Small Gains in Wood Recovery Rate when Disobeying the Recommended Motor-Manual Tree Felling Procedures: Another Reason to Use the Proper Technical Prescriptions

Stelian A. Borz,* Gheorghe Ignea, and Maria M. Vasilescu

An efficient wood harvesting activity aims to fully recover wood as a measure to increase the profit, but safety prescriptions should be obeyed each time when harvesting operations are performed. A study was carried out in three forest compartments in order to determine whether the actual tree felling procedures match the recommended ones and, if not, to compare how the used practices may affect the wood recovery when felling trees using a conventional undercut. The study yielded significant statistical differences between the recommended and used cuts dimensions, as well as significant differences between the procedures used by three studied work teams. The general trend was to make deeper cuts and smaller openness when performing undercuts. Since one reason for such tree felling procedures may be the increment of wood recovery rate, we conducted a comparative analysis between the potential volume loss in the two mentioned scenarios, and only small differences were found; this should discourage the use of such tree felling techniques. The present estimates suggest that the potential volume loss was 0.89 to 1.20% of the harvested volume, yielding small gains in terms of wood recovery if compared to that of 1.74 to 3.17% corresponding to the recommended practices.

Keywords: Wood recovery; Chainsaw; Undercut; Safety; Group shelterwood cuttings; Clear cuttings; Accidental cuttings

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INTRODUCTION

At the operational level, round wood harvesting activity is performed around the world using different equipment designed for tree felling and primary transportation. In these conditions, an efficient wood harvesting aims to fully recover wood as a measure to reduce the operational costs and increase the profit, as well as to enforce work safety prescriptions in harvesting operations. Therefore, one of the important issues in harvesting operations is the amount of wood which may be potentially lost due to the use of certain equipment or operational procedures. While the level of mechanization differs from region to region depending on forest types, wood species, management methods, terrain, and climatic conditions (Vusić *et al*. 2013), the use of motor-manual tree felling is still very common in Europe (Brachetti Montorselli *et al*. 2010; Gerasimov and Seliverstov 2010; Zinkevicius *et al*. 2012; Borz and Ciobanu 2013) and around the world (Wang *et al*. 2004; Behjou *et al*. 2009; Mousavi *et al*. 2011; Balimunsi *et al*. 2012; Ghaffariyan *et al*. 2013; Jourgholami *et al*. 2013; Nikooy *et al*. 2013). On the one hand, it is well known that by using a chainsaw in tree felling operations, a certain quantity of wood would be lost as a consequence of the cuts performed in order to fell the tree (Oprea and Sbera 2004). Furthermore, the use of chainsaws in association with other primary transportation equipments may lead to volume losses as high as 5% (Gerasimov and Seliverstov 2010). When performing a conventional undercut by the means of a motor chainsaw, a part of the potential wood loss will be that remaining in the stump, while another part will be lost due to the performed cuts (Oprea 2008). In these particular conditions, controlling the amount of potential volume loss may be accomplished by limiting the dimensions of certain cuts (Oprea and Sbera 2004). However, as a general rule, recommended dimensions of cuts are provided by specialized literature (Conway 1976; Koger 1983; Oprea and Sbera 2004; Oprea 2008) as measures for safe tree felling when using chainsaws, since these operations are more likely to cause severe occupational accidents or even fatalities (Lindroos and Burström 2010). Motor-manual tree felling is particularly hazardous because certain operational conditions may lead to unpredicted landing directions of felled trees (Nikooy *et al*. 2013) and in some cases may cause serious injuries. In Romania, a recent report published by the Ministry of Work, Family and Social Protection (2014) shows that there were 106 average number of forestry-related accidents that occurred in the 2009 to 2014 period per year. Of these, 63 resulted in temporary incapacity to perform work, 10 in disabilities, and 33 in fatalities. According to the same source, 26.9% of the disabilities and fatalities occurred due to falling objects and materials. Also, a proportion of 21.2% of the occupational accidents from the same category occurred due to the improper risk assessment as well as to the non-performing of operations needed for safety ensurance. Top of the nonconformities list in the same document refers to the operations performed by nonqualified workers. At the same time, information about the recommended *versus* observed practices when performing motor-manual tree felling are quite scarce. One of the few studies addressing procedural disobeying in motor-manual tree felling was conducted by Koger (1983). On the other hand, several studies dealt with potential volume and value loss due to the use different systems and equipments. Unver and Acar (2009) studied the volume loss during skidding operations and developed models predicting this scenario, to find out that the volume loss is somehow attenuated in winter. Gerasimov and Seliverstov (2010) analyzed the harvesting systems used in Russia and they found that motor-manual and mechanized cut-to-length systems generated less losses in terms of industrial rejection rate of wood assortments if compared to full-tree harvesting systems, even if the mechanical felling and processing may affect the resulted wood assortments (Nuutinen *et al.* 2010). However, little is known about how much volume would be potentially lost when performing conventional undercut procedures in tree felling. Furthermore, it is unclear how the used procedures (in terms of dimensions) may affect the wood recovery when performing motor-manual felling. At the same time, an assessment of potential wood recovery when using non-recommended felling procedures may support the enforcement of procedural prescriptions in such operations by emphasizing that the potential economic benefits do not compensate the exposure to occupational risks.

