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# Comparison of Two Felling & Processing Methods in Beech Forests

**Dane Marčeta, Boštjan Košir**


***Abstract***

*In this research, two motor-manual felling & processing methods were compared, assortment and half-tree length, in beech stands. Investigation was done in two compartments in the northern part of Bosnia and Herzegovina (B&H), where four sample plots were chosen that differed by felled tree diameter and harvesting method. On the sample plots A1 and B1 assortment harvesting method was performed and on the sample plots A2 and B2 half-tree length method. In the study, 318 trees were felled in total, of which 163 by the assortment method and 155 by the half-tree length method. With the increase of* DBH*, productivity was constantly increasing and it was higher when the half-tree length method was applied than the assortment method. The main reason why half-tree length was more productive was the fact that some working operations, like production and stacking of fuel wood, were avoided or minimized.*


*Keywords: motor-manual, assortment, half-tree length, productivity*

## 1. Introduction

A harvesting system refers to tools, equipment and machines used to harvest an area, while harvesting method refers to the form in which wood is delivered to the logging access road, and depends on the amount of processing (Pulkki 1997). According to Rebula (1988), working method determines the form and size of assortments transported from the forest. According to him, there are different methods: assortment, half-tree length, tree length, full-tree method, part-tree method and chipping method. Pulkki (1997) emphasizes five harvesting methods in use throughout the world: cut-to-length, tree length, full tree, whole tree and complete tree.

In the area of Bosnia and Hercegovina (B&H), several studies have been conducted on the introduction of tree length and half-tree length harvesting method (Kulušić et al.1980, Kulušić 1981, Ljubojević 1990, Kulušić and Miodragović 1979). Results of those investigations led to the conclusion that tree length and half-tree length methods are recommended along with better organization of the production process. Some studies proved that long-log methods cause higher damages to the stand, standing tress, seedlings and soil (Doležal 1984, Meyer 1966). Naghdi (2005) compared the production rate and costs, as well as damage to the residual stand when using the cut-to-length and tree length method. The productivity of the tree length method was higher than that of the cut-to-length method. Damage to the residual stand in the cut-to-length method was higher than in the tree length method. Adebayo et al. (2007) studied productivity and cost of the whole tree method and cut-to-length method. Their results proved that the whole tree method was more productive than the cut-to-length method, and consequently the production cost was lower. Spinelli et al. (2014) compared motor-manual cut-to-length (*CTL*) harvesting, motor-manual whole-tree (*WT*) harvesting, mechanized *CTL* harvesting and mechanized *WT* harvesting as applied to the production of energy chips from the second thinning of Mediterranean pine plantations in flat terrain, and concluded that mechanization increased productivity, reduced costs and damages. In Greece, the use of tree length system is introduced mainly in stands with terrain with low inclination, and cutting of stacked wood into length by chainsaw is a typical technical and technological wood harvesting solution (Galis and Spyroglou 2012). In central Sweden, studies of conventional Scandinavian short wood processing vs. a differentiated processing method were performed. The latter signifies processing only sawlogs at the logging site. Pulpwood and fuelwood are transported off the site as undelimbed tree sections. Each operation of collecting, processing and transportation of biomass requires some energy consumption at related costs (Vasković et al., 2015). Differentiated processing was found to be recommendable for ergonomic, economical, and efficiency reasons (Bjöerheden 1998). Although, safety hazards increase in motor-manual felling, there are certain advantages because chainsaw felling is not as limited by the ground slope or tree size as mechanized felling. Motor-manual felling is also used to meet management objectives such as pre-commercial thinning, salvage operations and selective harvesting (Behjou et al. 2009).

Bojanin et al. (1989) compared harvesting in oak and alder stands. They applied assortment felling & processing method, where technical roundwood and long pulpwood in transport lengths were produced, and emphasized the advantages of producing wood in transport lengths. Application of motor-manual assortment, tree length and half-tree length methods in different working conditions were also investigated by Bojanin and Krpan (1994). They established that instead of classical 1-m length fuelwood, 4-m transport length fuelwood was made. Krpan and Zečić (1996) investigated effective work time in harvesting of poplar by using of group work, where harvesting was done with modified tree length method, after which skidding to forest landing was done, where processing continued. Zečić and Marenče (2005) examined the characteristics of work and efficiency of a work team. Zečić and Krpan (2004) examined group work for felling, processing, skidding and classification in mountainous broadleaf thinning stands. Empirical performance models are generally developed by collecting field data and testing the statistical significance of any relationship with regression analysis (Samset 1990). This technique is used to calculate an equation that can represent the relationship between a dependent variable (typically time consumption or productivity) and one or more independent variables (Costa et al. 2012).

Many studies have reported that tree diameter (*DBH*), ground slope and species of tree influence the felling time in motor-manual felling (Kluender and Stokes 1996, Hartsough et al. 2001, Wang et al. 2004, Ghaffariyan and Sobhany 2007, Ghaffariyan et al. 2013). Notably, the back cut has the highest share of the felling time, and delay times account for about one-fifth of the total working time. Tree diameter (*DBH*) was found to be the most important factor of time consumption and productivity. In addition to the *DBH*, distance between trees was also found to influence productivity of felling operation (Behjou et al. 2009). Behjou (2012) established that felling time per tree was mostly affected by *DBH*, the distance among harvested trees in single-tree selection method and *DBH* in group selection method.

