ANALYSIS OF OPERATION PERFORMANCE IN THE PROCESS OF MACHINE WOOD HARVESTING WITH FAO FAR 6840 MINI-HARVESTER

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ABSTRACT

The article presents analysis of operation of Fao Far 6840 mini harvester for machine wood harvesting. Analysis was made based on working day timing. The investigations were carried out on the area of Lubliniec Forest Inspectorate, Bór Forestry on the habitat forest site – fresh mixed forest where pine wood was obtained with the use of a harvester. Timing was carried out based on the registration of the exploitation time of a harvester with the use of a video camera and stopwatch and measurements of the obtained size grade. Based on the obtained results low values of performance in the exploitation change time 9.61 $m^3 \cdot h^{-1}$, and effective performance 12.14 $m^3 \cdot h^{-1}$ were reported. Low machine performance was affected mainly by conditions of harvesting, low log volume (at the average 0.62 m^3) and concentration of trees. The head structure (applied feed system), weak work organization (short time of a single 6 hour shift) and weak skills of the machine operator were additional factors that reduced the performance

Introduction

A harvester is a popular multi-operational machine used in the Polish forests (Glazar and Maciejewska, 2008). These are machines, which as a rule perform cutting, pruning and logging (Skarżyńskie and Brzózko, 2010). Savings in labour force (one person operation), increase in forest farming, precise recording of the performed work, fast removal of wood raw material in case of natural disasters, work safety and hygiene, fast reaction to the recipients' needs, maintaining cleanness of the logged wood and limitation of damages in forest stands and on the surface of soil are advantages of using harvesters (Dvorak et al., 2015). The first harvesters in Poland have appeared under the end of the 80s when fully mechanized logging was initiated by the State-owned Forest Farm by purchase of Makersi 34T harvesters for thinning (Błuszkowska and Nurek, 2016). In Poland in 2001 there were 10 harvesters working and the highest increase of their number took place in 2006 – 2008 when the number of harvesters increased to more than 120 pieces. In 2010 there were as much as 160 types of this machine and in 2011- 351 (Informacja RDLP, 2010; Skarżyński and Brzózko, 2010). In 2014 460 harvesters were reported in Poland and at the end of 2016

approximately 530. It means that these machines are permanently used in forestry (Mederski et al., 2016). Due to the fact that in our country more than 75% of the forest area is occupied by coniferous forest stands as well as due to the growth of logged wood the use of these machines on a large scale may be applied (Mederski et al., 2016; Skarżyski and Brzózko, 2010). In Poland in 2009 harvesting with multi-operational machines constituted approximately 5% of the wood mass obtained in State-owned Forests and in 2012 as much as 10% of wood was harevsted in Poland (Sowa et al., 2013). Fast grow of the number of multi-operational machines is slowed down by a high purchase and exploitation costs of machines, low manual work costs, species structure of forest stands, small-area chipping, no concentration of works, high requirements regarding labour organization, time-consuming and cost-consuming repairs as well as a long-term and expensive process of training of operators (Błuszkowska and Nurek, 2016; Dvorak et al., 2015, Sowa et al., 2013). With regard to these obstacles there is still a need of searching for new solutions which would be more adjusted to the requirements of the sustainable forest farming which combines requirements of ecology, ergonomics and work safety and relevant efficiency of performed tasks (Moskalik, 2004). One of the methods for greater availability of harvesters is the use of small, cheap machines, constructed based on the existing structural solutions. One of the examples of this type of a machine is Fao Far 6840 mini harvester constructed based on ATLAS loader. The objective of the paper was analysis of performance of this type of a machine at the machine wood harevsting based on the working day timing.

