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PREDICTING TIME CONSUMPTION OF CHIPPING TASKS IN A WILLOW SHORT ROTATION COPPICE FROM GPS AND ACCELERATION DATA

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Abstract: *Biomass procured from willow short rotation coppice has a promising potential to ensure the provision of clean energy. To evaluate and validate the effectiveness of different harvesting techniques and equipment for small-scale willow short rotation coppice applications, time and motion studies are usually implemented in small trials. Nevertheless, the results of such trials may be biased by the exclusion of the variability which could be generated by a long-term data collection approach; therefore, techniques and methods should be developed to sustain the implementation of long-term studies. This study tested the capability of GPS and acceleration data to accurately document chipping tasks in a small-scale willow short rotation coppice. Coupling location and acceleration data, followed by a threshold-setting based on video recorded data and direct surveys in the field, led to the possibility to accurately separate the time spent in moving, chipping and non-chipping tasks. In addition, it was possible to observe, but not to extract, other events such as the transition time between the chipping and non-chipping states of the machine. The approach described in this study could be used to conduct long-term studies being suitable also for monitoring other harvesting equipment such as that chipping the stems during moving, as this could be enabled by a higher response in terms of acceleration induced by the vibration during chipping than by the movement itself.*

Key words: *willow, short rotation coppice, static chipping, time and motion, data collection, automation.*

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1. Introduction

The forecasted changes in climate and the increasing depletion of fossil fuel resources changed the contemporary socio-economic paradigms, with obvious effects in the change of views, policies and regulations, towards the preference in use of renewable energy sources that hold a promising potential to develop a bio-based, circular economy. For instance, to be able to sustain the European energy consumption, a significant effort has been undertaken to develop the willow short-rotation cultures (WSRCs), with major innovations in both, the breeding material [12] and in the practice and technology used to establish, manage and harvest the biomass [14, 16, 29].

Typical procurement operations in WSRCs are those making use of either a cut-and-chip or cut-and-store harvesting system which can be operationally implemented by the use of motor-manual or fully mechanized equipment [9, 13, 23, 30]. Nevertheless, both, motor-manual and mechanized harvesting of WSRCs still account for a significant share of the biomass delivery costs [13, 30]. While such costs can be sustained under the conditions of large-scale industrial WSRC applications [14], they may become a limiting factor under the conditions of small-scale farming, a reason for which self-employed small entrepreneurs often choose to use inexpensive multipurpose equipment [25] such as brush-cutters [28], chainsaws [9, 23, 30] and small chippers powered by agricultural tractors [14]. Obviously, this approach could be also the result of a lack of association [25] or of a limited availability of technology which is known to depend on the economic condition of a country [20, 22].

In Romania, the experience with willow cultivation is rather new [24], holding most of its background in the establishment of some test plots back in 2007-2008. Since then, an important area has been cultivated year-by-year, with many of such cultures being now in the harvesting stage. On the one hand, the Romanian farmers learnt on-the-job about the technology used in harvesting, and some local tacit experience exists about the most suitable equipment to be used in harvesting. Nevertheless, a significant part of the equipment used today in the Romanian WSRCs was purchased based on subjective opinion of farmers, including purpose-built small-sized harvesters.

To evaluate the time consumption and productivity in harvesting operations of the Romanian WSRCs, a series of pilot studies have been carried so far with focus on the motor-manual felling [8, 28], showing that the time consumption per hectare was high and the productivity was low. Nevertheless, the productive performance of such operations may be affected by several factors [28], including the limitations brought by human capability and the size of the harvested stems [28], confining the motor-manual harvesting to very short rotations [27]. This is a reason to test easy-to-use reliable technology for long-term data collection [8] and to elucidate the effects of various factors to be able to design new ways to harvest the willow.