A time study is usually done either as a comparative study, a correlation study or a combination of the two (Acuna et al. 2012). The objective of comparative studies is to compare two or several machines, work methods, etc., while the objective of the correlation or relationship study is to describe the relationship between performance and the factors influencing the work (Nurminen et al. 2006). Time studies can be carried out using continuous time study methods, such as continuous or repetitive timing or indirect work sampling (Samset 1990, Harstela 1991, Spinelli et al. 2013). Wang et al. (2004) developed a productivity model for motor-manual felling, which included variables such as *DBH* and the distance among harvested trees. Jovanović (1980) conducted time study for two technologies, assortment and tree length method. He used work sampling method for data collection. Poje and Potočnik (2007) studied group work in forestry and concluded that group work demands a highly skilled worker, who is able to perform any work in the group and this requires constant education and employment stability.

Technical and economic harvesting of forest biomass depends on various factors related to terrain conditions, transportation networks and harvesting technologies, as well as systems, silviculture and forest operations management (Picchio et al. 2011). Time studies are usually used for the analysis of productivity of various forest biomass harvesting systems (Magagnotti et al. 2012, Picchio et al. 2009, Savelli et al. 2010).

Although comparison of cut-to-length method and tree length method provides important information about the effect of log length on the productivity and cost and also damage to the residual stand, it is not sufficiently detailed, because performing cut-to-length method involves large variations in log length that require more detailed studies. Therefore, further comparative studies on the short-log and long-log method are needed to determine various positive and negative aspects of both methods applied under similar conditions (Adebayo et al. 2007).

Due to the higher initial costs of mechanized harvesting machines, larger diameters and crowns of hardwoods and the relatively steep terrain in B&H forests, motor-manual felling & processing is still the most commonly used method. Forest practitioners mostly apply motor-manual assortment method. Consequently, processing of wood at the stump has a short log, which could have negative effects on the productivity and costs of skidding. With the production of stacked wood in 1-m length pieces in the forest, the problem arises of increased costs of the cutter in the

**Table 1** Research site description

| Stand description | Felling site A (Sample plots A1 and A2) | Felling site B (Sample plots B1 and B2) |
|---|---|---|
| Method | A1 – assortment; A2 – half-tree length | B1 – assortment; B2 – half-tree length |
| Subcompartment | 98a, Management Unit »Potoci – Resanovača« | 65a, Management Unit »Šiša – Palež« |
| Altitude, m above sea level | 970–1150 | 690–1230 |
| Inclination, ° | 15–30 | 15–30 |
| Exposition | S–SE | W–NW |
| Geologic surface | Limestone, medium or deep rocky land | Limestone and dolomite, medium or deep rocky land |
| Climate | Mountain, humid | Mountain, humid |
| Stand | Beech and fir forests with spruce on a series of limestone, predominantly deep soil (*Picea-Abieti-Fagetum*) | High beech forests on predominantly deep limestone and illimerised soil (*Fagetum montanum illyricum*) |
| Site index | 3 | 2 |
| Canopy | Dense (0.7) | Dense (0.8) |
| Management system | Group-selection | Group-selection |
| Growing stock, $m^3$/ha | 513.72 | 343.74 |
| Cutting intensity, % | 14.53 | 20.94 |
| Average diameter of marked tress | 21 cm | 35 cm |
| Regeneration | Medium dense | Medium dense |

forest, as well as increased stacked wood transport costs (Halilović 2012). A part of woody biomass with low value or minimal value is often called fuel wood (fire wood or wood fuel) and used as a traditional or classic source of energy (Eker 2014). Wood stacked in the forest applying the assortment method has to be carried out by animal, and due to the lack of animal labour force on the labour market, stacked wood in practice often remains unused in the forest. The problem of stacked fuel wood produced by applying the assortment method can be solved if long fuel wood is produced instead of classical stacked fuel wood. Producing of long wood is a rational solution because productivity increases and human labour decreases (Bajić et al. 2007). The problem of practice is that, in applying the assortment method, cutters often crosscut the stem at the stump and produce definite shape of logs without the supervision of specialists for classification.

The aim of this study was to compare two motor-manual felling & processing methods, assortment and half-tree length, in beech stands in order to determine the difference in produced wood assortments, productivity and cost competitiveness.

## 2. Material and Methods

Investigation was conducted in the northern part of the B&H in the area of municipality of Ribnik. The terrain was mountainous, in winter period without or with minor amount of snow. Temperature varied from 0 to 7 °C. Sample plots were placed in two subcompartments (Table 1): subcompartment 98a MU »Potoci – Resanovača« (Felling site A) and subcompartment 65a MU »Šiša – Palež« (Felling site B).

