Research paper

Productivity and Cost of a Small-scale Timber Forwarding System Using Farm Tractors in the Hyrcanian Forest, Northern Iran

Meghdad Jourgholami[1,2)]

【Summary】

Tractor-based systems are the most common type of small-scale forestry equipment. In the Hyrcanian Forest of northern Iran, farm tractors equipped with a 2-wheel trailer are mostly used to perform forwarding operations of pulpwood and fuelwood for with small-scale timber harvesting. A continuous time study was conducted on pulpwood and fuelwood forwarding using farm tractors in the Hyrcanian Forest, to assess farm tractor productivity and costs and develop time regression models and estimate forwarding costs. The analysis indicated that two of the most important factor affecting forwarding productivity are the skidding distance and number of logs per turn. The average hourly productivity values of forwarding with farm tractors were estimated to be 2.66 and 3.83 m^3 for pulpwood and fuelwood, respectively. When the skidding distance increased, the total time of a cycle increased. The productivity of farm tractors logarithmically decreased with extraction distance. The cost of the farm tractor forwarding system was US$50.85 per productive machine hour. Hourly costs of using farm tractors for pulpwood and fuelwood forwarding were US$13.3 and 19.1 m^{-3}. The cost of farm tractor forwarding increased by a simple power equation as the extraction distance increased. The loading phase required the largest time per trip, because of manual loading and physical handling of logs that was a labor-intensive operation. In conclusion, a forwarding operation has advantages such as larger payloads, and transporting logs off the ground that are good alternatives in order to extract pulpwood and fuelwood from gentle slopes of the Hycanian Forest.

Key words: small-scale timber extraction, farm tractor, pulpwood, fuelwood, time study.

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研究報告

應用農用曳引機於伊朗北部Hyrcanian森林小規模木材運送之生產力與成本分析

Meghdad Jourgholami[1,2)]

摘 要

曳引機是普遍使用在小規模林業的設備，在伊朗北部Hyrcanian森林常使用兩輪曳引機來載運小規模收穫的紙漿材及薪炭材。為評估農用曳引機使用於紙漿材及薪炭材的生產力及成本，應用連續測時法來發展時間迴歸模型及估算集運成本。研究指出，每迴次的集運距離與原木數量兩項因子是影響生產力最重要的因子。農用曳引機平均每小時可集運的紙漿材與薪炭材分別為2.66及3.83立方公尺，隨著集運距離增加，每迴次作業時間亦增加，生產力隨伐採距離增加而呈對數遞減，每小時機器生產成本(PMH)為50.85美元，換算每立方尺紙漿材與薪炭材成本分別為13.3及19.1美元，集運成本隨伐採距離之簡單乘函數而增加，因為裝載及原木處理需要人工密集操作，故每趟裝載則需要花最多的時間。總之，農用曳引機具裝載量大及可將原木牽引離開地面的優點，可為將紙漿材及薪炭材運出平緩Hycanian森林的建議作業模式。

關鍵詞：小規模木材伐採、農用曳引機、紙漿材、薪炭材、工時研究。

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INTRODUCTION

In many countries, small-scale timber harvesting usually implies the use of inexpensive machinery operated on a part-time basis (Russell and Mortimer 2005). Farm tractors can be modified and used as wheeled skidders. These modifications usually include a logging winch, roll-over protective canopy, a blade, belly pan protection, valve stem protection, wheel chains, and wheel weights (Conway 1984, Greulich et al. 1999, Russell and Mortimer 2005). With such modifications, farm tractors can be an excellent choice for small, private forests or in developing countries where farm machinery is often easier to obtain than specialized forestry equipment (Rodriguez and Fellow 1986, Dykstra and Heinrich 1996, Shaffer 1998, Updegraff and Blinn 2000, Akay 2005, Sessions et al. 2007). Kent et al. (2011) found that small-scale harvesting and extraction methods had extensively been studied and found to be technically feasible in both conifer and broadleaf stands.

Turner et al. (1988) found that on a range of site conditions, tractors produced 3.77 m^3 per scheduled hour. At full-time tractor operation of 1800 scheduled hours per year, producing 6782.6 m^3, the machine cost was US$1.49 m^{-3} for an average skidding distance of 267.7 m. Huyler and LeDoux (1989) and LeDoux and Huyler (1992) developed prediction equations for estimating the cycle time for 5 small tractors studied under various silvicultural treatments and operating conditions. They measured variables included slope yarding distance, turn volume, logs per turn, and volume per log. Results showed that as the slope yarding distance increased, the cost per volume produced increased. Spinelli and Baldini (1992) studied the applicability of logging arches used with farm tractors. Sowa et al. (2007) studied the costs of timber harvesting using the NIAB 5-15 processor mounted on a farm tractor. Susnjar et al. (2008) conducted a morphological analysis of 9 different types of tractor assemblies used in forestry practice in timber forwarding of thinning operations of lowland forests. Turk and Gumus (2010) found that variables such as the slope of the area, volume of logs, number of log, class of the ground, and features of the ground were the most important effective factors for log skidding with farm tractors. Magagnotti and Spinelli (2011) found that integration of horse bunching with tractor skidding proved cheaper than direct tractor skidding, and allowed the distance range of horse skidding to be extended. Spinelli and Magagnotti (2012) developed a productivity model for skidding timber with wheeled farm tractors, equipped with a winch and sulky and indicated that depending on the tractor power and piece size, the average turn volume and productivity could exceed 2 m^3 per cycle and 4 m^3 per scheduled machine hour (SMH), respectively.

