. However, even this last scenario is highly unrealistic since the forwarded wood was fresh.

5. Conclusions

Results of this study bring evidence on the performance improvement by the modular innovation approach as a measure to increase the effectiveness of forwarding operations. In particular, for excessively long extraction distances, a synergic integration of the suspended cabin with an innovative transmission system enabled a faster and safer operation of the machine with improved effects in the productivity and fuel economy. As such, the machine was able to operate in the most efficient range of the transmission, which not only enabled driving at higher speeds but also contributed to a significant fuel economy. As the speed is known to affect the productivity and therefore also the cost of operations and since the fuel intake in forwarding is a crucial aspect for sustainability in terms of both cost and environmental impact, it can be concluded that the prototype tested has a lot of proven potential to ensure the sustainability of operations in low access forests. Also, without any exaggeration, in case of better road conditions, the machine could be characterized by an even higher, unleashed potential to positively contribute to the key performance indicators discussed above. In turn, this can contribute to less costs involved by the development of transportation infrastructure as well as to enabling forwarder users to invest in new technology based on an improved expected return in terms of cost effectiveness.

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Authors' address:

İsmail Baysal, PhD *
e-mail: ismailbaysal@duzce.edu.tr
Düzce University
Faculty of Forestry
Department of Forest Engineering
81620, Düzce
TURKEY

* Corresponding author

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SOIL DISTURBANCE

Soil disturbance during harvesting operation

Introduction

In the last decades the technological evolution in the forestry sector and in particular in the branch of mechanics and forestry uses has led to an almost exponential increase in the use of more powerful but also heavier machines. At the same time, interest has also grown in more eco-sustainable and environmentally friendly working methods, also turning attention to the perturbations of trees and soil caused by the use of these new machines in forestry operations (Toivio et al. 2017; Ala-Ilomäki et al. 2011; Hartanto et al. 2003; Jansson and Johansson, 1998; Rohand et al. 2003). If in the past through the use of traditional methods thanks to a state of low level mechanization the environmental impact did not arouse much attention, today instead, especially thanks to the progressive modernization it is very common to see machines in the woods much more complex and heavier than to simple traditional agricultural tractors, which are still widely used today. Forest soils are increasingly subject to anthropogenic threats and the main risks, linked to particular atmospheric conditions, occur precisely in the periods in which forest uses are usually carried out. The sustainable use of the wood resource implies, for economic reasons, the use of effective working processes which, however, often in contrast with the need to keep the forest soil health over time. The presence of healthy soils is the necessary condition for the conservation, as a whole, of sustainability in the forest. Some studies about the impact of logging on soil have been conducted in Mediterranean countries (e.g., Macrì et al. 2017; Proto et al. 2016; Jourgholami et al. 2014; Picchio et al. 2012) with a detailed review of the available literature on machinery induced negative effects on forest soils is provided by Cambi et al. (2015b). The pass of heavy vehicles on forest soil in conditions of low humidity causes, in most cases, deep and persistent ruts that cause serious disturbances to soil functions (Ampoorter et al. 2011 and 2007). It also causes the compaction and deformation of the soil. When the phenomenon reaches the deep layers of the soil it is almost irreversible. The overall deterioration of soil structure caused by compaction limits root growth, water and air storage capacity, fertility, biological activity and stability (Sirén et al. 2013; Frey et al. 2009; Demir et al. 2007; Bygdén et al. 2003; Nugent et al. 2003; Marshall, 2000). Furthermore, in the event of heavy rainfall, water can no longer easily penetrate the soil. The resulting large volumes of runoff water increase the risk of erosion (Elliot et al. 1999). A reduction in fertility has, as a direct consequence, a reduction in the productivity of the forest, the maintenance of which is obviously of primary interest to forest owners. Natural renewal is also heavily conditioned by the characteristics of the soil in the germination and root development phase. The living conditions for roots and soil organisms therefore worsen considerably and the reduced availability of air and water prevent the roots from penetrating the soil and exploiting it optimally. The natural processes of regeneration are not able to bring improvements except in a very long time. Soil is a non-renewable resource and a fundamental element for the life of future generations, which is why its protection has a very special meaning, being that the natural processes of regeneration are not able to bring improvements except in a very long time. Soil compaction has been reported as the principal form of damage associated with harvesting traffic (Hatchell et al. 1970; Dickerson 1976), therefore, information on the degree of compaction from normal logging operations and its effect on forest growth are needed to determine if current management of forests is sustainable (Williamson and Neilsen, 2000). Articulated forestry tractor (skidder machines) are widely used in mechanized forest harvesting operations and their impact on soil physical proprieties has been evaluated (Solgi et al. 2015; Naghdi and Solgi, 2014), but each skidder model has different mechanical features, such as overall height and width, weight, and different configurations of the front axle, all of which can impact soil physical proprieties in different ways. So, this work aims to analyse the environmental impact of compaction on the soil component caused by the repeated passes of a skidder machine during skid operations, adopting semi-trawl wood extraction system, in flat ground conditions on a forest track that has never been used before. Since thanks to many studies in the sector it is now known that as soil compaction increases bulk density increases and soil moisture content and porosity decrease (Proto et al. 2016; Cambi et al. 2015a; Jourgholami and Majnounian, 2011; Han et al. 2009), the objective of this study is to obtain a rapid method that evaluates the impact on the soil at the passes of a machine, studying the soil penetration resistance only with the use of a simple instrument such as the portable penetrometer. In detail, the research focused on the study of soil compaction by resistance to soil penetration after different numbers of machine passes, at different depths and, also, investigating the effects on the carriageways of the trail.

Materials and Methods

Study site

This work was conducted in a forest used for forestry in Transylvania in the municipality of Sighisoara in Romania. The forest is located at 24°47.5674′ E - 46°13.2846′ N, at an altitude of 570 m a.s.l. The climate in this part of the region is moderate continental, the average annual temperature is 8.2 °C, with average temperatures in January and July respectively of -4.3 °C and 18.6 °C. The average annual rainfall is between 500 and 620 mm. The type of soil that characterizes this forest is classified as Luvisol by the FAO-UNESCO Soil Map of the World (www.fao.org). It is a type of soil characteristic of wooded regions and is identified by the presence of eluvial and illuvial horizons where clay accumulates (Stănilă and Dumitru, 2016). Soil texture along the trail was determined to be clay loam after analysis using the Bouyoucos hydrometer method (Kalra and Maynard, 1991).

The ground of study site is flat (slope < 5%) and the forest top is represented by an oak wood (*Quercus petraea* Matt. Liebl), the tree layer is also made up of other species such as hornbeam (*Carpinus betulus* L.) and beech (*Fagus sylvatica* L.). The herbaceous layer consists of several species such as: *Festuca valesaica*, *Carex montana*, *Carex humilis*, *Potentilla alba*.

Machine description, tools, and processing techniques

The forest tractor used in this study is an IRUM 657 skidder (Figure 1 and Table 1) with a 4-stroke D110 diesel engine with a power of 47 kW (65 HP). Logs were skidded by the winch installed in the rear part of the skidder. The average logged volumes in each pass were 1.74 m^3 (2-3 logs) and all logs were extracted from the stump area to the roadside landing using a ground-based skidding system.

The instrument used during the surveys was the Fieldscout SC900 Soil, Compaction Meter, portable penetrometer. This tool is a specific instrument for the study of soil compaction, and, its main function is to allow to determine the soil density. The instrument has a stainless-steel rod with depth notches of 3", 6", 9", 12", 15", 18" which, inserted at the end, has a cone that enters the ground and can be chosen the diameter of the cone between 1/2 "and 3/4". The 1/2" cone is used for fine-grained soils while the 3/4" cone is recommended for coarser-grained soils. The operator pushes the rod and the resistance that the cone encounters when entering the ground is measured (in pounds per square inch) through an analogue pressure gauge that reacts to the pressure the cone undergoes as it penetrates the ground.

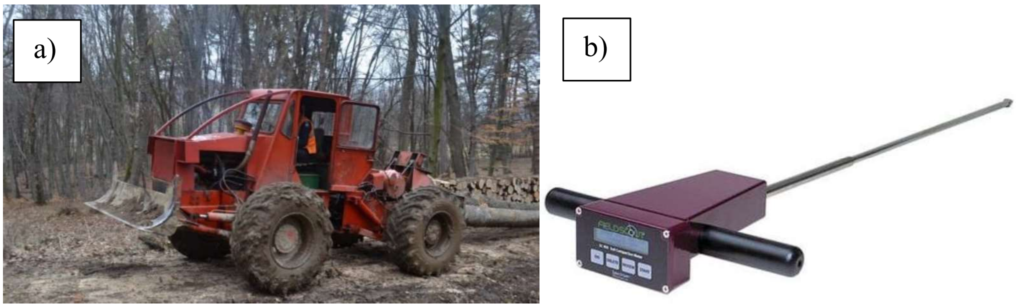

Figure 1 – a) IRUM 657 skidder machine left. **- b)** Fieldscout SC 900.

Table 1 - Technical characteristics of the IRUM 657 Skidder.

Parameter	Unit	Value
Power	kW	47
Weight	kg	6.850
Width	mm	2500
Length	mm	5850
Height	mm	2750
Wheelbase	mm	2850

As Day and Bassuk (1994) recommended, before carrying out the compaction study, to obtain initial information on the soil conditions, samples of (undisturbed) soil (n. 10) were taken from 10 cm depth to characterize its bulk density and moisture content using a rigid metallic cylinder (250 cm^3) after first removing any litter on the soil surface. The water content (WC) was determined according to the ‘Official Methods of Chemical Soil Analysis’ (G.U., 13/09/1999), for which, the soil moisture content is determined and expressed as a percentage of its oven-dried (constant) weight, and soil bulk density (Db) is calculated by dividing dry weight by the sample volume and expressed in units of g cm^{-3} (Proto et al. 2016; Naghdi and Solgi 2014; Ezzati et al. 2012; Tan et al. 2005; Fernández et al. 2002).

The surveys were carried out on a 100 m long and 3.5 wide track used for logging. Not far from the track, 45 measurements were carried out on undisturbed ground and used precisely as a reference. It is assumed that the reference area had not been driven on by harvesting machines because the forest floor was intact and there was no indication of soil compression. the track was divided into 15 segments, each of which was 6.5m long and 3.5m wide. Subsequently, for each segment, the effects of the propulsion organs were measured on three points, namely right, left and central carriageways, R, L and C, respectively (as schematized in a simple way in the figure 2). Each point was detected at three different depths 5, 10 and 15 cm, for a total of 9 measurements per segment, 135 considering the entire route. This procedure was replicated seven times, i.e. it was applied for each level of machine traffic taken into consideration, and therefore after 1, 3, 5, 7, 11, 15, and 20 times of machine passes, to evaluate the gradual compaction process. In total, 990 measurements were taken, of which 45 on undisturbed ground and 945 after the machine passes.

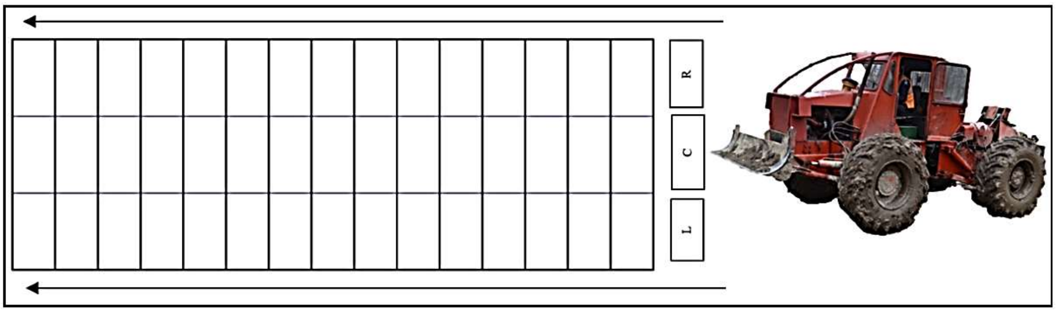

Figure 2 - Sample scheme of a trail divided into carriageways.

Statistical Analysis

The statistical analyses were done using IBM SPSS 25 Statistics program. Descriptive statistics for the soil penetration resistance (in kPa) were carried out and the data were tested for Gaussian distribution (Shapiro–Wilk test). A general linear model (GLM) was used to study the relationship of soil penetration resistance to the machine passes and other fixed factors and their interactions, defining as fixed factors in the model the number of machine passes, the carriageways and the soil depth. The GLM was followed by multiple comparisons tests made using Tukey's honestly significant difference (HSD) test, to assess the statistical differences between groups. All tests were performed at a probability level of 5%.

Results

Before machine passes, soil moisture content was ranging from 15% to 18% and bulk density was 1.58 g cm^{-3}. During the survey, the operator who drove the skidder, carried out the skidding operations very well, also facilitated by the very minimum slope conditions that did not affect the production dynamics. To understand the influence of the machine passes on the soil during skidding operations, mean values and descriptive statistics for the data measured on the field were shown in figure 3 and table 2. The average values found after the various machine passes had increased from 117% (after the first pass) to 262% (after 20 passes) (Figures 4 and 5). By the Shapiro-Wilk test, the data resulted to be normal distributed and a general linear model (GLM) was used to identity which variables were significantly different between the groups.

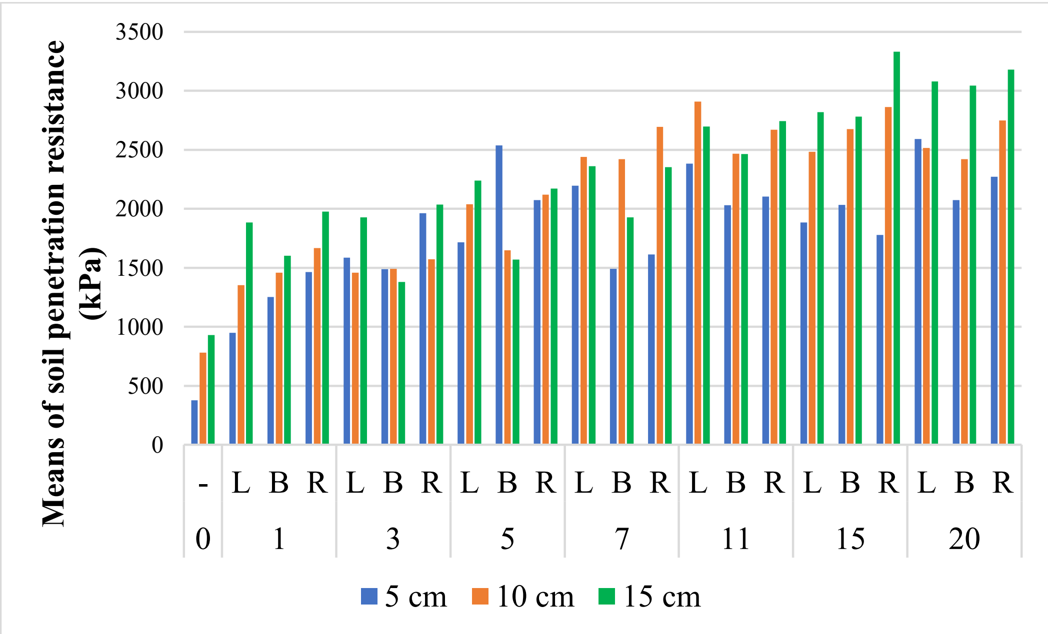

Figure 3 - Mean values of soil penetration resistance distinguished by soil depths, numbers of skidder passes and carriageways.

There were significant effects of carriageways, soil depth and machine passes on the SPR. All factors, and also their interactions, have proved very important in predicting the SPR level with strong statistical evidences (Table 3). In particular, as shown in Figure 6, by the HSD post hoc test it was found that the resistance to soil penetration in the undisturbed soil presented statistically significant differences between the three carriageways. The values obtained in the central carriageway were also statistically different from those of the both side carriageways ($p < 0.001$).

Table 2 - Descriptive statistics of soil penetration resistance (kPa).