When choosing the felling sites, stand conditions and characteristics of forest infrastructure had to be average for beech forests in B&H. In each compartment, two sample plots i.e. work fields were selected, (A1, A2, B1 and B2). Sample plots were selected according to the similarity of their stand and habitat conditions. In this way, as many factors as possible were isolated in order to compare technologies with more reliability. Felling & processing with chainsaw was performed on each sample plot. The width of the work fields was 100 m. The length of each work field was 500 m. So the surface of each sample plot was 5 ha.

Assortment motor-manual felling & processing method was performed on the sample plots A1 and B1, where cutters cut the trees with chainsaw and tree processing was done at the felling site. Technical assortments were made and stacked wood (traditional 1-m length fuelwood) was produced and piled. Fuel wood was made from the thinner part of the stem and branches. Half-tree length felling & processing method was performed on the sample plots A2 and B2, where cutting of trees, delimbing and, if necessary, crosscutting of the stem was done at the site. The stem remained whole or was cut into the transport lengths to allow easier skidding. Stacked wood was made only from branches. Processing continued at the landing site.

Workers were in group of two. Both workers were cutters but while one of them worked with chainsaw, the other was an assistant. After half of the working day, they changed roles. During the time when the cutter worked with the chainsaw, the assistant was engaged in several jobs like work place cleaning, accessories carrying, moving the branches away after delimbing, producing and stacking of fuel wood, etc. Productivity was calculated for the working crew. All work was performed by the same working crew so as to avoid the influence of skill and devotion of workers. Working crew was selected on the basis of last tree month productivity sheets. The crew with average productivity was selected. They worked with professional chainsaw Husqvarna 372XP.

Productivity was investigated by time and work study method (Björheden et al. 1995, Acuna et al. 2012). Time was divided into time elements, each corresponding to one specific task. Time consumptions for work elements were measured by continuous chronometry method and recorded. The distance between marked trees was measured by measuring tape, slope gradient was measured by clinometers and the produced wood data were collected by measuring the diameter and length of each piece of roundwood and by measuring of pile dimension of 1-m length stacked wood. For conversion of staked volume into solid wood volume, conversion coefficient 0.65 was used. Workers, who worked on processing at the landing site during the research, were paid per shift, not per productivity, because processing at the landing site was part of the study and it is not common for local forestry organizations. Their productivity was roughly determined on the basis of work time and produced wood volume.

When data were collected, the influence of different variables on all phases of technological process

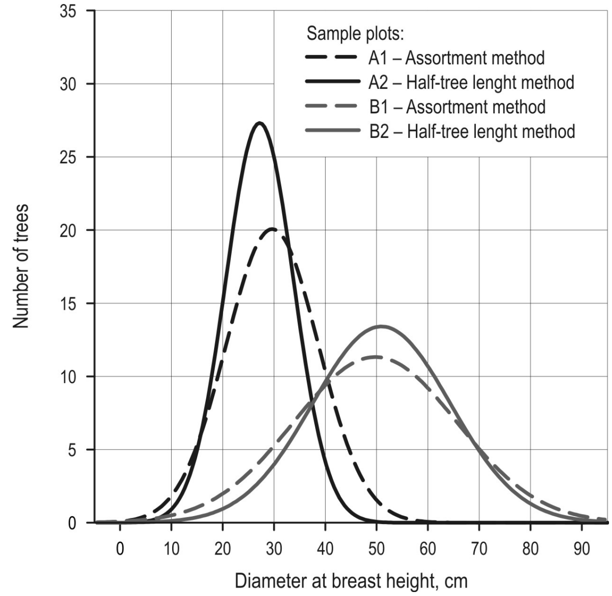


**Fig. 1** *DBH* distribution of felled trees

was examined on the tree level. Several statistical methods were used (Descriptive statistics, Regression and Multiple regressions with dummy variables, etc.) with the help of software Statistica10. Standard times for both methods were calculated. Cost calculation was done according to official methodology, which is in use in the Public Company »Šume Republike Srpske«, based on Myiata (1980).

## 3. Results

### 3.1 Description of sample

In the study, 318 trees were felled in total, of which 163 applying the assortment method (sample plots A1 and B1) and 155 applying the half-tree length method (A2 and B2). The average diameter of felled trees on sample plot A1 was 30 cm and varied from 9 to 54 cm,

**Table 2** Sample description

| Sample plot | Method | $N$ | *DBH*, cm | | | | $V_{fuelwood}$, m$^3$ | | | $V_{roundwood}$, m$^3$ | | | $V_{total}$, m$^3$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Min. | Max. | Std.Dev. | Mean | Sum | % | Mean | Sum | % | Mean | Sum | % |
| A1 | Assortment | 113 | 30 | 9 | 54 | 8.39 | 0.124 | 14.001 | 15.53 | 0.705 | 76.172 | 84.47 | 0.798 | 90.173 | 100 |
| B1 | | 50 | 49 | 23 | 78 | 15.78 | 0.643 | 32.149 | 17.13 | 3.173 | 155.500 | 82.87 | 3.762 | 187.649 | 100 |
| A2 | Half-tree length | 110 | 27 | 10 | 49 | 7.47 | 0.072 | 1.362 | 1.95 | 0.629 | 68.593 | 98.05 | 0.636 | 69.955 | 100 |
| B2 | | 45 | 50 | 18 | 69 | 13.39 | 0.288 | 12.942 | 8.12 | 3.256 | 146.530 | 91.88 | 3.544 | 159.472 | 100 |
| Σ | – | 318 | – | – | – | – | – | 60.454 | – | – | 446.795 | – | – | 507.249 | 100 |

