Annals of Silvicultural Research
45(1), 2020: 1-11
https://journals-crea.4science.it/index.php/asr

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]

Received: 16/01/2019 *Accepted: 4/09/2019* *Published: 21/07/2020*

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

http://dx.doi.org/10.12899/asr-1883

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^{3}h^{-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^{3}h^{-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).

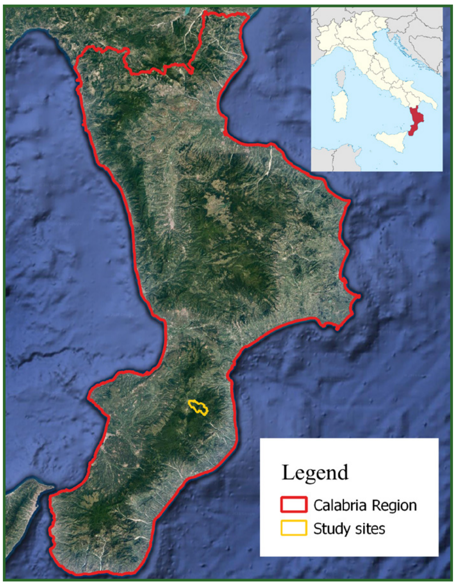

Table 2 - General characteristics of wood extraction with winches and grapple.

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.

Acknowledgements

This study was funded by the National Operational Programme for Research and Competitiveness (PON R&C) 2014-2020, XXXIII Cycle - "Investments in Human Capital" - Action I.1 - Innovative doctorates with industrial characterization.

References

Ackerman P., Belbo H., Eliasson L., de Jong A., Lazdins A., Lyons J. 2014 - *The COST model for calculation of forest operations costs*. International Journal of Forest Engineering 25 (1): 75-81.

Akay A. 2005 - *Determining cost and productivity of using animals in forest harvesting operations*. Journal of Applied Sciences Research 1 (2): 190–195.

Baraldi G., Cavalli R. 2008 - *Innovazioni nel settore delle tecnologie meccaniche per le produzioni agricole e forestali di qualità*. Italian Journal of Agronomy 3: 155–159. doi.org/10.4081/ija.2008.1s.155.

Bîrda M. 2013 - *Evaluation of winch performance in round wood harvesting. Bulletin of the Transilvania University of Brasov*. Forestry, Wood Industry, Agricultural Food Engineering. Series II 6 (2): 1.

Borz S.A., Ciobanu V. 2013 - *Efficiency of motor-manual felling and horse logging in small-scale firewood production*. African Journal of Agricultural Research 8 (24): 3126-3135. DOI: 10.5897/AJAR2013.7306

Borz S.A., Dinulică F., Bîrda M., Ignea G., Ciobanu V.D., Popa B. 2013 - *Time consumption and productivity of skidding Silver fir (*Abies alba *Mill.) roundwood in reduced accessibility conditions: a case study in windthrow salvage logging form Romanian Carpathians*. Annals of Forest Research 56 (2): 363-375.

Borz S.A., Ignea G., Popa B., Spârchez G., Iordache E. 2015 - *Estimating time consumption and productivity of roundwood skidding in group shelterwood system–a case study in a broadleaved mixed stand located in reduced accessibility conditions*. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering 36 (1): 137-146.

Borz S.A., Niţă D., Talagai N., Scriba C., Grigolato S., Proto A.R. 2019 - *Performance of small-scale technology in planting and cutback operations of willow short rotation crops*. Transactions of the ASABE 62 (1): 167-176. doi.org/10.13031/trans.12961

Brachetti Montorselli N., Lombardini C., Magagnotti N., Marchi E., Neri F., Picchi G., Spinelli R. 2010 - *Relating safety, productivity and company type for motor-manual logging operations in the Italian Alps*. Accident Analysis and Prevention 42 (6): 2013–2017.

Calafatello A.R., Catania P., Vallone M., Pipitone F. 2005 - *Technical analysis of mechanized yards in the forest utilization in Sicily*. Journal of Agricultural Engineering 3: 55–59.