Our study aimed to compare the “as-performed” *versus* recommended procedures of felling trees using conventional undercuts, in order to draw attention to the fact that by disobeying the procedural prescriptions in such operations the economic gain is not worth the risk, especially since no scientific knowledge was available in the studied region about how the felling procedures are performed in the field. For this purpose, we collected data in three randomly chosen forest compartments for three different extraction types by observing the work performed by three different experienced fellers. The field-collected data pool regarding the "as-performed" procedures was compared against the recommended ones in order to emphasize significant differences if any. Also, the potential volume loss due to the observed cuts was compared against that calculated using recommended practice guidelines in order to distinguish how the observed and recommended procedures may affect the wood recovery rate.

MATERIALS AND METHODS

Case Studies

Field sampling was carried out in three forest compartments (Table 1) in the spring of 2014. As usual in Romania, tree felling operations were performed at each studied location by a team, each one consisting of two men. Of each team, one worker was responsible of performing the required cuts in order to fell the trees, and each of the three subjects had more than 10 years of work experience at the field study time, as well as having possible knowledge about safe tree felling procedures. During the field study, no additional tools such as wedges or hydraulic jacks were used.

Table 1. Description of Study Locations

Forest Compartment	Stand Composition	Silvicultural treatment	Felling Intensity - Proportion of volume removed (%)	Ground Average Slope (%)
Braşov - B	Fir (*Abies alba*) Norway Spruce (*Picea abies*) Beech (*Fagus sylvatica*)	Accidental cut *	10	45
Predeal - P	Spruce (*Picea abies*)	Clear cut	100	25
Sighişoara - S	Sessile Oak (*Quercus petraea*) Hornbeam (*Carpinus betulus*) Beech (*Fagus sylvatica*)	Group shelterwood cut	35	5
* Removal of fir trees affected by drought				

Data collection

Case study data were collected on field books for each felled tree after measurements performed on the tree height (TH), breast diameter (DBH), stump diameter (SD), depth of undercut (UD), depth of back cut (BCD), and the maximum undercut height (UH). Stump diameter was measured at the mid distance between the bottom cut of undercut and back cut level. Tree species was visually assessed in the case of each felled tree. Breast and stump diameters (DBH and SD) were measured using a forest caliper at a one centimeter accuracy, tree height (TH) was measured after felling using a specialized tape at one decimeter accuracy, while the dimensions of cuts (UD, BCD, and UH, respectively) were measured using a pocket tape after tree felling at a one centimeter accuracy. A number of 15, 70, and 263 trees were studied in B, P, and S forest compartments, respectively (Table 1).

