Silva Balcanica, 18(1)/2017

TIME CONSUMPTION AND PRODUCTION COST OF LOG LOADING IN THE HYRCANIAN FOREST USING FRONT-END LOADER

Seyed Rostam Mousavi Mirkala
Urmia University, Faculty of Natural Resources

Ramin Naghdi
University of Guilan, Faculty of Forestry, Somehsara, Department of Forestry, Faculty of Natural Resources, University of Guilan

Abstract

This paper presents the research results of the performance of the loader Volvo 4500 BM (front-end loader) in timber loading in Northern Iran. To evaluate the current loading operations in Hyrcanian forest and possibility of finding out the better techniques and group organization, the empirical time study has been conducted. The elements of loading work phase were identified and 80 cycles were recorded. The models for effective time consumption and total productivity, and also unit cost of loading were introduced. The validity of the model was tested at 95% confidence interval.

According to the results, the average load per cycle was 13.14 m^3; the average time consumption was 25.65 min per payload. The average output was 31.34 m^3/effective hour and loading cost was 1.53 USD/m^3.

The models developed in the study are a promising initial tool to know production rate and cost of loading performance with front-end loader.

Key words: Hyrcanian forest, Iran, loading, front end loader (FEL), time study, cost

INTRODUCTION

Wood transportation from forest to the roadside landing is the most expensive phase of harvesting system and loading works as a link between primary transportation and secondary transportation. Since it has important influence on the productivity of harvesting, it is called bottleneck. Log loading is a key component in any logging system, since it is the means by which forest products (tree-length stems, logs, or bolts) are transferred from the ground to some form of conveyance that completes the transportation cycle (Conway, 1979). The terminal functions of loading and unloading influences directly on hauling productivity. Minimum turn-around time is desired goal. When hauling distance is short, the terminal times should be short; otherwise they will continue too large a part of the total round trip time. A major factor is the choice of loading method and equipment in relation to the volume or weight of timber to be moved.

Loading and unloading of trucks is carried out in a number of different ways. For loading, one will find the whole range between manual work and the mechanized work such as using skidder or tractor (FAO, 1974). In the Iranian condition, log loading is done using a front-end loader. Wheeled skidder machines may also be used for loading by employing an extended arch to give sufficient height to lift one or possible two tiers of logs onto a hauling vehicle.

While there are several studies on skidding in Iran, very few studies on loading have been performed. Azizi (2001) compared loading by GMC self-loading trucks and Volvo BM 4500 front end loader (FEL). The results found that productivity of loading with the GMC was less than the FEL. GMC is basically truck which is equipped with grapple for loading. Naghdi et al. (2009) studied productivity and cost of loading at roadside landing and forest landing. In the forest landing, a special landing was constructed for decking the logs in the forest, but in the undesigned landing, the roadside was used for decking logs. The authors found that the productivity at the forest landing is higher than at the roadside landing.

Typical work methods for studying the harvesting system have been time study, in combination with measures of the production (Ovaskainen, 2009). Time study is one of the most common practices of work measurements (Björheden, 1991). It is defined as analysis of the methods, material, tools and equipment used in the production process (Barnes, 1968; Gonzáles, 2005). The conditions of performing the time study should be as equal to the normal forest work. One of the most remarkable points in it is determining the average work to be able to generalize its production rate so that its results can be generalized to other similar studies (Hamedi Qazi, Mousavi Mirkala, 2016).

Time study is usually done either as a comparative study, a correlation study or a combination of the two (Eliasson, 1998). The objective of a correlation study is to describe the relationship between performance and the factor influencing the work (Samset, 1990; Bergstrand, 1998).

A usual way to assess work methods and machines is through cost calculation, these are also needed when adjusting piece rate and contracting payments and when monitoring operations. An important application of cost calculation is in the estimation of the most economic replacement schedule for a machine.

The aim of this study is to determine the production rates and cost in the loading. The specific objectives of this study are: *i*) to find the production rates (m^3/h) and costs (USD/m^3) of loading operations in the Iranian conditions applying front-end loader; *ii*) to develop a model for time consumption and productivity of loading operations, to determine the partial model of the work phases, and to find the most influencing factors in each work phase.