Besides that, there are many reasons why data collected for a long period of time is useful to understand the behavior of a given harvesting system. Long-term collected data can account for variability which cannot be observed in small trials characterized, for instance, by complex tasks [5-6] and particular conditions to be surveyed [4, 7], enabling this way more informed decisions based on conclusive results [1]. Time and motion studies are usually implemented to collect such data but the traditional approaches have a series of limitations related to the accuracy [11], safety [1] and resources committed to the study [2-3, 21]. In contrast, the use of different available technologies which are currently developed to a reliable consumer-grade standard may enable long-term data collection and partial automation of the data processing effort [2, 27]. This is particularly important for that kind of equipment which is not characterized by the integration of measurement and production management systems [5], and which is further characterized by a low integration of mechanization or automation [27], limiting the possibility to extract data on long term and to support the management and decision-making in production. In fact, such limiting features characterize most of the equipment that is currently used in both, WSRC and typical timber harvesting operations from the south-eastern Europe [15, 20].

While there are many equipment options that could be used to harvest the willow by chipping, in our knowledge, chipping the willow at fixed points as a technical alternative which uses regular wood-designed chippers has not been studied so far. Such technical choices are versatile in the sense that they could be easily switched to operate with regular wood or willow, enabling the chipping in the field but, at least in WSRCs, they involve additional operations such as motor-manual stem felling, bunching (collecting) and feeding the chipper.

The aim of this study was to test to what extent is possible to automate data collection and processing in time and motion studies used to evaluate the time consumption and productive performance in fixed-point in-field chipping operations. The study was designed as a combined approach to collect GPS and acceleration data that were used to extract meaningful information about the time consumption on tasks, after data pairing.

2. Material and methods

Chipping operations were carried out on a 1.4-hectare WSRC plot located at approx. 46° 04'20.2" N - 26° 11' 04.2" E, 580 m about sea level, near Poian, Covasna County, Romania (Figure 1). The stems were motor-manually felled, chipped using a small-sized tractor-powered chipper (Figure 2) and the resulted wood chips were transported to a terminal using trailers powered by agricultural tractors (Figure 3). Motor-manual felling operations were carried out as typical to Romania, by a team consisting of two men, of which one used a brush-cutter to fell the stems and the other one assisted the felling using a wooden stick. A description of such work tasks is detailed in Talagai et al. (2017) and Borz et al. (2018). Chipping operations, which were the subject of this study, were carried out using a small chipper powered by a tractor. The work included both manual and mechanized tasks.

A team consisting of 6-7 workers was used to manually bunch, move and feed the willow stems into the chipper (Figure 3). Such tasks were organized on smaller sub-plots having a length less than 15 m and a width up to 10 m (7 twin rows). When finishing a given sub-plot, the chipper was moved ahead on a given strip to start a new sub-plot and when reaching the headland, the chipper was maneuvered to enter a new strip and to operate in the opposite direction. The chipper operated in parallel with a tractor-powered trailer designed to store and transport the wood chips. When the trailer was almost loaded, one of the workers was used to manually arrange the wood chips into it and when fully loaded, the tractor started the transportation to a terminal, being replaced by the other one operating in the area.

Fig. 1. Study location

Chipping operations were monitored using three devices. A Garmin 62 STC GPS unit (Garmin Ltd., Olathe, USA) was placed on the tractor used to power the chipper into a position that enabled a clear sky for the antenna and it was used to collect location data at a 5-second rate (Figure 2). An Extech® VB 300 acceleration datalogger (Extech Instruments, FLIR Commercial Systems Inc., Nashua, USA) was placed on the chipper, on the left side of the inlet, and it was used to collect data at a 1-second rate (Figure 2). The third device consisted of a digital video-camera mounted on a tripod that was used to videotape the operations at random intervals. It was used to collect 10 to 20 minutes in length digital video files that were used at the office to recognize specific events and to assist the decision algorithm used to categorize the time consumption data extraction from the GPS and acceleration datasets.

At the office, GPS data was transferred into a computer using the regular data downloading procedures and it was stored as GPX files. Then, the acceleration data was transferred and paired with GPS data using the dedicated software of the datalogger. The full data transfer, pairing, processing and analysis procedures used in this study are similar to those described in Borz et al. (2018). Resampling of the data collected by the acceleration datalogger was also made according to the procedures described in Borz et al. (2018) and it was necessary to be able to pair it with the GPS-collected data.