**Table 3** Characteristics of produced roundwood

| | Sample plot | | Mean | Min. | Max. | Std. dev. |
|---|---|---|---|---|---|---|
| Number of assortments per tree | A1 | Assortment | 2.30 | 1.0 | 6.0 | 1.52 |
| | B1 | | 1.81 | 1.0 | 7.0 | 0.92 |
| | A2 | Half-tree length | 6.23 | 1.0 | 12.0 | 3.03 |
| | B2 | | 4.77 | 1.0 | 12.0 | 2.57 |
| Average diameter of assortments, cm | A1 | Assortment | 25.73 | 13.0 | 51.0 | 7.22 |
| | B1 | | 20.01 | 8.0 | 46.0 | 6.89 |
| | A2 | Half-tree length | 34.83 | 12.0 | 79.0 | 16.23 |
| | B2 | | 26.90 | 10.0 | 61.0 | 13.81 |
| Average length of assortments, m | A1 | Assortment | 5.16 | 1.0 | 9.0 | 1.72 |
| | B1 | | 8.83 | 3.8 | 14.5 | 2.09 |
| | A2 | Half-tree length | 4.95 | 1.0 | 9.0 | 1.68 |
| | B2 | | 8.66 | 1.6 | 18.0 | 3.23 |
| Average volume of assortments, $m^3$ | A1 | Assortment | 0.262 | 0.032 | 1.079 | 0.13 |
| | B1 | | 0.319 | 0.035 | 1.594 | 0.26 |
| | A2 | Half-tree length | 0.501 | 0.054 | 2.694 | 0.45 |
| | B2 | | 0.691 | 0.028 | 3.505 | 0.80 |

on sample plot B1 it was 49 cm and varied from 23 to 78 cm (Fig. 1). On sample plots A2 and B2, the average tree diameter was 27 cm and 50 cm, respectively, and varied from 10 to 49 cm on A2 and 18 to 69 cm on B2 (Table 2).

Total volume of produced wood was 507.25 $m^3$, of which 277.82 $m^3$ in assortments and 229.43 $m^3$ in half-tree length. From the total amount, 231.67 $m^3$ of roundwood was in assortments and 215.12 $m^3$ in half-tree length (Table 2). TTK 50S

The share of stacked wood on sample plots in assortments (A1 and B1) was 15.53% and 17.13%, respectively. On sample plots where half-tree length method was performed (A2 and B2), the share of stacked wood was 1.95% and 8.12%. The number of roundwood assortments per tree and dimension of assortments are presented in Table 3.

### 3.2 Comparison of samples

Multiple regression with dummy variables was performed in order to determine which factors influence effective work time per tree. Results showed that felling & processing method and *DBH* have significant influence on the level $p \leq 0.05$ (Table 4). These results

**Table 4** Regression summary for effective time per tree

| $N=318$ | Regression Summary for dependent variable: min/tree<br>$R=0.88$, $R^2=0.78$, Adjusted $R^2=0.78$<br>$F(3.314)=366.80$, $p<0.0000$, Std. error of estimate: 7.397 | | | | | |
|---|---|---|---|---|---|---|
| | $\beta$ | Std. err. of $\beta$ | $b$ | Std. err. of $b$ | $t(314)$ | $p$-value |
| Intercept | – | – | –16.0588* | 2.137513* | –7.51283* | 0.000000* |
| Felling site | –0.052280 | 0.036335 | –1.7820 | 1.238457 | –1.43885 | 0.151188 |
| Method | 0.232889* | 0.026665* | 7.2688* | 0.832261* | 8.73380* | 0.000000* |
| *DBH* | 0.799484* | 0.036408* | 0.8719* | 0.039706* | 21.95914* | 0.000000* |

* Significant at $p<0.05$

**Table 5** Regression summary for net volume per tree

| $N=318$ | Regression Summary for dependent variable: $m^3$/tree<br>$R=0.94$, $R^2=0.88$, Adjusted $R^2=0.88$<br>$F(3.314)=785.87$, $p<0.0000$, Std. error of estimate: 0.649 | | | | | |
|---|---|---|---|---|---|---|
| | $\beta$ | Std. err. of $\beta$ | $b$ | Std. err. of $b$ | $t(314)$ | $p$-value |
| Intercept | – | – | –1.78630* | 0.187694* | –9.51709* | 0.000000* |
| Method | 0.004242 | 0.019402 | 0.01598 | 0.073080 | 0.21865 | 0.827061 |
| *DBH* | 0.828727* | 0.026491* | 0.10907* | 0.003487* | 31.28351* | 0.000000* |
| Felling site | –0.152354* | 0.026438* | –0.62669* | 0.108748* | –5.76275* | 0.000000* |

* Significant at $p<0.05$

indicated that further analysis should be done separately for both examined work methods. Felling site did not show significant influence on the effective time per tree and this result indicated that felling sites with similar work conditions were chosen in accordance with the purpose.