In the Hyrcanian Forest of northern Iran, small-scale harvesting operations include tractor forwarding and mule skidding. Jourgholami et al. (2008) found that the hourly production of hauling with mules (m^3 h^{-1}) with delay time, for hauling of lumber uphill and downhill were 1.00 and 1.20 m^3 h^{-1}, respectively and without a delay time were 1.21 and 1.50 m^3 h^{-1}, respectively. Jourgholami (2012) indicated that hourly production rates of hauling with mules were 0.84, 0.52, and 0.42 m^3 for sawn-lumber, pulpwood, and fuelwood, respectively. However, few studies on timber extraction with farm tractor have been conducted in forests of northern Iran. Gilanipoor et al. (2012) studied the productivity and costs of farm tractor skidding and found that effective independent variables of skidding time were the skidding distance and the slope of the skid trail. Average productivity rates ranged 2.43~2.60 m^3 h^{-1} of total time and effective time, respectively.

Most of the harvested trees in northern forests have a large diameter and heavy crown, and are used to produce pulpwood and fuelwood after delimbing operations. The logs are extracted with ground-based skidding systems, and the remaining wood is forwarded with farm tractors and hauled with mules. The objective of this study was to carry out a comprehensive time study of farm tractors equipped with a trailer for pulpwood and fuelwood forwarding, to develop a model for the time consumption and productivity, find the production rate, and production costs, determine the influencing factors on time consumption and farm tractor forwarding productivity, and provide an appropriate system to replace the traditional mule logging operations.

MATERIALS AND METHODS

Study site

The research was carried out in Compartments 311 and 319 of Gorazbon District, at the Kheyrud Educational and Research Forest Station in the Hyrcanian Forest region, northern Iran. The elevation of the compartments ranges 1050~1270 m and the forest lies on a southern aspect. The average rainfall ranges 1150~1260 mm yr^{-1}, the heaviest rainfall occurs in summer and autumn and the forest stands are unevenly aged. Table 1 summarizes

Table 1. Some characteristics of the study site

Compartment no.	Area (ha)	Terrain slope (%)	Average growing stock (m^3 ha^{-1})	Stand density (trees ha^{-1})	Total removed trees	Total volume of removed trees (m^3)
311	27.8	34	289.1	273	240 (9 trees ha^{-1})	940.2 (33.8 m^3 ha^{-1})
319	42.7	22	555.2	255	210 (5 trees ha^{-1})	1177.3 (27.5 m^3 ha^{-1})

some characteristics of the study site. This area is dominated by natural forests containing native mixed deciduous tree species including *Fagus orientalis*, *Carpinus betulus*, *Alnus subcordata*, and *Quercus castaneifolia*. The silvicultural regime is selection based, with harvesting as a combination of group selection and single tree selection. Field data were collected in October 2012. The combination of timber type and topography limits mechanization to the transport function. The felling, limbing, topping, and on-site processing of trees are motor-manual (Jourgholami 2012).

Fig. 1. UTB/Universal 650 farm tractor equipped with a 2-wheel trailer forwarding pulpwood from the forest in the study area.

Farm tractor forwarding system

A farm tractor model UTB/Universal 650 equipped with a trailer for forwarding pulpwood and fuelwod from the forest in the study area was used on gentler slopes (Fig. 1). Because of differences between types of wood, 2 separate studies were carried out, for pulpwood (usually 2.2~2.8 m in length and 10~20 cm in diameter) and fuelwood forwarding. Technical specifications of the farm tractor equipped with a trailer are as follows: a 2-wheel drive vehicle with a UTB/Universal 650 Engine UTB, diesel, 4-cylinder, 290.5 in^3 (4.8 L) engine, a fuel capacity of 98.0 L, a weight of 3999 kg, engine power of 62 hp (46.2 kW), a length of 414 cm, a width of 199 cm, and a height of 260 cm.

Time study

The basic cycle time used for this study was the farm tractor forwarding turn around time, that is, the time from when the tractor leaves the landing until it returns with the wood. In this study, the time concept introduced by Bjorheden and Thompson (1995) was used. A time-motion study was carried out to evaluate machine productivity and identify those variables that are most likely to affect it. Each forwarding cycle was individually timed with a stopwatch, separating productive time from delay time. The elements which make up the cycle were traveling empty, loading, traveling loaded and unloading. In addition to these productive elements, there was a single delay category. Any time during the study that was not spent in one of the 4 productive time elements was categorized as delay. In addition to measuring the mule hauling cycle time with a stopwatch, independent variables expected to affect mule hauling productivity were documented. There are 3 kinds of delay time (Mousavi 2009). Personal delay time included any interruption or non-working time such as resting or any other breaks related to the personnel. Technical delays were of different types including breaking the chain saw chain and replacing a new one, sharpening of the chain, pinching the chain, and down time of the skidder, loader, and truck. Operational delays were related to inappropriate planning. For example, in forwarding, loading, and hauling, when a log was not ready for skidding or the operator had to wait for logs to be prepared.