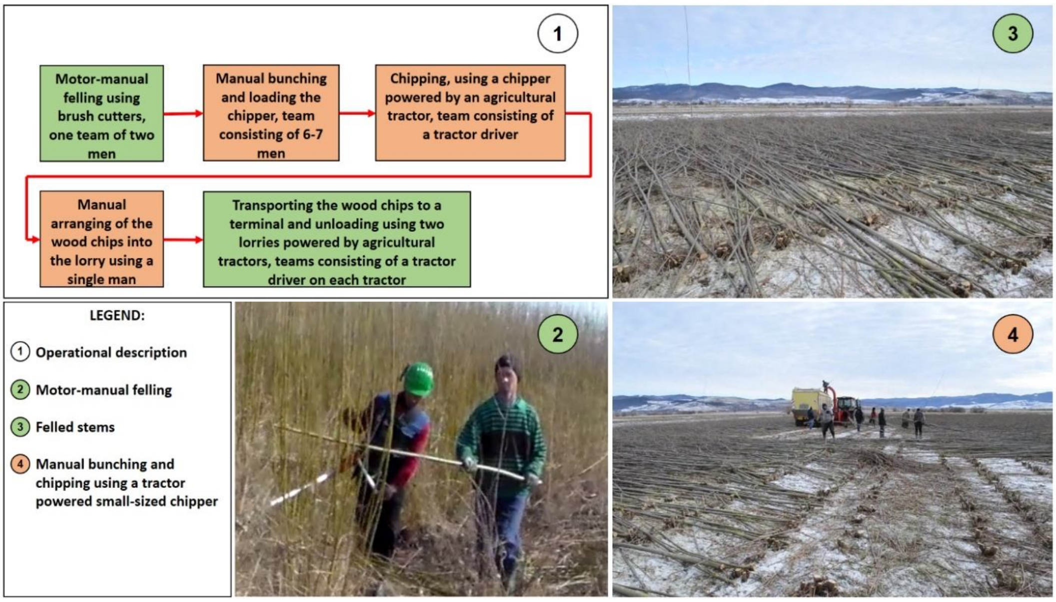

Fig. 2. Work organization: 1) general operational layout and the work teams, 2) procedures used to fell the stems, 3) felled stems to be bunched and 4) manual bunching and chipping

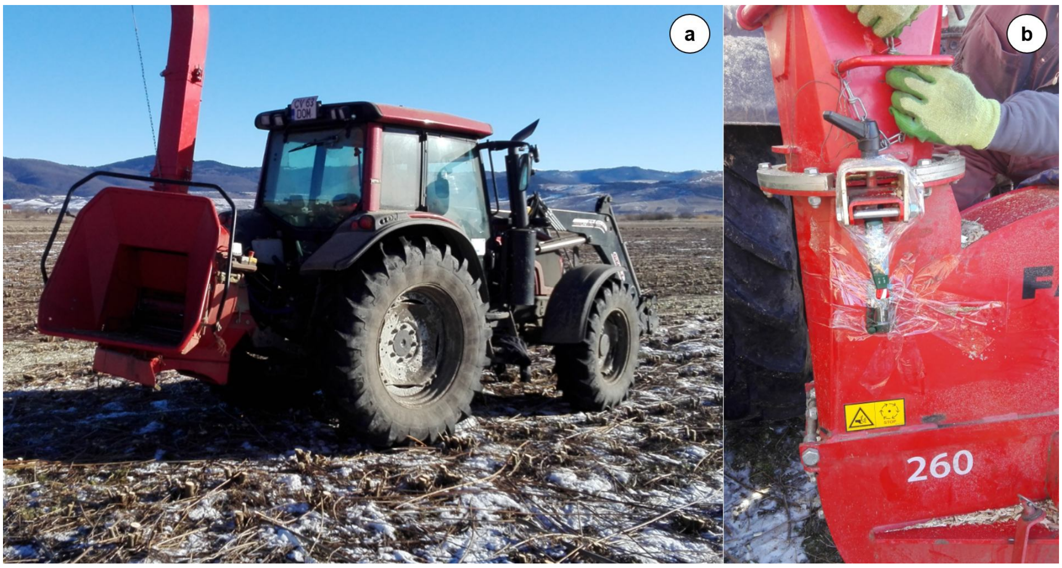

Fig. 3. The Tractor-mounted chipper observed during the field study (a) and the placement of acceleration datalogger (b)