Comparison of net volume per tree on each feeling site showed that work method had no significant influence on the net volume per tree but *DBH* and felling site did show significant influence (Table 5). Trees on the felling site B had larger net volume per tree for the same *DBH* (Fig. 2). The difference in the net wood volume, as a result of different site index of felling site and different working method, indicated that productivity should be calculated separately for both work method and felling site.

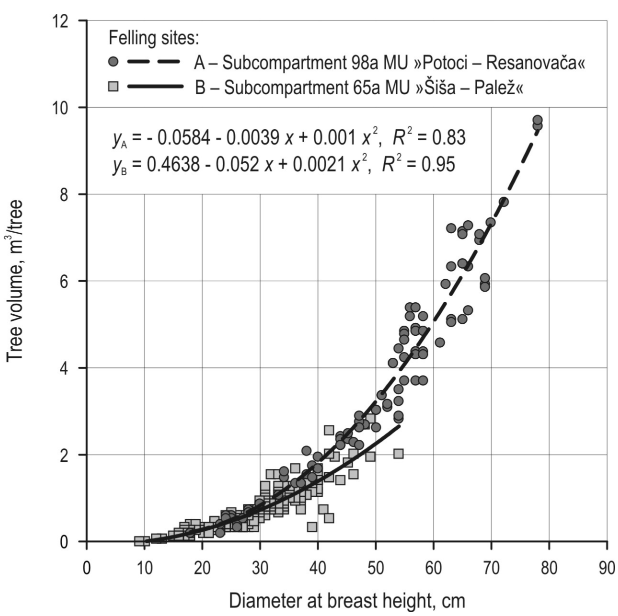


**Fig. 2** Net wood volume per tree

### 3.3 Analysis of work operations

Total studied work time was 4519.44 min on the sample plots where the assortment method was applied and 2502.72 min on the sample plots where half-tree length method was applied. From total time, productive work time was 3469.12 min (assortment) and 1913.29 min (half-tree length) with relative share of delays 30.28% and 30.81%, respectively (Table 6).

Productive work time was divided into work operations. Most time consuming work operation in applying the assortment method was stacking of fuel wood with 6.29 min/tree, then follows delimbing with 4.44 min/tree and production of fuel wood with 3.78 min/tree. In applying the half-tree length method, most time consuming work operations were delimbing with 4.16 min/tree, stacking of fuel wood with 2.61 min/tree and moving with 1.81 min/tree. The shortest time operation in both methods was preparing of work place.

In both methods, most of the allowance work time is related to personal delay, 43% in applying the assortment method and 51% in applying the half-tree length method. Then follow technical delays with the share of 26% and 30%, preparatory-final time with 19% and 11% and organizational delay with the share of 12% and 8%, respectively.

### 3.4 Analysis of influencing factors on time consumption of work operations

Research of different factors influencing the time of work operations was done with the regression and correlation analysis. The influence strength was presented with correlation coefficient ($R$), with the level of significance, $p\leq0.05$. The mathematical models that best show the dependence between variables were presented with regression equations. In work operations, where no significant dependences were evidenced, mean values were used for productivity calculations.

**Table 6** Descriptive analysis of work time

| Working methods | Assortment method | | | | Half-tree length method | | | |
|---|---|---|---|---|---|---|---|---|
| Work operations | Sum | Mean | Minimum | Maximum | Sum | Mean | Minimum | Maximum |
| | Min. | min/tree | | | Min. | min/tree | | |
| Moving | 348.26 | 2.14±1.53 | 0.13 | 8.23 | 279.72 | 1.81±1.07 | 0.35 | 5.23 |
| Preparing of work place | 123.33 | 0.76±1.04 | 0.03 | 7.38 | 71.59 | 0.46±0.73 | 0.08 | 4.80 |
| Felling | 234.23 | 1.44±1.18 | 0.12 | 6.98 | 187.87 | 1.21±0.78 | 0.10 | 3.37 |
| Delimbing | 723.69 | 4.44±3.37 | 0.30 | 18.63 | 645.38 | 4.16±3.07 | 0.67 | 21.08 |
| Processing | 398.42 | 2.44±4.19 | 0.12 | 35.35 | 148.44 | 0.96±1.81 | 0.12 | 8.85 |
| Production of fuel wood | 615.66 | 3.78±3.45 | 0.17 | 19.27 | 176.47 | 1.14±2.01 | 0.20 | 10.35 |
| Stacking of fuel wood | 1025.53 | 6.29±7.17 | 0.42 | 35.00 | 403.82 | 2.61±7.11 | 0.33 | 40.00 |
| Productive work time, min | 3469.12 | | | | 1913.29 | | | |
| Allowance time, min | 1050.32 | | | | 589.43 | | | |
| Allowance time, % | 30.28 | | | | 30.81 | | | |
| ∑ Total, min | 4519.44 | | | | 2502.72 | | | |

### Assortment method

Work operations *Moving* and *Preparing of work place* did not show significant difference of any examined variable. Their mean value was used for productivity calculation. All other work operations showed dependence on *DBH* (Table 8).

