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Comparison of Timber Extraction Productivity between Winch and Grapple Skidding: A Case Study in Southern Italian Forests

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Abstract: Forests in southern Italy are mainly located in mountainous areas, where ground-based extraction is still the most common harvesting technique. In particular, 60% of southern Italy's forests are on slopes with an angle of inclination between 20–60%. The low level of mechanization in forest operations is due to the difficult site conditions, as well as the small-scale characteristics of both the forest owners and the harvesting contractors. The most common work method uses chainsaws to fell the trees, and animals or farm tractors equipped with winches for bunching and extraction. This study assesses the productivity and cost effectiveness of extraction with a purpose-built John Deere 548H skidder, including a comparison of winch and grapple configurations. The results show that the productivity of skidding depends on distance as well as the condition of the skid trail. The number of trees per cycle and volume of each load also had a clear effect. While large purpose-built skidders represent a significant investment, this study demonstrates that the productivity is very high compared to traditional extraction methods and the resulting extraction costs are very competitive. As such, this study indicates that, over time, southern Italian harvesting operations should invest in purpose-built harvesting systems.

Keywords: skidder; mechanization; wood extraction; cost; terrain transport; efficiency

1. Introduction

More than a third of Italy is covered by arboreal and shrub vegetation, equivalent to 35% of the national surface [1]. Out of all the regions of Italy, several regions in South Italy have the largest percentage of forest. In this area, delineated geographically as southern Italy, woodlands are very important, not only in terms of forest production, but also for the variety of typical landscapes that they form. Their economic potential is considerable due to the favourable seasonal conditions, which prolong the vegetative time, consequently increasing productivity levels [2]. In fact, forests in southern Italy present an average increment of 6–8 m^3 ha^{-1} per year and these forests can provide a significant wood resource for the economy of the entire Mediterranean basin with over 1,517,000 ha of forest cover [1]. Making up 32% of the total are beech (*Fagus sylvatica* L.), chestnut (*Castanea sativa* Mill.), Corsican pine (*Pinus nigra* Arnold subsp. *Calabrica Delamare*) and silver fir high forests (*Abies alba* Mill). With improved, more efficient mechanization of harvesting operations, the production of wood-based products could be an increasingly significant resource for the southern Italy economy. In fact, forests and wood represent a basis for economic, environmental and social stability in rural areas and wood harvesting has always represented one of the most important management interventions for the future of forests [3,4]. Additionally, several techniques have been developed during the last fifty years to increase operator productivity, work qualifications and occupational safety [5–7]. However, in these regions, the level of mechanization in harvesting is low: the most common harvesting method can be described as being at an early stage of mechanization [8]. This level of mechanization in forest utilization is due to the site features of the forests, where almost half of the forest areas have slopes of over 40%, prevalence of state ownership with respect to private owners, abundance of coppice stands in comparison to high forests, preponderance of firewood and wooden pole production as opposed to roundwood, the small-scale characteristics of the forest ownership structure (approximately 75% of the forests are owned in parcels of less than 250 hectares) and the small size of many forest enterprises [1,8]. In the Calabrian region of southern Italy, the most widely used means of timber extraction is the farm tractor equipped with forestry winches (87%) [8]; a similar trend is seen in other southern and central Italy regions [9]. The remnant 13% of wood is extracted by tractors with a trailer or bin, cable cranes, forwarders, chutes and animals (horses, mules and oxen) [10]. The use of forestry skidders is largely unknown. Several studies have evaluated the performance of innovative harvesting systems (cable cranes and forwarders) in southern Italy, highlighting profit margins sufficient to justify higher investment costs [11–13]. However, no previous study has analysed the productivity and costs of harvesting using skidders in heterogeneous forests, despite the fact that skidders have been diffused abundantly over the last several decades.