MATERIAL AND METHODS

Study sites

The research was carried out in Sorkhkola forest, Mazandaran Province, Northern Iran, between 36°11'N and 36°17'N, and 52°17'E and 52°57'E. The tree stand in the study area was dominated by *Fagus orientalis* and *Carpinus betulus* with crown cover exceeding 80%. The average tree diameter was 29.72 cm, the average height was 22.94 m, and stand density was 220 trees/ha. The altitude was approximately 700 m a. s. l., slopes north aspect. The average annual rainfall recorded at the nearest national meteorological station was 1280 mm. The mean maximum monthly rainfall (120 mm) usually occurs in October, while the minimum rainfall (25 mm) occurs in August. The mean annual air temperature is +15˚C, and the lowest air temperatures are recorded in February.

Equipment

Front end loader (FEL), performing loading in Iran. The specification of the machine are as below (Table 1).

Data collection

The time study of loading was conducted in summer 2012. The study covered regular working hours of the machines and operators. A video camera was used for measuring both partial times and accumulated time in minutes and seconds. A reversible metric tape and a tree calipers were used for measuring log lengths and diameters in order to calculate volume.

The number of required samples is calculated by formula [Eq. 1, Eq. 2] (Saarilahti, Isoaho, 1992; Zobeiry, 1994).

$$n = \frac{t^2 \times (S_X\%)^2}{(E\%)^2} \qquad (1)$$

$$S_x\% = \frac{S_X \times 100}{\overline{X}} \qquad (2),$$

where n = sample size;

t = the value from normal distribution table (e.g. t = 1.96 for a 95% confidence interval);

S_x = standard deviation from preliminary inventory;

E = tolerance error for the confidence interval (10%);

$\overline{X}$ = Average value (time consumption value) from preliminary inventory.

Work operation classification

Log selection: begins when the loader starts to move towards the right log and ends when the loader operator selects the logs;

Embracing or grappling: when the fork is lowered to the ground and positioned beneath the logs and ends when the log is positioned in the fork or grapple;

Loading: starts when the loaders lift the log and ends when the loader releases the log onto the truck;

Sorting or positioning: starts when the driver starts to position the log on the truck and ends when the loader returns to do the next cycle;

Fastening and securing the load: begins when the operator assistant starts to fasten the load and ends when the truck is ready to leave the landing;

Table 1. Technical specifications of Volvo BM 4500

Specification	FEL BM 4500
Length	7.2 m
Width	2.7 m
Height with attachment	5.2 m
Weight	13920 kg
Power	134 kw
Fuel tank capacity	230 l

Table 2. Detailed cost of loading by FEL VOLVO BM 4500

Cost factor for front end loader Volvo BM4500	Cost
Purchase price, USD	130 000
Salvage value, USD	32 500
Economic life, years	5
Tire life, h	4000
Tire price, USD	720
Repair factor, f	0.9
Interest (annually), USD	15 015
Deprecation (annually), USD	19 500
Tax and insurance (annually), USD	345
Total fixed cost, USD/PMH	23.1
Maintenance and repair, USD/PMH	10.6
Fuel and lubricate cost, USD/h*	3.62
Tire cost, USD/h	0.8
Total variable cost, USD/h	15.1
Total labor cost, USD/h	9.6
Total cost (system cost), USD/h	47.8
SMH (annually), h	2200
PMH (annually), h	1375
Utilization, % Ut = (PMH×100 / SMH)	75%

Delays: are divided into three categories:; technical, operational, and personal delay.

Statistical procedures

The homoscedasticity of the variance of dependent variables was evaluated with the Levene's test. Standard normality test of Kolmogorov-Smirnov was applied to determine normality of dataset. The general stepwise linear multiple regression was applied to test for relationship among dependent variables (selecting the log, loading, pure time, productivity) and independent variables (interaction of number of logs and volume, volume, diameter, log length). Before running the regression, the assumptions of normality, linearity, multicollinearity and homoscedasticity were also checked. With the use of a $p<0.001$ criterion for Mahalanobis distance no outliers were found (Steel et al., 1997; Shanock et al., 2010). All statistical analyses were performed using SPSS 23 statistical software package at the significance level of $p<0.05$.