Materials and methods

The research was carried out on the territory of Lubliniec Forest Inspectorate, Bór Forestry. The investigated area was in the timberland where the age of the forest stand was 65 years old, the index of stand density 0.9, medium interrupted density, medium density, habitat forest type mixed fresh forest, moisture variant - strongly fresh, natural habitat, flat forest land. A forest stand consists mainly of pine and the tree stand is compliant with the habitat. On the research area, late negative thinning due to disasters forced by damage from thuft was carried out. Works were performed with the use of Fao Far 6840 harvester equipped with Arbo Stroke 400 S head (fig 1, tab. 1). Fao Far 6840 is a machine made on the base of German loader ATLAS. The main reconstruction of the loader was performed at the machine producer in Germany where the measurement system Arbro Mat S, safety framework on the windscreen, crane and hydraulic system distributor were mounted. ARBRO 400 S Finnish head was mounted in FAO FAR and its characteristic feature is that it uses a telescope driven by the hydraulic actuator for moving wood during pruning. Operational parameters of the machine on the site were determined based on the working day timing. It consisted in measuring with a stopwatch (precision ±0.5 s) of the time necessary to reach and return from the area where harvesting and video recording was performed with Sony CCD TR600 camera of the harvester's operation from the moment it reached the site. The total time of recording was almost 6 hours and included 93 full treatment cycles.

Table 1.
Basic technical data of Fao Far 6840 and Arbo Stroke 400 S head

Mini harvester Fao Far 6840					
Specification	Unit	Value	Specification	Unit	Value
Height/width	(m)	2.62/ 2.19	Engine Deutz TD 2011 10114i	number of cylinders	4
Distance between axes	(m)	1.97	Engine capacity	(m^{-3})	3.243
Transport distance/ arm stretched	(m)	5.25/ 555	Power/maximum torque	(kW)/ (Nm)	59.5/ 245
turning radius	(m)	3.5	Maximum driving speed	$(m \cdot s^{-1})$	5.55
Operational scope from the turning radius of the arm	(m)	6.9	Output / hydraulic pumps pressure (lift and head)	$(m^3 \cdot h^{-1})$/ (MPa)	19.2 34
Gross lifting moment	kNm	43	Output / hydraulic pumps pressure (driving system)	$(m^3 \cdot h^{-1})$/ (MPa)	2 x 18 40
Operational mass	(kg)	6240	Tyres width	(m)	0.625
Arbo Stroke 400 S Head					
Maximum oil flow	$(m^3 \cdot h^{-1})$	5.4	Mass (without oil)	(kg)	300
Maximum working pressure	(MPa)	20	Maximum pruning diameter	(m)	40
Rotator rotational angle	(°)	∞	Felling diameter	(m)	0.4
Feed speed	$(m \cdot s^{-1})$	0.35	Measuring control system	–	Arbro Mat S

Inf. materials Fao Far

Determination of the log volume was made based on the measurement of the diameter of 35 trees (with the use of a circumeter with precision up to +1 cm) of the first cutlog of each tree in the thicker end and the last one in the thinner end. Length of the remaining trees was determined based on the logs made and recorded by the machine. During the works, logs with the length of 2.5 m were made. Their length was programmed in the machine control system Arbro Mat S. Additionally five randomly selected and made stacks were taken down with the use of the measuring tape with precision up to ±1 cm, in order to control the measurement of logs by the computer. Based on two diameters and length of a tree, log volume of particular trees which were marked with subsequent numbers were calculated. It enabled measurement of the duration of particular technological operations with regard to particular trees. Log volume of particular trees V_s (m^3) was calculated with Smalian's formula (Jaszczak and Magnuski, 2010), and the total log volume V (m^3) as a sum of log volume of trees harvested within one working day. Particular components of work time were separated based on the measurement with a stopwatch and from the recording according to the agricultural standard, adjusted to the forestry requirements in Poland (BN-76/9195-01; Szewczyk and Kulak 2015).
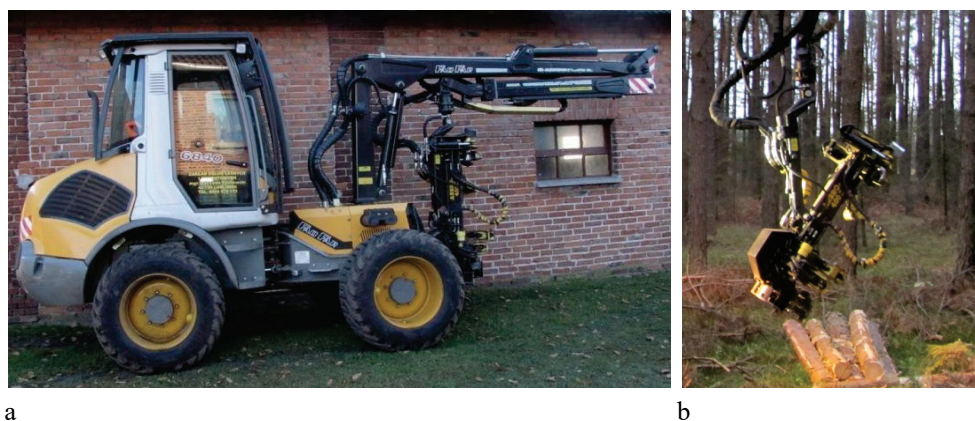
a   b