The general knowledge of ground-based harvesting and extraction technology is considerable [14,15]. Several studies have examined skidders in order to find out the influence of different factors on productivity and cost, or to compare different methods (winch versus grapple) in different countries and different terrain and stand conditions [16,17]. Kluender et al. [18] studied the productivity of rubber-tired cable and grapple skidders in southern pine stands in Arkansas: they found that grapple skidders were considerably faster and more productive than cable skidders. In the hilly and mountainous forests of Croatia, wheeled skidders equipped with winches are the most commonly used vehicle for timber skidding after preparatory and selective felling [19], while the use of adapted farming tractors and tractor assemblies has decreased [20]. Mederski et al. [21] compared the productivity of grapple skidders and rope skidders under the same stand conditions in North Poland. Recently, in southern Poland, Kulak et al. [22] evaluated the efficiency of a variety of skidding operations performed in stands. In Romania, the most frequently used harvesting system uses skidders and skidding distance has been found to be one of the most relevant independent variables for explaining the time consumption [23]. In Austria, extraction is predominantly carried out using skidders while cable yarding is commonly used on more difficult and sensitive sites [24]. Over the last decade, numerous studies on skidding were conducted in Iran [25]. Najafi et al. [26] carried out a time study to obtain a mathematical model and to calculate the production cost. Eghtesadi [27] studied the influencing factors on skidding performed by the TAF skidder in relation to several variables (skidding distance, longitudinal slope, number of trees and volume per cycle). Wang et al. [28] mentioned that the skidding cycle time was mainly affected by turn payload size and skidding distance on the Appalachian Mountains (West Virginia). In New Zealand, cable skidders (rather than grapple skidders) remain the preferred machine for extracting felled trees from the felling face to the landing, and were first introduced many decades ago [29]. In particular, the object of a research, conducted in New Zealand in 1987, was to compare the performances of a grapple and a cable skidder working under the same conditions [30]. Based on literature data and on the experience of converting from manual to mechanised systems in other countries, this study focused on the potential benefits of introducing a more mechanised, purpose-built extraction system—specifically a John Deere 548H skidder. The objectives were (1) to calculate the production rates ($m^3 \cdot h^{-1}$) and costs (€$\cdot m^{-3}$) of skidding under South Italy conditions; and (2) to develop models of time consumption and productivity for skidding [16,18,23,26].

2. Materials and Methods

2.1. Study Site

The tests were carried out in the Serre Massif (VV) forest (Figure 1). The work phases were recorded separately at two different test worksites, indicated with the letters A and B. During skidding operations, the machine was constantly monitored, the various work phases were observed using a time and motion study, and the extraction distances were recorded for each cycle. The total number of trees transported was counted and each tree was measured using Huber's formula [31]. The volume of each tree was calculated. The chestnut forest is located at an elevation of 1200 m above sea level. The study was conducted at a selective felling site, which had an area of 4.5 ha with N–E exposition. The forest land is classified as I class for roughness, while the slope is between III and IV class in accordance with the terrain classification of the UK Forestry Commission [32]. The stand density was 800 and 880 trees per hectare for site A and B, respectively. The total volume was 675 m^3 at site A and 585 m^3 at site B. The density of the forest in both sites is generally uniform; small gaps are present only in the areas with lower soil depth. The forest area has a good main road network (25 m ha^{-1}) and is flanked by a provincial road; the trails opened during felling were used as a secondary road network [33]. Site characteristics are described in Table 1.

