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Productivity Analysis of Modified Farm Tractors in Forwarding Industrial Wood Products

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Public demands for forest products and services have been increasing gradually in many countries all over the world. Among the forest products, mostly round woods are produced in Turkey due to high economic value. On the other hand, there is a significant increase in demand for industrial woods in the domestic market in recent years. The reason behind this increase is the need of domestic companies in the wood-based panel industry for a large amount of wood raw material. . Farm tractors are the most widely used forest machinery in the extraction of industrial wood in Turkey. Farm tractors can be effectively used in mechanized harvesting operations after receiving some modifications and additional attachments. The modified farm tractors are affordable machinery for small logging contractors since their initial purchasing costs and hourly operating costs are quite low comparing with the forest harvesting equipment (i.e. skidder, forwarder, cable yarder). In this study, productivity of a modified farm tractor was analyzed during forwarding of industrial wood products. The study was implemented in Pinus nigra stand located in (?) the city of Afyonkarahisar in Turkey. In the study, the effects of forwarding distance on productivity were evaluated using statistical analysis. The results indicated that the most time-consuming work stage was unloading the truck and piling the wood products at the landing area, followed by (in terms of time-consumption) collecting woods and loading the tractor at the stump. The average productivity of the forwarding operation was 6.06 stere/h (stere is the amount of wood pile with the height, width, and depth of one meter). It was also found that the productivity of the forwarding was significantly affected by the forwarding distance.

Key words: Forestry; Ground-based harvesting; Mechanized logging; Timber extraction; Skidding; Time study; Efficiency; Black pine; Afyonkarahisar; Turkey.

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Introduction. Due to the high economic value, round-wood harvesting takes a leading position among the forest products in Turkey. On the other hand, there has been a significant increase in the demand for industrial wood in the domestic market in recent years. One of the reasons for this increase is that domestic firms need a large amount of wood raw materials in the wood-based panel industry (Bilici, Akay, & Abbas, 2019). Factories processing industrial wood raw materials have to satisfy their increasing raw material needs timely and regularly for the continuity of their production. Most of the wood raw material demand (60%) in the domestic market is satisfied by the General Directorate of Forestry (GDF) (Türk, 2016). Under conditions of increasing competitiveness in Turkey's forest products industry, in order to respond to the demand for raw materials of the forest products sector and, on the other hand, to meet the need for community forest products, forests are to be managed and function on the principles of sustainability.

According to the OGM 2017 annual report (GDF, 2017), it is stated that annual wood consumption in Turkey is around 31 million m³, approximately 21 million m³ of it is produced by GDF, and the rest is covered by private sector and imports. According

to GDF's production plans for 2018 (URL-1), it was reported that the target stumpage sale was 25.7 million m³ in which 20 million m³ was industrial wood and 5.7 million m³ was firewood. The production amount for 2018, where the realization rate is 99%, was 24.85 million m³. Approximately 19 million m³ of this amount was industrial wood and the rest was firewood. The largest amount of wood products was fiber-chip board and followed by the log production (Tab. 1). This also corresponds to 75% of the industrial wood produced.

The forested areas in Turkey generally have a steep terrain, which increases the costs of traditional logging method based on human and animal power, compared to machine-based logging operations (Eroğlu, Sarıyıldız, Küçük, & Sancal, 2016). The fragmented structure of the forest lands and operating in small harvesting units are also the key factors that increase the cost of timber extraction. In addition, traditional logging methods are limited in terms of amount of extracted wood per unit area. In today's social and economic conditions, various mechanized logging equipment is used in forestry activities in Turkey in order to increase the productivity while protecting the forest ecosystem and to improve the socio-economic life of the forestry workers who mostly live in forest villages.

Table 1

Distribution of wood production regarding product types in 2018 (×1000)

Product types	Production		Planned Sale		Actual Sale	
	Planned	Actual Amount	Amount	Profit (YTR)	Amount	Profit (YTR)
Log (m ³)	7,000	6,996	4,409	1,256,067.54	4,179	1,646,924
Wire pole (m ³)	60	71	54	20,014.45	56	23,328
Mining pole (m ³)	775	707	464	110,169.17	357	115,889
Industrial wood (m ³)	1,035	864	636	129,624.90	478	130,381
Pulp wood (m ³)	3,033	3,099	1,958	361,309.93	1,629	366,261
Fiber-chip (m ³)	8,085	7,316	5824	675,291.72	6,079	738,880
Pole (m ³)	12	12	11	1,909.79	8	1,675
Rod wood (stere)	0.00	0.00	0.15	20.80	0.12	18
Fire-wood (stere)	5,700	4,832	4,317	132,347	3,837	115,457