Parameter		**Soil penetration resistance (kPa)**			
Carriageway	**N.**	**Mean value**	**Std. Dev.**	**Min. value**	**Max. value**
Undisturbed	45	696,13	292,88	74,00	1184,00
L	315	2167,65	734,67	197,07	4144,50
C	315	2012,73	734,33	164,06	4033,80
R	315	2257,42	724,16	290,05	4265,64
Depth (cm)					
5	330	1812,24	743,83	74,00	4144,50
10	330	2132,07	761,55	483,00	4033,80
15	330	2295,80	768,72	518,00	4265,64
N. Passes					
0	45	696,13	292,88	74,00	1184,00
1	135	1512,20	489,48	164,06	2745,92
3	135	1656,42	460,62	197,07	2691,25
5	135	2013,27	668,28	361,13	4144,50
7	135	2166,68	618,18	290,05	3625,57
11	135	2497,03	598,02	845,25	4014,94
15	135	2517,01	801,38	336,96	4265,64
20	135	2658,95	597,18	970,14	4035,26

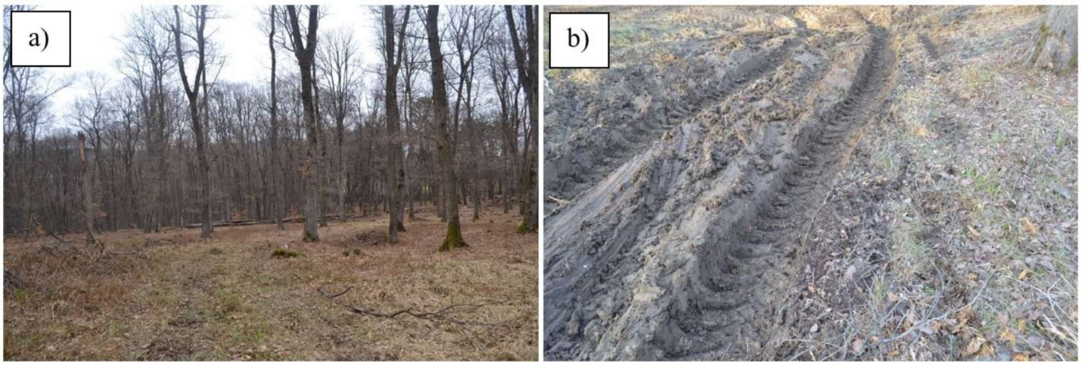

Figure 4 - a) Soil conditions after one skidder pass. - **b)** Soil conditions after 20 skidder passes.

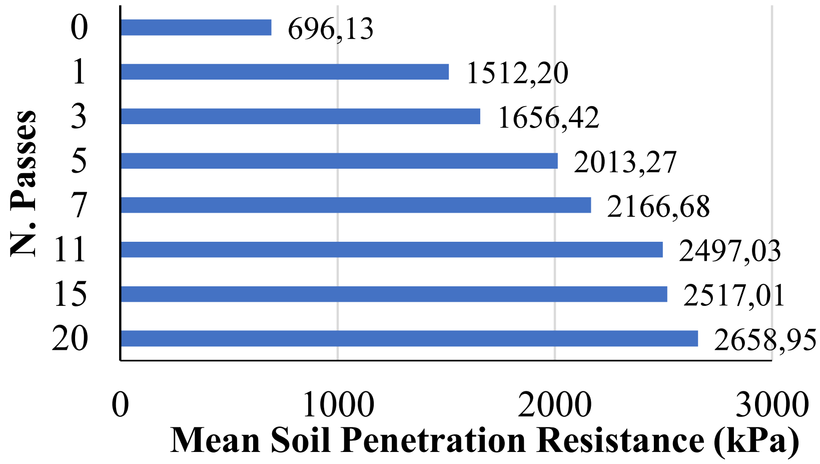

Figure 5 - Average values of soil penetration resistance after different machine passes.

Table 3 - The relationship of soil penetration resistance to the carriageways, soil depth and machine passes, and their interactions in a general linear model.

Dependent variable: soil penetration resistance (kPa)				
Source	**df**	**Mean square**	**F**	**Sig.**
Carriageway	2	4826345,081	18,307	0,000
Depth	2	16586209,992	62,912	0,000
N. Passes	6	26627074,382	100,998	0,000
Carriageway * Depth	4	1119865,907	4,248	0,002
Carriageway * N. Passes	12	556140,321	2,109	0,014
Depth * N.Passes	12	2952002,850	11,197	0,000
Carriageway * Depth * N. Passes	24	721033,430	2,735	0,000

Analyzing the resistance to soil penetration based on depth, it was statistically different at all the depths examined ($p < 0.000$). Based on the number of machine passes, the resistance to soil penetration was significantly different between that detected on the undisturbed ground and the other groups ($p < 0.000$). There was no significant difference between 1 and 3 skidder passes, and between 5 and 7 passes. After 11, 15, and 20 passes of the machine there were significant differences with the resistance to soil penetration compared to the all previous passes ($p < 0.000$).

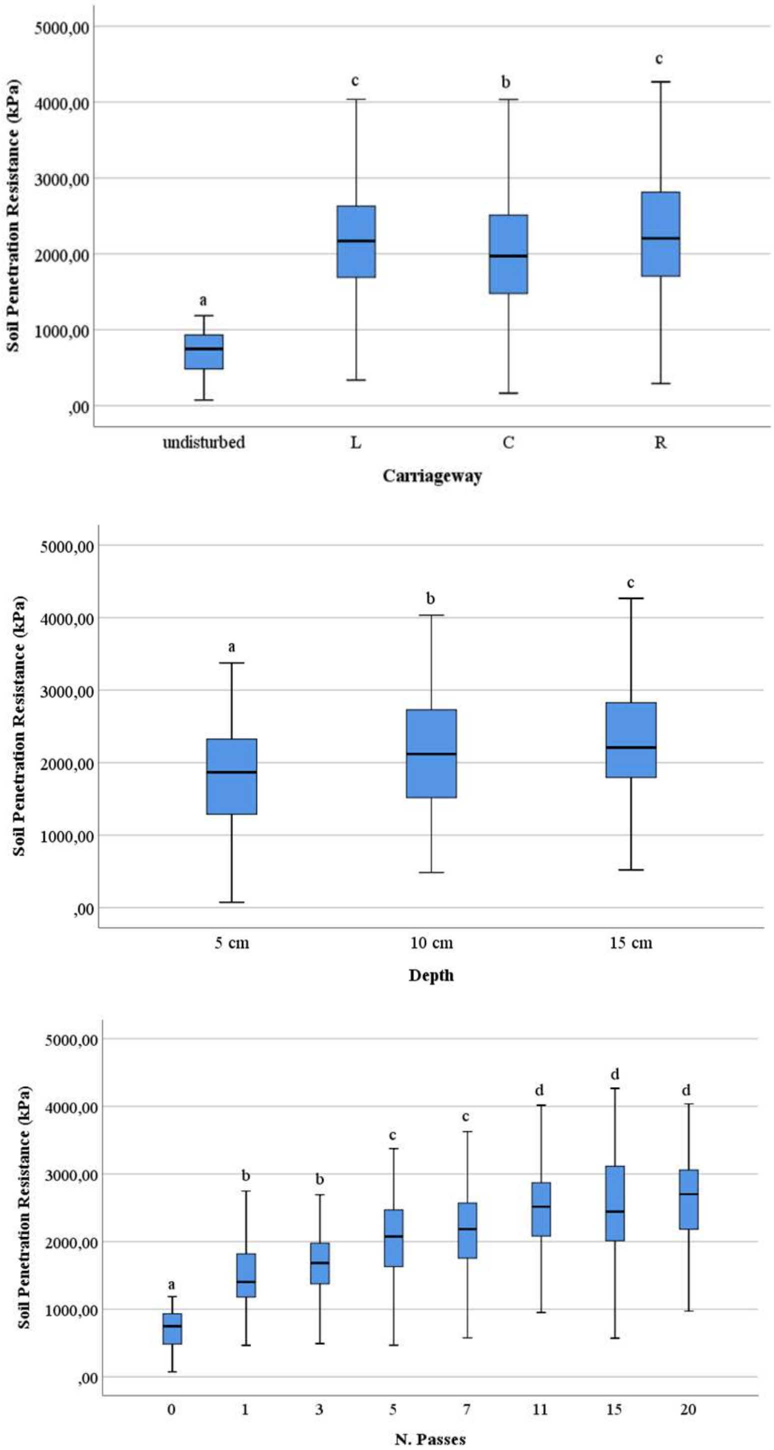

Figure 6 - Distribution of the soil penetration resistance related to carriageways, soil depth and machine passes. Boxplots followed by the same letter are not statistically different by HSD's test.

Discussion

The initial conditions of sound in terms of bulk density were in according with the values found by other authors in the same type of soil (Silva et al. 2011; Beutler et al. 2004).

By comparing the different tables with the respective graphs, it is evident that the soil penetration resistance values relating to the first pass are very different from those of the undisturbed soil, as also Macrì et al. (2017) had found after one pass of farm tractor in a forest in southern Italy.

On the fifth and fifteenth passes the highest values are more concentrated on the central of the carriageway and this can be attributed to the weight of the transported logs, which in general weighs on a large part of the carriageway but especially in the center of it, where precisely in those particular passes were transported two logs with sizes 43 cm in diameter and 14 m long and 46 cm in diameter and 12 m of length for the fifth, and 54 cm of diameter per 12 m long and 43 cm of diameter per 12 m long for the fifteenth pass respectively. These were the only two turns of skidding that transported a load higher than the mean volume skidded. However, this effect did not reach the most depth investigated (15 cm).

Soil compaction values among the lateral carriageways were found similar. This could be because the weight of the machine on flat ground was equally distributed on both sides and the weight of the loads transported by skidder machine were concentrated mostly in the central carriageway.

Similar studies (Froehlich et al. 1985) have shown that the soil is subject to impact damage in the first ten passes, in fact in this study it was found that significant increases of soil penetration resistance occurred after 1 and 5 passes. However, it was found that even after 11 passes the values increase considerably but from the subsequent passes investigated, almost similar or in any case not significantly different values were detected.

The subsequent passes taken into consideration in this study do not show excessive differences in compaction values between the different depths and this most likely because the succession of continuous steps has been characterized by numerous tire slipping processes which led to cutting processes and a mixing of the particles with consequent modification of the soil structure. In fact, except for the fifteenth pass

already explained for the heavy load transported, after the eleventh pass it was evident that at depths of 10 and 15 cm for the left and right carriageways there are differences in higher compaction values compared to those measured at the central carriageway and this can be attributed to slippage phenomena of tires that have increased the level of soil compaction and led to the formation of very deep ruts.
Finally, after the twentieth and last pass there are no consistent differences between the different depths and between the different carriageways, this confirms the fact that the soil has completely lost its initial structure.
Many authors (Macrì et al. 2017; Toivio et al. 2017; Proto et al. 2016; Cambi et at. 2015a; Jourgholami and Majnounian, 2011; Brais, 2001; Frolehlich, 1978,) have studied the impact of the frequency of vehicle passes on soil compaction. The result is that the number of machine passes is a key factor that significantly affects the degree of soil damage.
In particular, in this study very high compaction values were recorded as well as after the first pass, also after the fifth and eleventh passes. At the seventh pass occurred the formation of ruts characterized by the limited presence of lateral bearings due to the lateral pressure of the tires were already evident.
During forest utilization, the extent of soil compaction depends on various factors, which are not limited only to the characteristics of the soil (e.g. its texture) (Ampoorter et al. 2007). Also the soil moisture and organic matter (Greacen & Sands, 1980; Rohand et al. 2003), the frequency of the machine passes must also be considered (Wang et al. 2007), the logging system (Froehlich et al. 1985), the type of machine and its characteristics (Krag et al. 1986; Nugent et al. 2003), the mass of vehicles and their loads (Šušnjar et al. 2006), including the number of wheels and tire inflation pressure (Eliasson, 2005), are parameters that influence the soil and its susceptibility to compaction.
Indeed, the weight of a loaded vehicle and the number of passes are the main factors negatively affecting root formation and development (Jansson & Johansson, 1998; Bygdén et al. 2003; Eliasson, 2005). More pressure, slipping, and lower speed dramatically increase soil disturbance on steep slope trails (Najafi and Solgi, 2010). Proto et al. (2016) found that traffic intensity (number of machine passes) plays an important role in forest soil compaction: soil deformation can increase with the

number of passes and may lead to excessive soil disturbance. One pass of the skidder is enough to cause ruts classified as medium–heavy disturbance and to induce a significant increase in soil bulk density. Jourgholami and Majnounian (2011) studied the effects of wheeled cable skidder on rut formation in skid trail by the moisture content and the traffic intensity. They found that, in general, rut depth increased significantly with soil moisture and after repeated passes of skidder machine. Toivio et al. (2017) studying the impacts of timber forwarding on physical properties of forest soils found that penetration resistance and soil compaction were clearly lower in moist conditions and also soil penetration resistance, in general, increases with depth.

Cambi et al. (2015a) studied the impact of wheeled and tracked tractors on soil physical properties in a mixed conifer stand founding in all treatments, bulk density, and shear and penetration resistances significantly higher in the trafficked soil portions than in the undisturbed ones, while the opposite was true for porosity. In particular, considering five passes of wheeled tractor, they found 0.42 MPa and 0.39 MPa in dry (about 12%) and in moist conditions (about 25%), respectively.

As Curran et al. (2005) state in their study, penetration resistance can be a good measure of relative compaction and conditions of high soil strength can restrict root growth. However, they affirm that penetrometer readings are dependent on soil moisture content at the time and observations are affected by soil texture, and the amount of coarse fragments and roots. But knowing water content and taking a large number of measurements, these limitations can be overcome.

From this study, it can be understood that all other variables being equal, the weight of the skidder and its load could influence the compaction and above all the deformation of the soil structure since with this semi-trawl wood extraction system most of the weight of the logs that rest on the ground, they compress that part located mainly in the middle of the carriageway, as evidenced by the results of the measurements carried out after the fifth and fifteenth passes which were characterized by the heaviest load.

Even a moderate increase in penetration resistance (28-54%) is an indicator of soil deterioration (Panayiotopoulos et al. 1994, Coelho et al. 2000). This research found much higher machinery-induced values, in accordance with what reported in the literature (Cambi et al. 2015a and 2015b).

Conclusion

The use of machines for deforestation of wood always involves a disturbing condition towards the soil and often the underestimation of this effect generates very serious consequences on the health of the soil, and therefore on the health and production of the forests.

This work consisted to analyse the environmental impact of compaction on the soil component caused by the repeated passes of a skidder machine during skidding operations, adopting semi-trawl wood extraction system, in flat ground conditions on a forest track that has never been used before.

In detail, the research focused on the study of soil compaction by resistance to soil penetration after different numbers of machine passes, at different three depths and, also, investigating the effects on the carriageways of the trail.

The survey made it possible to know the behaviour and impact of forest utilizations, and in particular the handling of wood, on the soil compaction. The results presented in this research represent a contribution to the study of the impact of forest utilization on the soil in Romanian country.

In this study, the main results consisted in identifying the critical number of machine passages that affects the state of soil compaction, they also provided information on the influence of the machine passage on the ground considering the carriageways: the lateral ones subjected to the weight of the machine and in part of the timber that was semi-dragged, and the central one which instead was subjected exclusively to the weight of the loads of transported logs, and how the ground responded according to the depth investigated. From this work, it emerged that the soil penetration resistance increased with increasing depth and subsequent machine passages, and also, the distribution of weight on the number of logs transported, even if it was not a factor taken into consideration in the survey because the volume transported on average, was similar for each load, it showed its effects on increasing soil compaction in the two trips where the transported volume was slightly above average and concentrated in only two logs instead of three.

The use of simple tools such as the portable penetrometer, associated with preliminary sampling for the characterization of soil conditions, can be validly employed in the study of soil compaction. The portable penetrometer allowed the rapid acquisition of data in multiple points and at different depths, therefore it could be used in the study of soil compaction impacts in the use of other types of machines, other logging systems and in different forest contexts. Because if on the one hand it is true that harvesting operations and heavy machinery are linked to negative influences on the soil, since the damage resulting from harvesting operations cannot be completely avoided, however, knowing the phenomena that occur in the soil, these should be minimized where possible.

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USE OF NON-DESTRUCTIVE TECHNOLOGY

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ORIGINAL

A tomographic approach to assessing the possibility of ring shake presence in standing chestnut trees

Andrea R. Proto[1] · Maria F. Cataldo[1] · Corrado Costa[2] · Salvatore F. Papandrea[1] · Giuseppe Zimbalatti[1]

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Abstract
Ring shake is a widespread phenomenon affecting a great number of species of both softwood and hardwood and is found in trees grown in temperate and tropical climates. Chestnut (*Castanea sativa* Mill.) represents one of the most important hardwood timbers that is very often affected by ring shake. This defect seems to be the only real limit to the spread and use of chestnut wood worldwide on a scale closer to the availability of this wood. The aim of this study was to examine the potential of tomographic measurement as a non-destructive method for predicting the possibility of the presence of ring shake in standing chestnut trees. For this reason, the experiments were carried out in a chestnut coppice stand where one hundred chestnut standards were monitored using an acoustic tomographic device, and subsequently harvested by a local company and cross-sectioned corresponding to the acoustic tests. This work proposed an applied approach to predicting and determining wood quality (sound wood vs. defective wood) from tomographic data. The model, based on a non-linear approach, showed that sonic tomography can identify ring shake in a tree trunk without affecting its biological activity, overcoming the difficulties of predicting ring shake using only visual inspection.