Figure 1. Fao Far 6840 mini harvester, Arbo Stroke 400 S head during operation − b

Components of the timing such as: effective operation time T_1 which comprised the time of felling T_{11} and time of delimbing and bucking T_{12}; auxiliary time T_2 which comprised technological crossings between trees T_{21}, as well as time of technological stopovers related to marking trees for cutting T_{22}; time of daily technical service T_3; time of removing faults T_4 which comprised the removal time of technological T_{41} and technical faults T_{42}; relax time T_5; transport crossings time T_6; technical service time of a harvester not related to starting and technical service of working units of the machine T_7. Based on the measured times the operational working time of the machine T_{02}, working time of the shift T_{04} and operational time of the shift T_{07} were calculated. Based on the operation time balance the following were calculated: coefficient of using the operational time K_{02}; coefficient of using the working time of shift K_{04}; coefficient of using the operational time of shift K_{07}; auxiliary coefficient which characterizes technical certitude K_{42} (BN-77/9195-02). Using the operation time balance of the machine the following were calculated:
– operational performance of the harvester operation time (1):

$$W_1 = V \cdot (T_1 + T_{21})^{-1} \ (m^3 \cdot h^{-1}) \tag{1}$$

– performance in the operational work time (2)

$$W_{02} = V \cdot T_{02}^{-1} \ (m^3 \cdot h^{-1}) \tag{2}$$

– performance in the operational work time (3):

$$W_{04} = V \cdot T_{04}^{-1} \ (m^3 \cdot h^{-1}) \tag{3}$$

– performance in the operational work time (4):

$$W_{07} = V \cdot T_{07}^{-1} \ (m^3 \cdot h^{-1}) \tag{4}$$

Analysis of results and discussion

As a result of the measurements and analyses it was stated that during the cycle of treatment of one tree, felling T_{11} lasted at the average – 18.2% (22.5 s). As a rule only one cutting was performed which resulted in tree felling. There were two situations when felling was long (1 min 26 s, and 1 min 51 s) which was related to suspension of the felt tree. Relation (figure 2a) of the duration of felling to the breast height diameter of trees (for a sample of 35 trees) has a low value of the determination coefficient which proved high variability of the duration of this treatment for trees with a similar diameter. Similar results were obtained by Sadowski et al., (2014) or Kormanek and Kępa (2016). Except for suspension of trees, the variability resulted from situations when the operator felt trees too fast and a piece of wood was torn off and the tree had to be cut again which considerably prolonged the duration of felling. These situations resulted from both difficulties of harvesting on a particular area but also short experience of the machine operator.
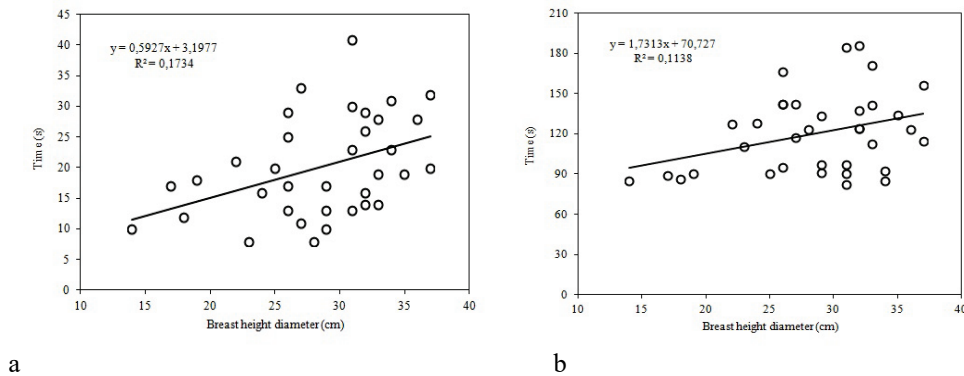

a   b

Figure 2 Relation of the breast height diameter and the felling time and the delimbing and bucking time – b