Câmpu V.R., Ciubotaru A. 2017 - *Time consumption and productivity in manual tree felling with a chainsaw – a case study of resinous stands from mountainous areas*. Silva Fennica 51 (2) 1657. 19 p. doi.org/10.14214/sf.1657

Cavalli R. 2008 - *Linee evolutive nel settore delle utilizzazioni forestali e dell'approvvigionamento del legname. (Innovations in the field of mechanical technologies for forest utilization and wood supply)*. L'Italia Forestale e Montana 4: 297–306.

Ciubotaru A., Maria G.D. 2012 - *Research regarding structure of working time in spruce felling with mechanical chainsaw Husqvarna 365*. Bulletin of the Transilvania University of Brașov, series II: forestry. Wood Industry. Agricultural Food Engineering 5 (54): 43-48.

Cosola G., Grigolato S., Ackerman P., Monterotti S., Cavalli R. 2016 - *Carbon footprint of forest operations under different management regimes*. Croatian Journal of Forest Engineering 37: 201-217.

Enache A., Kühmaier M., Visser R., Stampfer K. 2016 - *Forestry operations in the European mountains: a study of current practices and efficiency gaps*. Scandinavian Journal of Forest Research 31: 412–427. doi.org/10.1080/02827581.2015.

Ghaffarian M.R., Shobani H. 2007 - *Cost production study of motor-manually felling and processing of logs*. Forest Science 3: 69-76.

Gilanipoor N., Najafi A., Heshmat Alvaezin S.M. 2012 - *Productivity and cost of farm tractor skidding*. Journal of Forest Science 58 (1): 21–26.

Gülci S., Büyüksakallı H., Taş İ., Akay A.E. 2018 - *Productivity Analysis of Timber Skidding Operation with Farm Tractor*. European Journal of Forest Engineering 4 (1): 26-32.

Gullberg T. 1995 - *Evaluating operator-machine interactions in comparative time studies*. Journal of Forest Engineering 7 (1): 51–61. doi.org/10.1080/08435243.1995.10702678.

Gumus S., Turk Y. 2016 - *A new skid trail pattern design for farm tractors using linear programing and Geographical Information Systems*. Forests 7. 306 p. doi.org/10.3390/f7120306.

Harstela P. 1993 - *Works Studies in Forestry*. Silva Carelica 25, Joensuu University Library: Joensuu, Finland. 35 p.

Heinrich R. 1999 - *Sustainable forest harvesting 1. Environmentally sound forest harvesting operations*. In: Food and Agriculture Organization of the United Nations (FAO).

Iranparast Bodaghi A., Nikooy M., Naghdi R., Venanzi R., Latterini F., Tavankar F., Picchio R. 2018 - *Ground-Based Extraction on Salvage Logging in Two High Forests: A Productivity and Cost Analysis.* Forests 9 (12). 729 p. doi.org/10.3390/f9120729

Johansson J. 1997 - *Small tree harvesting with a farm tractor and a crane attached to the front.* Journal of Forest Engineering 8 (1): 21–33.

Jourgholami M. 2014 - *Productivity and cost of a small-scale timber forwarding system using farm tractors in the Hyrcanian forest, Northern Iran*. Taiwan Journal of Forest Science 29 (2): 103-116.

Jourgholami M., Majnounian B., Zargham N. 2013 - *Performance, capability and costs of motor-manual tree felling in Hyrcanian hardwood forest*. Croatian Journal of Forest Engineering 34 (2): 283-293.

Kellogg L.D., Bettinger P., Studier D. 1993 - *Terminology of Ground-Based Mechanized Logging in the Pacific Northwest*. Research Contribution 1; Forest Research Laboratory, Oregon State University: Corvallis, OR, USA, 1993.

Koutsianitis D., Tsioras P.A. 2017 - *Time consumption and production costs of two small-scale wood harvesting systems in northern Greece*. Small-scale Forestry 16 (1): 19-35.

Leszczyński K., Stańczykiewicz A. 2015 - *Workload analysis in logging technology employing a processor aggregated with a farm tractor.* Forest systems 24 (2). 3 p.