1 Introduction

Several technologies were introduced in the early twentieth century in Europe and North America to assess wood quality in standing trees in response to the numerous requests by wood products manufacturers and forest managers worldwide. A significant effort has been devoted to developing robust non-destructive technologies (NDT) that are capable of predicting the intrinsic wood properties of individual trees and assessing wood quality at the stand and forest scale. Wood quality can be assessed by several techniques, such as the use of penetrometers and drilling resistometers, acoustic methods and imaging (Pellerin and Ross 2002). Drilling resistance measurement is a semi-destructive method commonly used for wood defect detection where a thin steel probe penetrates into the wood. Low resistance in a resistance profile typically indicates decay, cavities, or large internal cracks (Wu et al. 2018), but one problem with this technique is that the results are restricted to a single perforation, with no scanning of the cross-section. The acoustic method is based on the observation of stress wave propagation. In general, stress waves travel faster in high-quality wood than in deteriorated and low-quality wood (Divos and Szalai 2002; Wang et al. 2007). Based on this fundamental conclusion and signal acquisition of stress wave propagation velocity in wood cross-sections, the horizontal distribution of the stress wave velocity in wood can be analysed (Fang et al. 2011; Li et al. 2014; Du et al. 2018). A typical approach for measuring wave propagation velocity in standing trees involves inserting two sensor probes into the sapwood and introducing stress wave energy into the tree trunk from a point source through a hammer impact (Proto et al. 2017). This procedure is referred to as a single-path stress wave timing measurement, and the stress wave velocity obtained suggests the physical condition of the tree. An important limitation of this method, as reported by Wang et al. (2005), is the absence of a standard reference velocity for data interpretation for each tree. A single-path stress wave measurement can only detect internal decay that is above 20% of the total cross-section area (Wang et al. 2007). To remedy the several limitations of single-path stress wave timing tools and to define the extent and location of any

✉ Andrea R. Proto
andrea.proto@unirc.it

1 Department of AGRARIA, University of Reggio Calabria, Feo di Vito snc, 89122 Reggio Calabria, Italy

2 Consiglio Per La Ricerca in Agricoltura E Analisi Dell'economia Agraria (CREA), via Della Pascolare 16, 00016 Monterotondo, RM, Italy

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internal decay, sonic tomography has been introduced, and its applicability to standing trees has been evaluated positively. Acoustic tomography technology simultaneously uses multiple sensors that function both as signal emitters and receivers, evenly distributed around the cross-section of the tree trunk, to measure the variation in acoustic transmission speeds in multiple directions. Computer projection software then uses the acoustic wave data matrix to create an image (a tomogram) of the acoustic wave velocity for the cross-section of the tree (Wu et al. 2018). The use of acoustic tomography technology is beneficial for appropriate tree management in urban communities; in fact, an acoustic tomographic device permits the acquisition of data from the inner part of the trees, and the tomograms allow the determination of the stability of the trees to minimize the risk of tree failure. Numerous previous studies have determined, using this tomograph method, different types of structural defects, such as heartwood and sapwood decay, internal and lateral cracks, ring shake and hollows in urban trees (Bucur 2003; Nicolotti et al. 2003; Deflorio et al. 2008; Lin et al. 2008; Feng et al. 2014; Rinn 2015). Ostrovský et al. (2017) demonstrated that tomograms were 83% accurate for the determination of area and location of defects in the laboratory using green sample discs from extensively damaged trees in an urban environment. Several years after its use became widespread in urban forestry, some researchers have turned this NDT technique from urban forestry to the wood products industry for determining wood properties; however, the potential of this technology for assessing the quality of high-value hardwood trees in production forests has not been fully investigated (Wang et al. 2005).

Ring shake is a widespread phenomenon affecting a great number of species. In chestnut (*Castanea sativa* Mill.), in fact, ring shake seems to be the only real limit to the spread and use of chestnut wood worldwide, on a scale closer to the availability of this wood in the countries of the Mediterranean basin (Macchioni and Pividori 1996). The study of the internal state of this species has a long tradition in Italy and throughout Europe due to the high economic value of its wood products. It is one of the most important forest tree species; it grows commonly in hilly and mountainous areas, where it is primarily used as timber in construction and furniture. Ring shake defect is a type of wood crack that develops as a circular failure on the tangential plane in the ligneous tissue along the annual growth ring in standing trees (Owen and Wilcox 1982; Chanson et al. 1989). Many studies (Bourgeois 1992; Macchioni and Pividori 1996; Fonti et al. 2002a, b; Becagli et al. 2002–2004; Spina and Romagnoli 2010) have focused on describing the anatomical features of the ring shake phenomenon and on the possible causes that determine their occurrence using destructive techniques and laboratory analysis. The defect of ring shake occurrence greatly reduces the value of the timber assortment; in the worst cases, the incidence of ring shake is so high that only a few logs of a stand can be brought to the sawmill (Fonti et al. 2002a). In fact, Chanson et al. (1989) and Fonti et al. (2002b) reported the presence of ring shake in 39–60% of trees in sample plots observed immediately after felling at several locations in France, Italy, Switzerland, and Spain. Mutabaruka et al. (2005) carried out a study to assess the value of external tree characteristics in predicting ring shake. The study by Birbilis et al. (2018), in accordance with that of Romagnoli and Spina (2013), has shown that it is possible, based on the age and diameter of the trees, to successfully predict the presence of ring shake. Mariño et al. (2010) have reported on detecting pith location in chestnut lumber by non-destructive evaluation in laboratory tests using a different tomographic device, while Dündar et al. (2016) examined the potential of ultrasonic velocity as a rapid and non-destructive method for predicting the dimensional stability of the chestnut specimens commonly used in the flooring industry. Opinions diverge on whether ring shake is already present in standing trees, with several authors believing that it might be present at least in standing trees or in green wood discs (Bonenfant 1985; Leban 1985; Cielo 1988; Chanson et al. 1989; Fonti 1997). Giudici et al. (1998) used ultrasonic measurement on stems; Götz and Mattheck (1999) tested a fractometer on wood samples taken directly from standing trees. Fonti et al. (2002a) detected ring shake directly on green wood discs in 70% of the entire observed sample, while ring shake developed in the remaining 30% during the drying process, particularly concentrated in those wood discs that were already affected by the defect in their green state. Therefore, the purposes of this study were to determine the best non-destructive parameters for predicting ring shake in standing chestnut trees and the accuracy of the tomographic techniques.

2 Materials and methods

2.1 Study sites and tree samples

The test site was situated in Southern Italy (Calabria region), in the municipality of Cardinale in the Serre Massif. In Calabria, chestnut occupies 101,600 hectares, 21.1% of the regional woodland surface, divided into high forests (47.3%) and pure coppices (52.7%). The majority of chestnut orchards (88.3%) are private property, and the remaining 11.7% are under public ownership. The study area covers a total of 15 hectares with an altitude ranging from 610 to 780 m. The climate is temperate, with an annual mean temperature of approximately 13.5 °C, and the annual rainfall is 930 mm unevenly distributed through the year, with the minimum precipitation occurring in the summer. The study site was coppiced with first-class standards derived from coppice shoots growing from the previous cut. The shoots were approximately 14 years old, whereas the standards were 28 (II cycle) and 42 (III cycle) years old. The breast height (DBH) was measured using a classic diameter calliper, and tree height was measured with a vertex IV hypsometer. Based on these measurements, one hundred chestnut standards of the III cycle with regular cross-sections (cylindrical body) were selected, and each tree was marked with a red plastic tag and assigned a tracking number for conducting the tomographic study and for the subsequent felling phase (Fig. 1a, b). The choice of this population was dictated not only by their favourable characteristics for production silviculture but also by the assured presence of ring shake in the trees, identified through inquiries among local foresters. The main characteristics of the study sites are shown in Table 1.

Table 1 Study area characteristics and dendrometric parameters

Parameters	Unit measure	Value
Altitude—range a.s.l	m	610–680
Slope—range	%	15–20
Average basal area for tree	m^2	0.102
Average basal area for hectare	$m^2\ ha^{-1}$	26.14
Volume for hectare	$m^3\ ha^{-1}$	214.15
Coppice shoots diameter	cm	20.12
Standard diameter	cm	33.03
Number of stump	n ha^{-1}	370
Shoots—number of trees	n ha^{-1}	1720
Standards—number of trees	n ha^{-1}	65

2.2 Field acoustic tomography test and laboratory measurements

All 100 standards were first non-destructively tested using a commercial ArborSonic 3D acoustic tomograph device (Fakopp Enterprise Ltd., Hungary) and the sample trees were monitored at a height of approximately 50 cm above the ground (Macchioni and Pividori 1996; Spina and Romagnoli 2010). The sampling height was chosen because it is the most susceptible to ring shake defects. At this height, the circumference was measured by an operator using a tape measure; this data was inserted in the software (ArborSonic3D software, ver. 6.2.), which calculated the positions of the sensors that were used to map the approximate geometric form of the cross-section. The tests were performed in accordance with the manufacturer's (Fakopp Enterprise Ltd. 2019) and software's instructions and these test procedures are explained in many similar papers (Deflorio et al. 2008; Johnstone et al. 2010; Alves et al. 2015; Ostrovský et al. 2017; Marra et al. 2018; Trenyik et al. 2018). Eight sensors were used for each tree and the travel times (in µs) generated from each sensor were captured by the other sensors. Every measurement was repeated three times on each sensor (repetitions) in order to obtain averaged travel times to reduce uncertainties from individual testing. After using the last sensor as a transmitter, the recording stopped, the measurement was saved and the software, applying a filtered back projection evaluation (Buza and Göncz 2015), constructed the two-dimensional tomographic image adapting to the anisotropy condition (Maurer et al. 2006; Dikrallah et al. 2010). The velocity of wave movement was automatically calculated based on the time registered for the passage of the impulse between sensors. The tomograms in the software displayed the relative sound transmission speeds on a four-colour discrete scale, and the operator associated different speeds with different colours. The colour of the lines from every sending to every receiving sensor visualizes the virtual speed: green means the stress wave travelled fast. Yellow, red and purple lines indicate that the waves circumvented the defect and did not travel straight through it. During testing, each sensor position was marked so that the original location in the stem disc could be traced in order to assess the condition of the wood at the area of sampling. The tomographic acquisitions lasted 5 consecutive days (June 2016) to guarantee similar environmental conditions.

After the acoustic measurements had been taken, the 100 trees were subsequently harvested by a local company and cross-sectioned corresponding to the acoustic tests. A 5-cm thick disc was collected from each stem (Fig. 1c) and taken to a laboratory where the physical characterization (ISO 3130, 3131, 4469, 4858) was performed. The physical

Fig. 1 In situ acoustic tomography test on a standing tree (**a**) and successive harvesting phase (**b**) and collection of a wood disc (**c**)

characteristics were determined to compare the physical properties of trees affected by ring shake and those that are not (shaken trees and healthy trees). In particular, the following parameters were measured: density at 12% moisture content (ρ_{12}); basic density (ρ_y), which is the ratio between the oven-dried weight and green volume; total shrinkage (radial (β_r), tangential (β_t), and volumetric (β_v) shrinkage) coefficients measured from the maximum water content to oven-dried moisture content. The data were processed to align the propagation velocity data with the corresponding region, either healthy or defective. Each wood disc was subdivided into four regions (A, B, C and D), or quadrants like a Cartesian plane, where $1 \leftrightarrow 5$ and $3 \leftrightarrow 7$ paths represented *x*-axis and *y*-axis respectively, using the same orientation as for the installation of the tomographic sensors to permit the correct localization of the defects on the reciprocal paths. The presence of ring shake was evaluated with a visual inspection in laboratory identifying the critical year (ring position), and the extent was measured on the wood discs as the ratio between the arc of the circle of the shake and the corresponding total circumference (Spina and Romagnoli 2010). At the end, its location on the wood disc was used to overlay the paths generated by tomography.

2.3 Data analysis

Acoustic reconstruction based on the transmission velocity of a stress wave can be performed in different ways depending on the type of defect. For this reason, in this study, the velocity of the acoustic wave transmission measured from each chestnut tree was studied and used to predict the presence of ring shake with respect to the typical application of two-dimensional tomograms to detecting cavities or decay. The proposed methodology aims to find a velocity reference value to detect the defective region considering the relationship between stress wave velocity and its propagation direction, with the assumption that the tree has a regular cross-section (Li et al. 2014; Rinn 2015; Espinosa et al. 2017). The acoustic velocities obtained from different angles (±67.5°; 45°, 22.5° and 0°) were compared, and the ratio between the tangential velocity and the radial velocity was analysed. In particular, the orientation angle represented the position of the receiver point relative to the source point, with $\theta = 0$ representing the velocity in the radial direction, i.e., the angle between an emitter sensor and the diametrically placed receiver sensor. A total of 2800 paths, excluding repeated data, were registered, and the comparison between the paths of stress wave measurements on one cross-section (sound wood vs. defective wood) was applied. Using the tomographic technique, a complete data matrix was obtained through the measurement of stress wave transmission time with the aim of intercepting the localization of ring shake using the intersection of the paths generated simultaneously during the test.

2.4 Statistical approach

The statistical analyses were based on an artificial intelligence approach. The analysis was performed on the matrix composed of 2 sets of variables for the 100 samples. The first was composed of mean velocity, and the second was composed of Vt/Vr values. Both datasets represent values at 0°, ±22.5°, ±45°, and ±67.5°. Both datasets include tree circumference and diameter and wood density values. The Vt/Vr dataset does not include 0° values reporting equal values for all the samples. The models were developed using a non-linear classification Artificial Neural Network (ANN) approach. The ANN was developed based on an input layer (*x*-block) to estimate the binary output layer (sound wood *vs*. defective wood; *y*-block). In detail, the eight average velocities of wave movement, having the same propagation direction (i.e. $1 \rightarrow 2$, $2 \rightarrow 3$, $3 \rightarrow 4$, etc.), were copied from the ArborSonic3D software to a MS Excel spreadsheet and in each row, the Vt/Vr values were calculated as the ratio between the tangential velocities (+67.5°, ±45° and ±22.5°) and the radial velocity (source point 0°). This operation was repeated for each tree monitored and separated between sound wood and defective wood. The ANN model was developed using a probabilistic neural network (PNN). PNN is a feedforward neural network that is widely used in classification and pattern recognition (Specht 1990). In the PNN algorithm, the parent probability distribution function (PDF) of each class is approximated by a Parzen window and a non-parametric function (Specht 1990). Then, using the PDF of each class, the class probability of a new input data is estimated, and Bayes' rule is then employed to allocate the class with the highest posterior probability to the new input data. Using this method, the probability of misclassification is minimized (Zeinali and Story 2017). This type of ANN was derived from a Bayesian network (Friedman et al. 1997) and a statistical algorithm called kernel Fisher discriminant analysis (Cheung and Cannons 2003). In a PNN, the operations are organized into a multi-layered feedforward network with four layers: the input layer, in which each neuron represents a predictor variable; the pattern layer, which contains one neuron for each case in the training data set; the summation layer, which contains one pattern neuron for each category of the target variable; and the output layer, which compares the weighted votes for each target category accumulated in the pattern layer and uses the largest vote to predict the target category. The PNN was trained with a back-propagation learning algorithm. From the 100 observations, to avoid overfitting, only 75 samples (75%) were used to construct the models. The remaining 25 samples (25%) were then used to test the performance of the models (internal test). The partitioning of the two datasets was optimally chosen with Euclidean distances, based on the algorithm developed by Kennard and Stone (1969), which selects objects without a priori knowledge of a regression model (i.e., the hypothesis is that a flat distribution of the data is preferable for a regression model). The training of the ANN was carried out using a learning equal to 0.5 and a momentum equal to 0.1. The training procedure was repeated 1,000,000 times, and the best-performing PNN was selected based on the independent test set. The percentages of correct classification on the model and the test sub-sets were reported. A variable impact neural network analysis was performed to assess the relative importance of each variable (Abdou et al. 2012). Operatively, this index is similar to the linear regression variable importance in the projection (VIP) scores (Chong and Jun 2005; Febbi et al. 2015). The ANN analysis was performed using Palisade Neural Tools 7.6.

3 Results

After cutting the stem disc with a chainsaw, in several cross-sections, some ring shake decay, visually invisible on the external surface of the trees, was observed from the visual inspection only after a few weeks, in the laboratory, showing the typical aspect. Of the 100 trees examined, 61 standards were affected by ring shake, and only 39 were intact. The laboratory measurements described in Table 2 show several of the monitored characteristics of chestnut wood. The mean and standard deviation (SD) values confirm that the physical properties and density were high in healthy trees, whereas shrinkage values were low in shaken trees. In particular, the values of radial, tangential, and volumetric shrinkage of the shaken trunks were different from those of the healthy trees.

