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# COMPARISON OF PRODUCTIVITY AND COST OF TIMBER EXTRACTION BY FARM TRACTOR, SKIDDING VS. FORWARDING IN NORTHERN IRAN

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**ABSTRACT :** This paper presents research results of the comparing timber extraction using a farm tractor at two different methods including forwarding and skidding. Time studies were conducted to qualify the productivity and the operational cost of logs forwarding and skidding by farm tractor in *cut-to-length* and tree length method in a plantation in even terrain conditions in Shafaroud, Northern Iran. Farm tractor is commonly machines which are used in many part of Iran as Northern part. The models for effective time consumption, total productivity and work phase models are calculated. The time consumption and productivity of log extraction with a farm tractor depends on several variables such as distances and slope, number of logs per cycle and volume. The average load per cycle was 3.84 $m^3$ and 0.5 $m^3$; the average one-way skidding distance was 167 and 233 m, in the forwarding and skidding, respectively. The average travel speeds of unloaded tractor were 4.54 km/h and the average speeds of loaded tractor were 0.39 and 0.82 km/h in forwarding and skidding, respectively. The average output was 3.44 and 1.07 $m^3$/effective hour; the average cost was 5.86 and 19.7 US$/$m^3$ for forwarding and skidding, respectively.

***Keywords :*** *Cost, farm tractor, forwarding, skidding, time consumption.*

In the north of Iran, there are several small patches of aspen plantations which are established by the forest wood companies. Due to the new forest policy in Iran about decreasing the wood removal from natural forests, these plantations are good resource in order to respond the high wood demand in the country. The state-owned forest company manages both relatively small plantations and large areas of natural forest. In 2010, the plantation had reached to the target diameter and was ready for harvesting.

In many regions of the world, farm tractors have been used in forestry where the terrain condition and the size of the forest operation are not limiting. Log extraction with farm tractor is one of traditional extraction system in flat and mid slope area and also small wood procurement area. The productivity of the skidding operation with farm tractor is often limited by the type of soil, terrain condition, and the size of trees and their accessibility. To improve the productivity and efficiency of the skidding operation, directional felling techniques should be applied (Cadorrette, 3). Directional felling may also reduce labor cost, residual stand damage, and soil compaction. Skid trails should be well planned and located in the harvesting unit before directional felling takes place. Winch and grapple is mostly used to perform skidding operation.

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Many studies were carried out that were aimed at productivity and cost of felling and skidding operation and effective hours influencing the machine performance (Klepac and Rummer, 11; Najafai *et al.,* 14, Mousavi, 12). Some independent factors affect the cycle time and consequently the machine productivity (Mousavi *et al.,* 13). Studies indicated that the skidding cycle time was mainly affected by skidding distance (Behjo *et al.,* 2), skid trail slope and the number of logs in each cycle (Jourgholami and Majnounian, 9; Mousavi *et al.,* 13) and interaction between them (Behjo *et al.,* 2).

However the farm tractor is not the main machine for log extraction in Iran but it is used in small wood procurement area which applying skidder is not economically justified. Therefore farm tractor is unique machine for log extraction. The loaded tractor can travel on a skid trail up to 15 % (uphill direction).

Farm tractor can be used in different way for log extraction. The common method for using tractor in logging is skidding operation. Grapple skidding and forwarding are the other methods for wood extraction using farm tractor.

Time consumption of forest harvesting is studied for various reasons. The most typical task is to investigate the main factors affecting work productivity and to establish a base for cost calculation and salaries or payment. A time study is usually done either as a comparative study, or correlation study or a combination of two (Eliasson, 4). The objective of comparative studies is to compare two or several machines, work methods, etc, while the objective of correlation studies is to describe the relationship between performance and the factors influencing the work (Bergstrand, 2). Time studies can be carried out using continuous time study method or repetitive timing or indirect work sampling (Forest Work, 5; Samset, 17; Harstela, 8; Nurminen *et al.,* 15).

The aims of this study were to (1) compare farm tractor skidding and forwarding in order to find the most suitable method for carrying logs; (2) calculate production rates and unit costs of the machine in each method.

## MATERIALS AND METHODS

### *Study stands*

The study was carried out at the Shikhneshin plain in the Shafaroud forest, Guilan province. The terrain is located in plain, and runs at gentle slope in the study area (Table 1). The study area is located between 37°20’ N, and between 49°10’ E (Fig. 1).

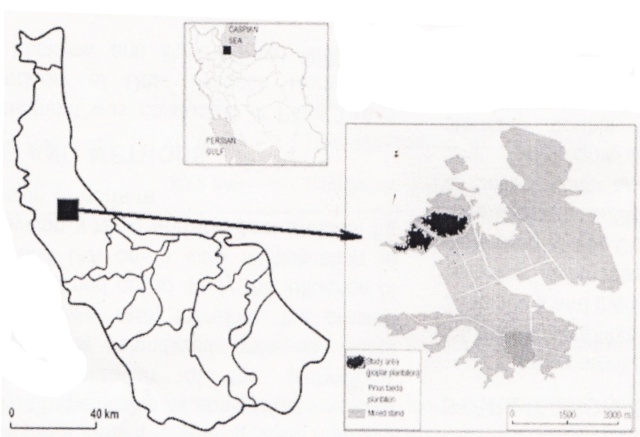



Fig. 1. Map of Study area.