Statistical Analysis

All the data were transcribed into Microsoft Excel® spreadsheets where subsequent analyses were performed during the office phase of the study. Data regarding the dimensions of cuts recorded in the field were compared against the literature recommendations for conventional undercuts as a function of the stump diameter (SD). In order to achieve this, for each forest compartment, a comparative set of data was derived based on the literature provisions (Oprea and Sbera 2004; Oprea 2008). Recommended depths of undercut (RUD) and back cut (RBCD) were calculated using Eqs. 1 and 2. The recommended undercut openness (RUO) was set at a 45° angle, which also allowed the calculation of the undercut height (RUH) in this scenario. In our calculations, we assumed a minimum hinge width (HW) of 3 cm, as provided by Romanian literature (Oprea 2008), but we fully acknowledge other sources which indicate that the hinge width should be one tenth of the stump diameter (Conway 1976; Oprea 2008). A description of the recommended *versus* "as-performed" felling cuts is given in Fig. 1. In order to choose the adequate statistic tests, a normality check was performed on all the variables taken into consideration using a Shapiro-Wilk test. Data comparison between the two sets ("as-performed" *versus* recommended) belonging to each compartment was performed on UD-RUD, BCD-RBCD, and UH-RUH pairs using either a two-tailed t-test assuming equal or unequal variances (normal distributed data) depending on the results of a F-test performed in advance, or a Wilcoxon matched pairs test (nonparametric data) in order to emphasize eventual significant differences. Comparisons between the used tree felling procedures in the three compartments were made based on the "as-performed" field recorded data in order to emphasize the differences between teams and working conditions. For this, a Kruskal-Wallis unpaired test was used. All the tests were performed using Microsoft Excel® 2007 (Microsoft, Redmond-USA) and Statistica 8.0 (StatSoft Inc.) software packages.

$$RUD\ (cm) = 0.333 \times SD \quad (1)$$

$$RBCD\ (cm) = 0.667 \times SD - 3.000 \quad (2)$$

The potential volume loss due to felling cuts (PVL) was calculated in two scenarios, *i.e.*, "as-performed" *versus* recommended procedures for tree felling. To provide suitable results in a first step, the yielded results of potential volume loss (m^3) under "as-performed" conditions (EPVL) were expressed as functions of breast diameter (DBH) and stump diameter (SD). The EPVL was calculated based on the "as-performed" undercut height (UH) and stump diameter (SD), while the potential volume loss in case of using the recommended procedures (RPVL) was calculated based on the recommended undercut height (RUH) and stump diameter (SD). In order to estimate the rate of potential volume loss due to felling cuts (PPVL), the volume of each tree (TV) was calculated as a function of tree species, DBH and TH using the logarithmic estimation equations of general form presented in Eq. 3, where the coefficients a_0 to a_4 are specific to given tree species (Giurgiu *et al.* 2004). Then, the PPVL was computed for both scenarios as a percentage of lost wood volume relative to the total tree volume (TV).

$$log(TV)=a_0+a_1\times log(DBH)+a_2\times log^2(DBH)+a_3\times log(TH)+a_4\times log^2(TH) \quad (3)$$