Delimbing and bucking time T_{12} which was as much as 81.8% (at the average 100.7 s) constituted the remaining processing time of a single tree (table 2, fig. 2b). The high percentage share of this time was affected by the bucking time related to the duration of the log production and the time of delimbing. A 2.5 m log was made which was in demand at that time which at usual production of 5 cutlogs of one tree forced to make 4 cuttings. The process of delimbing with the head of Arbo 400 S was long (fig. 2b) because of the head structure and to- and fro- motion which drives the hydraulic cylinder. The feed speed in this case during bucking is only 0.35 m·s^{-1} while for heads with a wheel and roll drive of the feed it fluctuates within the range of approximately 3 m·s^{-1} for small heads (Log Max 928A with the weight of 407 kg) to 7 m·s^{-1} big heads (SP 591 LX with the weight of 1700 kg) (Sowa et al., 2013). Relation (fig. 2b) of the duration of bucking and delimbing to the breast height diameter of trees (for a sample of 35 trees) has a low determination coefficient value which proved high variability of the duration of these treatments for trees with similar diameters, similar results were obtained by Sadowski et al., (2014). Effective operation time T_1 (fig. 3,

table 2) for 6 hour working shift was 3 h 10 min 58 s, which constitutes 53.0% of time in the operational shift time.

Table 2.
Working day components

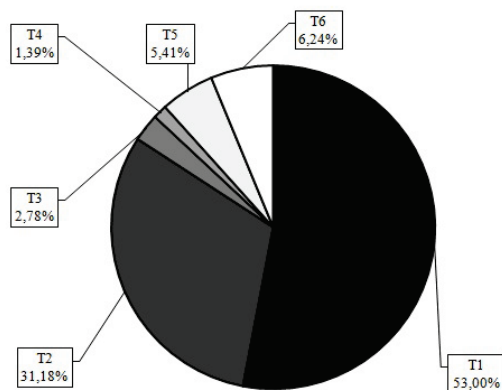| Parameter	Unit	Result	Parameter	Unit	Result	Parameter	Unit	Result
T_1	(s)	11458	T_{23}	(s)	1078	T_6	(s)	1350
T_{11}	(s)	2090	T_{31}	(s)	600	T_7	(s)	0
T_{12}	(s)	9368	T_4	(s)	300	V_s	(m³)	0.62
T_{21}	(s)	5664	T_5	(s)	1170	V	(m³)	57.66

Figure 3. Shift operational time structure

Technological crossings time T_{21} of getting to another tree was considerable, at the average ca. 1 minute (26.2%) and resulted from great distance between trees which was from 10 to 15 m and which was related to average density (stand density 0.9) and growth phase of the forest stand (thin forest stand). The average time of the harvester operation cycle which is the total time of processing operations of wood T_1 with time indispensable for accessing a tree T_{21} in the investigated case was 184 s (3 minutes and 4 seconds). This time is comparable to the duration of the treatment cycle of a single tree with Highlander harvester (Kormanek and Kępa, 2016) which was 195.5 s (3 min 15.5 s). However, in case of Highlander the average volume of the processed wood was almost twofold higher and it was 1.017 m³ while for the mini harvester it was only 0.63 m³. As a rule, an important factor which may affect the length of the technological crossing durations T_{21} in the timing is the operator's organization of work. In this case, based on observations one may state that the operator's work organization was good, crossing took place as a rule with the shortest possible route. Technological stopovers time T_{23} related to marking the trees for felling (the operator marked the trees by himself) was considerably short and it was 17 min 58 s, which