All trees were felled and delimbed with a chainsaw and delivered to the landing with farm tractor through skidding and forwarding. Usually farm tractor travel nearby logs or trees in the cutting area and leaves when full load is provided. Special small truck (5tn) hauls log from roadside to mill.

The specifications of the tractor used for the study are given in the Table 2. The tractors operators had several years of experience and the driver performed all services and most of the repair works.

**Table 1: Stand descriptions for the study area.**

| Study area | |
|---|---|
| Silvicultural treatment | Clear cutting method |
| Elevation range (m) | 25(10-50) |
| Aspect | No Direction |
| Total surface of plantation (ha) | 65.1 |
| Slope (avg.) | 0-5 |
| Regeneration condition | – |
| Crown cover percentage | 80 % |
| Weedy species | *Alder (Alnus glutinosa), Caucasian walnut (Petrocarya fraxinifolia), Chestnut-leaved Oak (Quercus castaneifolia), Persian ironwood* (*Parrotia persica*) |
| Soil pH | 7-8 |
| Gross volume ($m^3$/ha) | 380 |
| Average tree per hectare | 620 |

**Table 2: Technical specifications of tractor model 8502 four wheels drive vehicle.**

| | | | |
|---|---|---|---|
| Length | 3.8 m | Weight | 3114 kg |
| Width | 2.1 m | Power | 75 hp |
| Height | 2.52 m | Distance between two front wheel | 1.35-1.94 m |
| Distance from earth | 0.36 m | Distance between two rare wheel | 1.4-2.13 m |
| Engine power | 80.5 kwt | Fuel tank capacity | 90 lit |

### Forwarding :

**Driving empty:** begins when the tractor leaves the landing area and ends when the tractor stops at working site.

**Collecting the logs:** starts when the worker loads the logs and ends when the loading is completed. Collecting time can also be divided to sub elements such as reaching the pile, lifting the logs, and sorting and handling the logs in the tractor.

**Travel loaded:** begins when the tractor moves to the landing and ends when the tractor reaches the landing area.

**Unloading:** starts when the tractor stops at the landing area and ends when the last load is lifted onto pile.

### Skidding :

**Driving empty:** begins when the tractor leaves the landing area and ends when the tractor stops at working site.

**Maneuvering:** begins when tractor reaches to cutting area and end when he starts to release the cable

**Collecting time:** starts when the worker releases the cable and ends when the logs reach the machine.

**Travel loaded:** begins when the tractor starts to move on skid trail and ends when the tractor is on the landing.

**Unhooking:** begins when the tractor driver leaves the tractor and ends when he opens the cable.

### *Data collection*

Field studies concentrated on collecting operational and financial data that are essential for subsequent evaluation. The Nordic Forest Work Study Council (NSR) time concept is used for data collection. Delays are recorded as technical, personal and operational delays. Personal delay, any interruption or non-working time such as resting or any other breaks related to the personnel were placed in this category. Technical delay has different types including any interruption in the work due to break down of the machine and other technical failure during the working time. Operational delay is related to inappropriate planning. For example, when there was no accessible fuel in working time and therefore should be brought from another place, or required spare parts are unavailable, it was put in this category. Technical delay is largely inevitable, while operational delay and personal delay can be avoided or significantly decreased.

No attempt was made to normalize individual performance by means of productivity rating, recognizing that all kind of normalization or correction can introduce new sources of errors and uncontrolled variation in the data material (Gullberg, 7; Spinelli and Magagnotti, 18). All work phases were recorded just as if the operators were in a normal working condition without any special arrangements. A number of variables including forwarding and skidding distances, number of logs per turn and load volume were measured. In order to develop productivity model for the machine, multiple regression analysis using the least square method was applied to test the correlation among the cycle times and the variable under study. The number of samples needed for a reliable estimate is calculated using related formula (Mousavi, 16). In order to examine the goodness-of-fit of regression models and to test the co-significance of coefficient, an F-test was conducted. Each coefficient of the work phase models was also tested separately by t-test. The null hypotheses were rejected if the test results indicated p-values higher than 0.05 that the null hypotheses were not true and the differences in the time consumption resulted only from random variation.

### *Cost calculation*

The operation cost of the farm tractor was based on fixed cost and variable cost. Total costs were calculated by totaling machine cost and labor cost (Table 3). Fixed costs included cost for interest, depreciation and tax and insurance. The interest rate was 20%. The depreciation was calculated assuming an economic life of 5 years. Salvage value is 25% of purchase price. The fuel consumption rate was 13 liters/hour. The lubricants costs were assumed to be the 30 % of the fuel cost.