In forwarding with the farm tractor, time consumption, volume per turn, number of logs per turn, slope, and extraction distance were recorded for each turn. A reversible metric tape and a diameter tape were used to measure log lengths and diameters. In this study, the volume of pulpwood was calculated using Huber's formula ($V = g_m{*}L$), where, V is volume of logs in cubic meters (m^3), g_m is basal area in the average of logs in square meter (m^2), and L is the length of logs in meters (m). In general terms, timber of higher value is sampled with greater intensity or using a more-precise measurement method than timber of lower value. A stack measurement[1)] method was used to measure the fuelwood volume, and the conversion factor for fuelwood volume was 0.8 m^3. In order to measure the slope of the skid trail, a Suunto Clinometer (Suunto, Vantaa, Finland) was used, and a measuring tape was used to determine the extraction distance. The operators of the tractors were skilful and had more than 15 yr of work experience in different conditions, and there were 4 persons (1 as a farm tractor operator and 3 for manually intensive loading and physically handling logs in the loading phase). In order to determine the required samples, 10 cycles of hauling were timed prior to the main study to estimate the variance of the forwarding cycle time without delays. Finally, 55 observations were studied each for forwarding of pulpwood and fuelwood. Also, 10% of the observations were used for model validation. The statistical program SPSS 15.0 (SPSS, Chicago, IL. USA) was used to create cycle time models based on a stepwise regression. In the study, a multivariate regression was used to model time consumption of pulpwood and fuelwood forwarding with the farm tractor. An hourly production rate ($m^3\ h^{-1}$) of the farm tractor was estimated using the production volume and time data collected during the time study (Eq. 1):

$$\text{Production rate} = TP/TT; \qquad (1)$$

where, TP is the total extracted volume (m^3), and TT is total machine time (h).

Operational cost

The operation cost of the farm tractor was based on the fixed cost and variable cost. The system cost was calculated by totaling the machine cost and labor cost. For cost calculations, instructions prepared for harvesting planning by an Iranian forest organization were used (Mousavi 2009). This machine cost was then divided by the estimated production rate ($m^3\ h^{-1}$) at a given forwarding distance to estimate the forwarding cost per unit of volume (US\$ m^{-3}). A purchase price of US\$14,000 was used in the machine cost estimating model, and the annual interest rate was set to 19%. A machine life of 20 yr was assumed. The insurance and tax rate and utilization rate were set to 5 and 71.4%, respectively. The productive machine hour (PH) and scheduled machine hour (SH) for the skidder were considered to be 900 and 1260 h, respectively (Eq. 2):

$$U = \frac{SH}{PH} = \frac{180 \times 7}{180 \times 5} = 71.4; \qquad (2)$$

where U is the utilization rate (%), SH is the scheduled machine hour (h), and PH is the productive machine hour (h).

The labor cost for the forwarding operation depends on the number of people that are involved in each phase, the salary of each worker, and the length of time they are hired to do the work. In Iran, almost all workers in the company are paid monthly. The hourly cost is derived from the monthly salary divided by the annual production hours. The forwarding operation using the farm tractor typically involves a crew of 4 people (Eq. 2):

$$LC = \frac{\text{Total labor cost}}{\text{Productive hour}}; \quad (3)$$

The unit cost of production in different work phases was calculated by dividing the system cost by the average productivity per hour (Eq. 4):

$$\text{Unit cost (US\$m}^{-3}\text{)} = \frac{\text{System cost (US\$h}^{-1}\text{)}}{\text{Average productvity (m}^{3}\text{ h}^{-1}\text{)}}. \quad (4)$$

RESULTS

Time study variables

Table 2 summarizes the time study variables for farm tractor forwarding of pulpwood and fuelwood. The forwarding distance for fuelwood ranged 49~387 m and averaged 215.7 m, while the forwarding distance for pulpwood ranged 40~419 m with an average of 222 m. The volume per turn for fuelwood forwarding was 1.15~2.77 m^3 with an average of 1.97 m^3, while the volume per turn for pulpwood forwarding was 0.88~4.07 m^3 with an average of 2.62 m^3. The total delay-free time for forwarding fuelwood varied 18.38~53.09 min with an average of 37.52 min, while the total forwarding time was 18.38~96.03 min with an average of 44.3 min. However, the total delay-free time for forwarding pulpwood ranged 18.83~52.58 min with an average of 33.11 min, while the total forwarding time was 20.73~128.6 min with an average of 40.99 min.

The travel empty times for fuelwood and pulpwood fowarding averaged 5.06 and 5.16 min, respectively. The average load times were 24.23 and 18.4 min for fuelwood and pulpwood fowarding, respectively. The most time-consuming component of the total forwarding cycle for fuelwood and pulpwood was the loading time. Travel loaded times for fuelwood and pulpwood fowarding averaged

Table 2. Summary of time study variables for farm tractor forwarding of pulpwood (Pulp) and fuelwood (Fuel)

Parameter	Traveling empty (min)		Loading (min)		Traveling loaded (min)		Unloading (min)		Refueling time (min)		Meal & Rest time (min)		Personal time (min)		Technical delays (min)	
Wood type	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel
Average	5.16	5.06	18.4	24.23	7.02	5.87	2.54	2.35	0.24	0.6	2.4	4.47	1.67	0.67	2.93	0.48
Minimum	1.02	1.7	10.81	8.81	2.16	1.03	0.98	0.88	0	0	0	0	0	0	0	0
Maximum	9.06	7.58	30.2	39.1	12.75	12.51	4.88	4.31	4.28	5.36	32.68	46.2	46.25	12.28	85.7	8.67
Std. deviation	2.04	1.46	4.39	6.35	3.07	2.17	0.87	0.93	0.96	1.53	8.24	12.5	7.48	2.44	13.56	1.94