The forest operations in which mechanization is most commonly used are tree felling and the extraction of forest products from the felling sites (Erdaş Acar, & Eker, 2014). However, the utilization rate of mechanized logging methods in Turkey is still quite low, while the target is to increase this rate to around 15%. Farm tractors are used in many countries in the concept of small-scale forest harvesting (Yu, Gallagher, Mitchell, & O'Neal, 2016). In Turkey, the mechanized equipment that is most frequently used in timber extraction is the modified farm tractors as well (Gülci & Akay, 2017). Proto et al. (2018) reported that the modified farm tractors are also widely used in European countries such as Italy, Croatia, etc.

The modified farm tractors are used in different ways as a skidder, loader, and forwarder (Öztürk &

Akay, 2007). Cable systems can be also applied in both uphill and downhill directions by farm tractors (Marenče & Krč, 2016; Lee et al., 2017). Transporting forest products from stump to landing is a difficult and dangerous job. For the farm tractors to be used in these hard works, especially motor power, tail shaft and hydraulic equipment are of great importance. The tractor must be structurally and powerfully suited to forestry works. For instance, there should be a correct ratio between the tractor's engine power and weight. Besides, the weight has a positive effect in terms of increasing the pulling force of the tractor and decreasing wheelslip.

Since farm tractors have proportionally more engine power than their weight, wheelslip increases in heavy jobs such as skidding and winching in the forest. In this

case, it can cause work accidents and damage to the machines. In order to eliminate the drawbacks caused by the decrease in the weight of the tractor, additional weights are attached to various parts of the tractors. When extracting industrial woods, carrier saddles are attached in the front and at the back of the tractor to carry wood products, which also help to balance the weight. Besides, additional measures can be taken to empower traction such as reducing tire inflation pressures and using an open profile tire or attaching a chain to the rear tires (Öztürk & Akay, 2007). Due to the drums attached to the back of the farm tractors, they can be used as a skidder. The rotation of these drums, which depend on the steel cable rolling capacity of a certain length, is carried out with the power taken from the tail shaft of the tractor.

Tractors can get the logs out of the forest by moving in the forest along skid roads, and they can pull the logs from the slopes under the road to the side of the road with their drums by standing on the roadside landing (Fig. 1). In areas where the slope of the land is less than 30%, the products can be removed from the felling site by skidding them on the skid roads with the farm tractor

Figure 1. Cable winching (left) and skidding (right) with farm tractor

Figure 2. Extracting stere woods with a saddle attached to the tractor

Time studies are applied in three different ways; continuous time measurement, repeated time measurement and work sampling (Gülci, 2014). In

(Figure 1). Since the farm tractor's mobility is limited in mountainous areas where the slope is more than 30%, the tractor stands in a suitable place on the forest roadside and removes the products from the stump by cable winching method (Türk, 2011). When the transported products are industrial wood in the unit of stere (i.e. height, width and depth is a meter of wood), removal operations are carried out by means of a saddle attached to the tractor (Fig. 2). In this way, wood is loaded on the saddles mounted on the front and rear part of a tractor and carried to the landing (Türk, 2016).

The productivity of the equipment and methods used in the logging operations are generally determined depending on the operation time. The most commonly used work measurement technique in calculating the operation time is the time study method. Within the scope of the time study, the work is divided into sub-sections or stages, and the standard time is determined. In order to apply the time study, the work needs to be subdivided into stages. Basic tools used in time studies are chronometers and time study forms. Besides, distance measuring instruments, clinometer, and metal compass are also used in time study.

the continuous time measurement technique, the work is constantly monitored and the value read from the chronometer is recorded at the end of the work stages. In the repeated time measurement technique, the chronometer is read at the beginning of the stages, and it is reset at the end and restarted. In the work sampling, the work is observed with equal time intervals and the current work stages are recorded. In this study, the productivity of a modified farm tractor during the extraction of stere wood products was analyzed. The study was carried out in a Black pine stand in the city of Afyonkarahisar in Turkey. In the study, the effects of the skidding distance on productivity were also evaluated using statistical analysis.