Cost calculation

Data collection for calculating machine cost. The operation cost of each machine was based on fixed cost and variable cost. System cost is calculated by totaling machine cost and labor cost. Personal costs included all costs related to worker, fringe benefit and rewards (Table 2). Salvage values for loader is 25% of the purchase price (Hedin, 1980; Naghdi et al. 2009). Fuel cost is calculated as below:

$$* Fc = gkw.x_1.CL \quad (3)$$

$$* Oil\ and\ grease = \frac{gkw.x_2}{100} \quad (4)$$

Gkw= engine power

x_1= 0.18 for diesel oil

CL = cost per liter.

x_2 = 0.2 for tractor, skidder, front-end loader and trucks

RESULTS

Distribution of time consumption

Time distribution of different elements of loading with FEL Volvo BM 4500 is presented in Fig. 1. Log loading was the most time consuming element which is followed by log selection (Table 3).

Delay time was calculated as a mean time consumption value. In the study, time consumption for personal, technical and operational delay was 26.2, 42.9, and 51.9 seconds per payload.

A summary of loading opeartion with FEL Volvo BM 4500 during the time study is presented in Table 4. The average loading productivity was 31.34 m^3/h.

Time consumption models of loading operations

Log selection. Time consumption for log selection depended on the log length and interaction of number of logs and volume.

$$t_1 = 243.88 + 3.71x_{nv} - 49.125x_l \quad (5),$$

where

t_1= time consumption of loading, s/cycle;

x_{nv}= interaction of number of logs and volume;

x_l= log length, m.

Embracing. Time consumption for log embracing was not related to any variables

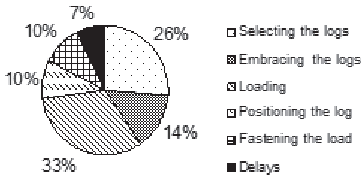

Fig. 1. Time consumption distribution of FEL Volvo BM 4500

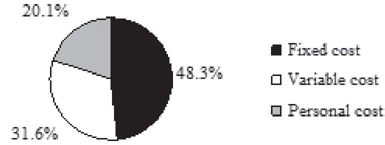

Fig. 2. Time consumption of loading as a function of diameter and interaction of number of logs and volume in the FEL

Table 3. Average time consumption as a proportion of total gross-effective time

Loading element	(FEL)
Logs selection	26[13-37]
Embracing, grappling	15 [7-32]
Loading	32[14-42]
Positioning of logs on the truck	10[2-26]
Fastening the rope	11[5-18]
Delays	7[0-23]

other than the logs diameter, landing condition, and loader operator's skill may influence the time consumption of log embracing.

Loading. Time consumption for log loading depended on the log length and interaction of number of logs and volume. Time consumption of loading at each time was also modeled and it depended on the volume of logs.

$$t_3 = 252.71 + 4.09\, x_{nv} - 42.75\, x_l \quad (6)$$

$$t_l = 16.13 + 4.09\, x_{nv} - 42.75\, x_l \quad (7),$$

where

t_3= time consumption of loading, s/payload;

t_{lo} = time consumption of loading, s/cycle;

x_v= volume at each time in cycle, m^3.

Sorting or positioning of the logs. Time consumption for log positioning was not related to any variables and was calculated as mean values.

Fastening the rope. Time consumption for fastening the rope is calculated as a mean values.

Delay time. Since delay time was not influenced by any variables it was calculated as a mean value.

Total time consumption model

Total time consumption model of delay free loading time was defined by totaling the individual time consumption elements.

$$t_t = t_1 + t_2 + t_3 + t_4 + t_5 \quad (8),$$

where t_t = total effective time consumption of loading, s/payload;
t_1= time consumption for log selection, s/payload;
t_2 = time consumption for embracing, s/payload;
t_3 = time consumption for loading, s/payload;
t_4 = time consumption for positioning of logs, s/payload;
t_5 = time consumption for fastening the rope, s/payload.

Overal time consumption and productvity model

$$t_o = 210.73 + 6.01\, x_{nv} + 9.48\, x_d \quad (9)$$

$$P_e = 13.65 + 3.98\, x_l - 0.06\, x_{nv} \quad (10),$$

where t_o = overal time consumption, s/ payload;
p_e= productvity of loading, m^3/effective h.

Table 5 shows descriptive statistics for the elements of loading (e.g. fastening of the cable) that were not modeled. The mean value was used for constructing the total time consumption model. Maximum and minimum values show possible variation of the time consumption in each element.