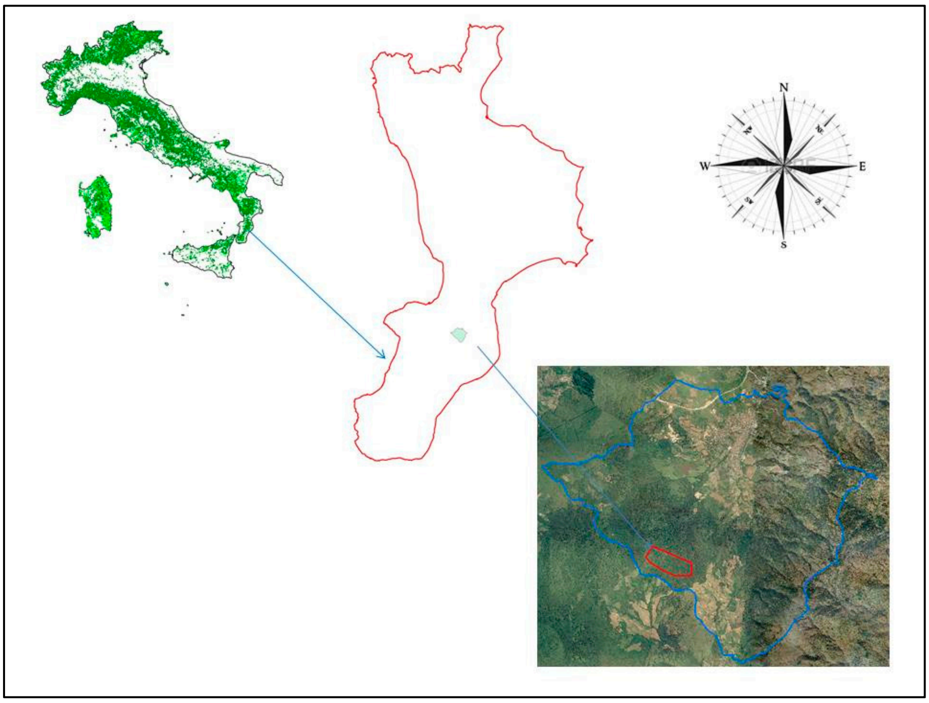

Figure 1. Location of case study.

Table 1. Test site characteristics.

Features	Site A	Site B
Silvicultural system	High forest	High forest
Stand density	800 trees/ha	880 trees/ha
Basal area	36.2 m^2/ha	34.9 m^2/ha
Average DBH	24 cm	22.4 cm
Average height per tree	21 m	20 m
Average volume per tree	0.52 m^3	0.47 m^3
Average Slope	27%	27%
Range of Slopes	23–37%	19–32%

DBH: diameter at breast height.

2.2. Machine Characteristics

The skidder used was a John Deere 548H, equipped with both a cable winch and a grapple (Table 2). At site A, the skidding operation has been conducted using the cable winch because it was not possible to drive up to the felled timber. At site B, the grapple was used as the timber had been felled and pulled to the skid road. Elevation was measured using a handheld Global Positioning System (GPS), Magellan Triton^{TM} 2000 while the gradient was assessed with a Suunto clinometer. Extraction distances were measured with a laser rangefinder. 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 data collected during the phases of winching and skidding allowed the calculation of the hourly productivity of the machine.

Table 2. Specifications of the skidder.

Parameters	Unit	Value
Make		John Deere
Model		548H
Power	kW	110
Weight	tonnes	12.16
Height	mm	3002
Width	mm	2640
Length	mm	6662
Clearance	mm	493
Wheelbase	mm	2920
Grapple area	m^2	0.74
Diameter Winch Cable	mm	15.8
Drum capacity	m	80
Nominal Pulling Force of Winch	kN	193

2.3. Working Systems

The time study data were collected during the autumn of 2016 and the spring of 2017. At both sites, the work system adopted was the Full Tree System (F.T.S.). At site A, the working group consisted of one skidder operator, two choker setters and one operator at the landing site. The operator drove the skidder from the roadside to the felling site, then released the cable for hooking (Figure 2). Loads were attached to the cable by the choker setters, winched to the skid trails, and extracted to the landing area by the skidder. In contrast, at site B, the crew consisted only of two workers: a skidder operator (same as the skidder operator working at site A), who used a skidding grapple to drag the trees to the landing area where the second operator awaited the load.

Figure 2. Extracting trees with a John Deere skidder at site A.

2.4. Productivity and Costs

The study used continuous elemental time study format to determine the total extraction cycle times [34–36]. The extraction cycle was divided into several elements:

- **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
- **Grabbing** (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

The time required for the completion of each phase was measured using a digital chronometer (1 min = 100 units), Tag-HeuerMicrosplit™. Operational, technical and personal delay types were measured in skidding [11].

This study measured the impact of several independent variables: "Skidding distance", "Winching distance", "Number of trees" and "Load Volume" on the "total cycle time", considered as a dependent variable.

In order to calculate the hourly cost of wood extraction, many parameters were considered [37] and the Miyata [38] approach was applied. The machine rate method described by Miyata includes fixed costs, variable costs, and labor costs. The fixed costs (depreciation, interest, insurance, and taxes) were estimated using straight line depreciation [38]. The variable costs comprise fuel, lube and maintenance and repair, calculated as a percent of depreciation. Labor costs included hourly wages plus overheads and fringe costs.