**Table 3: Summary of detailed machine cost calculation parameters.**

| Cost factor | Cost | Cost factor | Cost |
|---|---|---|---|
| Purchase price, US$ | 16300 | Interest ( annually), US$ | 2282 |
| Salvage value, US$ | 4075 | Deprecation (annually), USD$ | 2445 |
| Economic life, years | 5 | Tax and insurance (annually), US$ | 472 |
| Tire life, hours | 3000 | Total fixed cost, US$/PMH | 5.8 |
| Tire price, US$ | 200(Front)<br>800(Rear) | Maintenance and repair, US$/PMH | 1.47 |
| Number of tires | 4-6 | Fuel and lubricate cost, US$/hour | 4.82 |
| Repair factor, f | 0.9 | Tire cost, US$/hour | 2.9-3.3 |
| SMH (annually), hours | 1200 | Total variable cost, US$ /hour | 6.33 |
| PMH (annually), hours | 900 | Total labor cost, US$/hour | 9.6 |
| Utilization, % Ut = (PMH×100 / SMH) | 75 % | Total cost (system cost), US$/hour | 21.7 |

SMH= scheduled machine hour, PMH= productive machine hour

## RESULTS AND DISCUSSION

### *Time consumption and productivity*

Average, minimum, and maximum time of timber extraction as a proportion of total gross-effective time was calculated for forwarding and skidding. In order to calculate this, the value of each element in each cycle was divided by the total gross-effective time. The average, in addition to the ranges, of all cycles is given in Table 4.Travel loaded was the most time consuming element of skidding and forwarding and it is followed by collecting the logs.

**Table 4: Average time elements of wood extraction as a proportion of gross-effective time. The range of time proportions is shown in brackets.**

| Processing Element | Forwarding, % | Skidding, % |
|---|---|---|
| Travel unloaded | 3.51 (1.65-7.96) | 9.72 (2.9-21.7) |
| Maneuvering | | 3.26 (0.89-16.18) |
| Collecting logs | 34.2 (19.64-41.06) | 35.25(13.98-68.3) |
| Travel loaded | 40.22 (22.5-55.1) | 47.5 (24.08-68.08) |
| Unloading | 18.29 (5.38-44.78 ) | |
| Opening the cable | | 0.79(0.4-1.13) |
| Delay | 3.79 (0.0-10.16)] | 1.58 (0-14.23) |

Figure 2 shows distribution of different kind of delays in two methods. In forwarding, operational delay was the most time consuming which is followed by personal delay and technical delay. In skidding, personal delay was the most time consuming elements which is followed by technical delay and operational delay. Delays took 1.5- 3.8 % of gross effective time in the forwarding and skidding method, respectively. It means delay time is not significant part of work in both methods.

Table 5 shows the detailed time study results for the forwarding and skidding. The mean values of different elements were used in constructing the total time consumption model for the elements which did not depend on any variables (Table 6).

**Table 5: Characteristics of timber extracted by farm tractor.**

| Harvesting item | Forwarding | Skidding |
|---|---|---|
| Study duration day (total observation time) | 6 | 5 |
| Total volume extracted, $m^3$ | 119.07 | 87.7 |
| Avg. number of logs per turn | 63.2 | 3.5 |
| Min. number of logs per turn | 25 | 1 |
| Max. number of logs per turn | 100 | 6 |
| Avg. log diameter, cm | 25.0 | 26.6 |
| Avg. log length, m | 1.20 | 16.5 |
| Av. distance , m | 167 | 233 |
| Min. distance, m | 85 | 53 |
| Max. distance, m | 250 | 480 |

A summary of skidding opeartion with farm tractor under two diffrent extraction system is presented in Table 7. The average time consumption of forwarding was 96 % higher than in skidding while total productivity of forwarding was 2.3 times higher than in the skidding.

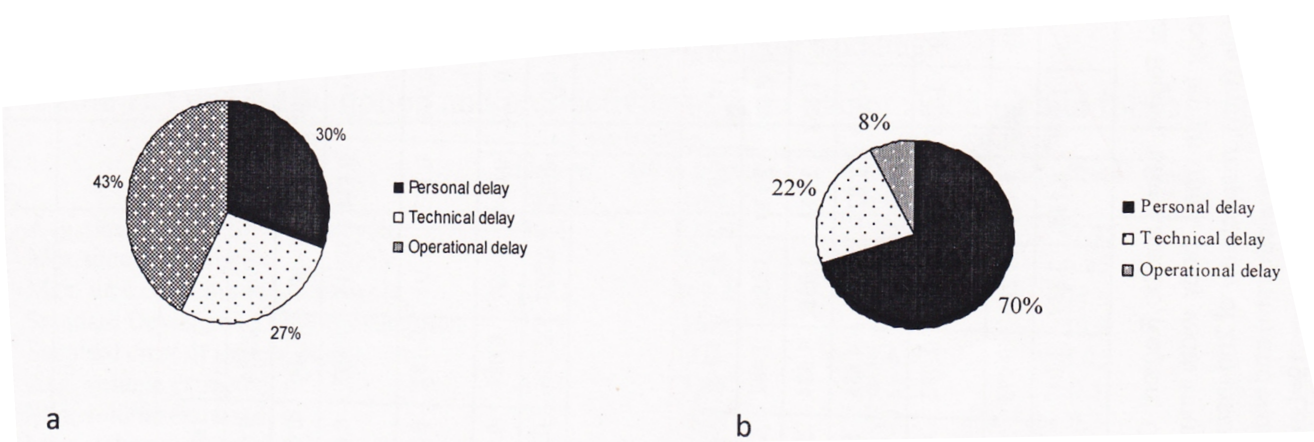



Figure 2. Distribution of different time consumption of delay in forwarding (a), skidding (b) with farm tractor.