Material and Methods. *Study Area.* Afyonkarahisar Forest Enterprise Chief (FEC), chosen as the study area, is located within the boundaries of Afyonkarahisar Forest Enterprise Directorate (FED) in Eskişehir Forest Regional Directorate (Fig. 3). Forest resources of the Afyonkarahisar FED are given in Tab. 2. Afyonkarahisar FED is about 172,000 hectares, of which 43,000 hectares

are covered with forests. The dominant tree species in the section 428 where the extraction study was carried out was Black pine. The average ground slope in the field was determined as 30%.

Time Study. The productivity of the mechanized logging equipment and systems used in harvesting operations are determined depending on the operation

time. In this study, the repeated time measurement method, which is one of the most common time study methods in forestry, was used in order to analyze the productivity of the timber extraction carried out with the New Holland 55-56 S farm tractor (Gülci, 2014). Technical features of the farm tractor used in the study are given in Tab. 3.

Figure 3. The location of the Afyonkarahisar FED

Table 2

Forest resources of the Afyonkarahisar FED (ha)

FECs	Productive Forest	Unproductive Forest	Forested Area	Unforested Area	Total Area
Hocalar FEC	9,664.50	19,754.80	29,419.30	29,890.50	59,309.80
Emirdağ FEC	10,170.90	36,230.20	46,401.10	217,629.60	264,030.70
Sinanpaşa FEC	11,241.20	9,218.70	20,459.90	658,78.90	86,338.80
Sandıklı FEC	15,255.80	17,778.00	33,033.80	101,018.20	134,052.00
Çay FEC	14,183.40	18,804.70	32,988.10	236,379.20	269,367.30
Afyonkarahisar FEC	18,789.40	24,282.70	43,072.10	129,265.40	172,337.50
Şuhut FEC	5,331.50	9,764.10	15,095.60	170,752.00	185,847.60
Total	84,636.70	135,833.20	220,469.90	950,813.80	1,171,283.70

Table 3

Technical features of the New Holland 55-56 S tractor evaluated in the study

Engine	unit of measure	Values
Max horse power	(HP)	55
Cylinder / Aspiration		3 / Turbo / Intercooler
Cylinder volume	(lt)	2.9
Max torque	(Nm)	226
RPM at max torque	(r/min)	1,400
Tail Shaft		
RPM of tail shaft	(r/min)	540
Engine RPM	(r/min)	1,967
Weight (kg)		
Total weight without cabin (2WD / 4WD)	(kg)	2,100 / 2,300
Total weight with cabin (2WD / 4WD)	(kg)	2,220 / 2,420

The work measured in timber extraction is divided into sub-sections and work stages. In this study, a digital chronometer was used to measure the operation time in four work stages; 1) the time for the unloaded tractor to reach the point where the wood products are located, 2) the time to collect and load the products at the stump, 3) the time for the loaded tractor to reach the landing area, 4) the time of unloading tractor and stacking the wood products at the landing (Figure 4). The first stage starts

with the tractor being unloaded on the ramp and ends when it stops for loading the products at the harvesting site. At the second stage, the forest workers collect the products at the stump and load them on the tractor. The third stage starts with the movement of the tractor from the harvesting area and ends when the tractor reaches the landing area. At the last stage, the tractor is unloaded on the landing and the wood products are stacked. The lost time and delay time was not evaluated in the study.

Figure 4. The work stages of the tractor skidding: 1) the unloaded tractor to reach the point where the wood products are located; 2) collect and load the products at the stump; 3) the time of the loaded tractor to reach the landing area; 4) the time of unloading tractor and stacking the wood products at the landing.

Time study forms were used to record time measurements for the extraction method evaluated in the study. In addition to the time measurements, the skidding distances measured by a steel tape and the quantity of products (stere) stacked on the ramp were recorded on the forms. A total of 45 turns were recorded during timber extraction. The amount of product per turn in the study was 5.5 stere in 40 turns, 5 stere in four cycles, and 4 stere in one cycle. Hourly productivity (P) in stere per hour for each turn is calculated as follows:

$$P = \frac{v}{t} 60 \quad (1)$$

v = Timber volume per turn (stere)
 t = Total time per turn (min)

Statistical Analysis. Within the scope of hourly productivity and time measurement studies, to examine the total cycle time and the factors affecting efficiency, firstly the correlation and then regression

analyses were conducted. As the skidding (forwarding) distance varied in the study, only the skidding distance was evaluated as an independent variable since the amount of product transported remained constant in 89% (5.5 stere) of the cycles. The relationship between the skidding distance variable and the cycle time and productivity were examined with the one-way ANOVA analysis at 0.05 significance level.