The main differences in this study were those related to the chipping functions that were observed and the thresholds set to separate between specific events. To this end, given the work organization, two chipper movement events were monitored: not moving (*NM*) and moving (*M*). The first one characterized the time in which the chipper was stopped in a given point irrespective of the carried-out operations (chipping - *C* or not chipping - *NC*), while the second one was used to characterize the movements within the plot assuming, on logical reasons, that no chipping events occurred during movement. To document such events a speed threshold of the GPS collected data was set at 0.5 km/h (*S* = 0.5 km/h). Following a video analysis at the office, a threshold set at 5 g for acceleration (*A* = 5 g) was used to characterize the utilization of the machine by chipping and not chipping events. This was necessary as following the video analysis, the chipper was identified to be in three specific states: engine stopped, engine running without chipping and engine running and chipping. The last event was that in which the response of the acceleration datalogger exceeded 5 g. Therefore, this study attempted to separate between three events that characterized the operation of chipper: not moving and chipping - *NM_C*, not moving and not chipping - *NM_NC*, and moving - *M*.

3. Results and Discussion

This study used 6,945 GPS-collected locations and a dataset consisting of 34,715 acceleration samples.

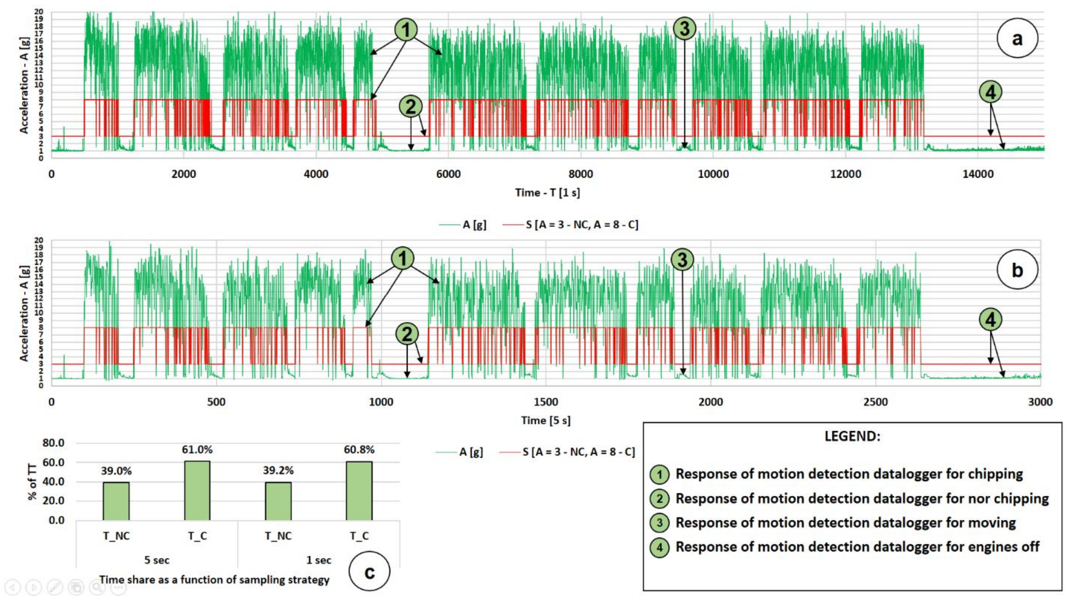

Fig. 4. Resampling accuracy and distinguishable events. Legend: a) accuracy and distinguishable events on the original acceleration data; b) accuracy and distinguishable events after resampling: in red - threshold set for chipping, in green - response in acceleration; c) resampling strategy & accuracy

Each fifth acceleration sample was extracted from the original dataset and paired to the corresponding GPS location. Figure 4 shows a comparison of two subsamples extracted from the original (a) and resampled (b) acceleration data sets. The acceleration threshold set at 5 g was used to differentiate between chipping and not chipping events in both datasets, events that were distinguishable using this threshold. Also, this approach enabled the identification of other kind of events such as operational breaks and chipper movement. Examples of such events are also given in Figure 2.