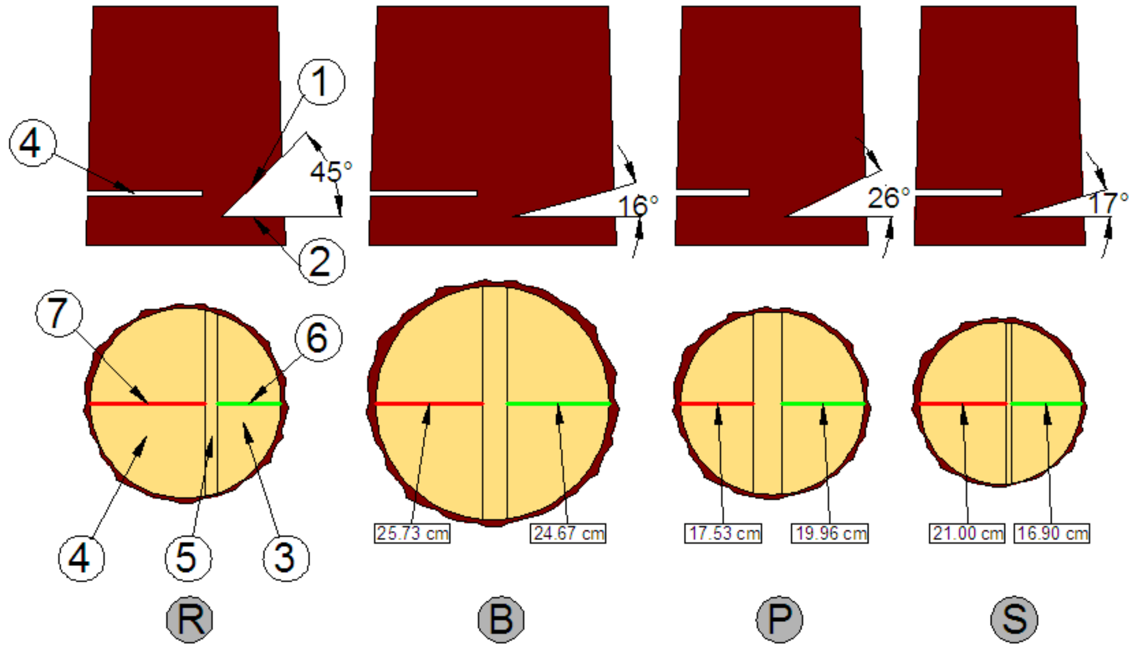

Fig. 1. Recommended versus experimental dimensions when performing a conventional undercut. Legend: 1 – top cut, 2 – bottom cut, 3 – undercut, 4 – back (main felling) cut, 5 – hinge wood, 6 – undercut depth, 7 – back cut depth, R – general (recommended) procedures, B – Braşov compartment, P – Predeal compartment, S – Sighişoara compartment

RESULTS AND DISCUSSION

Descriptive statistics regarding the operational conditions specific to the three case studies are given in Table 2. As shown, a total number of 348 trees were considered in the study. Usually, when performing cuts in order to get a conventional undercut, the depth of undercut (UD) is recommended to be no greater than 0.25 to 0.33 of the stump diameter (SD). Contrary to the recommended dimensions provided by literature for the depth of undercut (UD), in all the studied forest compartments the fellers tended to lead this cut almost to the half of SD (Table 2). This trend in making deep cuts was also preserved in case of back cut depths (BCD) which in this study accounted for 0.40 to 0.54 of SD. Despite the fact that when leading the back cut it is recommended to keep a hinge having a width of at least one tenth of the stump diameter (Conway 1979; Oprea and Sbera 2004; Oprea 2008) and minimum 3 cm (Oprea and Sbera 2004; Oprea 2008) in many cases of the current study fellers led their cuts almost to the joining with the undercut. A similar contrary habit in what concerns the felling procedures was observed also by Brachetti Montorselli *et al.* (2010) when analyzing feller crews working for private companies. As provided by most of the tree felling standards and handbooks, it is well known that a sufficient openness must meet an angle of at least 45° when performing conventional undercuts, since this recommended value helps to ensure safer tree felling (Oprea 2008). However, according to our calculated results (Fig. 1, Table 2), this recommendation was systematically disregarded, since much smaller opening angles (UO), ranging from 16° to 26°, were recorded. As a result, mean undercut heights (UH) of 5 to 10 cm were recorded in our study.

In Table 3 are enclosed regression models developed for the "as-performed" *versus* recommended dimensions of cuts. These explain the variation of cuts dimensions as a function of the stump diameter (SD). The regression models developed in case of "as-performed" conditions may help in better understanding how the operations were actually performed in the three case studies, although these procedures are not recommended.