Table 2 Physical properties of trees: sound wood (SW) and defective (D)

Property	Tree type	Mean	SD	N
β_r	SW	3.29	0.84	39
	D	3.15	0.76	61
β_t	SW	6.93	0.82	39
	D	6.45	0.78	61
β_a	SW	0.42	0.36	39
	D	0.37	0.47	61
β_v	SW	10.41	1.29	39
	D	10.24	0.98	61
ρ_{12}	SW	601.79	51.15	39
	D	597.21	43.18	61
ρ_y	SW	509.64	41.24	39
	D	501.29	37.81	61

β_r radial shrinkage (%), β_t tangential shrinkage (%), β_a, axial shrinkage (%), β_v, volumetric shrinkage (%), ρ_{12} density at 12% moisture content (kg/m^3), ρ_y basic density (kg/m^3)

The results separated and catalogued the paths derived from sound and defective wood to evaluate the comportment of the stress wave in detail. The mean, standard deviation, and range of the acoustic velocity measurements on standing trees are reported with the different and sequential paths generated by the eight sensors on sound wood (Table 3) and defective wood (Table 4). The data obtained in sound wood confirmed that the velocity in the radial direction Vr (with $\theta = 0°$) was the highest, and the velocity in the tangential direction Vt (with $\theta = \pm 67.5°$) was the lowest. The average speed in the radial direction (1944 m s^{-1}) was approximately 3.2%, 5.8% and 8.7% higher than that for the paths generated by angles of 22.5°, 45° and 67.5°, respectively. In sound wood, the standard deviation was low in each of the 28 paths registered from the 39 trees examined, which suggests a strict interval in which the acoustic signal travels between two sensors indifferently from various angles.

During the tests conducted on trees affected by ring shake, the tomographic software recorded 210 paths indicating slow speeds with respect to the others on the same tree cross-section. On average, each defective tree showed 3–4 slow paths, and the majority (96%) was collected with an angle of 0° and 22.5°. The high values of the standard deviations registered on paths generated (Table 4) with respect to the other two tangential directions (45° and 67.5°), confirmed the possibility of finding this defect in the radial direction, or with a small directional angle between the source point and receiver point. The mean of the acoustic velocity measurements registered in these 210 paths were 1403 m s^{-1}, 1434 m s^{-1} and 1507 m s^{-1} for the paths generated by angles of 45°, 22.5° and 0°, respectively. The tomograms generated from defective wood showed a typical round form with a red/yellow area in the centre, which could indicate severe heartwood decay damage, but the examination of the disc conducted in the laboratory showed that the defect was ring shake, not heartwood decay (Fig. 2). Purple lines, in fact, are never shown on tomograms because no trees were hollow or deeply damaged. The presence of a red (dark) area inside the yellow (light grey) shape, for example tree n. 45, indicated a lower speed of transmission with respect to the closest angle. In the laboratory, this deterioration was confirmed with an accentuated detachment of the annual ring. In particular, in the A region, a small ring shake was identified with a yellow colour, while in the C region, an additional ring shake was located deeper in the tree. In fact, the ring shake acted as a barrier that cut off the linear propagation of the acoustic waves. As a result of the geometric shape of the ring shake (round), the acoustic tomogram produced by the software erroneously indicated the presence of heartwood decay or internal cracks. Figure 3 shows the paths of stress wave measurements (a) before the software generated the tomogram and (b) the subsequent superimposition on the corresponding cross-section of tree no. 87, where the paths

Table 3 Acoustic velocity data of sound wood

Paths 67.5°				Paths 45°				Paths 22.5°				Paths 0°			
	Speed m s^{-1}				Speed m s^{-1}				Speed m s^{-1}				Speed m s^{-1}		
Way	Min	Max	Mean (σ)	Way	Min	Max	Mean (σ)	Way	Min	Max	Mean (σ)	Way	Min	Max	Mean (σ)
1↔2	1599	1946	1796 (±67)	1↔3	1687	2039	1844 (±74)	1↔4	1711	2058	1883 (±73)	1↔5	1727	2095	1936 (±77)
2↔3	1572	1878	1769 (±84)	2↔4	1664	1972	1814 (±75)	2↔5	1680	2012	1855 (±86)	2↔6	1735	2069	1931 (±78)
3↔4	1579	1897	1774 (±74)	3↔5	1622	2017	1838 (±92)	3↔6	1723	2024	1884 (±74)	3↔7	1737	2079	1942 (±75)
4↔5	1580	1933	1765 (±87)	4↔6	1612	1961	1830 (±78)	4↔7	1754	2043	1884 (±71)	4↔8	1798	2113	1964 (±69)
5↔6	1616	1945	1764 (±74)	5↔7	1678	1956	1812 (±69)	5↔8	1699	2032	1883 (±68)				
6↔7	1553	1893	1769 (±95)	6↔8	1674	1988	1848 (±75)	6↔1	1587	2034	1860 (±98)				
7↔8	1620	1894	1783 (±72)	7↔1	1699	1982	1822 (±69)	7↔2	1765	2026	1891 (±72)				
8↔1	1611	1931	1773 (±65)	8↔2	1643	1964	1836 (±70)	8↔3	1724	2045	1908 (±84)				

Standard deviations are given in parentheses

Table 4 Acoustic velocity data of defective wood

Paths 67.5°				Paths 45°				Paths 22.5°				Paths 0°			
	Speed m s^{-1}				Speed m s^{-1}				Speed m s^{-1}				Speed m s^{-1}		
Way	Min	Max	Mean (σ)	Way	Min	Max	Mean (σ)	Way	Min	Max	Mean (σ)	Way	Min	Max	Mean (σ)
1↔2	1742	2046	1862 (±51)	1↔3	1420	2066	1889 (±126)	1↔4	1325	2021	1809 (±249)	1↔5	1416	2222	1976 (±223)
2↔3	1761	1991	1874 (±46)	2↔4	1509	2072	1920 (±71)	2↔5	1328	2105	1803 (±244)	2↔6	1354	2194	1806 (±295)
3↔4	1806	1983	1865 (±40)	3↔5	1485	2211	1927 (±80)	3↔6	1345	2250	1834 (±233)	3↔7	1411	2207	1883 (±270)
4↔5	1789	2073	1870 (±47)	4↔6	1851	2570	1945 (±89)	4↔7	1382	2087	1857 (±197)	4↔8	1327	2194	1860 (±285)
5↔6	1782	2065	1874 (±49)	5↔7	1861	1995	1929 (±32)	5↔8	1327	2104	1867 (±226)				
6↔7	1799	2197	1873 (±67)	6↔8	1891	2113	1950 (±46)	6↔1	1364	2224	1818 (±253)				
7↔8	1721	2138	1876 (±65)	7↔1	1374	2190	1902 (±109)	7↔2	1321	2069	1790 (±244)				
8↔1	1798	2051	1875 (±48)	8↔2	1457	2097	1924 (±87)	8↔3	1367	2239	1823 (±247)				

Standard deviations are given in parentheses

7↔2, 7↔3, 7↔4, and 8↔5 in the C region intercepted the ring shake. In the laboratory, the location and extent of ring shake on defected trees were measured and reported in Table 5. In particular, in this table, the exact position (region and annual ring) of the defect was correlated with the corresponding paths (speed, direction and angle) to demonstrate the accuracy of model predictions. For example, in the case of tree no. 49, a major arc of circumference generated by ring shake intercepted more slow paths. For this reason, the study involved a complete examination of the paths and their interactions between the sensors, and the statistical analysis conducted with two sets of variables confirmed the necessity of evaluating an accurate travel time reading for each path. The results used in the construction of an applicative model

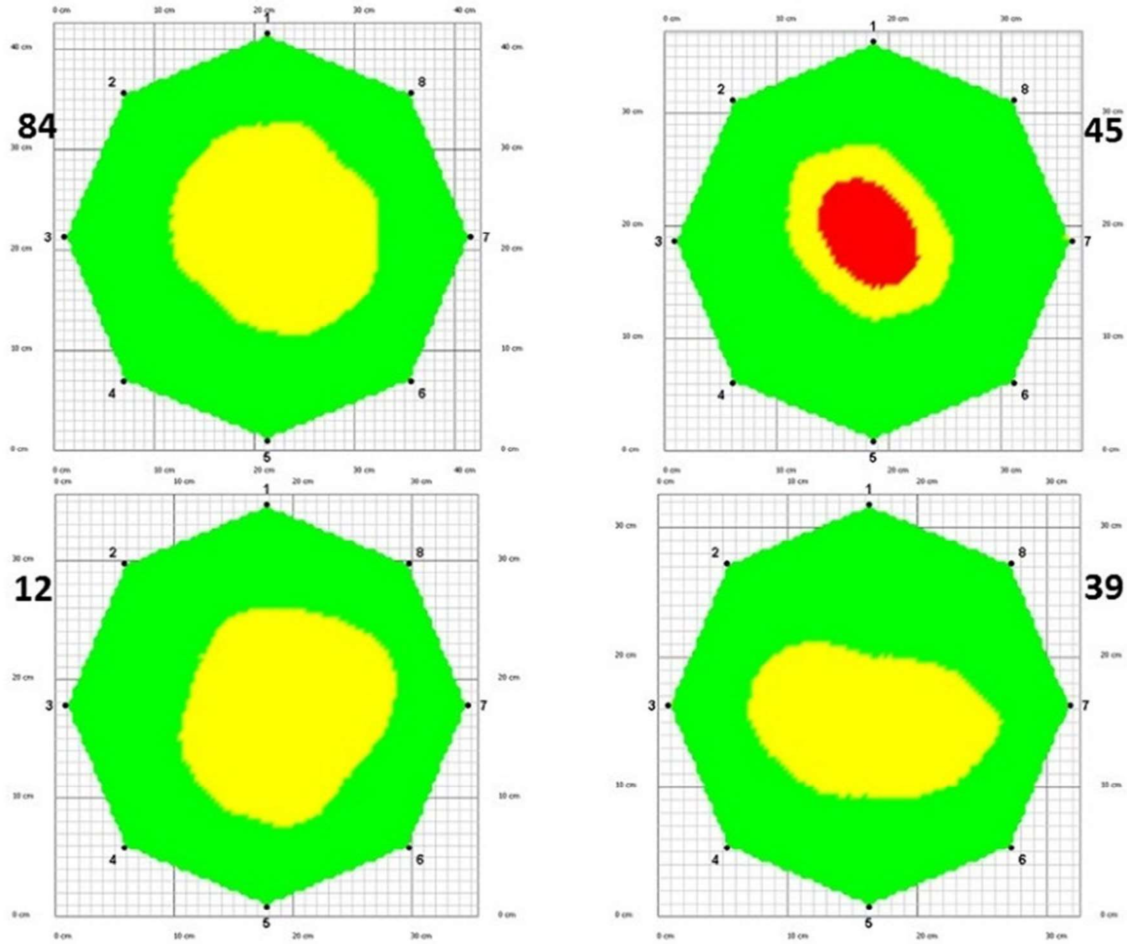

Fig. 2 Sonic tomographic images of cross-sections in four different sampled chestnuts showing internal defects

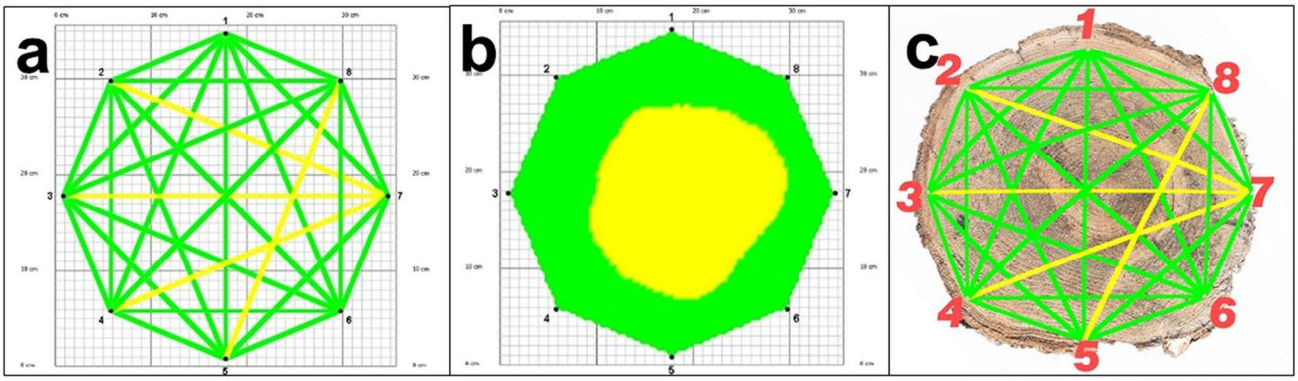

Fig. 3 Comparison of the 28 independent paths generated (**a**), the corresponding sonic tomogram (**b**) and the superimposed paths on the cross-section (**c**)

used to predict sound wood vs. defective wood from mean velocity and Vt/Vr data, are summarized in Table 6. The PNN model reported a perfect classification (by percentage of correct classification) of all the samples, including those in the 25% test set. The relative variable impact (Figs. 4,5), which indicated the importance of the different variables in the non-linear classification process, showed that in the Vt/Vr dataset, the more important variables are the ones

Table 5 Location and extent of ring shake on several trees sampled

Sample (no.)	Diameter (cm)	Region	Path	Angle (°)	Speed (m s^{-1})	Extent of the defect (%)	Ring position (years)
86	37	C	1↔5	0°	1434	13	24th
			5↔8	22.5°	1329		
91	41	A	2↔5	22.5°	1425	17	29th
			2↔6	0°	1354		
			7↔2	22.5°	1321		
70	38	A, B	2↔5	22.5°	1398	19	31th
			3↔6	22.5°	1364		
			3↔7	0°	1412		
			8↔3	22.5°	1396		
49	39	A	1↔3	45°	1420	22	33th
			2↔5	22.5°	1453		
			2↔6	0°	1461		
			7↔2	22.5°	1417		
			8↔3	22.5°	1449		
88	40	C	3↔7	0°	1457	14	30th
			4↔7	22.5°	1397		

Table 6 Characteristics and principal results of the PNN model used to determine sound wood vs. defective wood samples using mean velocity and Vt/Vr datasets

	Mean velocity	Vt/Vr
No. samples	100	100
No. classes (*y*-block)	2	2
Mean sensitivity	1	1
Mean specificity	1	1
Efficiency	1	1
Random probability, %	50	50
Mean classification error, %	0	0
Mean % correct classification calibration/validation set (75%)	100	100
Mean % correct classification test set (25%)	100	100
Mean incorrect probability (test set)	0.00	0.01
Std. deviation of incorrect probability (test set)	0.00	0.06

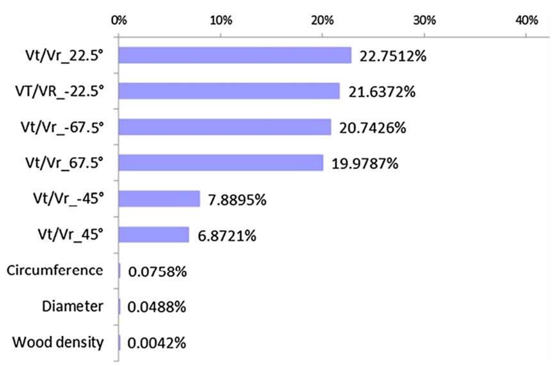

Fig. 4 Relative variable impacts, Vt/Vr

at ± 22.5° and ± 67.5°, while in the mean velocity dataset, the most important variables are at 0°, ± 67.5°, ± 45°.