Data resampling resulted in a similar accuracy of the data set as shown in Figure 4. The differences were less than 0.02% in the case of chipping and non-chipping events. Therefore, chipping time, accounted for almost 61% of the total time, while the non-chipping time and chipper moving time accounted for the rest. Nevertheless, moving time characterizes moving events that were needed to relocate from a chipping point to another; therefore, it was reasonable to separate it from the observed time and particularly from that time category indicating no movement and no chipping which, in turn, may stand for organizational, technological and personal delays. The separation was based on the speed parameter extracted from the GPS files. Figure 5 shows the geospatial prediction of results obtained using three separation algorithms. Figure 5a shows the geospatial prediction of the moving versus non-moving time, Figure 5b shows the geo-spatial prediction of chipping versus non-chipping time while Figure 5c shows the geospatial prediction of the moving, chipping and non-chipping time accounting, therefore, also for possible delays.

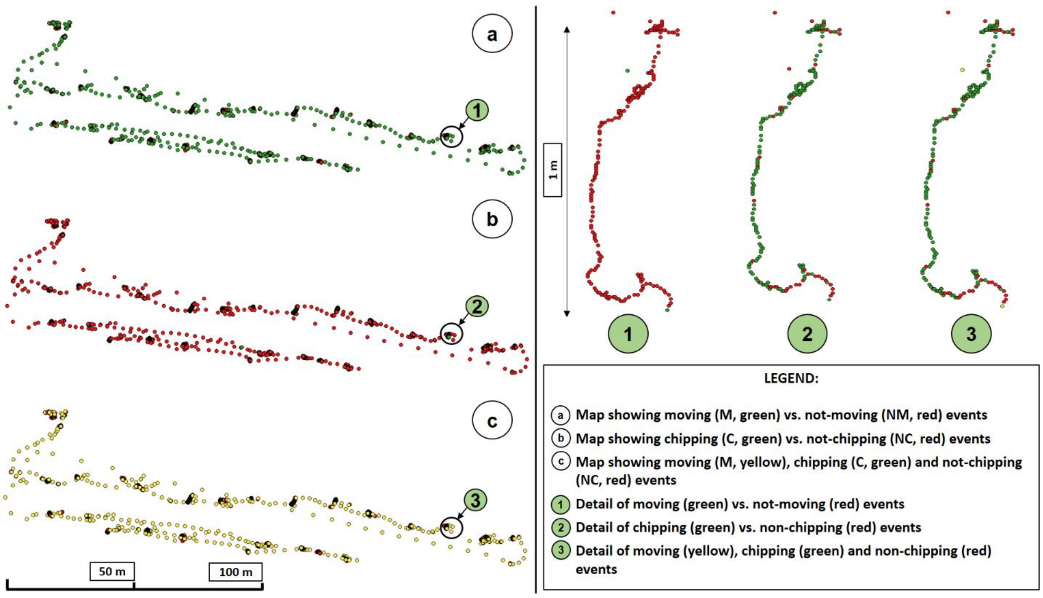

Fig. 5. Geo-spatial prediction of moving, chipping and non-chipping events

Differences shown for chipping versus non-chipping locations in the details shown in Figure 5 are the result of those events in which the chipper engine worked while it was not fed with willow stems. Therefore, the two are not characterizing the engine events such as the engine turned on or off but the effective chipping versus non-chipping. There were events in which acceleration responses were affected by the chipper movement, but not to the extent shown during the effective chipping. Other specific events such as turning off or on the chipper’s engine may also be seen in Figure 4 right before and after those responses characterizing the chipper’s movement.

As separated by the used algorithm, in the total study time - TT (9.64 hours), chipper moving time which included movement between successive subplots, movement to turnaround the chipper and to enter or exit the operated strips accounted for 4.8% (0.46 hours). More than 60% of the total study time was consumed during the effective chipping operations while the rest represented delays of organizational, technical and personal nature. In this category were included also those small parts of time in which the chipper engine worked without chipping between two successive feeds made by the workers. A detailed description of the moving, chipping and non-chipping time is given in Figure 5, which also shows the results of the separation algorithm that succeeded to differentiate between the three studied events.