Table 2. Descriptive Statistics of Experimental Setups and Working Conditions

Forest Compartment	No. of Obs.	Min.	Max.	Mean (Median)*	St. Dev.
Braşov - B					
TH (m)	15	10.80	30.50	19.84	6.21
DBH (cm)	15	22.00	76.00	44.67	15.87
TV (m^3)	15	0.209	5.468	1.247	1.524
SD (cm)	15	28.00	100.00	56.27	21.60
UD (cm)	15	10.00	42.00	24.67	10.69
UH (cm)	15	2.00	12.00	6.63	2.58
BCD (cm)	15	13.00	45.00	25.73	9.84
UO (°)	15	9.46	28.61	15.78	4.74
EPVL (m^3)	15	0.001	0.094	0.024	0.026
RUD (cm)	15	9.33	33.33	18.76	7.20
RBCD (cm)	15	15.67	63.67	34.51	14.40
RUH (cm)	15	9.33	33.33	18.76	7.20
RPVL (m^3)	15	0.005	0.262	0.046*	0.078
Predeal - P					
TH (m)	70	20.00	37.30	30.10	3.62
DBH (cm)	70	20.00	50.00	34.89	6.80
TV (m^3)	70	0.380	2.810	1.378	0.573
SD (cm)	70	25.00	74.00	44.20	9.54
UD (cm)	70	7.00	35.00	19.96	5.90
UH (cm)	70	4.00	16.00	9.73	2.94
BCD (cm)	70	10.00	30.00	17.53	4.55
UO (°)	70	14.04	39.81	26.42	6.23
EPVL (m^3)	70	0.002	0.056	0.016*	0.069
RUD (cm)	70	8.33	24.67	14.73	3.18
RBCD (cm)	70	13.67	46.33	26.47	6.36
RUH (cm)	70	8.33	24.67	14.73	3.18
RPVL (m^3)	70	0.004	0.106	0.026*	0.017
Sighişoara - S					
TH (m)	263	13.00	26.50	20.49*	2.60
DBH (cm)	263	18.00	80.00	30.00*	10.19
TV (m^3)	263	6.215	6.668	0.720*	0.835
SD (cm)	263	22.00	97.00	39.00*	13.62
UD (cm)	263	7.00	51.00	16.90*	7.18
UH (cm)	263	1.50	17.00	5.20*	2.84
BCD (cm)	263	10.00	55.00	21.00*	7.56
UO (°)	263	6.34	53.97	17.35*	5.55
EPVL (m^3)	263	0.001	0.082	0.007*	0.014
RUD (cm)	263	7.33	32.33	13.00*	4.54
RBCD (cm)	263	11.67	61.67	23.00*	9.08
RUH (cm)	263	7.33	32.33	13.00*	4.54
RPVL (m^3)	263	0.003	0.239	0.016*	0.034

* Median was used as the descriptive statistic in case of data failing the normality check

Table 3. Recommended versus "As-performed" Dimensions for the Studied Conditions

Forest Compartment	Model	R^2	p Value
R*	RUD (cm) = 0.333 × SD (cm)	-	-
	RUH (cm) = 0.333 × SD (cm)	-	-
	RBCD (cm) = 0.667 × SD (cm) - 3.00	-	-
B	UD (cm) = 0.445 × SD (cm) - 0.36	0.81	<0.0001
	UH (cm) = 0.113 × SD (cm) + 0.29	0.89	<0.0001
	BCD (cm) = 0.414 × SD (cm) + 2.45	0.83	<0.0001
P	UD (cm) = 0.436 × SD (cm) + 0.66	0.50	<0.0001
	UH (cm) = 0.159 × SD (cm) + 2.70	0.27	<0.0001
	BCD (cm) = 0.288 × SD (cm) + 4.78	0.37	<0.0001
S	UD (cm) = 0.473 × SD (cm) - 2.19	0.73	<0.0001
	UH (cm) = 0.140 × SD (cm) - 0.03	0.45	<0.0001
	BCD (cm) = 0.448 × SD (cm) - 0.39	0.72	<0.0001
* Deterministic models corresponding to the recommended dimensions			

Although the use of descriptive statistics may be sufficient when one tries to emphasize some differences between the literature descriptions and the field performing conditions, the use of statistical comparison tests may help in a better understanding of the phenomenon. Table 4 provides the results of comparisons made between the field-performed and recommended procedures. Because the sample data did not follow a normal distribution, comparisons between EPVL and RPVL were made for each compartment using a Wilcoxon matched-pairs test. The EPVL data were also compared between forest compartments using a Kruskal-Wallis unpaired test. As expected, significant differences (α=0.05) were found when we statistically compared the UD - RUD, UH - RUH, and BCD - RBCD pairs (Table 4) for the three forest compartments. Only few exceptions were noted in the Braşov forest compartment, where no significant differences (although the tests closely failed) were found between UD - RUD and BCD - RBCD pairs.

When comparing among forest compartments (Table 5), it was found that the dimension of cuts differed significantly in at least one forest compartment. This may be explained by the variability of operational conditions and the work habits of tree fellers.