Liepiņš K., Lazdiņš A., Liepiņš J., Prindulis U. 2015 - *Productivity and cost-effectiveness of mechanized and motor-manual harvesting of grey alder (*Alnus incana *(L.) Moench): a Case Study in Latvia.* Small-scale forestry 14 (4): 493-506.

Liu S., Corcoran T.J. 1993 - *Road and landing spacing under the consideration of surface dimension of road and landing*. Journal of Forest Engineering 5: 49–53.

Lortz D., Kluender R., McCoy W., Stokes B., Klepac J. 1997 - *Manual felling time and productivity in southern pine forests*. Forest Product Journal 47 (10): 59-63.

Macrì G., Russo D., Zimbalatti G., Proto A.R. 2016 - *Measuring the mobility parameters of tree-length forwarding systems using GPS technology in the Southern Italy forestry*. Agronomy Research 14 (3): 836–845.

Masson S., Greek M. 2006 - *Woodlot Management Home Study Course-Small Scale Harvesting Equipment.* Halifax, NS, Canada: Nova Scotia Department of Natural Resources.

Melemez K., Tunay M., Emir T. 2014 - *A comparison of productivity in five small-scale harvesting systems.* Small-scale Forestry 13: 35–45. doi.org/10.1007/s11842-013-9239-1

Menemencioglu K., Acar H. 2004 - *Ormancilikta bolmeden cikarma calismalarinda transport planlamasi ve etkileri*. GU Orman Fakültesi Dergisi 4 (2): 143- 163.

Moskalik T., Borz S.A., Dvořák J., Ferencik M., Glushkov S., Muiste P., Lazdiņš A., Styranivsky O. 2017 - *Timber harvesting methods in Eastern European countries: A review.* Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering 38 (2): 231-241.

Munteanu C., Yoshida M., Iordache E., Borz S.A., Ignea G. 2019 - *Performance and cost of downhill cable yarding operations in a group shelterwood system*. Journal of Forest Research: 1-6.

Nakahata C., Aruga K., Uemura R., Saito M., Kanetsuki K. 2014 - *Examining the optimal method to extract logging residues from small-scale forestry in the Nasunogahara area, Tochigi prefecture, Japan.* Small-scale forestry 13 (2): 251-266.

Nurminen T., Korpunen H., Uusitalo J. 2006 - *Time consumption analysis of the mechanized cut-to-length harvesting system*. Silva Fennica 40 (2): 335–363.

Olsen E.D., Kellogg L.L. 1983 - *Comparison of time study techniques for evaluating logging production*. Transactions of the ASAE 26 (6): 1665–1668.

Özturk T. 2010 - *Productivity of New Holland farm tractor at beech stands on mountainous areas in Black Sea Region*. Forestry Ideas 16 (1): 52-57.

Özturk T., Senturk N. 2010 - *Productivity and time studies of MB Trac 900 tractor at beech stands on mountainous areas in Turkey*. Baltic Forestry 16:132–137.

Philip M.S. 1994 - *Measuring Trees and Forests.* CAB International: Oxford, UK.

Picchio R., Neri F., Maesano M., Savelli S., Sirna A., Blasi S., Baldini S., Marchi E. 2011 - *Growth effects of thinning damage in a Corsican pine (*Pinus laricio *Poiret) stand in central Italy.* Forest Ecology and Management 262: 237–243.

Picchio R., Sirna A., Sperandio G., Spina R., Verani S. 2012 - *Mechanized harvesting of eucalypt coppice for biomass production using high mechanization level*. Croatian Journal of Forest Engineering 33: 15-24.

Picchio R., Spina R., Calienno L., Venanzi R., Lo Monaco A. 2016 - *Forest operations for implementing silvicultural treatments for multiple purposes*. Italian Journal of Agronomy 11: 156-161.