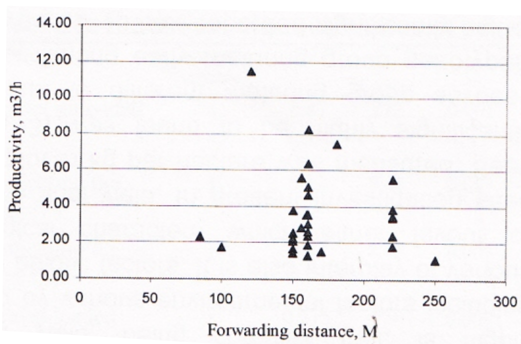
**Table 6 : Descriptive statistics of mean value based work phase model.**

| Element | Method | Parameter minute | Mean min/cycle | Min., min/cycle | Max., min/cycle | Std. dev. | N |
|---|---|---|---|---|---|---|---|
| Maneuvering | Skidding | $t_{s2}$ | 0.9 | 0.47 | 1.75 | 0.27 | 82 |
| Unhooking | | $t_{s5}$ | 0.29 | 0.06 | 0.59 | 0.12 | 82 |
| Delay (gross productivity) | | $t_{s6}$ | 1.58 | 0.0 | 14.23 | 3.58 | 82 |
| Unloading | Forwarding | $t_{f4}$ | 12.55 | 3.2 | 19.2 | 4.06 | 30 |
| Delay | | $t_{f5}$ | 2.65 | 0.0 | 7.10 | 2.06 | 30 |

**Table 7: Time consumption and productivity of farm tractor skidding and forwarding.**

| | Forwarding | | Skidding | |
|---|---|---|---|---|
| | Effective time | Gross-effective time | Effective time | Gross-effective time |
| Avg. time consumption min/cycle | 70.4 | 73.06 | 35.77 | 37.35 |
| Min. time consumoption, min/cycle | 33 | 36.4 | 6.85 | 6.85 |
| Max. time consumption min/cycle | 107.3 | 109.4 | 71.06 | 74.6 |
| Standard Deviation of time consumption | 18.1 | 18.4 | 15 | 15.9 |
| Standard error of time consumption | 3.3 | 3.3 | 1.6 | 1.75 |
| Avg. volume extracted, $m^3$ | 3.84 | 3.84 | 0.5 | 0.5 |
| Min. volume extracted, $m^3$ | 1.3 | 1.3 | 0.2 | 0.2 |
| Max. volume extracted, $m^3$ | 6.8 | 6.8 | 0.99 | 0.99 |
| Avg. productivity, $m^3$/hour | 3.59 | 3.44 | 1.07 | 1.04 |
| Min. productivity, $m^3$/hour | 1.11 | 1.07 | 0.21 | 0.19 |
| Max. productivity, $m^3$/hour | 11.46 | 10.49 | 4.13 | 4.13 |
| Standard Deviation of productivity, | 2.37 | 2.22 | 0.77 | 0.77 |
| Standard error of productivity | 0.43 | 0.4 | 0.08 | 0.08 |
| Number of observations | 30 | 30 | 82 | 82 |

Figure 3 shows the scatter plots of skidding distance and productivity. Cycle time increases with increasing skidding distance which could lead to decrease in productivity.



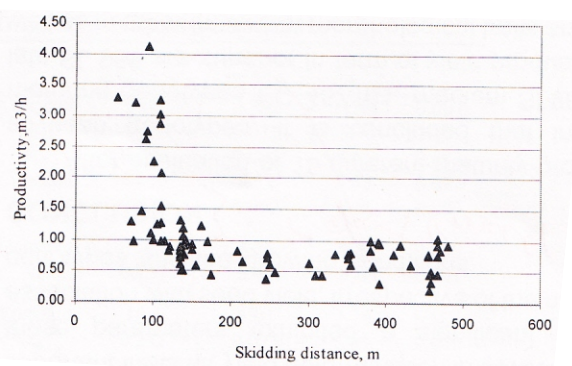




Figure 3: Scatter plots of productivity at different distances in the forwarding (a) and skidding (b) with farm tractor.

log is low and volume skidded is high. The figure is based on the productivity model.

Table 7 shows the time consumption model of skidding in all work phases, overall time consumption,

## *Total time consumption and productivity model*

The effect of two of the most important variables in skidding (skidded volume and number of logs) on its productivity is given in Figure 4. In both system, productivity has an inverse relationship with number of logs and direct relation with volume skidded; therefore the highest productivity was found when the number of

and productivity model. Total time consumption model of skidding is calculated by summing up different elements of skidding. The statistical characteristics of the regression models for skidding are also presented in the Table 8. F-value and P-value show the presented models are statistically significant.