Normality test based on the Skewness and Kurtosis coefficients was performed to examine the normality of the variables. In order to investigate the effect of skidding distance on cycle time and productivity, skidding distance was evaluated in three classes (short: < 200 m, medium: 200-300 m, long: > 300 m). The investigation of the relationships between the variables was carried out with the Pearson Correlation Test and the determination of mathematical models for the independent variables using the Linear Regression Analysis. SPSS 16.0 software was used to conduct statistical analysis in the study.

Results and Discussion. The basic statistical values (average, maximum, minimum and standard deviation) obtained for the productivity and the skidding distance factor are given in Tab. 4. It was found that the average skidding distance was 250 m while the average productivity of transporting stere wood with a saddle attached to the tractor was determined as 6.06 stere/hour. In a similar study where the average skidding distance was 320 m, the hourly productivity was reported as 7.7 m³/h in the skidding operation

with a farm tractor (Öztürk, 2010). The Skewness and Kurtosis coefficients were examined to check if the variables showed normal distribution. The closer these values are to zero, the closer the data is to the normal distribution. In addition, when the skewness and kurtosis coefficients are divided by their standard deviation values, the data is normally distributed if the result is in the range of -2 to 2 (George & Mallery, 2003). The results revealed that variables show normal distribution (Tab. 5).

Table 4

Basic statistical findings of productivity and skidding distance

Variables	Unit	Mean	Min	Max	Standard Deviation
Skidding distance	m	250	396.00	163.00	65.39
Productivity	stere/hr	6.06	10.27	2.73	2.01

Table 5

Findings of normality test

Variables	Unit	Skewness		Kurtosis	
		Statistics	Standard Dev.	Statistics	Standard Dev.
Skidding distance	m	0.643	0.354	-0.651	0.695
Productivity	stere/hr	0.024	0.354	-1.297	0.695

The basic statistical values (mean, maximum, minimum and standard deviation) of the time measurements of the work stages in the tractor skidding study are given in Tab. 6. According to the results, the average total time for skidding with the tractor was determined as 59.12 minutes. When the work stages are evaluated, it was found that the most time-consuming stage in a skidding cycle was unloading tractor and stacking the wood products at the landing (35.97%), followed by (in terms of time consumption) collecting and loading the products at the stump (33.14%).

Pearson Correlation Test was applied to reveal the relationship between hourly productivity and skidding distance with the tractor. Correlation test results are given in Tab. 7. The results showed that there was a significant ($p < 0.001$) relationship between skidding

distance and total cycle time and productivity at the 99% confidence level. Accordingly, it was determined that as the skidding distance increases, the total cycle time increases and consequently the productivity decreases. In similar studies, it has been stated that the increase in tractor skidding distance increases the total cycle time which decreases the productivity (Behjou, Majnounian, Namiranian, & Dvorak, 2008; Kulak, Arkadiusz, & Grzegorz, 2017; Öztürk, Varsak, & Bilici, 2019). In the study, the distances were divided into three classes (short: ≤ 200 m, medium: 200-300 m, and long: > 300 m) to examine the effect of skidding distance on total cycle time and productivity in more detail. Then, using the One-Way ANOVA with 0.05 significance level, the relationship between skidding distance classes and total cycle time and productivity was evaluated (Tab. 8).

Table 6

Basic temporal (min) findings of work stages in skidding operation

Work stages	Mean	Min	Max	Standard Dev.
The time of the unloaded tractor to reach the point where the wood products are located	6.30	1.85	18.45	3.82
The time to collect and load the products at the stump	19.59	12.45	26.93	4.22
The time of the loaded tractor to reach the landing area	11.96	4.97	32.68	6.81
The time of unloading tractor and stacking the wood products at the landing	21.27	10.43	36.57	6.80
Total Cycle Time	59.12	32.14	87.88	17.28

Table 7

Findings of correlation analysis

Variables	Coefficient used	Skidding distance	Total Cycle Time	Productivity
Skidding distance	Pearson Correlation Coefficient	1	0.905	-0.875
	Sig. (2-tailed)		0.000	0.000
	N	45	45	45
Total Cycle Time	Pearson Correlation Coefficient	0.905	1	-0.978
	Sig. (2-tailed)	0.000		0.000
	N	45	45	45
Productivity	Pearson Correlation Coefficient	-0.875	-0.978	1
	Sig. (2-tailed)	0.000	0.000	
	N	45	45	45