The skidding cost was calculated based on observed productivity. In order to calculate the production cost of extracting 1 m^3 of wood, the cost analysis measured the following parameters: the number of workers, the hourly cost of an operator, the hourly cost of the machine, the volume of wood extracted and productive machine hours. Machine costs per hour are reported as Scheduled Machine Hours (SMHs) (Table 3). The purchase prices and operator wages required for the cost calculations were obtained from catalogues and accounting records. Labor cost was set to 21 € SMH^{-1} inclusive of indirect salary costs. Diesel fuel consumption was measured by evaluating the volume of fuel used to fill the fuel tank to the brim and recording the amount of fuel used during that day. A salvage value of 20% of the purchase price was assumed and the Value Added Tax (VAT) was excluded. Cost calculations were based on the assumption that companies worked throughout the entire year with the exception of the rainy season, when the harvest areas of southern Italy are not normally accessible. In general, this correlates to 130–150 working days in the year (21 working days per month), at an average of 7 scheduled working hours per day (assuming one to two hours spent having lunch, rest and other breaks); it yielded an annual working time of 910–1050 SMHs with a coefficient of utilization of 70% [38–41]. These parameters are slightly lower in comparison to recent economic studies carried out by Mousavi [38], Spinelli and Maganotti [40], Nikooy [41], and have been chosen to represent the reality of small-scale nonindustrial private forestry, which may prevent the intense annual utilization of mechanical equipment.

Table 3. Assumed cost parameters for machine rate calculation.

Parameter	Value	Parameter	Value
Purchase price (€)	200,000	Interest (€ year^{-1})	8960
Salvage value (€)	40,000	Taxes and insurance (€ year^{-1})	10,240
Estimated life (n year)	10	Total fixed cost (€ h^{-1})	33.52
Scheduled machine hour (SMH) (h)	1050	Total variable cost (€ h^{-1})	25.62
Productive machine hour (PMH) (%)	70	Total labour cost (€ h^{-1})	21
Fuel & Lubricant (€ h^{-1})	14.95	Repair & maintenance (€ h^{-1})	10.67
Annual depreciation (€ year^{-1})	16,000	Total hourly cost (€ h^{-1})	80.14

2.5. Data Analyses

The time study data consisted of 80 skidding cycles (40 at each site). Two different techniques were adopted to construct the models for time and productivity. A delay-free time model was formed separately for each time element and a model for total time was formed by combining the elements. SPSS software version 20.0 (IBM Corp., Amonk, NY, USA) was used for the statistical analysis of the compiled data. A regression model was thus developed. Initially, a 95% significance level was chosen to test the null and alternative hypotheses given above. An *F*-test was conducted to examine the goodness of fit of regression models and to test the cosignificance of the coefficients. Each coefficient of the work phase models was also tested separately using a *t*-test. If the test results indicated *p*-values lower than 0.05, the null hypothesis was rejected and the differences in the time were due to treatments as reported in similar studies on the performance of skidders [16,17,25,28].

Regression analysis with variable transformation was used to model skidding: the total cycle time could be explained by the independent variables (number of trees, average volume, skidding distance, winching distance and number of trees). An additional variable was inserted to differentiate the two work sites: site A = 0 for the cable skidder and site B = 1 for the grapple skidder. Finally, the total time of a working cycle has been defined by summing the time for the individual cycle work phases.

3. Results

3.1. Elemental Time Study and Efficiency Analysis

At site A, the average number of trees extracted per cycle was 7, the average skidding distance was 276 m, the average and maximum winching distances were respectively 34 and 65 m, and the average volume skidded per turn was 3.88 m^3. At site B, the average number of trees per turn was 8, the average skidding distance was 266 m, and the volume per turn was 4.01 m^3. Travel loaded and travel unloaded were the two main time elements, and winching only occurred at site A. On average, the extraction cycle time at site A with the winch was 9.35 min (±1.34 standard deviation (SD)), while at site B the grapple extraction cycle time was 8.75 min (±0.99 SD), with the breakdown of the individual elements shown in Table 4. One confounding effect was the unloaded and loaded travel time. By adding the distance for the travel unloaded and loaded, and dividing it by the distance travelled within that element, it was possible to establish average travels speed. The average speed for travel unloaded was 8.58 km/h at site A and 4.91 km/h at site B. For travel loaded, the average speed was 6.02 km/h at site A and 4.33 km/h at site B. The grapple skidder working at site B traversed a much rougher trail and took considerably longer to travel an equivalent distance in comparison to site A. This off-set the time saving from not having to set chokers and pre-extract the trees to the skidder at site A.