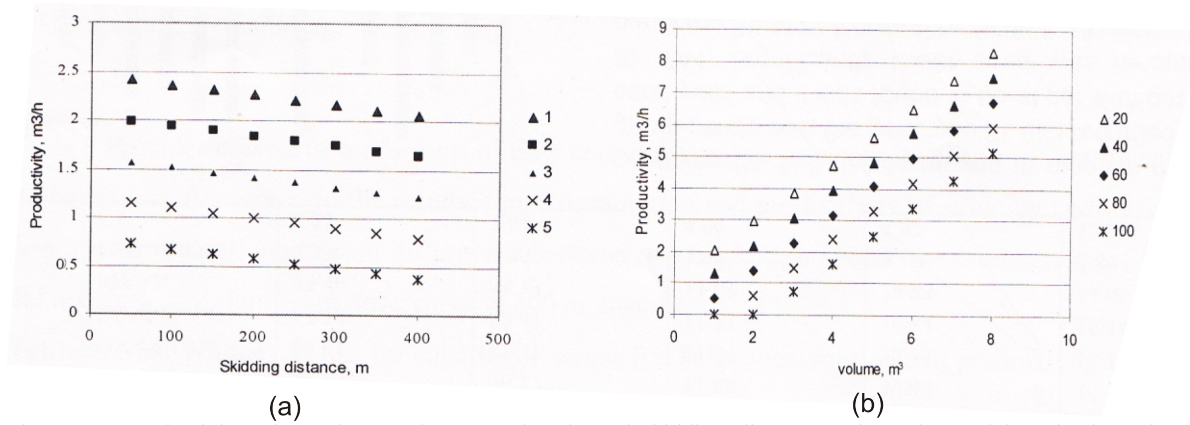



Figure 4 : Productivity of wood extraction as a function of skidding distance and numbeer of logs in farm factor skidding (a) and volume and number of logs in farm tractor forwarding (b)

**Table 8: Statistical characteristics of regression analysis based models.**

| Model | Dependent variable | $R^2$ | F-test: F-value | F-test: P | N | Term | Constant/ coefficient | Estimated SE | t-test: t-value | t-test: P |
|---|---|---|---|---|---|---|---|---|---|---|
| Travel unloaded | $t_1$ | 0.87 | 272 | 0.001 | 82 | Constant<br>$x_{fd}$<br>$x_{sp}$ | 3.46<br>-0.129<br>0.006 | 0.302<br>0.015<br>0.001 | 11.48<br>-8.75<br>8.55 | 0.001<br>0.001<br>0.001 |
| Collecting the logs (F) | $t_2$ | 0.22 | 8.45 | 0.007 | 32 | Constant<br>$x_n$ | 14.15<br>0.179 | 4.12<br>0.062 | 3.43<br>2.9 | 0.002<br>0.007 |
| Collecting the logs (S) | $t_3$ | 0.22 | 8.45 | 0.007 | 32 | Constant<br>$x_n$ | -1.528<br>04.37 | 1.76<br>0.47 | -0.86<br>9.3 | 0.039<br>0.001 |
| Travel loaded (F) | $t_3$ | 0.215 | 7.9 | 0.009 | 36 | Constant<br>$x_n$ | 16.5<br>0.212 | 5.03<br>0.075 | 3.28<br>2.81 | 0.003<br>0.009 |
| Travel loaded (S) | $t_4$ | 0.74 | 48.4 | 0.001 | 32 | Constant<br>$x_n$<br>$x_{sd}$ | 3.53<br>0.027<br>2.14 | 1.67<br>0.004<br>0.46 | 2.1<br>6.45<br>4.67 | 0.039<br><0.001<br>0.001 |
| Overall time *(F) | $t_o$ | 0.30 | 12.58 | 0.001 | 32 | Constant<br>$x_n$ | 42.2<br>0.45 | 8.4<br>0.126 | 5.02<br>3.5 | 0.001<br>0.001 |
| Overall time (S) | $t_o$ | 0.66 | 75.2 | 0.001 | 32 | Constant<br>$x_{sd}$<br>$x_n$ | 2.50<br>6.27<br>0.048 | 2.96<br>0.814<br>0.008 | 0.85<br>7.70<br>6.4 | 0.04<br><0.001<br>0.001 |
| Productivity (F) | $p_{ef}$ | 0.77 | 47.5 | <0.001 | 32 | Constant<br>$x_v$<br>$x_n$ | 1.95<br>0.892<br>-0.031 | 0.854<br>0.114<br>0.009 | 2.28<br>7.8<br>-3.29 | 0.03<br><0.001<br>0.003 |
| Productivity (S) | $p_{es}$ | 0.62 | 43.3 | <0.001 | 32 | Constant<br>$x_n$<br>$x_v$<br>$x_{sd}$ | 1.724<br>-0.421<br>2.317<br>-0.001 | 0.191<br>0.048<br>0.363<br>0.00 | 9.044<br>-8.85<br>6.37<br>-3.63 | <0.001<br><0.001<br>0.001<br>0.001 |