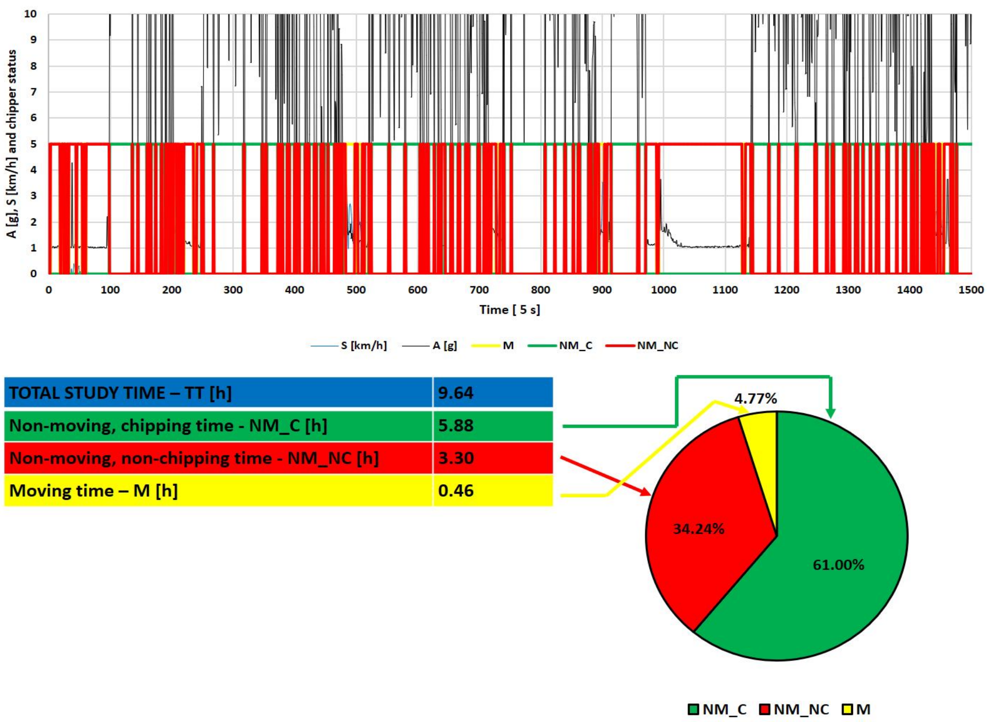

Fig. 5. Statistics of time consumption and results of the separation algorithm

Performance of a given system may be estimated using various metrics. Given the scope of this study, productivity and efficiency were estimated based on the operated area since no production outputs such as chipped volume or mass were measured. Based on estimates of the area operated during the study (cca. 0.5 ha), the gross production rate was evaluated at 0.05 ha/hour. This accounted for 23 points in which the chipper worked and another 3 major stops which were made for other reasons. The net production rate included only the time spent for moving and chipping and it was estimated at cca. 0.08 ha/hour. These figures translated into a gross and net efficiency of 12.68 and 18.92 hours/ha respectively.

The results of this case study indicate that coupling GPS and acceleration dataloggers to collect time and motion data in fixed-point chipping operations proved to yield very accurate results which could sustain the effort of collecting long-term data. As a fact, there are several studies which evaluated the capability of GPS in documenting time consumption of ground-based operations [17-18] including WSRC operations [10, 13, 28] but only few of them paired also the data collected by accelerometers [19, 26] to yield accurate separations of the time categories [8]. Given the experimental approach of this study, that accounted for static chipping operations, it is obvious that other operational layouts may result in different responses in terms of acceleration. Further studies could explore the potential of data collection using the procedures described in this study for those operations in which chipping is undertaken during the machine's movement over the WSRC plots. In such cases, the collection of acceleration data that differentiates between work tasks could be enabled to a greater extent by the amount of vibration generated by chipping devices; one could expect less acceleration generated by movement compared to the acceleration induced by the chipping vibration itself.