Table 4. Descriptive statistics of the mean value and standard deviation (SD) at sites A and B.

Work Phase	Measurements Unit	Site A Mean	Site A (SD)	Site B Mean	Site B (SD)
Travel unloaded	Minutes	1.93	0.39	3.25	0.35
Hooking/Grabbing	Minutes	1.88	0.36	0.78	0.25
Winching	Minutes	2.00	0.43		
Travel loaded	Minutes	2.75	0.56	3.68	0.53
Unhooking	Minutes	0.59	0.07	0.01	0.00
Delay time	Minutes	0.20	0.03	0.24	0.01
Total time	Minutes	9.35	1.34	8.75	0.99

3.2. Time Consumption and Productivity Models

Table 5 shows the time consumption model of skidding in all work phases, overall time consumption, and the statistical characteristics of both the regression models and the productivity model. The *F*-values and *p*-values show that the presented models are statistically significant. The average skidding productivity at site A was 30.4 m^3 per Productive machine hour (PMH) and 24.8 m^3 per SMH. At site B, the grapple skidder had an average hourly productivity of 35.1 m^3 per effective hour and 28.1 m^3 per gross effective hour. There was no significant difference (p-values: 0.94) in the productivity of skidding of the two methods of extraction (cable winch versus grapple) because of the confounding road effect. Winching time at site A was directly related to winching distance. At both sites, productivity has an inverse relationship with skidding distance and a direct relationship with the volume skidded; therefore, the highest productivity was found when the skidding distance is short and load volume is high. The number of valid observations collected during the tests was large enough to develop a reliable model for predicting cycle time. Two different models for predicting total times were evaluated using linear regression and selecting the independent variables with a step-by-step regression. According to the statistical analysis, the models presented for the work sites are valid ($p < 0.05$). The cycle time equations, calculated for the skidding operations in the two different systems (Cable winch versus Grapple), were correlated with several parameters (Skidding distance (Sd); Winching distance (Wd) and Volume (V), see Tables 6 and 7).

Winching distance, skidding distance and volume ($p < 0.005$) had a significant effect on total cycle time at both sites. Time consumption of unhooking did not show dependency on any of the independent variables. The number of trees ($p > 0.05$) had a reduced and a nonsignificant effect in the model of the total cycle time at both sites. In the productivity models, all variables showed a significant effect. Therefore, two models were developed and the resulting R^2_{adjusted} was used as a measure of the predictive capacity of the equations. The multiple correlation coefficients (R^2) of the two models of total time (Equations (1) and (2)) are 91% and 88% of the total variability for Winch and Grapple, respectively. The productivity model (Equation (3)), which can be used to predict output as a function of the same variables, is highly significant and explains almost 77% of the overall variability. There are significant differences between the two sites ($p < 0.05$).

Table 5. Statistical characteristics of regression analysis-based models.

System	Model	Unstandardised Coefficients		Standardised Coefficients	*t*	Sig.
		B	Std. Error	Beta		
Winch	(Constant)	−4.384	1.844		−2.378	0.023
	Winching distance	0.039	0.015	0.335	2.627	0.013
	Skidding Distance	0.037	0.008	0.570	4.857	0.000
	Volume	0.494	0.154	0.188	3.202	0.003
Grapple	(Constant)	2.505	0.387		6.4171	0.000
	Skidding Distance	0.017	0.002	0.765	10.885	0.000
	Volume	0.402	0.113	0.250	3.554	0.001

Table 6. Cycle time and productivity equations for sites A (cable skidder) and B (grapple skidder).