4 Discussion

This study was designed to evaluate the accuracy of a tomographic technique on standing chestnut trees, to determine the best non-destructive parameters for predicting ring shake. In each of the sound wood trees examined, the measured stress wave transmission times were in good agreement with the theoretical analysis of several studies (Watanabe and Payton 1997; Payton 2003; Schubert 2007). In fact, the correct relationship between the velocity ratio Vt/Vr and the angle θ has been statistically shown as a parabolic curve, with a coefficient of determination $R^2 = 0.94$, and the coefficients of the second-order polynomial regression were $a = -0.0094$, $b = 0.0754$, and $c = 0.841$ (Fig. 6). To the best of the authors' knowledge, there is no study that evaluates NDT techniques for predicting ring shake in standing chestnut trees, but several researchers have addressed accurately the effective prediction of sonic tomography using simultaneous NDT and destructive tests; therefore, comparison of the results reported here with those available in the literature has been partially difficult. Some studies (Deflorio et al. 2008; Brazee et al. 2011; Liang and Fu 2012) used acoustic tomography and destructive measurements to detect internal decay. Recently, Marra et al. (2018) demonstrated how acoustic tomography and electrical resistance tomography, used in combination, can be used to non-destructively quantify the extent of internal decay and the associated carbon loss. Burcham et al. (2019) estimated the accuracy of sonic tomography using colours associated with intermediate sonic velocities comparing the destructively measured

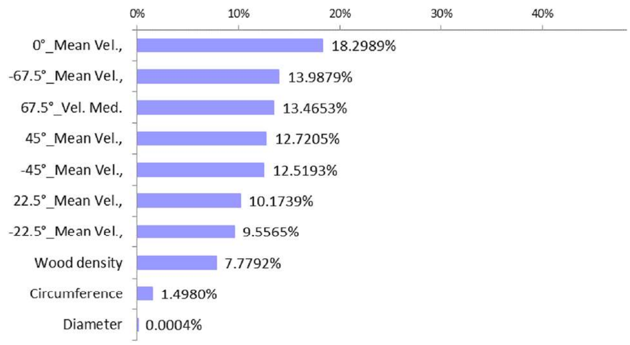

Fig. 5 Relative variable impacts, mean velocity

internal condition of the corresponding cross sections. Starting with the type and characteristics of the defect, the type of ring shake identified in this study can be defined as "healthy ring shake" because visible anomalies in the wood tissue or wounds caused during harvesting or external phenomena were not observed (Chanson et al. 1989; Macchioni and Pividori 1996; Fonti et al. 2002a). As opposed to traumatic ring shake, healthy ring shake has a mechanical origin and may appear, in standing trees (Chang 1972; Ferrand 1980; Chanson et al. 1989; Cielo 1988; Birbilis et al. 2018), with the detachment between cells at the ring boundary between the earlywood zone of the annual ring and the latewood zone of the previous one in the compound middle lamella layer between cells. In this study, the results confirmed what Giudici et al. (1998) found in their research: the discontinuity created by ring shakes caused slower transmission speeds observed on damaged trees. In the literature, this kind of fracture was often reported as a breakage of vessel members and fibre detachment in the area between two annual rings in standing trees, or after felling. It is called green wood ring shake (Chang 1972; Ferrand 1980; Chanson 1988; Cielo 1988; Fonti and Macchioni 2003). The

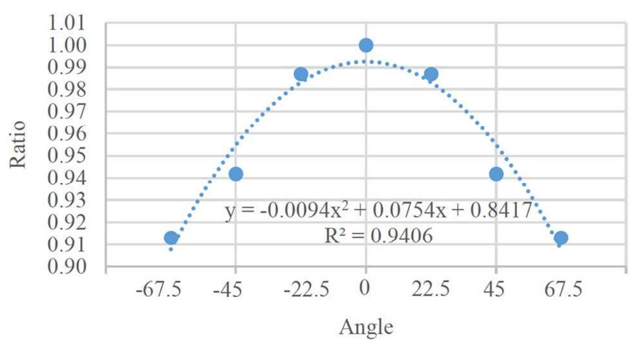

Fig. 6 Parabolic curve created by the average velocity ratio (Vt/Vr) generated by a measured average of 39 sampled trees

occurrence of the ring shake defect is not related to a particular cell type but to the effect of growth stresses imposed on the transversal/radial wood plane (Fonti and Frey 2002; Fonti and Sell 2003; Fonti and Giudici 2005; Birbilis et al. 2018). The range of stress velocities in sound wood samples was similar to the data obtained by Ostrovský et al. (2017), who used the same acoustic tomography technique for wood cross-sections on three chestnut trees. On standing trees, to the authors' knowledge, only Li et al. (2014), using a sonic tomograph, have determined the velocity patterns in eight healthy black cherry trees using the difference in values from four other defective trees. For each measure, Li et al. (2014) used 12 sensors at three different heights and validated the theoretical analysis of the wave velocity paths by applying the results obtained. Most studies have reported that sonic tomography underestimates the size of decay and overestimates the size of cracks (Gilbert and Smiley 2004; Liang et al. 2007; Wang et al. 2007; Deflorio et al. 2008; Liang and Fu 2012; Marra et al. 2018; Burcham et al. 2019), and under certain circumstances, the tomograms of trees with cracks, ring shake or cavities may look similar (Göcke et al. 2008). For this reason, Dackermann et al. (2014), Espinosa et al. (2017), Qin et al. (2018), and Du et al. (2018) have developed different methods to improve the accuracy of tomography techniques and overcome the overestimation problem. Unlike previous studies that evaluated the final accuracy of tomograms to reduce the over- and underestimation of the damaged area, this study applied the statistical accuracy of the Vt/Vr ratio to localize the exact area of the internal defect in the tree using the intersection between the different speeds of transmission. The high number of samples tested guarantees the solidity of the data and the homogeneity of the results, returning exactly the values collected on the standing trees without any necessary laboratory experimentation. This work proposed an applied approach to predicting and determining wood quality applying the ratio Vt/Vr, and the model, based on a non-linear approach (Assirelli et al. 2018), is able to perfectly predict wood quality by returning a correct classification of both validation and test sets. In particular, this PNN statistical model, tested on the Vt/Vr dataset, revealed more important variables necessary to consider before assessing the presence of ring shake. Starting from a correct statistical evaluation of the Vt/Vr ratio, the technique proposed in this study can be improved with the development of a specific application (software or app) capable of evaluating immediately in the field after the acoustic test where wood properties do not limit the use of Vt/Vr ratios as a predictor. This approach returns a ready-to-use dataset and can optionally be integrated into tomography software as second option to use it. The novelty of the present approach is based on a statistical model elaborated comparing the different propagation directions and analysing the velocity of each path. This study has not used a theoretical velocity model as proposed by Li et al. (2014) but rather the intersection between the different velocity patterns identifying the defect with respect to the healthy area. The use of eight sensors, although it required a few more minutes to conduct the test, permits the generation of a database able to identify defective regions in cross-section tomographic images. The use of a single-path stress method, for example, would not have allowed to localize the defect in a specific area of the cross-section but only to identify a slower path with respect to others generated not simultaneously in the same cross-section. In fact, the results from the current study suggest that destructive sampling may not be necessary to confirm the results of the NDT testing as long as the minimum number of sensors, at least eight, is used. The physical chestnut wood properties observed in the Calabrian Region site were in agreement with the reported mean values for chestnut wood in Italy (Nardi Berti 2006; Sarlatto et al. 2006; Spina and Romagnoli, 2010; Romagnoli and Spina, 2013) and confirmed that ring-shaken trees show lower shrinkage in accordance with several studies (Macchioni 1995; Romagnoli and Spina, 2013). In accordance with a previous study by Birbilis et al. (2018), this research demonstrated that ring shake rarely occurs in juvenile wood and usually occurs in adult wood between the 20thand 40th growth rings. For this reason, eight sensors generate a sufficient number of paths to intercept ring shake in this location; a lower number of sensors applied to this technique might not be enough to locate correctly the damaged paths. In addition, a smaller number of sensors, for example, 4 or 6, applied to trees having at least 30 cm of diameter, creates a data matrix that is able to detect a defect in a circle with minimum detectable defect sizes of 4% and 8%, respectively (Divos and Szalai 2002). Considering that ring shake is only an arc of a circle, the probability of detecting this defect reduces considerably with a lower number of sensors, and the image resolution is thus a function of the number of sensors. Another important aspect to be considered is the shape of the image that the software produces; in fact, compared to other types of decay, ring shake is shown as an irregular circle with clearly distinguishable colours.

5 Conclusion

The objective of this study was to develop a methodological approach using a NDT, i.e., conventional sonic tomography, based on fast/slow paths to assess the presence of ring shake in standing chestnut trees. The results confirmed that sonic tomography can identify several defects in a tree trunk, including ring shake, without affecting its biological activity, overcoming the difficulties of predicting using only visual inspection. These technologies can be applied directly to standing trees wherever quality chestnut wood has to be cultivated for production processes, but experts are still needed to perform an accurate diagnosis. This technique can represent a very important solution for companies because, in a short time, it can detect data from several points of the stem and possibly determine which trees are unsuitable for harvesting, because there are usually no external symptoms indicating this internal defect. In terms of the commercial importance of the species in Europe, the research is aimed at understanding the factors that cause ring shake in order to evaluate new preventive measures to minimize the risk of ring shake occurrence (Fonti et al. 2002b), and it would be of great value for public organizations and private owners to be able to evaluate the impact of ring shake in different forest stands in order to ascertain, which sites are likely to be most productive and obtain better quality material (Spina and Romagnoli 2010). In fact, the evaluation of potentially high quality forest trees requires a reliable and valid method for determining the correct economic value. Therefore, the method developed can be considered as a field method if supported by further studies, and this approach can be reliable for detecting not only ring shake but different structural defect types, too. Further research, using measurements at different tree heights or applying diverse tools to impedance tomography or ultrasonic devices, can confirm that non-destructive technologies can be used not only in urban forestry but also in important wood commercial sectors. In the field of NDT technologies, as well as in other fields of research, the use of these tools requires extensive experience with testing techniques because of the difficulty in interpreting the data. Only with an accurate interpretation is it possible to effectively translate the tomography data into an understanding of the type, location and dimensions of the internal defects in standing trees.

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FOREST CERTIFICATION

Evaluation of forest certification scheme standard in Calabrian forest

Introduction

In the last decades, the attention paid to the environment has reached very high levels, the whole community has acquired a strong sensitivity regarding environmental issues, and thanks to them a greater interest has developed in the sustainable management of natural resources, considering adequately their limited time and examining the speed of production with the speed of regeneration of resources. The attitude of consumers towards consumer goods has also gradually changed, resulting in greater consideration of all those goods obtained thanks to production processes with low environmental impact, which are even more able to guarantee their entire traceability supply chain; in this regard, in order to achieve proper planning on the use of natural resources, important regulatory instruments have been developed at EU level that highlight and encourage appropriate sustainable management practices. Thanks to these tools, it is now possible to objectively certify the compliance of entire production processes, according to the principles of the important and indispensable sustainable forest management.

The constant need from consumers to have access to wood products deriving from forests governed through the principles within the concept of not only environmental, but also economic and social sustainability, is a parameter of considerable importance, and forest certification can be considered the only tool capable of ensuring sustainable forest management and traceability of the finished product, from the cutting in the forest to the last step of the production process.

In order to make the most of the advantages that the certification process can offer in this sense, it is necessary that each producer is always careful to evaluate the attitude of the other operators with whom he interacts in the same supply chain.

Among the various aspects taken into consideration, the behaviour assumed by the company towards the environment, the corporate and non-corporate strategies adopted, as well as all the factors that affect the entire production cycle of a given asset, have played a key role in the sensitivity of the consumer who has gradually begun to make his purchasing choices with greater prudence, demanding brands and labels that increasingly meet certain quality criteria, without considering only the specific utility that each product can guarantee. Considering this, it is easy to state that the certification process, from a corporate tool, aimed at satisfying administrative burdens, today also assumes significant importance as a means of communication between business and consumer, in ensuring the complete consistency of the commitments undertaken by the company, with the expectations of the users themselves. Also the regional program for development activities in the forestry sector and for the management of regional forests for the year 2019 (Calabria Region, 2019), regarding the management of forestry companies, provides that supply chain activities must also be carried out in the areas of forestry companies, compatibly with the constraints imposed on protected areas.

By carefully analysing the data regarding the wooded areas throughout Calabria, it is obvious to consider the enormous potential that this territory offers, and in fact, the regional institutions have issued over the years, a series of rules capable of enhancing the wood resources of the territory and the products connected to them. Just think of the Regional Forest Law n. 45 of 12 October 2012 (Calabria Region, 2012) and currently to the new 2014-2020 Rural Development Program (Calabria Region, 2014) which, through measure 8, called Investments in the development of forest areas and in improving the profitability of forests, intends to give greater visibility and efficiency to the forest sector, through greater development of technological innovation in the forestry sector and first processing (Zimbalatti et al, 2005).

Hence the total need for ever more careful management, both from an environmental point of view, but also from an economic and social point of view. Among the most valid tools for achieving these purposes is forest certification, which if it well valued in all its aspects, would guarantee an immediate revival of the economy and of the various products connected to the forest - wood supply chain of this region (Zimbalatti et al. 2005).

It is therefore clear the importance that is attributed to the certification process by the legislator who, through the appropriate financial and economic instruments, intends to give concrete support for the development of this procedure in the various companies of the forest-wood supply chain in the region. Forest certification is recognized as the main tool capable of giving added value to the various wood products and forest resources present since thanks to it is possible to generate a virtuous process of improvement of the entire supply chain and of the entire reference market.

Starting from these assumptions, in this study are well specified the significant advantages deriving from forest certification through the application of the main Principles and Criteria (P&C) of FSC® (FSC Italia, 2015) in one of the most important Calabrian companies operating in the forestry sector. The company in question, after many years of activity, has expressed the need to approach this process in order to enhance the various wood products made in the national and international market. Specifically, the work was focused on verifying the company compliance of various criteria with particular value at the forest level and within the principles defined by FSC® International; to achieve this purpose, a specific checklist was considered with the corresponding criteria to be used, and subsequently, the respective corporate conformities or non-conformities were assessed, in order to obtain an initial summary of the current state of the company with respect to the P&C considered.

Materials and Methods

Company Description

The forest company "La Foresta S.r.l." by Antonio Poletto (Figure 1) is a historic company located in Serra San Bruno (Vibo Valentia), based near the sanctuary of Santa Maria del Bosco and the Certosa within the Serre Calabre regional natural park. It covers about 1700 hectares of forest distributed in three different municipalities (Serra San Bruno, Fabrizia and Capistrano) between the provinces of Catanzaro and Vibo Valentia.

Figure 1 - Headquarters of the production plant company "La Foresta".

Over the decades it has started a diversified production that has intercepted all the main components of the forest wood supply chain: from the care of the forest heritage with silvicultural interventions aimed at the protection and safeguarding of forest biodiversity with particular care for the enhancement of silver fir (*Abies alba* Mill., 1759) to the production of sawn products with different wood processing lines and to the development of prefabricated systems for building, up to the recent activation of a 1 MW thermoelectric power plant (Figure 2) powered by wood waste from forest cuts and the sawmill, and two photovoltaic systems. Specifically, in the plant where the first and second transformation phases of the wood material take place, the manufacturing processes are manifold, thus giving rise to diversified finished products. Among these there is a large number of sawn timber for construction attributable to: beams, brackets and boards up to 14 meters in length, as well as structural elements for the construction and finishing of wooden houses, gazebos, and for the manufacture of roofs and attics. The company also produces material for wooden fences, sculptures and furniture for outdoor use, provides special materials for the restoration or refurbishment of roofing structures of buildings of particular architectural value. The various residual materials of the processing are instead used as supplies for the paper industry or for subsequent transformation into biomass for the thermoelectric plant.

Figure 2 - Thermoelectric power plant.

In the municipality of Serra San Bruno, this company manages forests falling in zone B of the Serre Regional Park and in the SIC area called "Bosco Santa Maria". This wooded area in which the company plant falls has been defined as one of the most beautiful forests in Italy for the particular essences present in it, where an extremely significant forest of silver fir of over 325 ha stands out. It is considered of great value due to its strong resistance properties both to the pathogens typical of the different species belonging to the Abies genus, and to the chemical action resulting from acid rain. This characteristic is currently considered of enormous importance by the various operators of the German and northern European forest-wood supply chain, who use the aforementioned fir plants born from gamic renewal in these areas in order to better contrast the phenomena of degradation indicated above, which involve considerable damage from both an environmental and a purely economic point of view.

The body of the company falling within the municipality of Fabrizia includes various wood formations, where it is possible to identify pure spruce forests and mixed coniferous and broad-leaved forests, but above all of coppice and beech forests associated with conifers that extend for over 100 ha. Finally, taking into consideration the company body located in the municipality of Capistrano, it is possible to specify that in all its breadth of over 300 ha, it has wooded formations consisting of pure coniferous as well as mixed broad-leaved trees distributed almost equally in the hectares in which they exist. , but to occupy a wider surface, there are coppice woods that have an extension greater than 120 ha.

It can be understood that thanks to the vastness of the wooded property areas that include a multiplicity of tree species, the company is able to have a constant supply of wood material to be carried out in the various types of transformation indicated above. In order to make the most of its territories, the company has been operating for years of controlled and well-planned silvicultural interventions, ensuring that a harmonious development of the various wooded areas can be perpetuated over time, thus favouring the various evolutionary dynamics and natural renovation. To achieve this purpose more effectively, the company has prepared a specific Forest Management and Settlement Plan (PGAF) under approval by the Agriculture, Forestry and Forestry Department of the Calabria Region, which would be able to guarantee management even more efficient than the various territories, with a consequent benefit both for the natural heritage and for the company itself, in planning and developing its production process more effectively.

Application of the FSC® Principles and Criteria

The analysis of the case study specifically concerned the application of certain Principles and Criteria within the FSC scheme adapted to the national context and assessed within the company in question. In order to be able to carry out an accurate investigation of the various business processes, the collaboration of the managers and staff present was of fundamental importance, thanks to which it was possible to achieve an in-depth knowledge of the company. Subsequently, through the use of a specific checklist (Table 1), some Principles and Criteria of greatest forest interest and specific to the FSC (FSC, 2015) certification system were considered, to carry out a corporate compliance assessment regarding them and obtain a synthetic picture of the current situation of the company that can be of reference when you want to proceed to start the appropriate certification process. In detail, we can specify that 6 Principles and 15 Criteria have been considered and are described in the following checklist.

Table 1a - FSC Principles and Criteria for Forest Stewardship took in account in this study, 2015.