Table 8

Basic statistical values for skidding distance classes

Variables	Skidding Distance Class	N	Mean	Standard Dev.	Standard Error	Min	Max
Total Cycle Time (min)	< 200 m	23	48.32	13.01	2.71	32.14	77.57
	200-300 m	11	61.32	12.47	3.76	35.18	80.29
	> 300 m	11	79.50	7.43	2.24	65.70	87.88
	Total	45	59.12	17.28	2.58	32.14	87.88
Productivity (stere/hr)	< 200 m	23	7.27	1.75	0.364	4.25	10.27
	200-300 m	11	5.65	1.50	0.45	4.11	9.38
	> 300 m	11	3.96	0.63	0.19	2.73	5.02
	Total	45	6.06	2.01	0.30	2.73	10.27

When skidding distances were classified, it was found that total cycle time increased from short skidding distance (48.32 min) to medium (61.32 min) and long skidding distance class (79.50 min). On the other hand, it was determined that the productivity value increased from long skidding distance class (3.96 stere/hour) to medium (5.65 stere/hour) and short skidding distance class (7.27 stere/hour).

Considering the correlation test results, the Linear Regression Analysis was used to reveal the relationship between independent variable (skidding distance) and dependent variable (total cycle time and productivity). According to the One-Way ANOVA results, it was found that the regression model related to the total cycle time and skidding distance was statistically significant at 99% confidence level ($p < 0.001$) (Tab. 9). The R^2 value obtained (0.819) showed that the regression model adequately explained the total cycle

time for the farm tractor. The regression model with the dependent variable (y) representing the total cycle time and the skidding distance (x), which is the independent variable effective on the productivity, is shown in the following equation:

$$y = -0,645 + 0,239x \quad (2)$$

According to the One-Way ANOVA results, it was found that the regression model related to total productivity and skidding distance was 99% confidence level ($p < 0.001$) (Tab. 10). The R^2 value obtained (0.875) showed that the regression model adequately explained the productivity for the tractor. The regression model with the dependent variable (y) representing the productivity and the skidding distance (x), which is the independent variable effective on the productivity, is shown in the following equation:

$$y = 12,789 - 0,027x \quad (3)$$

Table 9

One Way Variance Analysis results for total cycle time

	Model	Sum Square	df	Mean Square	F	Sig.
1	Regression	10,750.87	1	10,750.87	194.11	0.000
	Residual	2,381.56	43	55.39		
	Total	13,132.43	44			

Table 10

One Way Variance Analysis results for productivity

	Model	Sum Square	df	Mean Square	F	Sig.
1	Regression	136.01	1	136.01	140.91	0.000
	Residual	41.50	43	0.965		
	Total	177.51	44			

Conclusions. A significant increase in industrial wood demand is observed on the global scale. In Turkey, the main reason for this increase is the high need for wood in the wood-based panel industry. Farm tractors that have been modified in accordance with forestry activities can be used effectively in removing industrial wood product from the forest. Modified farm tractors are more affordable machines in terms of initial purchase price and hourly operating costs compared to advanced harvesting machines (e.g. harvester, feller-buncher, forwarder, etc.). In this study, the productivity of a modified farm tractor during the extraction of industrial wood products was analyzed by time analysis method. In addition, the effect of skidding distance on total cycle time and productivity was investigated. The study was carried out in the Black pine stand located in Afyonkarahisar Forest Enterprise Chief. In the study, the skidding distance was accepted as an independent variable and regression models were developed for total time and productivity estimates in the study of transporting products in saddles attached to the farm tractor. As a result of statistical analysis, it was determined that the most time-consuming working stage was the unloading and stacking of products on the landing. It was determined that the collecting the products and loading the products to the tractor was the second most time consuming stage. The results of the analysis showed that the productivity of wood extraction was significantly affected by the skidding distance.

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Аналіз продуктивності модифікованих сільськогосподарських тракторів під час транспортування лісоматеріалів

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У багатьох країнах світу попит населення і державного сектора на лісоматеріали і послуги, пов'язані з лісом, поступово збільшується. З лісоматеріалів у Туреччині в основному заготовляють круглий ліс внаслідок його високої економічної цінності. З іншого боку, в останні роки спостерігається значне зростання попиту на ділову деревину на внутрішньому ринку. Причиною цього є висока потреба в деревній сировині з боку вітчизняних компаній у галузі виробництва деревних плит. Сільськогосподарські трактори є найширше використовуваним

лісозаготівельним обладнанням під час трелювання заготовленої ділової деревини в Туреччині. Сільськогосподарські трактори можуть бути ефективно використані в механізованих лісозаготівельних роботах, особливо для вивезення ділових лісоматеріалів з лісу, після здійснення деяких модифікацій і встановлення додаткових навісних пристосувань.