Parameter	Operational delay (min)		Total delay (min)		Delay-free time (min)		Total cycle time (min)		Number of logs per turn		Volume per turn (m^3)		Extraction distance (m)		Slope (%)	
Wood type	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel	Pulp	Fuel
Average	0.63	0.55	5.23	1.71	33.11	37.52	40.99	44.3	38.34	78.46	2.62	1.97	222.0	215.7	11.9	11.3
Minimum	0	0	0	0	18.83	18.38	20.73	18.38	20	61	0.88	1.15	40	49	7	7
Maximum	15.33	15.41	85.7	20.47	52.58	53.09	128.6	96.03	54	98	4.07	2.77	419	387	20	18
Std. deviation	2.69	2.74	15.24	4.41	7.94	7.75	18.99	16.25	8.66	9.69	0.79	0.41	102.7	93.64	3.14	3.07

5.87 and 7.02 min, respectively. The average unloading times were 2.35 and 2.54 min for fuelwood and pulpwood fowarding, respectively.

The time consumption distributions of different elements of forwarding fuelwood and pulpwood are presented in Fig. 2. When forwarding fuelwood, the loading time took 54.7% of the gross-effective time. This was the highest followed by traveling loaded, traveling empty, resting and meal time, unloading, delays, and refueling time. With forwarding pulpwood travel, the loading time also was the most time-consuming element, taking up 44.9% of the gross-effective time, followed by traveling unloaded, delays, traveling empty, unloading time, resting and meal time, and refueling time.

A scatter diagram of the total cycle times for pulpwood and fuelwood extraction relative to forwarding distance (Fig. 3) reveals that the cycle time was strongly influenced by the forwarding distance.

Regression model

A regression analysis with a stepwise method between independent variables (number of logs per turn, volume per turn (m^3), extraction distance (m), and slope (%)) and forwarding cycle time for fuelwood extraction as the dependent variable was employed to predict the forwarding time for the data collected. A stepwise regression analysis revealed that the forwarding cycle time for fuelwood extraction depended on the extraction distance and number of logs per turn, and thus a forwarding cycle time regression model was developed using the extraction distance and number of logs per turn as independent variables (Eq. 5). Statistical significance was checked by an *F*-test of the overall fit and *t*-tests for individual parameters (Table 3).

$$Y = 12.59588 + 0.06899X_1 - 0.1796X_2; \quad (5)$$

where Y is the forwarding cycle time for fuelwood (min), X_1 is the extraction distance (m), and X_2 is the number of logs per turn.

A regression analysis with a stepwise method between independent variables (number of logs per turn, volume per turn (m^3), extraction distance (m), and slope (%)) and forwarding cycle time for pulpwood extraction as dependent variable was employed to predict the forwarding time for the data collected. A stepwise regression analysis revealed that the forwarding cycle time for pulpwood extraction depended on the

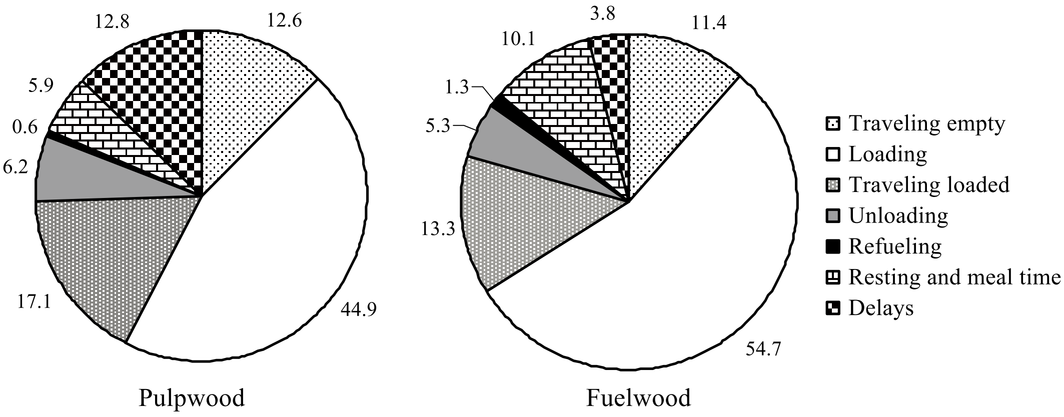

Fig. 2. Elemental time consumption of forwarding pulpwood (a) and fuelwood (b) with a farm tractor.

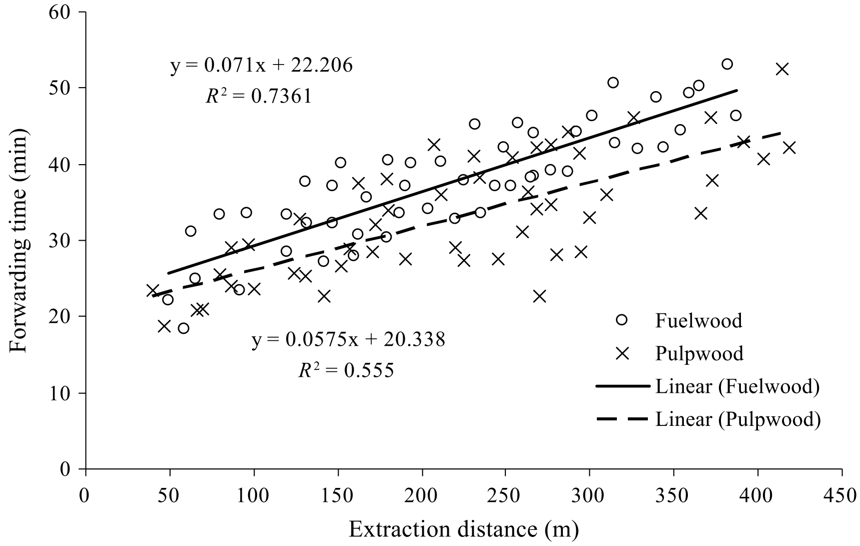

Fig. 3. Relationship between the time of forwarding pulpwood and fuelwood (Y) and extraction distance (X).