constitutes 4.9% of the working shift time. The time of daily technical service T_{31} was 10 minutes (2.78%) and also was satisfactory. The time was related to starting of the machine, warming up the engine and achieving relevant level of pressure and oil temperature in the system of hydraulics of the mini harvester. In time when the machine was started, the operator checked the general condition of the machine (condition of oil in the engine and hydraulic system, air pressure in tyres, general condition of the head and chain in the cutting system, he also performed indispensable smearing of sub-assemblies). During the analysed working day, the time of removal of technological faults T_{41} did not occur and the removal time of technical faults T_{42} was the least time consuming activity and it took only 5 minutes (1.39%) in the general working shift time. The repair concerned the hydraulic hose of the harvester head which was catching its arm during extension which as a result disturbed complete extension of the telescope end and as a result caused erroneous measuring out of logs to the programmed length. Elimination of the fault consisted in the improvement of hose mounting. Break and physiological needs time T_5 in this case was also short. Only its slight participation in the total operational time with the value of 5.41% was reported which corresponds to 19 minutes and 30 seconds. Transportation crossing time T6, namely the time of reaching and return to the place of stationing was 22 minutes and 30 seconds which constitutes 6.3% in the operational time of the shift and it is a good result. The area where the mini harvester was used was only 700 m from the place when the machine was parked. Storing the mini harvester at the private property of the farmer who lives by the forest was a good solution. A failure to apply this solution would extend by several times the time necessary to go from the base to the work place. Another possible solution which would practically eliminate the time related to reaching the work place would be leaving the machine directly in the forest. This solution is quite risky due to the possibility of theft or devastation of equipment thus it is not used in practice. During the research on the working day, T_7 time of technical service of the harvester not related to starting and technical service of working units of the machine was not specified. The machine was quite new and not much used. Operation time use ratio (table 3) K_{02} was only 0.63 which was considerably influenced by the time lost on reaching the tree T_{21}. A similarly low value was assumed by the working time use coefficient K_{04} equal to 0.60 with a small participation of the time of daily technical service T_3 and the removal time of technical faults T42. Coefficient of the exploitation use of the shift time K_{07}, was 0.53 and this value may be considered low. The value of this coefficient indicates that almost half of the 6-hour working day is not used for effective performance of work. While, the coefficient of technical certitude K_{42} was high as much as 0.98 and related to the lack of serious faults of the mini harvester which resulted mainly from the fact that the machine was quite new and not much used.

Table 3.
Machine working day balance

Parameter	Unit	Result	Parameter	Unit	Result	Parameter	Unit	Result
T_{02}	(s)	18180	K_{04}	-	0.60	W_{02}	$(m^3 \cdot h^{-1})$	11.42
T_{04}	(s)	19080	K_{07}	-	0.53	W_{04}	$(m^3 \cdot h^{-1})$	10.88
T_{07}	(s)	21600	K_{42}	-	0.98	W_{07}	$(m^3 \cdot h^{-1})$	9.61
K_{02}	-	0.63	W_1	$(m^3 \cdot h^{-1})$	12.14			