F= forwarding, S= skidding, xn= number of logs, xfd= forwarding distance, xsp= speed, xv= volume

Table 9 Provides comparison of means of time consumption and productivity at two different methods

Table 9 : Man Whitney U-test for equality of means for Time consumption and productivity of skidding and forwarding with farm tractor.

| Skidding distance, m | Time consumption Sig. (2- tailed) | Productivity Sig. (2- tailed) |
|---|---|---|
| 0-100 | 0.026 | 1.0 |
| 100-150 | 0.001 | 0.001 |
| 150-200 | 0.001 | 0.001 |
| 200-250 | 0.005 | 0.001 |

using statistical test. According to the results, time consumption and productivity of skidding and forwarding with farm tractor showed significant differences between two method, however the productivity of two methods did not show any significant differences at 100 m distances.

Figure 5 (a,b,c,d) and 6 (a,b,c,d) shows the error box plot of mean time consumption and confidence interval of time consumption and productivity at different distances, respectively. Same value on each bar in a figure shows that there are no differences between mean of time consumption of two methods.

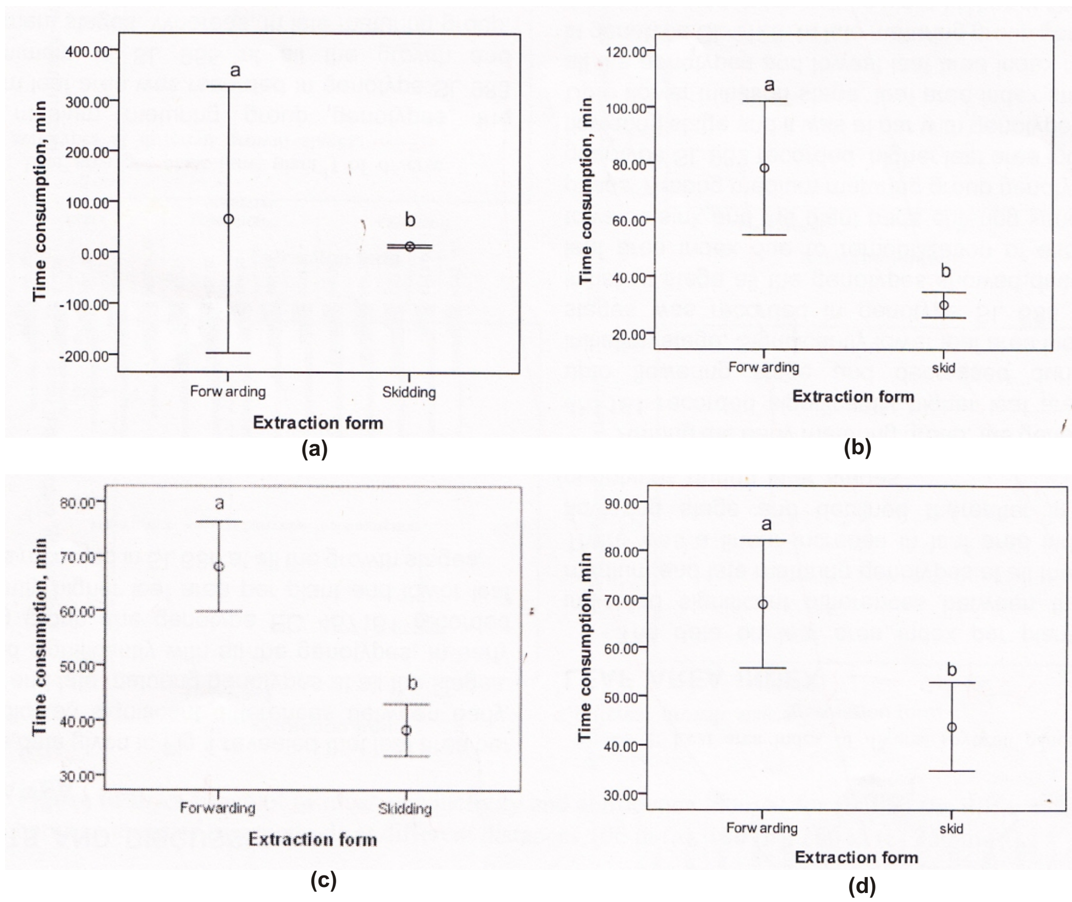



Figure 5: Error box plot of mean time consumption and confidence interval for finding the differences between mean of two methods at different distances,100 m (a), 150 (b), 200 m (c) 250 m (d).

## PRODUCTION COST

### *Production cost of farm tractor*

The average production cost of log extraction in the forwarding and skidding is 6.7 and US$22.9/m$^3$. The production cost of skidding was 2.4 times higher than in forwarding. The production cost of skidding in each cycle varied from 5.9 to US$117/m$^3$ and 2.1 to US$ 21.8 /m$^3$ in forwarding.

The purpose of this study was to compare the productivity and cost of farm tractor performance using two methods, skidding and forwarding, while the other variables were kept constant. Data collected in spring and good weather condition, the results can be used in similar condition. Since the same operator was used for both methods, the variation due to different operators is leveled. Moreover, the working condition and working shifts for both methods was also the same (day time).