FSC principle 1 - Compliance with laws **The Organization shall comply with all applicable laws, regulations and nationally-ratified international treaties, conventions and agreements.**
FSC criterion 1.1 Forest management must comply with all local and national administrative laws and regulations.
FSC principle 5 - Benefits deriving from the forest **The organization must effectively manage the variety of the different products and services of the management unit and maintain or improve the economic sustainability and the variety of environmental and social benefits over the long period.**
FSC criterion 5.2 Forest management, marketing activities and marketing operations must favour the optimal use and on-site processing of the various forest products. FSC criterion 5.3 Forest management must lead to the reduction of waste due to uses and processing operations carried out on site and limit damage to other forest resources. FSC criterion 5.4 Forest management must involve a strengthening and diversification of the local economy, which must not depend on a single forest production. FSC criterion 5.5 Forest management interventions must identify, maintain and, where possible, increase the value of forest resources for the protection of river basins and fisheries reserves. FSC criterion 5.6 The share of utilization of forest products must not exceed the levels that can be continuously offered following a long-term management of resources.
FSC principle 6 - Environmental values and impacts **The organization must maintain, preserve and/or restore the ecosystem services and environmental values of the management unit and must avoid, healthy or mitigate negative environmental impacts.**

Table 1b - FSC Principles and Criteria for Forest Stewardship took in account in this study, 2015.

FSC criterion 6.1 An environmental impact assessment must be planned in accordance with the degree, intensity of forest management and the uniqueness of the resources concerned; this assessment must be adequately integrated into the management systems. Assessments should include considerations at the level of individual landscape units as well as the impacts of on-site processing facilities. The environmental impacts must be estimated before the start of disturbance interventions in the affected areas. FSC criterion 6.2 Safeguards are envisaged for rare, threatened and endangered species and their habitats (for example nesting and feeding areas). Conservation areas and protection areas are established, suited to the scale and intensity of forest management and the uniqueness of the resources involved. Are hunting activities, fishing, the collection of non-wood products and the laying of traps controlled, if incompatible? FSC criterion 6.3 Ecological values and functions, such as renewal and succession of forest ecosystems, must be kept intact, increased or restored; the genetic diversity of ecosystem species; the natural cycles that involve the productivity of the forest ecosystem. FSC criterion 6.5 The principles reported in written documents must be prepared and put into practice, for the control of erosion, for the protection of water resources, to minimize forest damage during use, to reduce the disturbance effects connected to the construction of roads and use of mechanical means. FSC criterion 6.10 Wooded areas are generally not converted into areas for different uses (plantations or non-wooded areas) unless this conversion: a) affects a very limited portion of the forest management unit; and b) does not involve areas belonging to forests of high naturalistic value; and c) determines, on the entire forest management unit, clear, substantial, additional, safe and long-term benefits from a naturalistic point of view.
FSC principle 7 - Management planning **The organization must have a management plan consistent with its own policies and objectives and in proportion to the scale, intensity and risk of its management activities. The management plan must be made, maintained and updated on the basis of the monitoring information, in order to promote adaptive management. The planning and related procedural documentation should be sufficient to guide the staff, inform the stakeholders affected and stakeholders concerned and justify the management decisions.**
FSC criterion 7.1 The management plan and the related documents indicate: - the management objectives;

- the description of the forest resources that must be managed, the environmental limitations, the use of land and forms of ownership, the socio-economic conditions and the limits of neighbouring lands;
- the description of the silvicultural system and / or other management systems based on the ecological characteristics of the forest in question, and information obtained through resource inventories;
- the justification for the estimated annual recovery and the criteria for selecting the species for cutting;
- modalities for monitoring forest dynamics and development;
- forms of environmental protection based on precise assessments of the state of the environment;
- the methods for identifying and protecting rare, threatened and endangered species;
- topographic maps describing forest resources, including protected areas, planned management activities and land ownership;
- the description and justification of the techniques of use and the equipment to be used.

FSC principle 8 - Monitoring and evaluation

The organization must show that progress towards the achievement of the management objectives, the impacts of the management activities and the conditions of the management unit are monitored and assessed in proportion to the scale, intensity and risk of the assets in order to implement adaptive management.

FSC criterion 8.2
Forest management should include the research and collection of data necessary to monitor, at a minimum, the following indicators:
- the withdrawals of all forest products;
- the growth rates, renewal and general conditions of the forest;
- the composition of the flora and fauna and the changes observed in them;
- the social and environmental impacts of the uses and other interventions;
- the costs, productivity and efficiency of forest management.

FSC principle 10 - Implementation of management activities

The management activities conducted by or on behalf of the organization in the management unit must be selected and carried out consistently with the economic, environmental and social policies and according to the objectives of the organization, in accordance with the principles of the organization.

FSC criterion 10.1
The management objectives of the plantations, including those of conservation and restoration of natural forests, must be explicitly stated in the management plan and clearly demonstrated in its implementation

FSC criterion 10.2
The plantation design and scheme should promote the protection, restoration and conservation of natural forests and not increase pressure on them. In the organization of the plantation, according to the scale of the interventions, it is necessary to provide for the presence of natural corridors for wildlife, protection areas along the waterways and a mosaic of plants of different ages and subjected to different shifts. The scale and organization of the various plants must be consistent with the situation of the forest areas in undisturbed conditions.

Based on what has already been defined above, the FSC certification system in the great accuracy of its 10 Principles and 70 Criteria, ensures that the organization that intends to be certified fully complies with the basic principles of Sustainable Forest Management (GFS)(FSC, 2010); through the following analysis which was based on the assessment of company compliance with respect to some of the basic requirements of each Criterion within each Principle, it was possible to consider the level of the organization covered by the case study, with respect to a future certification audit FSC which can be operated by a specific accredited body for the evaluation of the entire production process.

Results and discussion

The careful investigation of the company production system, through the application of the specific 6 Principles and 15 Criteria mentioned in the previous chapter, has highlighted that with respect to them, the organization object of the case study is partially or almost completely compliant in the various activities affecting the various processes. It is useful to specify that in the survey, the presence of a specific Forest Management Plan was of considerable importance which, even if not yet fully approved by the competent bodies, is in fact a fundamental document in order to plan correctly and planned the various interventions that will affect the various corporate bodies; among other things, this important technical document of multi-year validity, appropriately approved, is essential for any organization that intends to start the forest certification process according to the Principles and Criteria established by FSC®. The various observations acquired regarding the specific Principles and Criteria considered are described below:

PRINCIPLE 1

Criterion 1.1

The organization responsible for forest management presents all relevant legislation on the activities of its interest; the interventions for the use of the various wood products, which will be used in the realization of the finished products, are based on the directives defined by the Prescriptions of the Maximum and Forest Police (PMPF), on the rules set out in the Forestry Law of the Calabria Region number 45 of 2012, as well as by the various provisions sanctioned by the Regulations of the

Regional Natural Park of the Serre, which entirely falls into a vast area of great naturalistic value.

PRINCIPLE 5

Criterion 5.2

The organization responsible for forest management has always been committed to the enhancement of products made through the use of wood material from its own forests, over the years it has increasingly managed to establish itself in its territory through a virtuous supply chain process that it involved the creation of niche products in the entire forest-wood sector of our region; moreover, through specific advertising campaigns the various products are enhanced, which are highly regarded both in the local and national markets.

Criterion 5.3

The company, in order to optimize the various processes of use in the forest and in particular to minimize the waste of wood during the logging procedure, has taken steps to abolish the use of large forestry tractors, which have been replaced by tractors. smaller in size, so as to reduce both the damage to the soil and to the various wood assortments obtained; Furthermore, within the production facility there is a dryer in order to avoid possible phenomena of wood rot and recently the possible purchase of a special debarking machine has been evaluated.

Criterion 5.4

Forest management, with a view to strengthening and diversifying the local economy which does not necessarily have to depend on a specific production, in addition to enhancing its products in the supply chain of its own interest, has also tried to enhance some tourist services; in fact, in the past, agritourism has been promoted within its own territory.

Criterion 5.5

In order to increase the value of forest resources, the company protects the water resources present in the territories owned as well as the fishing reserves in them in the best possible way, this is guaranteed through the full awareness of fully respecting the needs of using the courses water also through the collaboration of the

State Forestry Corps which constantly monitors and controls the fishing reserves, this activity also involves a large territory owned by the company falling precisely in an SIC area (Site of Interest Community) which must necessarily be safeguarded. The company organization also intends to create a hydroelectric plant in the future through the use of two different supply channels, in this sense a specific project has been developed that ensures the use of a correct quantity of water resources and guarantees the at the same time the maintenance and complete protection of ecosystems.

Criterion 5.6

With the aim of obtaining a constant supply of wood material, compatibly with the different ecosystemic needs of the territories in which it is used in the forest, the company has entrusted a professional in the sector to draft a specific Forest Management Plan, in which are clearly defined and described the appropriate silvicultural interventions to be adopted and the short and long term quantities of wood production that do not exceed the increases referred to the duration of the plan itself; this planning was appropriately conceived in order to safeguard both the productive aspects and the conservation and protection aspects of the forest with a view to sustainable forest management.

PRINCIPLE 6

Criterion 6.1

Among the main objectives that the company pursues on a daily basis is the optimization of the processing impacts on the environment that can be generated during the different working phases; in addition, a specific Environmental Impact Assessment (VINCA) was duly drawn up in an area owned by the company and defined as a Site of Community Interest, in order to preserve its total integrity.

Criterion 6.2

Considering the enormous importance of the area mentioned above and defined as a Site of Community Interest, in the specific Environmental Impact Assessment procedure on the various management activities of the site that could undermine the integrity of the habitats and species present in it, the species of flora, fauna and habitats to be protected have been well described, as well as the appropriate silvicultural intervention procedures for the purpose of proper management and sustainable use of the forest resources present within the SIC area.

Criterion 6.3

The organization of forest management, through adequate planning and implementation of the appropriate silvicultural systems (described in the specific PGAF) adopted in the areas affected by forest use, guarantees the maintenance and balance of forest ecosystems, preserving their ecological functions and allowing the natural processes of renewal and succession of the ecosystems themselves. In addition to adopting the appropriate silvicultural systems that support the evolutionary dynamics of the forest, the appropriate measures for the protection of the ecotone areas (the company implements particular reforestations in certain areas through the use of native plants rather than exotic species, in such a way to avoid possible genetic pollution between the various species. It is also possible to specify that the protection of a certain number of standing trees and dead trees has been appropriately planned, in accordance with the provisions of the Prescriptions of the Maximum and Forestry Police.

Criterion 6.5

In order to minimize forest damage during the phases of the wood assortments use in the territories affected by the various interventions, a specific map has been drawn up which indicates the entire forest road network on all the company property, and consequently allows the most appropriate operations through the handling of the various operating machines. These machines, as previously indicated, are adequately selected in order to minimize damage to the soil and to the various forest species during the cutting operations.

PRINCIPLE 7

Criterion 7.1

The organization responsible for forest management has drawn up a specific Forest Management Plan appropriate to the scale and intensity of the interventions to be adopted on the company territory, the objectives of forest management are well defined in it according to the current situation of the forest resources present in them. The aforementioned plan, having a fifteen-year validity, defines a long-term management, and describes in detail the different forms of governance and treatment according to the ecological conditions of the forest in order to preserve the integrity of ecosystems and their balance; silvicultural interventions are well defined for each year and for each parcel involved in the utilization intervention.

PRINCIPLE 8

Criterion 8.2
Through special paper and computer registers, the various quantities of wood processed in the forest, the woods used and the material that is transformed into the sawmill are recorded daily by the staff, in this regard among the company objectives there is precisely the implementation of a certification process of Forest Management and traceability of Forestry products or Chain of Custody, in order to be able to further enhance them, in a wider reference market.

PRINCIPLE 10

Criterion 10.1
All the management objectives of the entire territory owned by the company are clearly specified in the specific Forest Management Plan, which indicates all the appropriate procedures and adequate indications to be adopted in order to best preserve territories, in the various processes of use properly defined.

Criterion 10.2
All the landscape elements of high environmental value present in the areas pertaining to the company are clearly specified in the specific Company Forest Management Plan. In fact, each utilization project consistently follows the guidelines defined by the P.M.P.F. with regard to the protection of biodiversity, and also includes all the trees defined as monumental that have been appropriately registered and marked in order to characterize them in the entire territory in which they are located; It is also important to specify that the wetlands that fall within the Serre Regional Natural Park are adequately defined and preserved through the relevant legislation.

The results obtained, in full compliance with the corporate privacy that consented us to conduct a purely informative survey, allow us to ascertain that based on the Principles and Criteria described above, the organization is overall compliant in the various activities that affect the different processes in the short and long term objectives that it intends to pursue in order to be able to implement a more in-depth certification process for Forest Management (FSC Italy, 2015) and the Chain of Custody (National Secretariat of the FSC-Italy Group, 2009). the various Principles and Criteria defined by the FSC scheme.

In the future, a more in-depth analysis by an accredited certification body will certainly be necessary to identify any non-conformities to be resolved and ensure that the company can be prepared for the appropriate inspection audit. Thanks to the study in question it was possible to define a first approach to forest certification, as well as provide the basic knowledge about a virtuous process that would entail a multiplicity of advantages in the market in which the reality object of the case study is located, and become even more an example to follow for all operators in the forest-wood-energy supply chain operating throughout the region.

Conclusion

The issue of forest certification of wood products and its derivatives is gaining increasing interest from the various figures operating in the forest-wood-energy sector due to the important and multiple advantages that it can guarantee both in the enhancement of the productions and the various production processes, both at the promotional level in the corporate marketing activity in order to achieve greater consideration and interest from consumers, who now more than ever pay particular attention to the purchase of products derived from virtuous and environmentally friendly processes, able to ensure the traceability of the entire production chain, from origin to finished product. The latest statistical data show that in Europe the demand for certified products is increasingly increasing, therefore the enormous potential of forest certification as a marketing tool able to qualify the company product, can certainly represent the winning card to overcome the competition with wood from abroad, in particular from Eastern Europe. Therefore it can be said that the implementation of a training and information plan for all the protagonists of the forest-wood supply chain would be of fundamental importance for acquiring the necessary awareness of the concrete repercussions that this process would entail in enhancing the various construction site activities and wood products deriving from them; in this regard, the implementation of group certification initiatives could favor the adhesion of the various parties involved and consequently contribute to improving the organizational and production bases, to launch effective marketing strategies and to facilitate company management in a completely sustainable way (Proto, 2014).

The following work aimed precisely to promote the instrument of forest certification starting from the basic axioms within the concept of Sustainable Forest Management and then reaching an adequate analysis of the production process of an important entrepreneurial reality present in our region through the application of appropriate Principles and Criteria defined by the FSC® certification scheme. In this sense, the study in question, which is found almost exclusively in the deepening of the aforementioned scheme and applied with an experimental methodology, has made it possible to ascertain in the first place the current state of compliance of the company with respect to the Principles and Criteria considered, and at the same time, it allowed the company to define a first approach to the FSC certification system, understanding its various characteristics and particularities, which are essential in order to subsequently start the appropriate certification process.

As already defined above, in order to be able to start the forest certification process, each private owner and each entity that has forest areas must necessarily have its own Forest Management and Settlement Plan to ensure adequate programming and planning of forestry interventions to be carried out in the owned territories in compliance with the relevant legislation. In this regard, it is useful to consider that the manager of the company object of the case study, in order to make the most of his business reality as well as to fully comply with the legal obligations, has already for some years provided for the creation and presentation of this technical document to the competent authorities, which at present have not yet defined its complete approval. The forest certification will be supported by the new Rural Development Program 2014-2020, where it is clear from the appropriate measures, the importance of the same as a fundamental tool for the enhancement of the various realities operating in the forest sector, wood products and the immense forest heritage present throughout the region.

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WOOD TECHNOLOGY

The effect of heat temperature on several wood parameters

Introduction

The use of forest resources has always represented a basis for economic, environmental, and social stability in rural areas (Proto et al. 2018) but during the last decades, resource scarcity induced investments in both subsistence and efficient commercial uses of the forests. The topic of efficient utilization of forest resources is of great importance nowadays because of the increasing of public awareness (Hyde et al. 1996). So, it is necessary to improve the uses of wood resources, reducing waste and increase the noble uses of wood as in building construction. Wood is a natural material with good beauty aspects and superior formability which has been used as an engineering and construction material and also used for interior and exterior decoration (Hoseinzadeh et al. 2019). Moreover, wood has a good weight ratio and acoustic properties (Ateş et al. 2010). Despite its great benefits, wood also suffers a number of disadvantages, for instance, it is damaged when exposed to environmental conditions as a function of sunlight, humidity, wind, and microorganisms (Hoseinzadeh et al. 2019). Numerous studies have been conducted to improve the properties of wood, using different modification processes, including heat-treatment (Hill, 2007). The basic idea of heat-treatment of wood is to improve its overall properties. Heat-treatment of wood has been developed in Europe during the 1990s (Bakar et al. 2013) and nowadays represents an efficient method of wood modification without using chemicals, therefore could be an eco-friendly alternative for conventional wood preservation generally performed by chemical treatment using poisonous chemicals that likely affect the human health and environment negatively (Esteves and Pereira 2008; Mohareb et al. 2010; Li et al. 2011; Hoseinzadeh et al. 2019). There is a growing market for heat-treated wood in outdoor applications such as exterior cladding, window and door joinery, garden furniture, and decking. There are also many indoor applications for heat-treated wood where stability is important, such as flooring, panelling, kitchen furnishing, and interiors of bathrooms and saunas (Gunduz et al. 2008; Salca and Hiziroglu, 2014).