Для невеликих лісозаготівельних підприємств модифіковані сільськогосподарські трактори є доступнішими машинами з погляду початкової покупної ціни і погодинних експлуатаційних витрат порівняно з сучасною лісозаготівельною технікою (наприклад, комбайном, звальювально-пакетувальною машиною, форвардером і т. п.).

Методом часового аналізу проаналізовано продуктивність модифікованого сільськогосподарського трактора під час трелювання ділової деревини у повністю завантаженому стані. Крім того, було вивчено вплив відстані трелювання на загальний час циклу і продуктивність. Дослідження проводили у деревостані чорної сосни, розташованому в лісгоспі Афьонкарахисар в Туреччині. У дослідженні відстань трелювання було прийнято як незалежну змінну, були розроблені регресійні моделі для оцінки загального часу і продуктивності при дослідженні транспортування деревини в сидлах, прикріплених до сільськогосподарського трактора. В результаті статистичного аналізу встановлено, що найбільш трудомістким етапом роботи є вивантаження і укладання деревини на майданчик. Встановлено, що збір деревини і її навантаження на трактор є другим за тривалістю етапом. Середня годинна продуктивність трелювальної операції складала 6,06 м³.

Результати аналізу також показали, що на продуктивність трелювання деревини істотний вплив виявляє відстань трелювання.

Ключові слова: лісове господарство; лісозаготівля з наземним трелюванням; механізована заготівля лісу; вивезення деревини; трелювання; аналіз тимчасових витрат; ефективність; сосна чорна; Афьонкарахисар; Туреччина.

Анализ производительности модифицированных сельскохозяйственных тракторов при транспортировке лесоматериалов

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Во многих странах мира спрос населения и государственного сектора на лесоматериалы и услуги,

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связанные с лесом, постепенно увеличивается. Из лесоматериалов в Турции в основном заготавливают круглый лес из-за его высокой экономической ценности. С другой стороны, в последние годы наблюдается значительный рост спроса на деловую древесину на внутреннем рынке. Причиной этого является высокая потребность в древесном сырье со стороны отечественных компаний в отрасли производства древесных плит. Сельскохозяйственные тракторы являются наиболее широко используемым лесозаготовительным оборудованием при трелевке заготовленной деловой древесины в Турции. Сельскохозяйственные тракторы могут быть эффективно использованы в механизированных лесозаготовительных работах, особенно для вывоза деловых лесоматериалов из леса, после проведения некоторых модификаций и установки дополнительных навесных приспособлений.

Для небольших лесозаготовительных подрядчиков модифицированные сельскохозяйственные тракторы являются более доступными машинами с точки зрения начальной покупной цены и почасовых эксплуатационных расходов по сравнению с современной лесозаготовительной техникой (например, комбайном, валочно-пакетирующей машиной, форвардером и т. п.).

В этой работе проанализирована методом временного анализа производительность модифициро-

ванного сельскохозяйственного трактора при трелевке деловой древесины в полностью загруженном положении. Кроме того, было изучено влияние расстояния трелевки на общее время цикла и производительность. Исследование проводилось в древостое черной сосны, расположенном в лесхозе Афьонкарахисар в Турции. В исследовании расстояние трелевки было принято в качестве независимой переменной, и были разработаны регрессионные модели для оценки общего времени и производительности при исследовании транспортировки древесины в седлах, прикрепленных к сельскохозяйственному трактору. В результате статистического анализа установлено, что наиболее трудоемким этапом работы была выгрузка и укладка древесины на площадке. Установлено, что сбор древесины и ее погрузка на трактор являются вторым по длительности этапом. Средняя часовая производительность трелевочной операции составила 6,06 м³.

Результаты анализа также показали, что на производительность трелевки древесины существенное влияние оказало расстояние трелевки.

Ключевые слова: лесное хозяйство; лесозаготовка с наземной трелевкой; механизированная заготовка леса; вывозка древесины; трелевка; анализ временных затрат; эффективность; сосна черная; Афьонкарахисар; Турция.