Farm tractor is used mainly in agricultural land but depends on the equipment used it can be applied for many other applications. Since there no information about using this machine for wood extraction in gentle or moderate slope condition, this study is important to compare using the machine for wood extraction for finding the most rational methods.

Methodologically, the emphasis of this study was on the comparative area with less attention paid to the correlation aspects. The main problem of the correlation study is the multiplicity of influencing factors which was controlled by a detailed division of harvesting work phase into elements (Bergstrand, 1; Nurminen *et al.,* 15). In the comparative time study, two methods and machines are compared in the similar working condition.

Time consumption of wood extraction with farm tractor is recorded and different elements are recognized and analyzed individually. Time consumption of travel unloaded took around 3.5 and 10 % in forwarding and skidding, respectively. The average speeds of unloaded tractor were 9.2 km per hour. The average speeds of unloaded tractor were

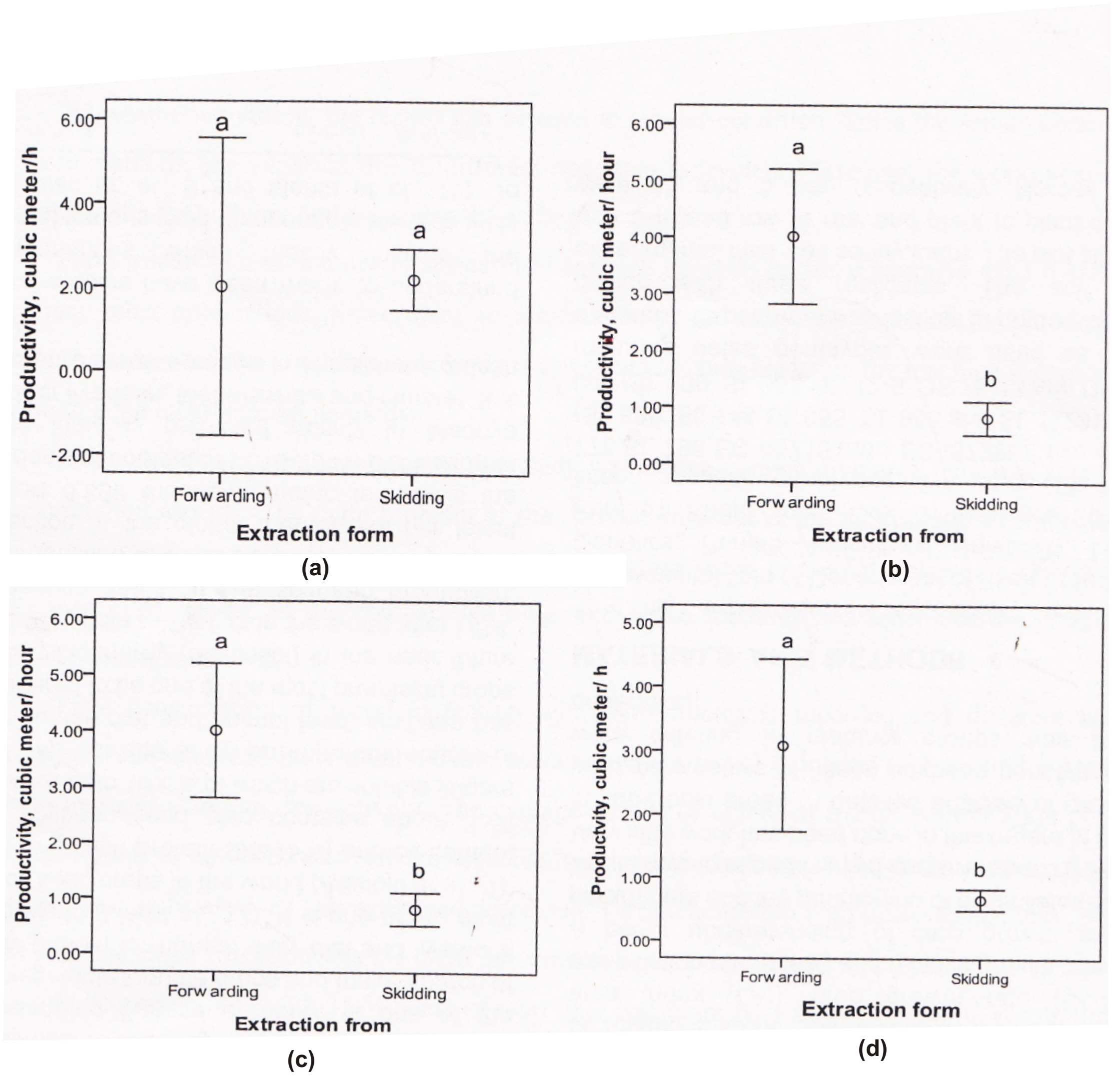



Figure 6: Error box plot of mean productivity and confidence interval for finding the differences between mean of two methods at different distances,100 m (a), 150 (b), 200 m (c) 250 m (d).

sensitive to extraction distance. In the study, in spite of general rule, with increasing distance, an average speed decreased. Terrain condition with micro topography, stump on the skid path and slope condition was the main influencing factor on the speed.