Table 4. Results of Wilcoxon' and t Tests for the Compared Pairs: "As-Performed" *versus* Recommended

Forest Compartment	Compared Pairs	Type of Test	p Value	Significant Difference
B	UD-RUD (cm)	t	0.0870	
	UH-RUH (cm)	t	<0.0000	*
	BCD-RBCD (cm)	t	0.0613	
	EPVL-RPVL (m^3)	Wilcoxon	0.0006	*
P	UD-RUD (cm)	t	<0.0000	*
	UH-RUH (cm)	t	<0.0000	*
	BCD-RBCD (cm)	t	<0.0000	*
	EPVL-RPVL (m^3)	Wilcoxon	<0.0000	*
S	UD-RUD (cm)	Wilcoxon	<0.0000	*
	UH-RUH (cm)	Wilcoxon	<0.0000	*
	BCD-RBCD (cm)	Wilcoxon	<0.0000	*
	EPVL-RPVL (m^3)	Wilcoxon	<0.0000	*
*Significance level = 0.05				

Table 5. Results of Kruskal – Wallis Tests: Comparison between "As-Performed" Data Yielded in the Three Forest Compartments

Tested Characteristic	Compared Forest Compartments	Type of Test	p Value	Significant Difference
UD (cm)	B-P-S	Kruskal-Wallis	0.01305	*
BCD (cm)	B-P-S	Kruskal-Wallis	<0.00000	*
UH (cm)	B-P-S	Kruskal-Wallis	<0.00000	*
EPVL (m^3)	B-P-S	Kruskal-Wallis	<0.00000	*
*Significance level = 0.05				

The potential volume loss (PVL) of wood when using chainsaws in order to perform a conventional undercut may be quantified as the sum of the wood that actually remains in the stump and the wood that has to be removed after tree felling and processing in order to get the final wood assortments. Knowing how the undercut dimensions are performed is particularly important for work safety, because in specific cases a small gain in wood recovery is just not worth the risk of procedural deviations. While an overview of how the tree felling procedures were applied in the studied forest compartments is given in Table 3, Table 6 presents exponential regression models which were used to estimate the EPVL as a function of DBH and SD for the studied conditions. Because the EPVLs were calculated as a function of SD, it was not surprising to find that the variation of SD may explain the variation of EPVL in proportions of 84 to 98%. However, for practical reasons, the models developed as a function of DBH may be used in order to get sufficiently reliable figures.

Table 6. Estimations on EPVL Variation as a Function of DBH and SD

Forest Compartment	Model	R^2	p Value
B	EPVL (m^3) = 0.0000001 × $DBH^{3.17}$ (cm)	0.93	<0.0001
	EPVL (m^3) = 0.0000001 × $SD^{3.09}$ (cm)	0.98	<0.0001
P	EPVL (m^3) = 0.0000005 × $DBH^{2.89}$ (cm)	0.74	<0.0001
	EPVL (m^3) = 0.0000004 × $SD^{2.79}$ (cm)	0.84	<0.0001
S	EPVL (m^3) = 0.0000004 × $DBH^{2.87}$ (cm)	0.75	<0.0001
	EPVL (m^3) = 0.0000001 × $SD^{3.11}$ (cm)	0.88	<0.0001

Performing a conventional undercut in a manner that disregards the procedural recommendations may lead to an improved wood recovery, but such approaches should be excluded for at least two reasons: safety concerns and small economic gains. For instance, in the conditions of this study it was found that even if the PVL when using non-recommended tree felling procedures may be almost half of that obtained by applying the recommended ones, the real quantities of lost wood were very small (Table 2). Thus, the EPVL in the studied conditions varied from a yield of 44% (Sighişoara - S forest compartment) to 62% (Predeal - P forest compartment) by applying the recommended cutting dimensions. The potential volume loss in "as-performed" (EPVL) and recommended (RPVL) scenarios are plotted in Fig. 2 along with regression models, which may be helpful in predicting the variation of PVL as a function of SD variation.

On the other hand, when statistically comparing the EPVL against RPVL, significant differences were found in the case of each forest compartment (Table 3), but the magnitude of economic gain would be rather small, as shown in Table 2 and Fig. 2. Significant differences between the EPVLs were also found when attempting to compare the field data yielded by the three forest compartments as indicated by the results of Kruskal-Wallis tests enclosed in Table 5. This fact suggests that differences between the used procedures as well as between the recovery rates may be associated with particular work conditions including operational habits of workers, at least in one forest compartment. Therefore, the issues addressed in this paper should be further researched by extending the sampling amplitude in order to get more widely representative results. On the other hand, according to this study, the potential volume loss based on the field collected data was as high as 0.89 to 1.20% of the estimated volume of felled trees in the studied conditions (Table 7), being somehow reduced when compared with the percentage of potential volume lost if the recommended procedures would have been applied (1.74 – 3.17%). This means that when felling each 100 mean trees as in the studied conditions, one could additionally gain only 0.9 to 2.5 m^3. Therefore, at least from this point of view, it was not worth taking such risks by adopting the felling procedures used in the studied forest compartments, and the forest workers from the studied region should reconsider their approaches when felling trees.