Table 3. ANOVA model of the time regression model for fuelwood forwarding with a farm tractor

Source	Sum of squares	d.f.	Mean square	F-value	R^2 (%)	p value
Regression	2238.38	2	1119.18	74.88	76.1	0.000
Residual	702.42	47	14.94			
Total	2940.8	49				

extraction distance, and thus a forwarding cycle time regression model was developed using the extraction distance as the independent variable (Eq. 6). Statistical significance was checked by an F-test of the overall fit and t-tests for individual parameters (Table 4).

$$Y = 20.33759 + 0.05754X_1; \quad (6)$$

where Y is the forwarding cycle time for pulpwood (min), and X_1 is the extraction distance (m).

Production rate

The average gross productivity (the average productivity with delay time) and net productivity (the average productivity without delay time) of fuelwood forwarding were 2.66 and 3.14 m^3 h^{-1}, respectively. The average gross productivity was 18% less than net productivity with the tractor fuelwood forwarding system. It was found that the production rate of fuelwood forwarding decreased as the skidding distance increased (Fig. 4). A logarithmic regression model was fitted to describe the relationship between the fuelwood forwarding distance and hourly production rates (delay free time), and statistical significance was checked using an F-test of the overall fit and t-tests for individual parameters.

The average gross productivity (the average productivity with delay time) and net productivity (the average productivity without delay time) of pulpwood forwarding were 3.83 and 4.74 m^3 h^{-1}, respectively. The average gross productivity was 24% less than the net productivity with the tractor pulpwood

Table 4. ANOVA model of the time regression model for pulpwood forwarding with a farm tractor

Source	Sum of square	d.f.	Mean square	*F*-value	R^2 (%)	*p* value
Regression	1714.11	1	1714.11	59.86	74.0	0.000
Residual	1374.52	48	28.64			
Total	3088.63	49				

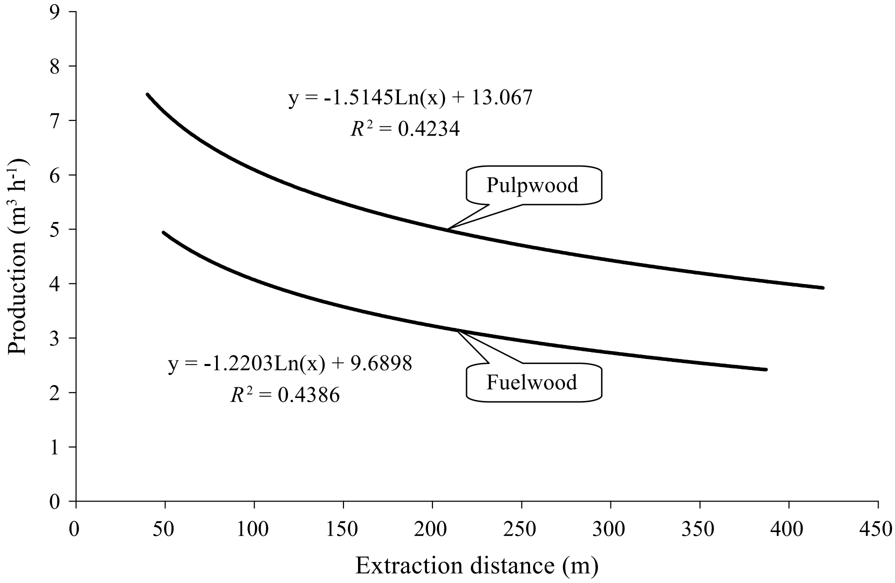

Fig. 4. Relationship between production of forwarding pulpwood and fuelwood (Y) and extraction distance (X).

forwarding system. The regression model and actual volume per turn were used to develop a relation between the productivity rate and pulpwood forwarding distance as it increased (Fig. 4). In pulpwood forwarding, productivity decreased as the skidding distance increased with a logarithmic regression model. The productivity of pulpwood forwarding seemed to have the greatest potential to be affected as the extraction distance increased. The performance rate excluding delays for pulpwood was 51% higher than for fuelwood forwarding. Also, Fig. 4 shows that the production rate for pulpwood forwarding was higher than that for fuelwood for each extraction distance. The independent *t*-test using a levene test (d.f. = 98; $F = 10.71$; $p = 0.001$) revealed that there was a statistically significant difference in net production between pulpwood (5.09 ± 1.34 m^3 h^{-1}) and fuelwood (3.27 ± 0.97 m^3 h^{-1}) forwarding with the farm tractor.