Collecting the log with 35 % share of total time consumption was the most time consuming elements of wood extraction in both method. Random trees felling and not using directional felling were the main reason for high time consumption of these elements in the both method. Time consumption of collecting log was directly related to the number of logs. Travel loaded was one of the most important elements of wood extraction in the both methods. It took roughly 40 % of total time consumption in both of the methods. The average speed of loaded tractor in forwarding was 53 % less than skidding, however the average volume per cycle in forwarding was 7 times higher than in skidding. The time consumption of travel loaded in forwarding was related to the number of logs while travel loaded in skidding was related to the number of logs and skidding distances. Similar to unloading, time consumption of travel loaded was sensitive to skidding distance. In spite of travel unloaded, with increasing distance, the travel speed of tractor increased in the both of extraction form. The terrain condition especially favorite slope was the main reason for increasing speed.

Time consumption of unhooking and unloading did not show any relevance with any variable. Nevertheless, Wang *et al.* (20) found that unhooking time depends on butt diameter, average merchantable length, and number of felled stems per cycle. Time consumption of extraction with farm tractor whether the logs is skidded or forwarded involves delay times. Delay times are time that is not related to effective working time. Delay time is unwanted time consumption in each work phase. Delay time is not expected to occur regularly but literature and work studies suggest it is likely. In forwarding, Operational delay took 43 % of share which was higher which it is followed by personal delay and technical delay while in skidding, personal delay took 70 % of total share which was the highest. It is followed by technical delay and operational delay.

Extraction distance is the single most important variable affecting skidding cost and productivity. If other variables stay constant, the further a machine has to travel from the logs to the landing, the lower will be the productivity (Özturk, 16). The other important variables on the productivity and cost of forest machine are stem size. Small stem size increases handling time which it influences cycle time. As a general rule, with increasing cycle time, production rate decreases which finally increase production cost. It has been proved by Kahala (10) and Jourgholami and Majnounian (9).

Production rate for farm tractor forwarding was 3.59 $m^3$ per effective hour which was 3 times higher than in skidding form. The variation of production rate was 1.11 to 11.4 $m^3$ per hour in forwarding and 0.2 to 4.13 $m^3$ per effective hour in skidding. The highest productivity in forwarding form, achieved when extraction distance was short and the number of logs was less. In skidding, the highest productivity was only when the time consumption of travel loaded and collecting log and, and number of log per cycle were the lowest. Productivity for this study in forwarding form was 47% higher than in Gilanipoor (6) study's using the same type of tractor but in skidding form was 77% less than his studies in mountainous area. In the study by Spinelli and Maganotti (18), the productivity varied from 2 $m^3$ (when piece size was small) to 8 $m^3$ per Scheduled Machine Hour (when piece size was large). The highest productivity which is reported was in Turkey in average skidding distance of 140 m by 11.35 $m^3$/effective hour while it is decreased to 7.7 $m^3$ per hour at 320 m (Özturk, 16).

In comparison with skidder in the same area, skidding with farm tractor had productivity roughly 6 times less than in skidding with cable skidder (Timberjack 45°C) and Grapple skidder (HSM-904). However in forwarding form, the production rate was only around 2 times less than in forest machines (skidder). The main reason for such a difference can be higher maneuverability and compatibility of forest machine for doing the job. Productivity of the study in forwarding form was almost the same as the productivity which is reported by Turner *et al.* (19).

Production cost is one of the most important issues using different machine and system. The production cost of cable skidding and grapple skidding was 3.7 and 2.3 times higher than in farm tractors forwarding, respectively, however in skidding form, it was even higher than in skidding with forest machine (Table 10).

Production cost of this study in forwarding form was 3.7 per cent and in skidding form was 3 times higher than in the study was done by Turner *et al.* (29). Further study can be done with applying qualified and trained workers and improving loading performance and it's influence on the study results.

**Table 10: Production cost of different machine in the study area.**

| Machine | Grapple skidder | Cable skidder | Farm tractor forwarding | Farm tractor skidding |
|---|---|---|---|---|
| Cost , US$ /$m^3$ | 20.7 | 12.9 | 6.7 | 22.9 |

## CONCLUSION

The average time consumption of skidding and forwarding for all cycles was 70.4 and 35.77 minutes and the average productivity was 3.59 and 1.07 $m^3$/effective hour.

This study presented a discussion on applying farm tractor in logs skidding and forwarding operation. It should be noted that using farm tractor has several advantages such as relatively low initial investment and operating cost in compare with skidder versatility. However farm tractor logging can be limited by some factors including the terrain condition, ground slope, and timber size. In the study terrain condition was not important issues due to moving vehicle in low slope terrain but existence of frequent obstacle can be hindering factor for decreasing productivity. In order to maintain the advantages and not to be constrained by limitation, the logging managers should develop an effective logging plan that ensures physically feasible and economically viable operations. They should also well understand the capabilities of the farm tractor and functionalities of their equipment to perform an effective farm tractor logging operation.

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