The operational performance of the harvester operation cycle (1) calculated as the sum of times of single tree processing and reaching it W_1 amounting to 12.14 $m^3 \cdot h^{-1}$ (average volume was 0.62 m^3) was slightly lower than the performance of the thinning harvester Valmet 901.3 (machine power 140 kW) operating on the late thinning area where the stand density was 0.8 and the volume of the average piece was 0.56 m^3 (Maksymiak and Grieger, 2008). Operational performance of Valmet in this case was at the level of 12.32 $m^3 \cdot h^{-1}$. On the other hand in comparison to the mini harvester performance with performance of Highlander thinning harvester (Kormanek and Kępa, 2016) the value is decisively lower because in this case the operational performance was as much as 18.74 $m^3 \cdot h^{-1}$. The main reason for this difference is a much higher average volume of trees which were felled by Highlander which amounted to 1.017 m^3. Another reason which may be taken into consideration also when comparing Fao Far mini harvester with Valmet harvester was much lower tree feed speed in the mini harvester head which affected bucking (fig. 2b) (both Valment as well as Highlander harvester during the research were equipped with heads with roll feed drive). Despite lower speed of feed, this type of a head is used in thinning because it has a quite simple structure, high reliability and low weight (Więsik, 2015). Additional reason behind the differences in the performance, which may be also taken into consideration in this case, was weak training and short experience of the mini harvester operator. Analysis of the performance within the operational time of shift of Fao Far mini harvester, which was 9.61 $m^3 \cdot h^{-1}$, shows that it was decisively lower than the compared Valmet where it was 12.32 $m^3 \cdot h^{-1}$, (Maksymiak and Grieger, 2008) or Highlander performance of which in the operational time of shift was 12.71 $m^3 \cdot h^{-1}$ (Kormanek and Kępa, 2016). Also operational performance of the mini harvester was lower when compared to Ponsse Ergon machine (tree stand age 52 years) and achieved performance in the operational time of shift at the level of 11.25 $m^3 \cdot h^{-1}$. By analysis of the obtained results one may state that performance of Fao Far 6840 mini harvester with Arbo 300 S head was in particular conditions lower than in comparison to machines of other makes. The basic reason for those differences is the average volume of trees in the felling site although the structure of the head is not without meaning (the applied feed system of the processed tree) or the operator's skills. Increase of the operational performance of Fao Far 6840 mini harvester may be achieved by extension of the working day of the shift. Taking into consideration high costs of machines one should aim at the most possible use during the day. According to Nurel (2008) based on the research, extension of the daily working time of the harvester from 8 to 12 hours results in shortening of the total time of performance of all tasks predicted for realization on a given area by 10% and as a result causes considerable reduction of unit costs of felling. On the other hand according to Szewczyk and Kulak (2015) extension of work by the use of the two-shift system and with the work by 250 working days causes reduction by half of the costs of felling which are incurred in case of one-shift work and 110 working days. Błuszkowska and Nurek (2016) also indicate the positive impact of a longer working day on the increase of operational performance of harvesters and thus the amount of harvested trees (better use of the machine) and reduction of the harvesting costs. Better training for the operator would also be crucial because in some instances it was poor (in particular in case of felling trees which was mentioned above). According to Brzózko and Dybcio (2007) the best skills, qualifications and poor experience of operators have a significant impact on the harvester's performance.

Conclusions

Based on the analysis of Fao Far 6840 mini harvester operation one may conclude that:
1. operational performance of the mini harvester operation cycle at the level of 12.14 ($m^3 \cdot h^{-1}$) as well as operational performance in the shift working time at the level of 9.61 ($m^3 \cdot h^{-1}$) was lower than in case of machines working in similar conditions,
2. lower machine performance was affected mainly by conditions of harvesting, low log volume (at the average 0.62 m^3) and concentration of trees. The head structure (applied feed system), weak work organization (short time of a single 6 hour shift) and weak skills of the machine operator were additional factors that decreased the performance.

Funding

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ANALIZA WYDAJNOŚCI PRACY
W PROCESIE MASZYNOWEGO POZYSKANIU DREWNA
MINI HARWESTEREM FAO FAR 6840

Streszczenie W artykule przedstawiono analizę wydajności pracy mini harwestera Fao Far 6840, przy maszynowym pozyskiwaniu drewna. Analizę wykonano w oparciu o chronometraż dnia roboczego. Badania przeprowadzono na terenie Nadleśnictwa Lubliniec, Leśnictwo Bór na typie siedliskowym lasu bór mieszany świeży (BMśw), gdzie mini harwester pozyskiwał drewno sosnowe. Chronometraż wykonano w oparciu o rejestrację czasu eksploatacji harwestera przy pomocy kamery wideo i stopera oraz pomiarów pozyskanego sortymentu. Na podstawie uzyskanych wyników stwierdzono niskie wartości wydajności w eksploatacyjnym czasie zmiany 9,61 m$^3\cdot$h^{-1}, oraz wydajności efektywnej 12,14 m$^3\cdot$h^{-1}. Na niską wydajność maszyny wpłynęły przede wszystkim warunki pozyskania, niska miąższość (średnio 0,62 m^3) i zagęszczenie drzew. Dodatkowymi czynnikami obniżającymi wydajność była konstrukcja głowicy (zastosowany system posuwu) słaba organizacja pracy (krótki czas trwania pojedynczej 6 godzinnej zmiany) oraz słabe umiejętności operatora maszyny.

Słowa kluczowe: harwester, pozyskiwanie drewna, wydajność harwestera