Farm tractor forwarding machine cost

Table 5 summarizes the machine cost estimate for a farm tractor equipped with a trailer. The hourly machine cost was estimated to be US$50.85. The fuelwood forwarding cost including delay times was US$19.1 m^{-3}, while the forwarding cost without delays was estimated to be US$16.2 m^{-3}. The pulpwood forwarding cost including delay times was US$13.3 m^{-3}, while the forwarding cost without delays was estimated to be US$10.7

m^{-3}. The forwarding cost of pulpwood was less than that of fuelwood, because the loading time for fuelwood was greater than the loading time for pulpwood. It was found that cost of fuelwood and pulpwood forwarding increased as the extraction distance increased, and power functions were fitted for each timber type by regression analyses (Fig. 5). Two factors primarily controlled the range of forwarding costs between fuelwood and pulpwood: the skidding distance and volume per turn. The greater forwarding distance at fuelwood extraction and resulting increase in the total travel time (traveling empty and traveling loaded + loading time) accounted for most of the difference in delay-free cycle times between fuelwood and pulpwood.

Table 5. Summary of detailed cost calculation parameters of the farm tractor (prices are for October 2012)

Cost element	Cost (US$) per hour
Fixed costs	
Depreciation	4.66
Interest	2.01
Tax and insurance	0.67
Subtotal (Fixed)	7.34
Operating costs	
Maintenance and repair	5.25
Fuel and lubricant	11.75
Tires	0.51
Subtotal (Operating)	17.51
Hourly labor cost	26
Total hourly machine-operating rate (Fixed + Operating + Labor)	50.85

DISCUSSION

There are various ways to implement forest harvesting with farm-based tractors. Two modified farm tractor logging systems are commonly used. They are (1) a skidder system and (2) a forwarder system (Akay 2005, Kent et al. 2011). In this study, a farm tractor equipped with a 2-wheel trailer was introduced and studied. This study also provided time consumption and productivity data of the forwarding operations using a farm tractor with a 2-wheel trailer for the small-

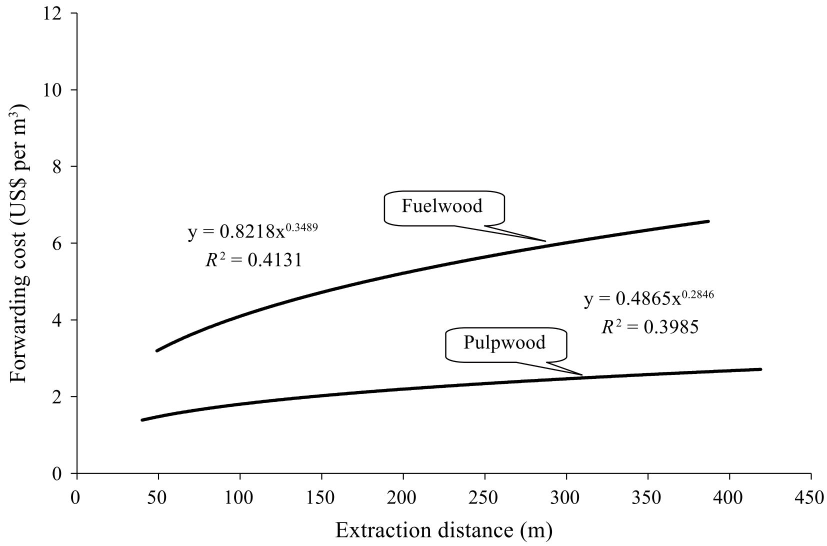

Fig. 5. Relationship between the forwarding cost of the farm tractor (Y) and extraction distance (X).

scale extraction of pulpwood and fuelwood. However, a forwarding operation with a farm tractor requires a greater initial investment than a skidding operation with a farm tractor. Forwarding operations also require a well-planned network and forwarding roads for efficient transportation (Akay 2005).

In this study, the trailer was not equipped with a hydraulic grapple loader to load logs from the roadside and unload them onto the landing. However, the farm tractor used in this study was equipped with a trailer which had a hydraulic compression system to unload logs at the landing. Without the hydraulic grapple loader to load logs, operators were on the ground, physically handling and loading logs most of the time, and their experience would heavily influence productivity. The loading operation of fuelwood and pulpwood on the trailer was done manually, so it required a lot of labor, usually 2 or 3 people were needed for loading operations. These manually intensive extraction methods were labor intensive. Also, these manually intensive extraction methods should preferably be used with small-sized logs. Although economically this forwarding system depends on the power of people, and most of the loading operation was done manually, using a farm tractor in small-scale forestry has several key advantages such as a relatively low initial investment and operating cost, versatility, and less damage to residual trees and forest soils (Dykstra and Heinrich 1996, Shaffer 1998, Akay 2005, Russell and Mortimer 2005). The unit cost of forwarding fuelwood and pulpwood was mostly affected by the labor cost. The labor cost accounted for 51% of the hourly forwarding cost, while only 49% was related to the machine cost. The fixed and operating costs associated with the farm tractor were 15 and 34% of the hourly forwarding cost, respectively. In other words, human labor was still a major part of the work of the forwarding operation with a farm tractor.

The element, time consumption, showed that the loading phase consumed the most time per turn, because of manually intensive loading and physically handling the logs that was a labor-intensive operation. Loading took approximately 54.7 and 44.9%, respectively, of the gross-effective time with both fuelwood and pulpwood forwarding with the farm tractor. However, the trailer was equipped with a hydraulic dump system, so the loading element was easily performed, and the average time was 2.35 min for fuelwood extraction. In fuelwood forwarding, the average empty and loaded travel speeds of the farm tractor were 2.56 and 2.2 km h^{-1}, respectively. The main reason for the slow speed of the tractor in this study that it was equipped it with a 2-wheel trailer, which reduced its maneuverability in forest stands (Spinelli and Baldini 1992, Susnjar et al. 2008). Loaded travel was performed at a lower speed than empty travel when skidding because of the volume per turn. Also in pulpwood forwarding, the average empty and loaded travel speeds of the farm tractor were 2.58 and 1.89 km h^{-1}, respectively.