### Half-tree length method

In half-tree length method it was similar. *Moving* and *Preparing of work place* did not show significant difference from any examined variables and all other work operations depended from *DBH* (Table 9).

## 3.5 Productivity and costs

Productivity was calculated according to the time for each work operation calculated by the regression equation in cases where significant dependence on influencing factors was established or the mean values were used if there was no dependence. The sum of work operations was multiplied by the coefficient of

**Table 7** Relative share of work operations in total and productive work time

| Working methods | Assortment method | Half-tree length method | Assortment method | Half-tree length method |
|---|---|---|---|---|
| Work operations | % of productive work time | | % of total work time | |
| Moving | 10.04 | 14.62 | 7.71 | 11.18 |
| Preparing of work place | 3.56 | 3.74 | 2.73 | 2.86 |
| Felling | 6.75 | 9.82 | 5.18 | 7.51 |
| Delimbing | 20.86 | 33.73 | 16.01 | 25.79 |
| Processing | 11.48 | 7.76 | 8.82 | 5.93 |
| Production of fuel wood | 17.75 | 9.22 | 13.62 | 7.05 |
| Stacking of fuel wood | 29.56 | 21.11 | 22.69 | 16.14 |
| ∑ | 100 | 100 | 76.76 | 76.45 |
| Allowance time, % | 30.28 | 30.81 | – | – |

**Table 8** Time dependence analysis – Assortment method

| Work operation | *N* | Independent variable | Equation | Parameters | | | *F* test | *R* | *p* | Standard error |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | $b_1$ | $b_2$ | | | | |
| Moving | 158 | Distance, m | – | No significance | | | 0.04 | 0.02 | 0.849 | 1.54 |
| Preparing of work place | 130 | *DBH*, cm | – | No significance | | | 3.93 | 0.17 | 0.049 | 1.03 |
| Felling | 161 | *DBH*, cm | Quadratic | 0.3810 | –0.0075 | 0.0009 | 315.30 | 0.82 | 0.000 | 0.69 |
| Delimbing | 162 | *DBH*, cm | Linear | –2.1889 | 0.1794 | – | 384.04 | 0.84 | 0.000 | 1.83 |
| Processing | 127 | *DBH*, cm | Quadratic | 0.2109 | –0.0699 | 0.0031 | 234.61 | 0.81 | 0.000 | 2.48 |
| Production of fuel wood | 161 | *DBH*, cm | Quadratic | 1.2539 | –0.0215 | 0.0021 | 203.89 | 0.75 | 0.000 | 2.29 |
| Stacking of fuel wood | 156 | *DBH*, cm | Quadratic | 1.8507 | –0.1583 | 0.0068 | 430.71 | 0.86 | 0.000 | 3.69 |

**Table 9** Time dependence analysis – Half-tree length method

| Work operation | *N* | Independent variable | Equation | Parameters | | | *F* test | *R* | *p* | Standard error |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | $b_1$ | $b_2$ | | | | |
| Moving | 155 | Distance, m | – | No significance | | | 8.97 | 0.23 | 0.003 | 1.04 |
| Preparing of work place | 91 | *DBH*, cm | – | No significance | | | 2.14 | 0.15 | 0.147 | 0.72 |
| Felling | 155 | *DBH*, cm | Linear | –0.4833 | 0.0490 | – | 565.73 | 0.89 | 0.000 | 0.36 |
| Delimbing | 154 | *DBH*, cm | Linear | –1.4454 | 0.1600 | – | 293.90 | 0.81 | 0.000 | 1.80 |
| Processing | 100 | *DBH*, cm | Quadratic | 0.5013 | –0.0618 | 0.0031 | 260.80 | 0.85 | 0.000 | 0.95 |
| Production of fuel wood | 59 | *DBH*, cm | Linear | –1.4280 | 0.0904 | – | 55.68 | 0.70 | 0.000 | 1.44 |
| Stacking of fuel wood | 51 | *DBH*, cm | Quadratic | 0.0264 | –0.0916 | 0.0068 | 41.65 | 0.68 | 0.000 | 5.28 |