4. Conclusions

This study tested the possibility to automate data collection in time and motion studies specific to static chipping operations carried out in WSRCs. The results indicate that the separation of productive and non-productive time was possible and accurate when coupling GPS and acceleration data, followed by their thresholding. Both, chipping and non-chipping time were accurately extracted from the engine running time category. Moving time was also accurately predicted from the speed derived from GPS data. An approach such as that described herein could sustain long-term data collection with less researching effort.

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References

1. Acuna, M., Bigot, M., Guerra, S. et al., 2012. Good practice guidelines for biomass production studies. Forest Energy. Available at: http://www.forestenergy.org/pages/cost-action-fp0902/good-practice-guidelines. Accessed on: 15th January 2018.
2. Borz, S.A., 2016. Turning a winch skidder into a self-data collection machine using external sensors: A methodological concept. In: Bulletin of the Transilvania University of Braşov, Series II: Forestry, Wood Industry, Agricultural Food Engineering, vol. 9(2), pp. 1-6.
3. Borz, S.A., Adam, M., 2015. Analiza fișierelor video în studii de timp prin utilizarea de software gratuit sau cu cost redus: Factori care influențează cantitativ consumul de timp la procesare și predicția acestuia. In: Revista Pădurilor, no. 3-4, pp. 60-71.
4. Borz, S.A., Dinulică, F., Bîrda, M. et al., 2013. Time consumption and productivity of skidding silver fir (*Abies alba* Mill.) round wood in reduced accessibility conditions: A case study in windthrow salvage logging form Romanian Carpathians. In: Annals of Forest Research, vol. 56(2), pp. 363-375.
5. Borz, S.A., Bîrda, M., Ignea, Gh. et al., 2014a. Efficiency of a Woody 60 processor attached to a Mounty 4100 tower yarder when processing coniferous timber from thinning operations. In: Annals of Forest Research, vol. 57(2), pp. 333-345.
6. Borz, S.A., Ignea, Gh., Popa, B., 2014b. Modelling and comparing timber winching performance in windthrow and uniform selective cuttings for two Romanian skidders. In: Journal of Forest Research, vol. 19(6), pp. 473-482.
7. Borz, S.A., Ignea, Gh., Popa, B. et al., 2015. Estimating time consumption and productivity of roundwood skidding in group shelterwood system - A case study in a broadleaved mixed stand located in reduced accessibility conditions. In: Croatian Journal of Forest Engineering, vol. 36(1), pp. 137-146.
8. Borz, S.A., Talagai, N., Cheța, M. et al., 2018. Automating data collection in motor-manual time and motion studies implemented in a willow short rotation coppice. In: BioResources, vol. 13(2), pp. 3236-3249.
9. Burger, F.J., 2010. Bewirtschaftung und Ökobilanzierung von Kurzumtriebsplantagen. Ph.D. Dissertation. Technical University of Munich, Munich, Germany.
10. Bush, C., Volk, T.A., Eisenbies, M.H., 2015. Planting rates and delays during the establishment of willow biomass crops. In: Biomass and Bioenergy, vol. 83, pp. 290-296.
11. Contreras, M., Freitas, R., Ribeiro, L. et al., 2017. Multi-camera surveillance systems for time and motion studies of timber harvesting equipment. In: Computers and Electronics in Agriculture, vol. 135, pp. 208-215.
12. Dickmann, D.I., 2006. Silviculture and biology of short-rotation woody crops in temperate regions: Then and now. In: Biomass and Bioenergy, vol. 30, pp. 696-705.
13. Eisenbies, M.H., Volk, T.A., Posselius, J. et al., 2014. Evaluation of a single-pass, cut and chip harvest system on

commercial-scale, short-rotation shrub willow biomass crops. In: BioEnergy Research, vol. 7(4), pp. 1506-1518.