In this study, variables with the greatest impact on the forwarding cycle time were the extraction distance and number of logs per turn, that is consistent with results of studies by Turner et al. (1988), LeDoux and Huyler (1992), Turk and Gumus (2010), Gilanipoor et al. (2012), and Spinelli and Magagnotti (2012). The time consumed for fuelwood forwarding greatly depends on the extraction distance. A multivariate regression model was constructed to estimate the unloaded travel time as a function of the skidding distance and number of logs per turn. Modeling of pulpwood forwarding showed that it was highly dependent on the extraction distance. The main reason was the relatively low volume per number of logs of fuelwood; in order to provide a sufficient volume per each turn, more logs had to be loaded, and thus, more time was needed for the loading element. We therefore concluded that the forwarding distance was a useful predictor in determining the delay-free forwarding cycle time for fuelwood and pulpwood.

The average gross productivity and net productivity of fuelwood forwarding were 2.66 and 3.14 m^3 h^{-1}, respectively. The average gross productivity and net productivity of pulpwood forwarding were 3.83 and 4.74 m^3 h^{-1}, respectively. The performance rate excluding delays for pulpwood was 51% higher than that for fuelwood forwarding, which is consistent with research by Turner et al. (1988), Spinelli and Magagnotti (2012), and Gilanipoor et al. (2012). Productivity with A farm-based tractor was reported by Turner et al. (1988) to be 3.77 m^3 per scheduled hour, by Spinelli and Magagnotti (2012) to be 2 m^3 per cycle and 4 m^3 per SMH, and by Gilanipoor et al. (2012) to range 2.43~2.60 m^3 h^{-1}.

The net production for pulpwood extraction was higher than the net production for fuelwood forwarding. The main reason for this difference was the reduced loading time for pulpwood because of the appropriate size of the logs. But with fuelwood forwarding, to provide a proper load volume each turn, dozens of pieces of fuelwood should be tied together which caused the loading time to increase. The regression model developed for fuelwood showed that in addition to the forwarding distance, the number of pieces of fuelwood per turn was included in the regression model, and had a direct effect on the fuelwood forwarding cycle time. It was found that the production rates of both fuelwood and pulpwood decreased as the skidding distance increased (LeDoux and Huyler 1992, Turk and Gumus 2010, Kent et al. 2011, Gilanipoor et al. 2012, Spinelli and Magagnotti 2012). Comparing production changes between fuelwood and pulpwood revealed that the net production rate was reduced with an increasing extraction distance as a logarithmic function. Comparison of production trends indicated that for each forwarding distance, the net production of pulpwood extraction was higher than that of fuelwood. With an increasing forwarding distance, the reduction trend for pulpwood production was less than that for fuelwood.

The forwarding cost of pulpwood (US\$13.3 m^{-3}) was less than that of fuelwood (US\$19.1 m^{-3}), because the loading time for fuelwood was greater than that for pulpwood. Unit costs of the forwarding operation increased with increasing distance for both fuelwood and pulpwood, and power functions were fitted for each timber type by regression analyses. Skidding distance considerably affects the hourly cost production of fuelwood and pulpwood (Turner et al. 1988, LeDoux and Huyler 1992, Turk and Gumus 2010, Kent et al. 2011, Gilanipoor et al. 2012, Spinelli and Magagnotti 2012). Delays were 3.8 and 12.8% of the average cycle time in fuelwood and pulpwood forwarding, respectively. The major reasons for technical delays included failure of the compressor, and oil pump, and boiling of water in the radiator.

This study showed that by changing the structure of agricultural tractors and equipping them with an arch, sulky, and forwarding trailer, they can be used for small-scale forest harvesting operations. However, this modification of the farm tractor structure did not help improve safety problems, but farm tractors equipped with a trailer can be used on gentle slopes of the Hyrcanian Forest. Farm tractors used for forestry will require modifications, both to improve functionality and comply with safety standards (Greulich et al. 1999, Updegraff and Blinn 2000, Russell and Mortimer 2005). In the Hyrcanian Forest, large-diameter timber is extracted by wheeled and tracked skidders, while farm tractors can be used for forwarding fuelwood and pulpwood which was obtained by delimbing of the heavy crowns of deciduous trees.

Production by pulpwood and fuelwood forwarding systems was 3~10-times greater than that of mule logging systems (Jourgholami et al. 2008, Jourgholami 2012). Note that the use of farm tractors, especially those that are equipped with a forwarding trailer, is suitable for specific forwarding routes and areas with gentle slopes (areas with slopes of < 15~20%), and this system, as Magagnotti and Spinelli (2011) showed, requires an integrating system such as a mule logging system. Magagnotti and Spinelli (2011) found that the integration of horse bunching with tractor skidding proved cheaper than direct tractor skidding, and allowed the distance range of horse skidding to be extended.