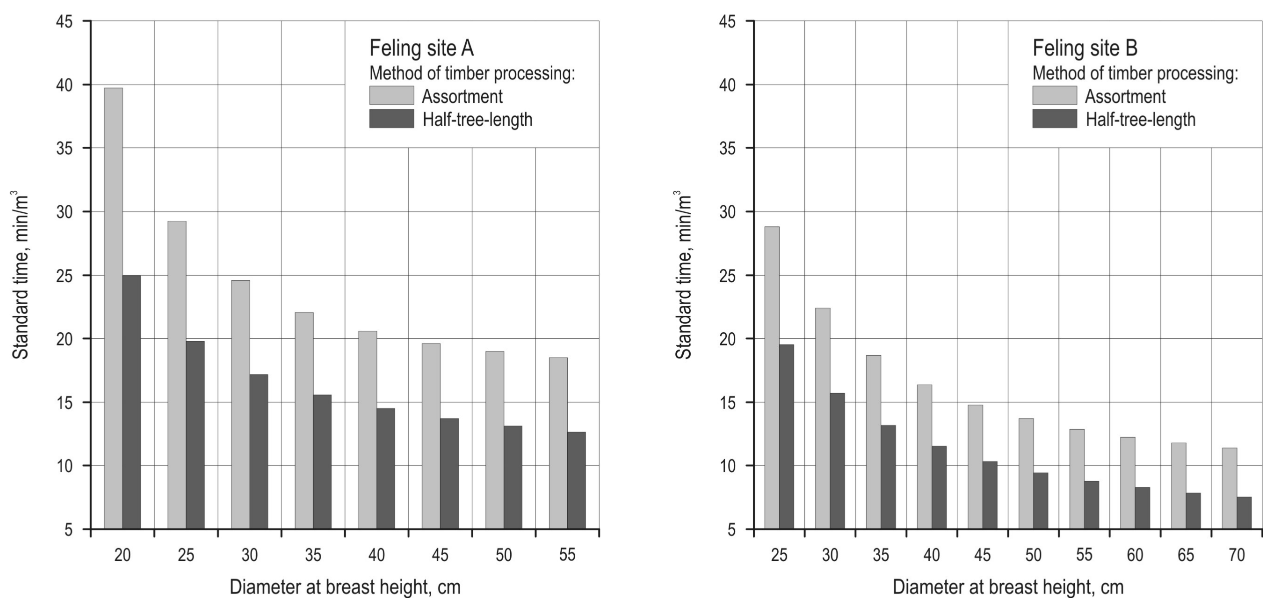


**Fig. 3** Standard times for felling sites and methods

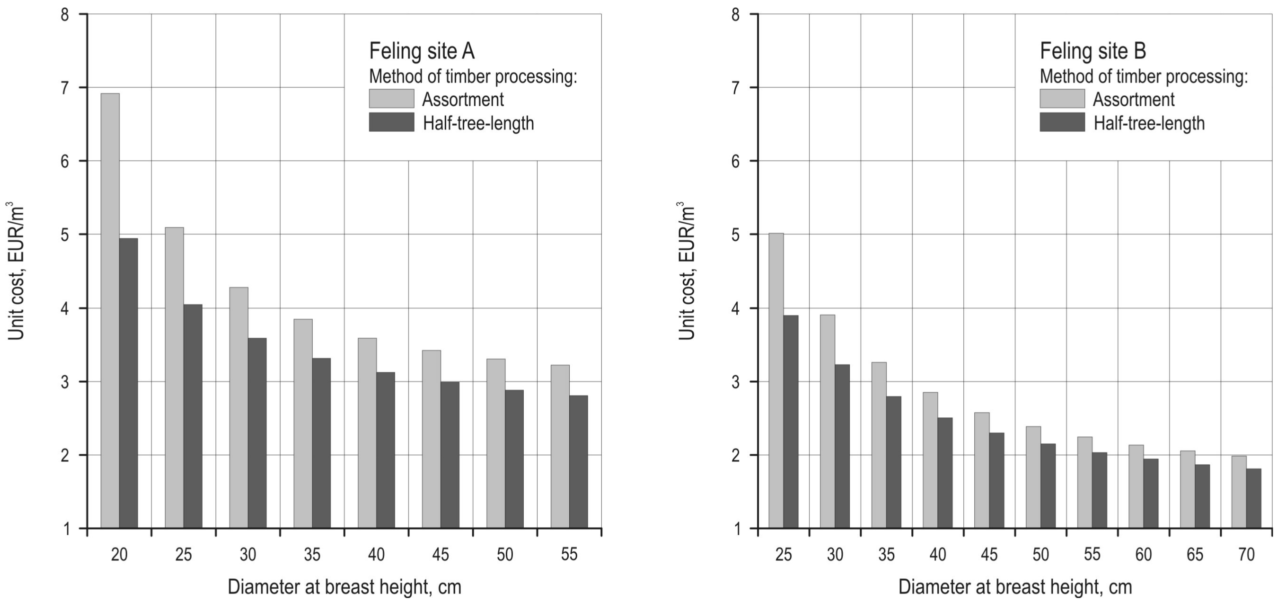


**Fig. 4** Unit costs for felling sites and methods

allowance time and divided by the volume of wood (Fig. 3).

The cost of the working day of chainsaw was calculated on the basis of official methodology used by the Public Company »Šume Republike Srpske«. Prices of material and labour, which were valid at the moment of research, were taken as inputs. The cost of one 8-hour-working day was EUR 78.4 (9.80 EUR/hour). In half-tree length method, workers who performed processing at the roadside landing were paid per shift and costs of processing at the landing site were 0.6 EUR/$m^3$ for felling site A and 0.5 EUR/$m^3$ for felling site B (Fig. 4) on the basis of daily productivity of 130.7 $m^3$ for felling site A and 156.8 $m^3$ for felling site B and daily costs of EUR 78.4.