Heat-treatment changes some chemical, mechanical and physical properties of wood (Yildiz et al. 2006). Hemicelluloses start to decompose, lignin softens, and cellulose and hydrophilic groups modify (Viitaniemi,1997; Alén et al. 2002; Sivonen et al. 2002; Bekhta and Niemz, 2003). As a result, treated wood with high temperatures loses its reabsorbing water capacity contrary to hydrophilic behaviour of the conventionally dried wood (Kocaefe et al. 2007). Because of chemical changes in the wood structure, from a physical properties point of view, heat-treatment results in a reduction of density, a reduction of EMC with moisture content around 4 – 5% instead of 10 – 12% of the untreated wood (Inoue et al. 2007), an improvement of dimensional stability (Kocaefe et al. 2008), an improvement of the decay resistance to fungi and in a darkening of wood natural colour (Esteves et al. 2008; Živković et al. 2008; Gunduz et al. 2008; Gunduz et al. 2009; Tuong and Li, 2010; Nemeth and Bak, 2012; Bakar et al. 2013; Kačíková et al. 2013; Goli et al. 2014). From a mechanical point of view, heat-treatment improves hardness, but, on the other hand, makes the wood more brittle, reducing bending strength, tensile strength and shear strength (Gunduz et al. 2008; Goli et al. 2014), although some difference in degree of change has been observed between softwoods and hardwoods depending on the treatment method (Kocaefe et al. 2010; Li et al. 2011).

Santos (2000) determined that strength properties were slightly affected. The apparent modulus of elasticity was slightly higher for treated wood than for untreated wood, despite a 26% reduction in transverse tensile strength. According to Bengtsson et al. (2002) and Bekhta and Niemz (2003), a reduction of approximately 50% in bending strength was found in tests of heat-treated spruce and pine. With heat-treatment, the least affected property is the modulus of elasticity, while the most affected properties are impact strength and static bending strength.

Despite these variations, heat-treatment can also change the wood's surface characteristics (wettability, gluing quality, surface hardness, roughness and colour) (Garcia et al. 2012).

A typical heat-treatment is applied at temperature levels and exposure times ranging from 120 to 250 °C and from 15 min to 24 h, respectively, depending on the process,

species, sample size, moisture content and the desired target utilization. Physical and chemical properties of wood under heat-treatment change at temperature near 150 °C and it continues with increasing temperature (Korkut and Guller, 2008; Kocaefe et al. 2010).
The aim of this study was to determine the effect of heat-treatment on some physical properties in the wood species most commonly widespread in South Italy. In particular, the main objective of this work was to obtain initial data on surface roughness, discoloration, abrasion and screw withdrawal resistances of heat-treated chestnut, Calabrian pine and beech woods. The purpose here was to carry out only a comparative study in order to investigate and compare the effect of the heat-treatment on some wood properties. It is expected that the heat-treatment can add potential value on wood material to be used more effectively in further manufacturing steps.

Materials and Methods

Given their wide diffusion in Mediterranean basin (Proto et al. 2018), three wood species, beech (*Fagus sylvatica* L.), chestnut (*Castanea sativa* Mill.), Calabrian pine (*Pinus nigra* Arnold subsp. *Calabrica* Delamare) were chosen for test materials used in this study. Defect free samples were cut from commercial products manufactured by a sawmill company (Fabiano Legnami S.r.l.) in the province of Catanzaro in Calabria region (South Italy) that, also, deals with the supply of wood resources from local forests on the Serre Massif.
A number of 20 boards with a dimension of 30 ×90 × 400 mm (Radial x Tangential x Longitudinal) of each species were divided in two groups: half part of total boards was left as control (Ctrl) while the other half material was exposed to heat-treatment (HT) of 200 °C for beech wood, 190 °C for Chestnut wood and 170 °C and 200 °C for Calabrian pine wood applied for 2 hours, in a heating unit controlled (THW 20.95.41 plant, by the BIGonDRY S.r.l., Vicenza, Italy) (Figure 1) to within ±1 °C under atmospheric pressure. Artificial drying is used to reduce the wood moisture content to set values, properly monitoring the climatic parameters in the plant such as temperature, humidity, pressure, and ventilation. After heat-treatment, treated and untreated samples (Figure 2) were conditioned at 20 ± 2 °C and 65% (±5%)

relative humidity (RH) in a conditioning room to reach equilibrium moisture content (EMC) of 12%.

Figure 1 - Exterior (on the left) and interior (on the right) of the THW 20.95.41 heat-treatment plant.

Figure 2 – Samples of control and heat-treated wood of beech, chestnut and Calabrian pine, from left to right.

Roughness measurement

The surface roughness of machined parts is a significant design specification that is known to have considerable influence on properties such as wear resistance and fatigue strength (Korkut et al. 2013).

Surface roughness profile of the both heat-treated and untreated samples was measured using a portable surface roughness profilometer (Mitutoyo Surftest SJ-310, Figure 3). Measurements were made with the profile method using a skid type diamond stylus with 5 µm tip radius and a 90-tip angle. The measuring speed was 0.5 mm/min, according to the standard ISO 4287:1997. Stylus method is a well-accepted technique, resulting in quantitative numerical values on the surface of sample (Korkut et al. 2013). The profiles were stored parallel and perpendicular to wood grain. For roughness measurements eighteen sample boards were used, six for each species (half samples of heat-treated and half samples of untreated wood). The points of roughness measurement were marked on eight squared surfaces of 10 × 10 mm size on the surface of each sample boards, for a total of 96 measurements per board (six and six measurements, on perpendicular and parallel direction to the fibers, respectively, for each square). This measure allows the main roughness parameters to be evaluated. In particular, average roughness (Ra), mean peak-to-valley height (Rz), and maximum roughness (Ry) – were used to evaluate the effect of heat-treatment on roughness of the specimens. Roughness values were measured with an accuracy of 0.01 μm, and the force on the surface of the samples from the stylus tip was only 0.4 g, which did not apply any significant pressure or any damage on the samples (ISO 4287-1997). Surface imperfections, such as cracks, scratches and dents were not included in the recording. Furthermore, in order to minimize the possibility of encountering profile defects linked to extrinsic factors to the wood, the measurements were carried out on the inside of the boards, keeping out of the measurements, the 2.5 cm surface on the edges of the samples as more exposed to shocks during handling.

Figure 3. Surface roughness test by means the Mitutoyo Surftest SJ-310.

Colour measurement

Colour measurements were carried out using eighteen sample boards divided in equal parts for species and treatment, like the preview test. For each board 20 measurements were recorded on random positions.

Colour analysis was obtained by a Konica Minolta CM-700d spectrophotometer (Minolta Corp, Osaka, Japan) with a spot probe of 8mm diameter. According to CIE L*a*b*, which is a colour space organized in a cube form and defined by the International Commission on Illumination (French Commission Internationale de l´Eclairage) the chromaticity coordinates as L*, a* and b* were measured. The CIE L*a*b* system is made up of coordinates L* (lightness), a* (green-red chromatic coordinate) and b* (blue-yellow chromatic coordinate). In detail, the L* axis from top to bottom and the value maximum is 100, which would be a perfect reflecting diffuser (lightness), while the minimum for L* would be 0, which would be black. The a and b axes have no specific numerical limits. Positive a* is red; negative a* is green. Positive b* is yellow and negative b* is blue (Cetera et al 2019). After measuring the colour coordinates, the mean values were used to calculate the difference in the lightness (ΔL*) and chroma coordinates (Δa* and Δb*). Finally, the total colour change (ΔE) was calculated as equation 1 (Bekhta and Niemz 2003, Johansson 2008; Nourian and Avramidis, 2019):

$$\Delta E = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{\frac{1}{2}} \qquad \text{(eq. 1)}$$

where:

ΔL* = L*heat-treated – L*control,

Δb* = b*heat-treated – b*control,

Δa* = a*heat-treated – a*control.

Screw Withdrawal resistance

The screws are commonly used as joint components of the wood construction in engineered wood structures and, since each wood species has its own properties, they also have different screw withdrawal resistance. Therefore, the determination of this withdrawal resistance for some wood species is important for wood applications (Aytekin, 2008; Altunok, 2017) because it is an indicator of the wood material strength, density, and shear modulus.

From the two groups of specimens, four sample boards for each species (two heat-treated and two untreated) were used for Resistance Against Screw Withdrawal (RASW) determination. Six measurements were conducted on random positions on each sample. RASW was measured with the commercial SWRM device (Fakopp Enterprise Bt., Sopron, Hungary). The screw applied was standard screw size of diameter 3 mm, and the length of the threads 15 mm. with a Spax (PZD) type head. It is a yellow zinc plated, 45 mm long screw, with a penetration depth of 15 mm, and 20 mm thread free length. RASW force is measured in N. The measure consisted of catching the screw head by the fork of the force transducer (Figure 4) and slowly turn the handle clockwise until the screw is removed. The tool screen showed the maximal force value (F_{max}) recorded for the resistance against screw withdrawal RASW.

Figure 4 - SWRM device (Fakopp Enterprise Bt.) removing a screw of diameter 3 mm from heat-treated beech wood.

Abrasion test

For the abrasion test, the UNI EN 15185:2011 standard was followed. The test simulated the ability of the furniture surface under test, to resist abrasive wear-through. Abrasion was achieved by rotating a specimen in contact with a pair of loaded cylindrical wheels covered with abrasive paper. The wheels were positioned so that their cylindrical faces were equidistant from the specimen's axis of rotation but not tangential to it. As they were turned by the rotating specimen, they abraded an annular track on the specimen's surface. The number of revolutions of the specimen required to cause one defined degree of abrasion, was used as measurement of resistance to surface wear. In this study, the abrasion resistance (AR) values of the untreated and heat-treated specimens were determined by using a Taber® 5135 Rotary Platform Abraser (Figure 5). The abrasion test was performed on 9 samples of untreated wood and 9 samples of heat-treated wood, 3 per each species and treatment, having dimensions 120 × 120 mm. The test specimens were abraded using loads of 1000 g, with 500 cycles at the controlled speed of 60 RPM. After every 250 cycles, the devices were stopped and the specimens were weighed, after which the devices resumed, and, at 500 cycles, the weights of the specimens were determined. S-42 sandpaper was used as the abrasive, and it was changed after every 250 test cycles.

Figure 5 - Taber 5135 Rotary Platform Abraser during the abrasion test on a heat-treated Calabrian pine wood specimen.

The amount of material lost due the abrasion was determined by the equation 2:

$$L = A - B \quad \text{(eq. 2)}$$

where

L = weight loss

A = weight (mass) of specimen before abrasion

B = weight (mass) of specimen after abrasion

The test results were used to calculate the percentages changes in WL by equation 3.

$$WL = \frac{(W_E - W_1)}{W_1} \cdot 100$$

(eq. 3)

where:

WL = Weight loss (%),

W_1 = Weight of test specimens before abrasion (g),

W_E = Weight of test specimens after abrasion (g).

Statistical analysis

Data assessment was performed by means of general descriptive statistics, and statistical analysis using IBM SPSS 25 Statistics software. Multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between average values of control and treated samples were determined using Tukey's honestly significant difference (HSD) test at a *p*-value of 0.05.

Results

Wood is a non-homogenous material; consequently, its properties can differ from one sample to the other. Therefore, tests were repeated 6-1728 times depending on the specific test in order to obtain valid average values.

Roughness measurement

The data recorded for the surface roughness showed that tendentially in the beech case, the roughness increased on perpendicular directions and decreased on parallel ones after heat-treatment. For chestnut and Calabrian pine, instead, the roughness profile was lower for every parameter, after the treatment. Furthermore, as it can see in Table 1, the result obtained from the analysis of the variance of the parameters Ra, Rq and Rz for each species showed that the heat treatment was a significant factor in the surface roughness of the wood. As for the beech, the roughness was statistically different on all three parameters only for the perpendicular direction of the fibers. The same situation occurred for the chestnut but for the parallel direction of the fibers. The Calabrian pine, on the other hand, showed statistically different results between control and heat-treated only on the parallel direction of the fibers for the parameters Ra and Rq and not for Rz.

Colour measurement

The total colour change (ΔE) is resulted 36, 31 and 25 respectively for chestnut, beech and Calabrian pine wood (Table 2). As expected, lightness (L*) decreased with heat-treatment for all the tested species corresponding to the darkening of the wood surface. The highest decrease was observed for chestnut wood with a decrease of 33.52 units (-49%) after the heat-treatment (Table 3). Simultaneously, red colour tone increased for Calabrian pine and beech woods, while yellow colour tone showed consistent decreasing, between the range of -11% for the beech wood and -66% for the chestnut wood.

Table 1 - Results of the multiple comparisons between heat-treated (HT) and untreated (Ctrl) wood by direction of fibers for the roughness parameters.

Species				Mean Difference	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Beech	**Ra**	Ctrl perpendicular	HT perpendicular	-1.145271	0.340927	0.005	-2.02901	-0.26154
		Ctrl parallel	HT parallel	0.340854	0.340927	0.750	-0.54288	1.22459
	Rq	Ctrl perpendicular	HT perpendicular	-1.477208	0.491282	0.016	-2.75069	-0.20373
		Ctrl parallel	HT parallel	0.574833	0.491282	0.646	-0.69865	1.84831
	Rz	Ctrl perpendicular	HT perpendicular	-6.697479	2.087782	0.008	-12.10934	-1.28562
		Ctrl parallel	HT parallel	-1.135208	2.087782	0.948	-6.54707	4.27665
Chestnut	**Ra**	Ctrl perpendicular	HT perpendicular	0.192333	0.159128	0.622	-0.22015	0.60482
		Ctrl parallel	HT parallel	0.979646	0.159128	0.000	0.56716	1.39213
	Rq	Ctrl perpendicular	HT perpendicular	0.219104	0.208483	0.720	-0.32132	0.75952
		Ctrl parallel	HT parallel	1.231708	0.208483	0.000	0.69129	1.77213
	Rz	Ctrl perpendicular	HT perpendicular	1.016354	1.029462	0.757	-1.65217	3.68488
		Ctrl parallel	HT parallel	5.196354	1.029462	0.000	2.52783	7.86488
Calabrian pine	**Ra**	Ctrl perpendicular	HT perpendicular	0.112937	0.187276	0.931	-0.37251	0.59839
		Ctrl parallel	HT parallel	0.515396	0.187276	0.033	0.02995	1.00084
	Rq	Ctrl perpendicular	HT perpendicular	0.364188	0.253911	0.480	-0.29399	1.02237
		Ctrl parallel	HT parallel	0.665063	0.253911	0.047	0.00688	1.32324
	Rz	Ctrl perpendicular	HT perpendicular	2.940813	1.272492	0.099	-0.35769	6.23931
		Ctrl parallel	HT parallel	1.962167	1.272492	0.415	-1.33633	5.26067

The results of the variance analysis, and multiple comparison of L*, a*, b*, for heat-treated and untreated wood from chestnut, Calabrian pine and beech are given in Table 3. They proved that only the interaction between heat-treated and untreated chestnut wood concerning the a* factor was found to be not significant, while all other interactions were found to be significant (according to α = 0.05).

Table 2 - Mean values of colour parameters and the total colour change (ΔE) results.

Species	Treatment	L*	a*	b*	ΔE
Chestnut	Ctrl	68.512	8.395	22.965	35.98
	HT	34.996	8.123	7.801	
Calabrian pine	Ctrl	76.7235	7.775	27.801	25.29
	HT	51.844	10.096	20.567	
Beech	Ctrl	78.1145	6.324	16.819	30.85
	HT	45.9575	9.7715	14.936	

Table 3 - Multiple comparisons between heat-treated (HT) and untreated (Ctrl) wood by colour parameters.

Colour parameter	Species	Mean Difference (Control – Heat-treated)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
L*	Chestnut	33.516	0.51097	0.000	31.9862	35.0458
	Calabrian pine	24.8795	0.51097	0.000	23.3497	26.4093
	Beech	32.157	0.51097	0.000	30.6272	33.6868
a*	Chestnut	0.272	0.20288	0.831	-0.3354	0.8794
	Calabrian pine	-2.321	0.20288	0.000	-2.9284	-1.7136
	Beech	-3.4475	0.20288	0.000	-4.0549	-2.8401
b*	Chestnut	15.164	0.34174	0.000	14.1408	16.1872
	Calabrian pine	7.2335	0.34174	0.000	6.2103	8.2567
	Beech	1.8835	0.34174	0.000	0.8603	2.9067

Screw withdrawal resistance

The results of the screw withdrawal tests are shown in the Table 4. Among the three species tested for resistance against screw withdrawal (RASW), the one with the most resistance was the control wood of beech (Figure 6), while the less performant wood was the Calabrian pine. After the heat-treatment, the best wood concerning the RASW was the beech, again, but the worst result was obtained with chestnut wood. In fact, the greatest variation of RASW recorded during this test was between untreated and heat-treated chestnut wood (-61%). The species that showed a minor change in terms of RASW was the Calabrian pine with only -13%, while the RASW from untreated to heat-treated beech wood decreased of 42%. From the analysis of variance (Table 5), in fact, the treatment has resulted a significant factor on the performance of RASW between untreated and heat-treated wood.