The characteristics of the regression models are presented in Table 6. Loading per cycle and pure time per cycle was found to be in direct relation with volume per cycle, however, for pure time of payload, volume per payload and interaction of the volume and the number of log was found to be an influencing variables. A model for productivity developed using variables such as volume, the average diameter, and the interaction of the number of logs and volume. F-value and P-value show that the presented models

Table 4. Time consumption and productivity of loading in the FEL Volvo BM 4500

	Effective time	**Gross–effective time**
Av. loading time, min/cycle	1539	1660
Min loading time, min/cycle	951	951
Max loading time, min/cycle	2235	2695
Av. loaded volume (m^3)	13.14	13.14
Min. loaded volume (m^3)	9.38	9.38
Max loaded volume (m^3)	16.69	16.69
Av. productivity ,m^3/h	31.34	29.05
Min. productivity, m^3/h	19.93	19.17
Max. productivity, m^3/h	51.1	42.1
Number of observations	80	80

Table 5. Descriptive statistics of mean value based work phase model

Element	**Parameter**	**Mean s/cycle**	**Min., s/cycle**	**Max., s/cycle**	**Std. dev.**	**N**
Embracing	t_{12}	234	137	491	69	80
Positioning of the logs	t_{14}	159	20	539	169	80
Fastening of the rope	t_{15}	169	85	229	105	80
Delays	t_{16}	185	0	695	134	80

Table 6. Stepwise multiple regression analysis output for loading operations (models (x_v= volume, x_{nv}=interaction between number of logs and volume, x_n= number of logs, x_l= log length, x_d= log diameter)

	Unstandardized coefficients	Standardized coefficients	t	p-value	Correlations			Collinearity statistics	
	B (±SE)	β			Zero-order	Partial	Part	Tolerance	VIF
	Selecting the log (payload)								
Constant	243.88 (68.60)		3.55	0.001					
x_{nv}	3.717 (0.58)	0.863	6.35	0.001	0.52	0.62	0.51	0.51	1.94
x_l	-49.125 (13.56)	-0.492	-3.62	0.01	0.11	-0.412	0.51	0.51	1.94
	R^2= 0.39, F (2, 67)=20.82, p-value=0.001								
	Loading (payload)								
Constant	252.71 (82.64)		3.05	0.03					
x_{nv}	4.09 (0.70)	0.80	5.84	0.001	0.55	0.59	0.57	0.51	1.93
x_l	-42.75 (16.25)	-0.36	-2.63	0.01	0.19	-0.31	-0.26	0.51	1.93
	R^2= 0.374, F (2, 67)=19.08, p-value=0.00								
Puretime (payload)									
Constant	210.73 (201.92)		1.04	0.30					
x_{nv}	6.01 (0.72)	0.70	8.26	0.001	0.69	0.71	0.70	0.99	1.00
X_d	9.48 (3.38)	0.23	2.79	0.07	0.21	0.33	0.23	0.99	1.00
	R^2= 0.54, F (2, 66)=37.21, p-value=0.001								
	Productivity (payload)								
Constant	13.65 (2.45)		5.56	0.001					
X_l	3.98 (0.52)	0.90	7.61	0.001	0.66	0.66	0.62	0.47	2.10
X_{nv}	-0.06 (0.02)	-0.33	-2.80	0.07	0.32	-0.23	-0.23	0.47	2.10
	R^2= 0.49, F (2, 67)=36.73, p-value=0.001								
	Loading (cycle)								
Constant	16.13 (3.51)		4.59	0.001					
X_v	39.7 (3.23)	0.66	12.08	0.001	0.66	0.66	0.66	1.00	1.00
	R^2= 0.44, F (1, 184)=145.95, p-value=0.00								

are statistically significant. R-square is low, proving that the model does not describe the prediction time for loading sufficiently. According to *beta* values, a criterion of total variance explained by the variable after controlling contribution of others, the effect of number of logs and volume was more considerable than that of other variables.

The effect of two of the most important variables in loading (interaction of the number of logs and volume and diameter) on the time consumption of loading is given in Fig 3. Time consumption of loading has a direct relationship with interaction of number of logs and volume and direct relation with volume loaded; therefore the highest