CONCLUSIONS

Traditional mule logging has the ability to work in steeper areas, and integrating traditional horse and mule transportation systems with agricultural tractors could be a suitable alternative for extracting fuelwood and pulpwood from forest stands in the Hyrcanian Forest. Using a trailer on the rear axle of the farm tractor reduced tractor maneuverability, especially in steep areas, and thus increased the loaded travel time. However, the arch, sulky, and skidding winch can be replaced with a forwarding trailer and its results compared to the previous system. However, forwarding operations have advantages over skidding operations such as larger payloads, less soil disturbance, and transporting logs from stump to logging truck off the ground.

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LITERATURE CITED

Akay AE. 2005. Determining cost and productivity of using animals in forest harvesting operations. J Appl Sci Res 1(2):190-5.

Bjorheden R, Thompson MA. 1995. An international nomenclature for forest work study. Paper presented at the XX IUFRO World Congress, Tampere, 6-12 August 1995. 15 p.

Conway S. 1984. Logging practice, principles of timber harvesting systems. San Francisco, CA: Miller Freeman Publications. 460 p.

Dykstra DP, Heinrich R. 1996. FAO model code of forest harvesting practice. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). 130 p.

Gilanipoor N, Najafi A, Heshmatolvaezin SM. 2012. Productivity and cost of farm tractor skidding. J For Sci 58(1):21-6.

Greulich FR, Hanley DP, McNeel JF, Baumgartner D. 1999. A primer for timber harvesting. EB1316. Washington, DC: WSU Cooperative Extension. 33 p.

Huyler NK, LeDoux CB. 1989. Small tractors for harvesting fuelwood in low-volume small diameter hardwood stands. In: Proceedings of the 12th annual meeting of the Council on Forest Engineering, 1989 August 27-30; Coeur d'Alene, ID. Atlanta, GA: US Department of Agriculture, Forest Service, Southern Region. p 61-6.

Jourgholami M. 2012. Small-scale timber harvesting; mule logging in Hyrcanian Forest. Small-scale For 11(2):255-62.

Jourgholami M, Majnounian B, Zobeiri M, Feghhi J. 2008. Evaluation of production and costs of mule logging in down and up slopes (case study: Kheyrud Forest). Iranian J Nat Resources 61(3):625-36. [in Persian with English summary].

Kent T, Kofman PD, Coates E. 2011. Harvesting wood for energy; Cost-effective woodfuel supply chains in Irish forestry. Dublin, Ireland: COFORD. 98 p.

LeDoux CB, Huyler NK. 1992. Cycle-time equations for five small tractors operating in low-volume small-diameter hardwood stands. Research Paper NE-664. Radnor, PA: US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 10 p.

Magagnotti N, Spinelli R. 2011. Integrating animal and mechanical operations in protected areas. Croat J For Engin 32(2):489-99.

Mousavi R. 2009. Comparison of productivity, cost and environmental impacts of two harvesting methods in northern Iran: short-log vs. long-log. PhD thesis. Faculty of Forest Sciences. Joensuu, Finland: Univ. of Joensuu. 93 p.

Purser P. 1999. Timber measurement manual, standard procedures for the measurement of round timber for sale purposes in Ireland. Dublin, Ireland: Forest Service in the Department of the Marine and Natural Resources. 73 p.

Rodriguez EO, Fellow AM. 1986. Wood extraction with oxen and agricultural tractors. FAO Forestry Paper no. 49. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). 121 p.

Russell F, Mortimer D. 2005. A review of small-scale harvesting systems in use worldwide and their potential application in Irish forestry. Dublin, Ireland: COFORD. 48 p.

Sessions J, Boston K, Murphy G, Wing MG, Kellogg L, Pilkerton S, et al. 2007. Harvesting operation in the tropics. Berlin, Germany: Springer-Verlag. 170 p.

Shaffer RM. 1998. Farm tractor logging for woodlot owners. Blacksburg, VA: College of Natural Resources, Virginia Polytechnic Institute and State Univ. 6 p.

Sowa J, Kulak D, Szewczyk G. 2007. Costs and efficiency of timber harvesting by NIAB 5-15 processor mounted on a farm tractor. Croat J For Engin 28(2):177-84.

Spinelli R, Baldini S. 1992. Productivity and cost analysis of logging arch used with farm tractor in Mediterranean forest skidding operations. Inv Agrar-Sist Rec F 1:211-21.

Spinelli R, Magagnotti N. 2012. Wood extraction with farm tractor and sulky: estimating productivity, cost and energy consumption. Small-scale For 11(1):73-85.

Susnjar M, Horvat D, Kristi A, Pandur Z. 2008. Morphological analysis of forest tractor assemblies. Croat J For Engin 29(1):41-51.

Turk Y, Gumus S. 2010. Logs skidding with farm tractors. FORMEC 2010, Forest Engineering: Meeting the Needs of the Society and the Environment, 2010 July 11-14, Padova, Italy. 6 p.

Turner TL, Huyler NK, Bousquet DW. 1988. Farm tractor skidding costs in relation to profitability of a fuelwood harvesting system. North J Appl For 5(3):207-10.

Updegraff K, Blinn CR. 2000. Applications of small-scale forest harvesting equipment in the United States and Canada. Staff Paper Series no. 143. St. Paul, MN: College of Natural Resources and Minnesota Agricultural Experiment Station, Univ. of Minnesota. 51 p.

[1] According to Purser (1999), 'Stack measurement involves the quantification of fuelwood volumes that are stacked at the tractor trailer. There are 2 steps involved in stack measurement: measurement of the stack or gross volume (i.e., the volume of the timber and gaps between it in the stack) and estimation of a conversion factor to apply to the stack volume to give an estimate of the solid or net volume (timber volume).