14. Kofman, P.D., 2012. Harvesting short rotation coppice willow. COFORD, Dept. Agriculture, Food and the Marine. Harvesting / Transport No. 29. Available at: www.woodenergy.ie/media/coford/.../HAR29_LR.PDF. Accessed on 11 May 2017.
15. Koutsianitis, D., Tsioras, P.A., 2017. Time consumption and production costs of two small-scale wood harvesting systems in Northern Greece. In: Small-scale Forestry, vol. 16(1), pp. 19-35.
16. Lechasseur, G., Savoie, P., 2005. Cutting, bundling and chipping short rotation willow. The Canadian Society for engineering in agricultural, food and biological systems. Paper no. 05-580. Available at: www.csbe-scgab.ca/docs/meetings/2005/05-080.pdf. Accessed on: 11 May 2017.
17. McDonald, T., Rummer, B., Taylor, D., 2001. Automating time study of feller-bunchers. In: Proceedings of the Canadian Woodland Forum's 81st Annual Meeting and Council of Forest Engineering's 23rd Annual Meeting - Technologies for the New Millenium Forestry, Kewlona and Montreal, Canada, pp. 1-4.
18. McDonald, T.P., Fulton, J.P., 2005. Automated time study of skidders using global positioning system data. In: Computers and Electronics in Agriculture, vol. 48(1), pp. 19-37.
19. McDonald, T.P., Fulton, J.P., Darr, M.J. et al., 2008. Evaluation of a system to spatially monitor hand planting of pine seedlings. In: Computers and Electronics in Agriculture, vol. 64(2), pp. 173-182.
20. Moskalik, T., Borz, S.A., Dvořák, J. et al., 2017. Timber harvesting methods in Eastern European countries: A review. In: Croatian Journal of Forest Research, vol. 38(2), pp. 231-241.
21. Mușat, E.C., Apăfăian, A.I., Ignea, Gh., et al., 2015. Time expenditure in computer aided time studies implemented for highly mechanized forest equipment. In: Annals of Forest Research, vol. 59(1), pp. 129-144.
22. Rauch, P., Wolfsmayr, U.J., Borz, S.A. et al., 2015. SWOT analysis and strategy development for forest fuel supply chains in South East Europe. In: Forest Policy and Economics, vol. 61, pp. 87-94.
23. Schweier, J., Becker, G., 2012. Motor manual harvest of short rotation coppice in South-West Germany. In: Allgemeine Forst und Jagdzeitung, vol. 183(7-8), pp. 159-167.
24. Scriba, C., Borz, S.A., Talagai, N., 2014. Estimating dry mass and bark proportion in one-year shoots yielded by one-year *Salix viminalis* L. plantations in Central Romania. In: Revista Pădurilor, anul 129, no. 3-4, pp. 57-66.
25. Spinelli, R., Schweier, J., de Francesco, F., 2012. Harvesting techniques for non-industrial biomass platations. In: Biosystems Engineering, vol. 113(4), pp. 319-324.
26. Strandgard, M., Mitchell, R., 2015. Automated time study of forwarders using GPS and a vibration sensor. In: Croatian Journal of Forest Engineering, vol. 36(2), pp. 175-184.
27. Talagai, N., Borz, S.A., 2016. Concepte de automatizare a activității de colectare a datelor cu aplicabilitate în monitorizarea performanței productive

în operații de gestionare a culturilor de salcie de rotație scurtă. In: Revista Pădurilor, anul 131, no. 3-4, pp. 78-94.
28. Talagai, N., Borz, S.A., Ignea, Gh., 2017. Performance of brush cutters in felling operations of willow short rotation coppice. In: BioResources, vol. 12(2), pp. 3560-3569.
29. van der Meijden, G.P.M., Gigler, J.K., 1995. Harvesting techniques and logistics of short rotation energy forestry. A descriptive study on harvest and transport systems in *Salix* production currently used in Sweden. JordbrukstekniskaInstitutet. Available at: http://www.jti.se/uploads/jti/JTI_Rapport_200.pdf. Accessed on 15th January 2018.
30. Vanbeveren, S.P.P., Schweier, J., Berhongaray, G. et al., 2015. Operational short rotation woody crop plantations: Manual or mechanized harvesting?” In: Biomass and Bioenergy, vol. 72, pp. 8-18.