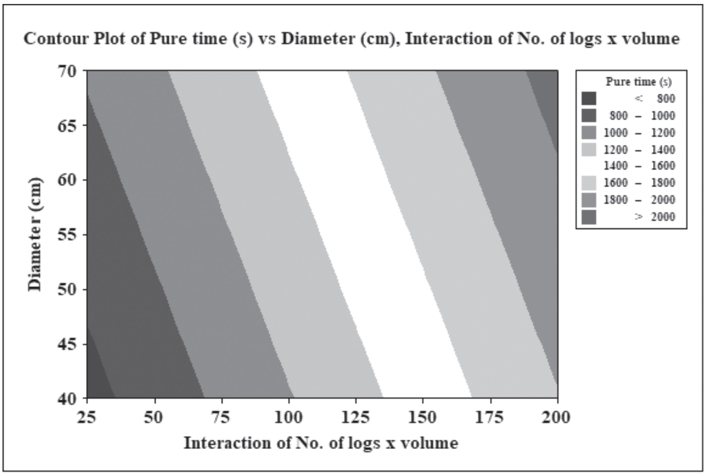

Fig. 3. Distribution of different types of cost in the FEL Volvo BM 4500

productivity was found when the number of log is low and volume loaded is high. The figure is based on the time consumption model.

Production cost

Production cost of loading. The average production cost of loading operation in the FEL Volvo BM was 1.53 USD·m^{-3}. The production cost of loading in each cycle varied from 0.92 to 2.4 USD·m^{-3} in the FEL Volvo BM 4500.

DISCUSSION

According to Harstela (1993), the productivity of a harvesting system is a function of the qualities of the labour force, and the characteristics of conditions as well as other factors of production. One of the main problems regarding the generalization of the study is related to labour; therefore a standard crew was used (Harstela, 1993; Nurminen et al., 2006).

Methodologically, the emphasis of this study was on correlation. In the correlation study, multiplicity of influencing factors is controlled by a detailed division of work phase into elements (Bergstrand, 1991; Nurminen et al., 2006).

Two techniques were applied to create the models: work phase time consumption models and overall time consumption models. Both techniques appeared to fit well with the observations and are reliable to predict the time consumption and productivity, as previously found by Nurminen et al. (2006).

The condition of landing area is important in relation to the efficiency of loading. The objectives of a well-designed, properly constructed, and efficiently operated landing are safety, cost minimization, landing size minimization, and proper transfer of logs to the transport system. The design and location of the landings should be established when planning the harvesting, preferably in connection with road planning. Landings should be as small as possible, taking into account the need to unhook logs from the extraction equipment, sort logs, store them temporarily, and provide for the loading of trucks (Conway, 1979). In this study, only roadside landing was used.

Log selection is the first element of loading. Log selection accounted for the second largest share of the total time consumption. Log selection took 26% of total time consumption. It depends on the interaction of number of logs and volume and log length.

Similar to log selection, time consumption of embracing is calculated as the mean value in the total time consumption model, because the model was not statistically significant.

Loading is one of the most important elements of loading performance including lifting the logs and putting onto the truck. It slightly depends on the log sizes (volume). It took 33% of total time consumption. Loading was modeled both for payload and cycle. Loading per cycle depended on log volume while loading per payload depended on interaction of number of log and volume and the average log length.

Positioning or sorting of the log was not found to be related to any variables. The logs should be placed on the truck properly; otherwise the load may take a lot of space which decreases the productivity of long distance transportation, the next work phase. The fastening of the cable onto the load is the last element of loading. The fastening time varies between 1 to 3 min.

Delays accounted for approximately 7% of the loading time in FEL. Among the different types of delay, operational one was the most time-consuming in loading, followed by technical and personal delay. A high percentage of operational delay time was related to cutting the log in appropriate length in order to be fit in the truck.

In the overall time consumption model of loading, a regression equation was developed to predict loading time as a function of independent variables: number of logs, volume of logs in each cycle, and interaction between number of logs and volume. An interaction of number of log and volume and average diameter were found to be the best variable in order to construct the time consumption model. Other variables were not statistically significant. In similar studies conducted in Iran, the loading depended on the interaction of volume and number of logs per payload (Naghdi, 2005; Javadpour, 2006). Similar procedure was done in order to find the most influencing variables on the productivity. An interaction of number of log and volume, log diameter, and log volume was found to be the best variables in order to construct the time consumption model.

Productivity of loading in the study was less than in the other studies performed in the eastern part of the Hyrcanian forest. According to (Naghdi, 2005), it was 56.8 m^3/effective h in the tree length method and 41.9 m^3/effective h in the cut-to-length method. Javadpour (2006) found the average productivity of loading was 64.8 m^3/effective h in the designed landing while the average productivity of undesigned or roadside landing was 31.0 m^3/effective h. The average productivity of the study was 31.34 m^3/effective h which was similar to the study done in the area by Javadpour (2006).