Table 4 - Descriptive statistics of screw withdrawal tests expressed in N.

Species	Treatment	Minimum	Maximum	Average	Std. Dev.
Beech	Control	2354	2572	2492.667	120.50
	Heat-treated	1396	1506	1439.333	58.59
Chestnut	Control	1972	2162	2042.667	103.93
	Heat-treated	728	864	789.3333	68.97
Calabrian Pine	Control	1464	1538	1499.333	37.11
	Heat-treated	1228	1354	1299.333	64.63

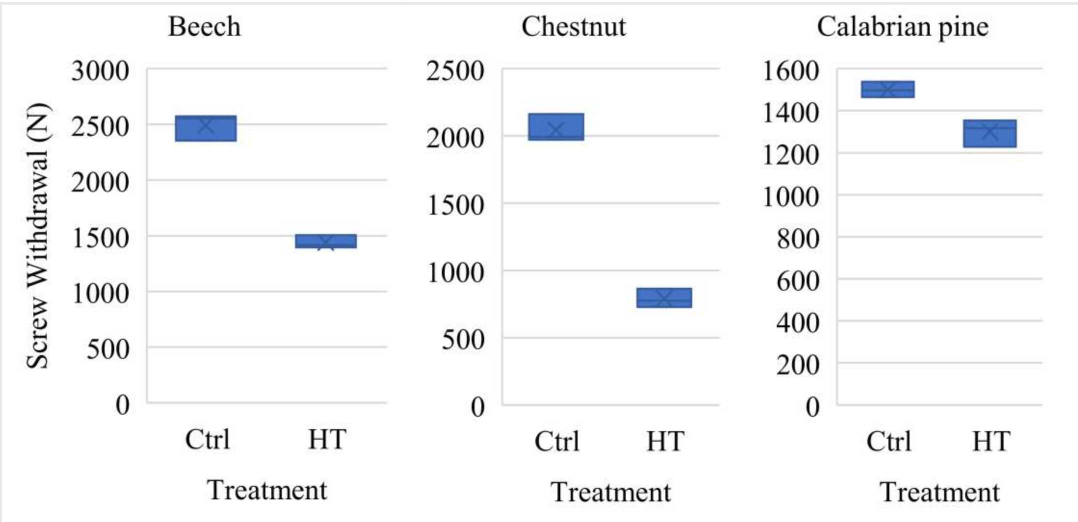

Figure 6 – Screw withdrawal resistance between untreated (Ctrl) and heat-treated (HT) wood.

Table 5 - Results of the Analysis of Variance for screw withdrawal resistance between untreated and heat-treated wood.

		Sum of Squares	df	Mean Square	F	Sig.
Beech	Between Groups	3328533.333	1	3328533.333	463.464	0.000
	Within Groups	71818.667	10	7181.867		
	Total	3400352.000	11			

Chestnut	Between Groups	4712533.333	1	4712533.333	757.220	0.000
	Within Groups	62234.667	10	6223.467		
	Total	4774768.000	11			
Calabrian pine	Between Groups	120000.000	1	120000.000	54.009	0.000
	Within Groups	22218.667	10	2221.867		
	Total	142218.667	11			

Abrasion test

The abrasion test revealed that the wood essence most resistant was the chestnut thermally untreated, losing only the 0.02 and 0.05% of the initial weight after 250 and 500 cycles of Taber Abraser, respectively (Figure 7). However, after the heat-treatment chestnut lost more weight than the beech wood (0.78% compared to 0.52%). The worst performance was obtained with the Calabrian pine where the weight loss was more than 1% after 500 abrasion cycles (Table 6).

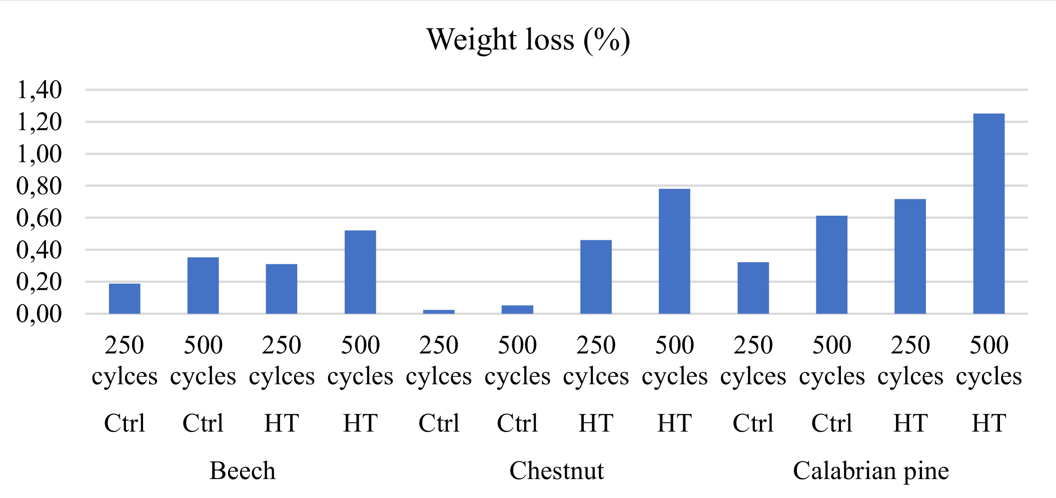

Figure 7 - Weight loss in percentage from initial weight to the weight after 250 and 500 cycles of Taber Abraser.

Table 6 - Weight of samples at 0 cycle, 250 cycles and 500 cycles of Taber Abraser.

		Weight			Weight loss (%)	
		W0	W250	W500	250 cycles	500 cycles
Beech	Ctrl	168.520	168.200	167.924	0.19	0.35
	HT	143.92	143.473	143.171	0.31	0.52
Chestnut	Ctrl	180.6	180.557	180.505	0.02	0.05
	HT	116.76	116.222	115.849	0.46	0.78

Calabrian pine	Ctrl	125.849	125.442	125.077	0.32	0.61
	HT	112.490	111.684	111.083	0.71	1.25

Discussion

Roughness measurement

Korkut and Guller (2008) studied the effects of heat treatment on the physical properties and surface roughness of red-bud maple and concluded that surface roughness decreased with increasing temperature treatment and treatment times. (Korkut et al. 2013) reported the effect of heat treatment on surface properties of wild cherry. These authors concluded that surface roughness decreased with heat treatment compared to those of control specimens. Similar results were reported for heat treated red river gum tree (*Eucalyptus camaldulensis*) (Unsal and Ayrilmis 2005), black pine (*Pinus nigra*) (Gunduz et al. 2008) and Turkish Hazel (*Corylus colurna*) (Korkut et al. 2008). The results of this study were in accordance with the previews researches in the cases of chestnut and Calabrian pine. However, the results showed that the surface roughness increased on perpendicular directions and decreased on parallel ones after heat-treatment in the case of beech wood.

Colour measurements

Colour is the most studied surface property that changes with heat treatment and this study has shown that wood types and treatment play an important role in colour proving that the treatment has to be tailored to each species in order to achieve the desired final properties. Thanks to heat-treatment, it is a well-known fact that wood becomes darker and at the same time lightness decreases as reported by many authors with different wood species and the results obtained in this study were in accordance with the changes presented by several authors like Bekhta and Niemz (2003) for Spruce, Esteves et al. (2008) with *Pinus pinaster* and *Eucalyptus globulus*, Aksoy et al. (2011) for Scots pine, Karamanoglu and Akyildiz (2013) for

Anatolian black pine, Calabrian pine, sessile oak and chestnut woods, Gurleyen et al. (2018) for different some commercial species in Turkey as chestnut, poplar, Uludag fir and hornbeam.

Screw withdrawal resistance

The heat-treatment reduced the screw withdrawal resistance of the wood. The reason for screw withdrawal resistance decreasing after heat-treatment may be caused by the mass losses as a result of the degradation of hemicelluloses and by degradation of wood (Viitanen et al. 1994; Fengel and Wegener, 1989). The chemical composition of wood varies from species to species. In general, hardwoods contain more hemicellulose than softwoods (Baeza and Freer 2001), and because of the degradation of the hemicelluloses starts to take place at a relatively low temperature (between 160 and 260 ºC), the softwoods are more thermally stable than hardwoods (Fengel and Wegener, 1989). Perçin (2015) studied screw withdrawal resistance of laminated samples produced from heat-treated oak (*Quercus petraea* Liebl.). As a result, increasing heat-treatment temperature decreased the screw withdrawal resistance of test samples. A study by Baltacı (2010) investigated the effects of heat-treatment on screw withdrawal resistance of several wood species. He applied heat-treatment to Scots pine, Oriental beech, Uludağ fir, and Carolina poplar. The highest screw withdrawal resistance was found in oriental beech, while the lowest resistance was found in Uludağ fir. Reza Taghiyari et al. (2012) studied the effect of heat-treatment on *Abies alba*, and they found that as a softwood, the difference was not so outstanding as in hardwoods. This clearly shows the importance of species that significantly affects screw withdrawal resistance.

Abrasion test

This study, in accordance with Aytin et al. (2015) which evaluated the abrasion resistance of the wood from wild cherry heat-treated, assessed that the abrasion resistance in terms of weight loss (WL) and observed more abrasion in the heated treated boards than in the untreated samples. However, Welzbacher et al. (2009) reported that there was no difference in resistance to abrasion between beech and heat-treated beech wood. The reason of the increase in the amount of abrasion might be the breaking of the intermolecular and intramolecular bounds in wood at high temperature (Ayrilmis, 2010; Welzbacher et al. 2009; Santos, 2020).

Conclusion

Due to improved moisture content, swelling, and shrinkage (dimensional stability), the high-temperature treatment allows the use of wood for exterior applications such as exterior cladding, window frames, and garden furniture. Additionally, heat treatment can be considered an environmentally friendly technique because no chemicals are involved in the process. But heat-treatment changes a several properties of wood that which can negatively affect the performance of the wood depending on the different applications.

In this research, the effects of heat-treatment on some properties of wood were studied. In particular, changing in terms of surface roughness, colour, screw withdrawal resistance, and abrasion resistance was evaluated for three different types of wood: beech, chestnut, and Calabrian pine heat-treated at 200 °C, 190 °C and 200 °C, respectively. Based on the results of this study, it is concluded that, in general, the investigated physical properties of wood decreased after heat treatment. Depending on the type of wood, these properties are more susceptible to change. In detail, the chestnut is the wood that, most of all, has darkened and has decreased the screw withdrawal resistance, moreover, it has also strongly decreased its resistance to abrasion resulting in the wood least resistant, in second place after the Calabrian pine. The beech wood has increased its surface roughness, more than the other species examined but it was the most resistant to abrasion. Being a conifer, the Calabrian pine was not very influenced by the heat-treatment, both in terms of change in surface roughness, both in colour, and in screw withdrawal resistance; only as regards the resistance to abrasion it was the species that responded in the worst way compared to the other species.

More tests need to investigate the performance of the same wood essences treated under different temperatures and exposition time, in order to determine an adequate heat-treatment time and temperature without excessively losing the resistance values and chemical characteristics of the wood.

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CONCLUSION AND FUTURE PERSPECTIVES

This PhD thesis developed different approaches to evaluate the wood supply chain in Calabrian Region. In particular, primary object of this study has been to determine the several parameters that influenced the productivity rate of the machines used during forest utilization in Calabria forestry. The choice can fall on machines traditionally used in agriculture and equipped with forestry tools such as winches or grapples, or on specialized machines in the forestry sector, depending on the characteristics of the forest site. The importance of this study was motivated to establish if these machines could be recommended for efficient harvesting in the forest conditions in Southern Italy.

In fact, the first results showed the necessity to have a good organization on the work site, in particular, planning a best road network to reduce the extraction distance, and consequently, to limit the time consumption linked to the extraction operations, because very often, extraction distance is the main cause of time consumption, during total work cycle time. When the site conditions do not allow the use of forestry machinery, especially large and heavy machines, in particular situations such as areas restricted by prohibitions or recognized as nature reserves, the use of farm tractors adapted to forest use could be the best applicable solution. Examining all work phases from tree felling to the extraction of roundwood to the landing under small-scale forestry conditions managed with different thinning treatments, whole tree system in coniferous plantation applied with typical harvesting system has guaranteed productivity standards at a reasonable cost reducing high operational cost per unit harvested. Furthermore, this study underlined that it was economically possible to harvest wood biomass relatively small-diameter from thinning stands favouring moderate and heavy thinning and evaluated the role of biomass supply chain, the use of forest and wood-processing residues can appear as a circular economy approach in the bio-energy sector.

Remaining on biomasses recovery, the study conducted on dismantled apple orchards in Romania, showed that it is very interesting the application of a forest machine (forwarder) in the agricultural environment, which reduced time to clean the ground for the next replantation and it guaranteed a medium productivity at quite a low cost.

A different study, conducted during the stage at Transylvania University, evaluated a new prototype of forwarder machine under the conditions of steep-terrain low-access forests. The results bring evidence on the performance improvement by the modular innovation approach as a measure to increase the effectiveness of forwarding operations. In particular, for excessively long extraction distances, a synergic integration of the suspended cabin with an innovative transmission system enabled a faster and safer operation of the machine with improved effects in the productivity and fuel economy this can contribute to less costs involved by the development of transportation infrastructure. This prototype can be used in different conditions, and potentially applied in Calabrian forest sites.

The second activity regarded the effect of compaction on the soil component caused by the repeated passes of a skidder machine during forestry operations, adopting semi-trawl wood extraction system and the main results consisted in identifying the critical number of machine passages that affects the state of soil compaction, and at which depth the effects were noticed. This study, conducted with a portable penetrometer showed that the use of this simple tools, associated with preliminary sampling for the characterization of soil conditions, can be validly employed in the study of soil compaction allowing the rapid acquisition of data in multiple points and at different depths.

The objective of the third part of this Ph.D. was to develop a methodological approach using a non-destructive technology (NDT), i.e., conventional sonic tomography, based on fast/slow paths to assess the presence of ring shake in standing chestnut trees. The results confirmed that sonic tomography can identify several defects in a tree trunk, including ring shake, without affecting its biological activity, overcoming the difficulties of predicting using only visual inspection. This method allowed the evaluation of the potential quality of forest trees, so, it could be adopted as an ordinary method by owners or buyers to determining the correct economic value of forest before a commercial deal, or it could be used to harvest consciously trees that really could offer the assortments that they actually intend to obtain.

The fourth study phase was about forest certification, and the investigation on the characteristics that distinguish a Calabrian company, interested in adhering to the

Principles and Criteria dictated by the Forest Stewardship Council (FSC). It was analysed, in full compliance with corporate privacy, to determine the possible suitability to obtain the certification in question, or whether needs changes in the organizational/operational structure of the company. Obtaining certification, as is now known, would bring advantages to the company in terms of prestige and would occupy a part of the market that is increasingly attentive to the issues for which forest certifications identify themselves and guarantee them. From this study, it emerged that the company in question would be suitable for obtaining the certification of its products, even if verification by the certifying body is necessary to certify its official status.

The fifth and last activity was the characterization of some wide wood species in Calabria comparing the performances among the heat-treated and untreated wood about the resistance against screw withdrawal and the resistance to surface abrasion, and also were measured the changes of colour and surface roughness after the heat treatment. The objective of this part of research aimed to enhance the commercial value of the Calabrian wood to better answer at the new requests of market in aesthetic and technological terms. The results showed that the heat-treated method represents a valid system to valorise the wood for different uses respect the traditional treatment. The heat-treated wood can represent a new commercial product permitting a new value-added favouring the Calabrian wood species with lower technological characteristics.

The outcomes of this Ph.D. thesis can be useful for forestry operators, wood farmers associations and stakeholders involved in forestry management as well as for technicians and decision-makers to support the development of a specific subsidy framework. Though related to forestry operations carried out in Southern Italy, the achieved results can be upscaled to other geographic forestry areas (e.g., Central and Eastern European Countries; Mediterranean Basin) with similar characteristics in terms of productivity, slopes, and road network.

The future investigations will be focused on the use of different methods to determine the environmental management using the application of LCA in forestry and in all sectors of wood supply chain. In fact, in forestry, environmental impact studies usually exclude the wood process (sawmill and furniture) impact, which is correlated, to silviculture management, mechanization and wood quality.

From the experience gained with Ph.D. research, it is possible to identify a significant potential for optimization, which could substantially improve the operational efficiency of all sectors of the Calabrian wood supply chain.

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