Site	Model		Equation	*F*	*P*	$R^2_{adjusted}$
A	Tot time	Equation (1)	$Tt = -4.384 + 0.039 \times \text{Wd (m)} + 0.037 \times \text{Sd (m)} + 0.494 \times \text{V (m}^3\text{)}$	133.3	0.00	0.91
B	Tot time	Equation (2)	$Tt = 2.505 + 0.017 \times \text{Sd (m)} + 0.402 \times \text{V (m}^3\text{)}$	151.3	0.00	0.88
	Productivity	Equation (3)	$P = 23.95 - 0.072 \times \text{Sd (m)} + 4.833 \times \text{V (m}^3\text{)} + 1.833 \times \text{St}$	91.6	0.00	0.77

Wd = Winching distance, Sd = Skidding Distance, V = Volume, St = Skidding type (0 = cable skidder; 1 = grapple skidder).

Table 7. Results of the analysis of variance on the productivity.

Factor	Model	Sum of Squares	*Df*	Mean Square	*F*	Sig.
Productivity	Regression	1188.896	3	396.299	91.653	0.000
	Residual	328.616	76	4.324		
	Total	1517.512	79			

Dependent Variable: Productivity.

3.3. Production Cost

The hourly cost of the skidder was €80.14 including the sum of machine cost and labour cost; the difference between the minimum and maximum cost of skidding was not considerable. The calculated extraction costs were €5.80 m^{-3} at site A and €3.60 m^{-3} at site B. In particular, there was lower measured productivity at site A due to the amount of time taken to complete a cycle and, consequently, higher unit costs in comparison to site B. Operational delay and technical delay accounted for almost 92% of the delay time and the percentage of personal delay was low. The total delay time was only 15% of the skidding time, and was low in comparison with other skid cycle elements. Delay times increase the operating cost by 18% at both sites and production costs increase when both the skidding distance and the load volume increases. Increasing each variable on this machine causes an increase in cost; skidding cost per cubic meter decreases only when the utilization increases.

4. Discussion

A few studies on skidding with traditional methods, such as using a farm tractor equipped with a skidding grapple or cable winch, have been carried out in central and southern Italy [36,42,43]. However, to date, no detailed time study has been performed on wood extraction using a purpose-built skidder. This study provides the cycle time and productivity of skidding, and also introduces partial and overall time consumption models.

Travel unloaded in terrain with a slope greater than 30% limits the skidder speed in downhill skidding because the skidder must perform the return leg of the trip uphill—increasing the time consumption (8.58 km/h at site A and 4.91 km/h at site B). At both sites, modeling the travel unloaded time showed that the time was highly dependent on the skidding distance, consistent with Wang et al. [28]. The amount of time spent travelling unloaded was the second largest element of the skidding cycle at both sites (21% at site A, 41% at site B).

Mousavi et al. [25] found that the winching phase can be modelled solely based on the winching distance; however, the condition of the cable, winch drum, understory trees and worker conditions may influence the time consumption of releasing. Underbrush may have an impact when the cable is pulled and the chokers are set. More time is required to prepare a load for skidding under heavy brush conditions [16].

When the number of trees in each cycle increases, the time consumption of hooking also increases. Attaching and releasing the chokers manually at site A took twice as long as grabbing and releasing the trees with the grapple at site B.

The winching phase at site A accounted for 21% of the total cycle time. The regression analysis conducted on winching cycle time has revealed that the winching distance as well as the number of winched trees significantly affected the time consumption.

Travel loaded is the most time-consuming element of skidding at both sites: 30% of the total cycle time at site A and 46% at site B. Similar to travel unloaded, travel loaded is strongly related to skidding distances and is also influenced by the number of trees. These findings are consistent with the results of studies by Wang et al. [28] and Mousavi [16,25].