## 4. Discussion

The share of stacked wood was significantly lower in applying the half-tree length method than assortment method, 1.95% (A2 – half-tree length method) vs 15.53% (A1 – assortment method) and 8.12% (B2 – half-tree length method) vs 17.13% (B1 – assortment method). These results were expected in accordance with the working methods. In applying the assortment method, stacked wood was made from branches and from thinner parts of the stem, while in the half-tree length method, it was only made from branches. The decision on the place where producing of roundwood stops and producing of stacked wood starts on the stem was based on recommendations of operation plans for the specific compartment. The difference in the amount of stacked wood within the same harvesting method was higher on the sample plots with smaller average tree diameter. The reason for that could be that thicker trees have a relatively higher amount of branches above 7 cm diameter from which stacked wood is produced. The average number of assortments per tree was smaller in half-tree length method, 1.81 pieces per tree (A2 – half-tree length method) vs 2.23 pieces per tree (A1 – assortment method) and 4.77 (B2 – half-tree length method) vs 6.23 (B1 – assortment method). The difference was slightly bigger on sample plots with larger *DBH*, 19% (A2 vs A1) and 23% (B2 vs B1). The diameter of assortments was lower in applying the half-tree length method than the assortment method. The difference was the consequence of the fact that in using the half-tree length method logs were relatively longer and stretched to the thinner parts of the stem, while in using the assortment method these parts were bucked into the stacked wood. The emphasis is on the fact that technical and firewood logs are the same in half-tree length method, which makes skidding of lower value wood cost competitive (Košir 2009, Bajić et al. 2007).

The average log length was lower when the assortment method was applied. In applying the assortment method, log length mostly depends on dimension and quality, which are inputs for wood classification. When the half-tree length method is applied, the length mostly depended on the skidding options. The density of remaining trees was the limiting factor in most cases. As a consequence of length and diameter, the average volume of assortments was larger in applying the half-tree length method 19% (A2 vs A1) on sample plots with lower *DBH* and 27% (B2 vs B1) on plots with larger *DBH*.

Relative structure of productive work time showed that work operations *Production of fuelwood* and *Stacking of fuelwood* consumed relatively less time in applying the half-tree length method than the assortment method, 9.22% and 21.11% in applying the half-tree length method and 17.75% and 29.56% in applying the assortment method, respectively. Time *Delimbing* takes relative larger share in half-tree length method, 33.73% vs 20.86% in assortment method. The explanation for that could be the fact that in upper parts of stem in applying the assortment method *Delimbing* can overlap with the *Production of fuelwood* and it is hard to define the border between those two operations during time study. Structure of additional times was similar in both methods, coefficient of allowance times are 1.30 for assortment and 1.31 for half-tree length method. Ghaffariyan et al. (2013) determined next-time distribution in chainsaw motor-manual felling: moving to tree 12%, reconnaissance 11%, under cut 27%, backcut 31% and delay 19%. In uneven-aged beech forests, Behjou et al. (2009) established mean delay times of 0.81 min per tree, based on 0.22, 0.44 and 0.15 min per tree for operational, mechanical and personal delays.

Regression and correlation analysis showed that in both methods, the operation *Moving* did not show dependence on distance. The reason could lie in the fact that trees marked for felling were equally distributed in the stand. The reason could also be the discipline of workers. *Preparing of work place* did not show significant dependence on any examined factor. Other work operations showed more or less strong significant dependence on *DBH*. Productivity was constantly increasing with the increase of *DBH* and it was higher in applying the half-tree length method than the assortment method. The reason for higher productivity of the half-tree length method was the fact that some working operations were avoided or minimized in applying the half-tree length method, like production and stacking of fuel wood. Also, bucking was mostly transferred to the landing site, where it could be done in a more productive way.

## 5. Conclusion

Investigation showed that performing of the half-tree length harvesting method was more productive and cost competitive than the assortment method. Unit costs were significantly lower. Large amount of stacked wood remaining after the assortment method is a transport problem for forest managers because it is more and more difficult to find animals on the labour market. Working with animals is very expensive. In some surrounding countries, forest managers sell wood felled by the stump to the local population that produces fuelwood for personal consumption (Vusić 2013), but in B&H local people are, in general, still not interested in it. In applying the half-tree length method, stacked wood also occurred, but in significantly less amount than in applying the assortment method. It only came from the branches, while the other fuel wood remained as roundwood and was skidded together with the other more valuable parts of the stem. This resulted in increased felling & processing productivity and allowed transport of lower value wood.

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Authors' addresses:

Assist. Prof. Dane Marceta, PhD.*
e-mail: danemarceta@gmail.com
University of Banja Luka, Faculty of Forestry
Bulevar Vojvode Stepe Stepanovića 75
78000 Banja Luka
BOSNIA AND HERZEGOVINA

Prof. Boštjan Košir, PhD.
e-mail: bokosir@gmail.com
University of Ljubljana, Biotechnical Faculty
Jamnikarjeva 101
1000 Ljubljana
SLOVENIA

* Corresponding author