Proto A.R., Bacenetti J., Macrì G., Fiala M., Zimbalatti G. 2016a - *Mechanisation of different logging operations: Environmental impact assessment using life cycle assessment (LCA) approach*. Chemical Engineering Transactions 58: 229-234. https://10.3303/CET1758039

Proto A.R., Bacenetti J., Macrì G., Zimbalatti G. 2017 - *Roundwood and bioenergy production from forestry: Environmental impact assessment considering different logging systems.* Journal of Cleaner Production 165: 1485–1498. doi.org/10.1016/j.jclepro.2017.07.227.

Proto A.R., Macrì G., Sorgonà A., Zimbalatti G. 2016b - *Impact of skidding operations on soil physical properties in southern Italy*. Contemporary Engineering Sciences 9 (23): 1095-1104. doi.org/10.12988/ces.2016.68132

Proto A.R., Macrì G., Visser R., Harrill H., Russo D., Zimbalatti G. 2018a - *A case study on the productivity of forwarder extraction in small-scale Southern Italian forests.* Small-Scale Forestry 17 (1): 71–87. https://doi.org/10.1007/s11842-017-9376-z.

Proto A.R., Macrì G., Visser R., Harril H., Russo D., Zimbalatti G. 2018c - *Factors affecting forwarder productivity*. European Journal of Forest Research 137 (2): 143-151. doi.org/10.1007/s10342-017-1088-6.

Proto A.R., Macrì G., Visser R., Russo D., Zimbalatti G. 2018b - *Comparison of timber extraction productivity between winch and grapple skidding: A Case study in Southern Italian Forests.* Forests 9 (2). 61 p.

Pulkki R. 1997 - *Cut-to-length, tree-length or full tree harvesting*. Central Woodlands 1 (3): 22-27.

Russell F., Mortimer D. 2005 - *A review of small-scale harvesting systems in use worldwide and their potential application in Irish forestry*. COFORD, Dublin. 56 p.

Savelli S., Cavalli R., Baldini S., Picchio R. 2010 - *Small scale mechanization of thinning in artificial coniferous plantation*. Croatian Journal of Forest Engineering 31(1): 11-21.

Sbera I. 2007 - *Resursele de lemn şi potenţialul pieţei din România [Wood resources and the market potential in Romania]*. Meridiane Forestiere 2: 3-7.

Spinelli R., Baldini S. 1992 - *Productivity and cost analysis of logging arch used with farm tractor in Mediterranean forest skidding operations*. Investigacion Agraria - Sistemas y Recursos Forestales 1 (2): 211-221.

Spinelli R., Lombardini C., Magagnotti N. 2014 - *The effect of mechanization level and harvesting system on the thinning cost of Mediterranean softwood plantations*. Silva Fennica 48: 1–15.

Spinelli R., Magagnotti N. 2011 - *The effects of introducing modern technology on the financial, labour and energy performance of forest operations in the Italian Alps*. Forest Policy and Economics 13 (7): 520-524. doi.org/10.1016/j.forpol.2011.06.009

Spinelli R., Magagnotti N. 2012 - *Wood extraction with farm tractor and sulky: estimating productivity; cost and energy consumption*. Small-Scale Forestry 11: 73–85. doi.org/10.1007/s11842-011-9169-8.

Stankić I., Poršinsky T., Tomašic Ž., Tonkovic I., Frntic M. 2012 - *Productivity models for operational planning of timber forwarding in Croatia*. Croatian Journal of Forest Engineering 33: 61–78.

UK Forestry Commission 1995 - *Terrain Classification; Technical Note 16/95*. Forestry Commission: Dumfries, UK.

Uotila K., Saksa T., Rantala J., Kiljunen N. 2014 - *Labour consumption models applied to motor-manual pre-commercial thinning in Finland*. Silva Fennica 48 (2): 982. doi. org/10.14214/sf.982.

Zimbalatti G., Proto A.R. 2009 - *Cable logging opportunities for firewood in Calabrian forest*. Biosystems Engineering 102: 63–68. doi.org/10.1016/j.biosystemseng.2008.10.008.

Zimbalatti G., Proto A.R. 2010 - *Productivity of forwarders in south Italy*. In Forest Engineering: Meeting the Needs of the Society and the Environment. Padova: 12-14.