Nevertheless, Wang et al. [28] found that unhooking time depends on butt diameter, average merchantable length, and number of logs per cycle. The comparison of the total operating cycle for winch skidding and grapple skidding revealed no significant differences between the two methods when operating on reasonably level terrain under the described conditions, although there were some differences in the specific phase components. For the total operating cycle under both methods, over 50 percent of the variation in cycle time was accounted for by the travel unload and travel load times. The model indicates that the most important factor affecting skidding productivity is skidding distance, and that comes only after other more important elements, such as load volume, winching distance and the number of trees [44]. There is little doubt that skidding distance significantly affected skid cycle time and productivity [18,45,46]. Productivity was high compared to the literature data on skidding with traditional methods. For example, Spinelli and Magagnotti [36] calculated a range from 1.5 to 7.9 m^3 PMH^{-1} using four wheel-drive farm tractors, with a nominal power ranging from 48 to 116 kW; in high forest, Calafatello et al. [43] measured a lower value of productivity of 6 m^3/PMH using a farm tractor equipped with a winch. The productivity of skidding in this study was similar and sometimes higher in comparison to the other studies conducted with other skidders. For example, in a similar study, Behjou et al. [47] showed that the production rate of a Timberjack 450C wheeled skidder was 22.93 m^3 PMH^{-1} in the Caspian forest over a distance of 300 m and Lotfalian [46] calculated (for the same wheeled skidder) a net and gross production rate of 20.2 PMH and 16.6 m^3 SMH, respectively, at a skidding distance of 980 m. Kulak et al. [22] monitored a similar John Deere grapple skidder, reporting efficiency of 14 m^3 h^{-1} PMH at a distance of 250 m. Borz et al. [23] measured the productivity of a TAF 657 wheeled winch skidder in the Romanian Carpathians, at a skidding distance of 1000 m. They found a net and gross production rate of 7.7 PMH and 3.75 SMH m^3 h^{-1}, respectively. In Northern Iran, Mousavi et al. [17] calculated a productivity of 7.1 m^3 PMH using a HSM-904 skidder. The unit cost of skidding was €4.50 m^{-3} at site A and €3.90 m^{-3} at site B, which is similar to other studies. Horvat et al. [19] reported that, for a skidding distance of 300 m using an Ecotrac 120 V skidder in the Croatian mountains, the costs amount to €4.88 m^{-3} for a hilly working site. Lotfalian et al. [46] reported that the unit cost in the Caspian region, considering the gross and net production rate, was €4.7 m^{-3} and €5.7 m^{-3}, respectively.

5. Conclusions

A work and time study of full tree skidding was performed using a John Deere 548H at two sites of chestnut high forest in southern Italy. The relationship between the time consumption and independent variables was introduced as a model for two methods of skidding (cable winch versus grapple). Two regression equations were developed for the total cycle time, and the results indicated that the total time was related to the number of logs per turn, distance, and load volume. The comparison of the two extraction methods in this study clearly shows that productivity depends primarily on skidding distance. Skidder efficiency in a full-tree system is strongly correlated to both the load volume and the average extraction distance, and is expected to increase with increasing volume, but decrease with increasing average extraction distances. The results obtained confirm high productivity through using a grapple, as previously reported in literature [18,29,30,39]. The presence of this innovative, articulated machine purpose-built for skidding logs has attracted particular interest in the forestry industry. Wood extraction has always been challenging, especially in mountainous environments, as in southern Italy, where the slope causes processing limitations [48]. The levels of productivity measured in this research far exceed the average productivity of a typical traditional skidding process and, taking into account the vast incidence of forests cover in southern Italy, the data presented appears to be very significant. In fact, the model developed by this paper may be useful in production organization when dealing with similar work conditions. The numerous observations recorded in this study confirm that this type of machine is a good investment, allowing high levels of productivity. The results of this study can be used to set the piece rate, in the rationalization of work, in work scheduling, and in cost estimation. Based on this study, it can be concluded that the investigated skidder is a highly productive machine that requires professional planning and supervision of work to obtain an improvement in productivity. In Italy, a specific license of competence for the skidder driver is not mandatory. This situation can penalise the performance of the skidder during the first periods of utilization despite similar studies [49,50] that have demonstrated that the costs of a training course can be recovered within a short period. Assuming an average annual utilization of 910 h year^{-1} and an average hourly productivity of 10 m^3 h^{-1} (which is lower than the values observed in this study), the skidder would harvest 9100 m^3 year^{-1} with a net profit for the owners of almost €8–10 per m^3 on the basis of the current conditions of timber markets. Therefore, the volume of trees needed to be cut in order to compensate the initial capital investment of purchasing this skidder is assessed to be around 25,000 m^3 in a period of less than three years.

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