The unit cost of loading was mostly affected by machine cost. Approximately 80% of the hourly cost of loading was related to machine cost while only 20% of loading performance was related to labor cost.

Naghdi (2005) found that unit cost of the tree length method was lower than that of the cut-to-length method. He showed that the unit cost of loading was 0.46 and USD 0.63/m^3 in the cut-to-length method and tree length method, respectively. Unit cost of loading was USD 1.6 /m^3. Javadpour (2006) calculated the unit cost of loading to be USD 1.88/m^3 in roadside landing; this is similar to the results of this study.

CONCLUSION

Loading is one of the most important phases of forest harvesting. It is a link between primary and secondary transportation, therefore need to be planned well in order to prevent delay time which results in higher productivity.

The time consumption of loading using front end loader is analyzed. Log loading was the most time consuming element in loading work phase followed by log selection. The unit cost of loading was mostly affected by machine cost. Approximately 80% of the hourly cost of loading was related to machine cost while only 20% of loading performance was related to labour cost.

Although, front end loader is a machine which is adapted for log loading in the forest but it may not be as effective as Knuckle boom loader which is more compatible for working in the forest.

REFERENCES

Azizi, R. 2001. Investigation of loading operation by GMC and grapple loader in Iran. Master Thesis, Tehran University, 87 (In Persian).

Barnes, R.M. 1968. Motion and time study-design and measurement of work. John Wiley and Sons, Incorporated, New York, 515-516.

Björheden. R. 1991. Basic time concepts for international comparisons of time study reports. J. of Forest Engineering, 2(2), 33-39.

Conway. S. 1979. Logging practice, principle of timber harvesting system. Miller Freeman, USA, 416.

FAO. 1974. Logging and log transport in tropical high forest, a manual on production and costs, Food and Agriculture organization of the United Nations, Rome, 107.

Gonzáles, D.D.J. 2005. A time study and description of the work methods for the field work in the National Inventory of Landscapes in Sweden. Department of Forest Resource Management and Geomatics, SLU. Arbetsrapport/Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning och geomatik, 140.

Harstela, P. 1993. Work studies in forestry. Silva Carelica 25, 131.

Hamedi Qazi, P., Mousavi Mirkala, S.R, 2016. Productivity and costs of extraction of small sized timber by mules – a case study: plantations in Northern Iran, Tyromrood basin, Tonekabon city, Silva Balcanica, 17 (2), 23-35.

Hedin, I. B. 1980. Comparison of two logging systems in interior British Columbia: central processing yard vs. conventional, Technical Report No.TR-45, 53.

Javadpour, A. 2006. Productivity and cost analysis of skidding and loading in designed and roadside landing. Master thesis, Guilan University, *Sowmeh Sara,* 85 (In Persian).

Naghdi. R. 2005. Investigation and comparison of two harvesting systems: tree length and cut-to-length method in order to optimize road network planning in Neka, Iran. PhD Thesis, Tarbiat Modares University Tehran, 177 (In Persian).

Naghdi, R., M. Nikooy, J. Javadpour. 2009. Efficiency comparison of Volvo BM 4500 loader in planned and unplanned loading practices (Case study: second district of Nav-Asalem Forest, Northern Iran).

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

Ovaskainen H., J. Uusitalo, K. Väätäinen. 2004. Characteristics and Significance of a Harvester operators working technique in thinning. International J. of Forest Engineering, , 62 (2) 221-232.

Saarilahti, M., P. Isoaho. 1992. Handbook for Ox skidding researches. The Finnish Forest Research Institute, 442.

Samset, I. 1990. Some observations on time and performance studies in forestry. Meddelelser fra Norsk institutt for skogforskning ,43(5), 80.

Shanock, L.R., B.E, Baran., W.A. Gentry., S.C. Pattison., E.D. Heggestad. 2010. Polynomial regression with response surface analysis: A powerful approach for examining moderation and overcoming limitations of difference scores. J. of Business and Psychology, 25, 543–554.

Steel R.G., J.H. Torrie., D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biological Approach. McGraw Hill Book, New York, USA, 666.

Zobeiry, M. 1994. Forest Inventory, Tehran University, Tehran, 401 (In Persian).

E-mail: r.mousavi@urmia.ac.ir