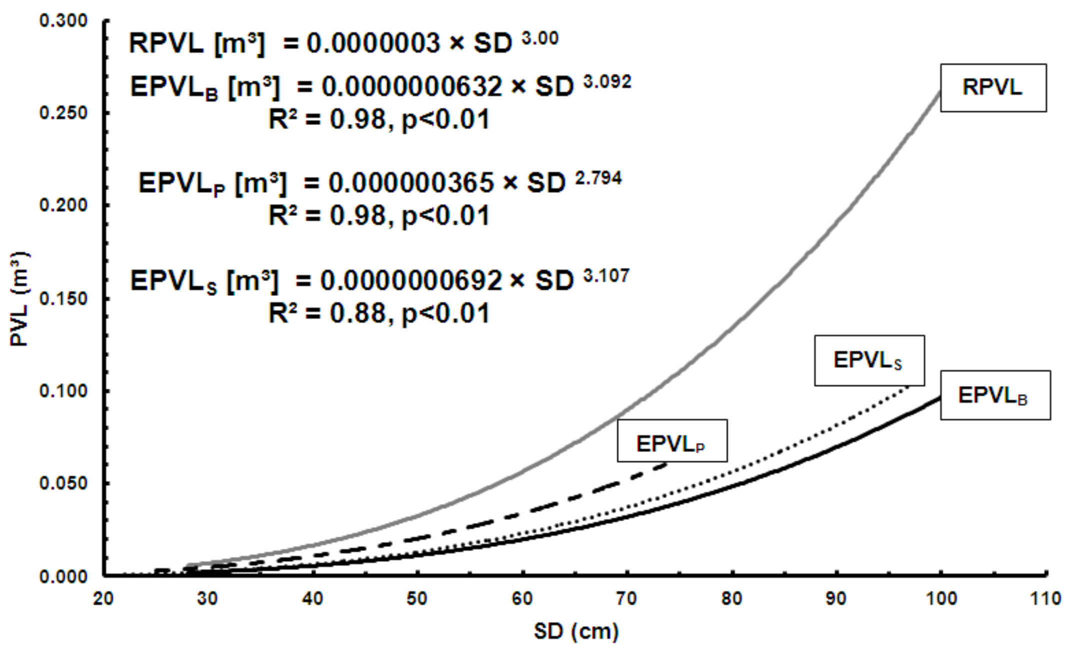

Fig. 2. EPVLs and RPVL variation as a function of SD. Legend: B –Braşov forest compartment, P – Predeal forest compartment, S – Sighişoara forest compartment.

Table 7. Shares of EPVL and RPVL within the Estimated Harvested Volume in the Studied Conditions

Forest Compartment	Mean (Median) Tree Volume ($m^3 \times tree^{-1}$)	Felled Tree Species	% of Volume Lost as EPVL	% of Volume Lost as RPVL
Braşov - B	1.25	Silver Fir (*Abies alba*)	1.20	3.17
Predeal - P	1.30	Norway Spruce (*Picea abies*)	1.11	1.74
Sighişoara - S	0.72	Sessile Oak (*Quercus petraea*) Hornbeam (*Carpinus betulus*) Beech (*Fagus sylvatica*)	0.89	2.25

CONCLUSIONS

1. The results indicate that the recommended procedures for making conventional undercuts in order to fell trees with chainsaws are significantly disregarded in the studied area, as we found significant differences when we compared the field collected data pools against recommended dimensions of cuts in the case of undercut depth, back cut depth, and undercut openness. Work experience seemed to have no impact over concerns about work safety; all the studied teams disregarded the recommended procedures even if the fellers had at the study time over 10 years of experience.
2. In what concerns the applied cutting dimensions, significant differences may exist among different work teams and working conditions as statistically proven in at least one case. This fact should encourage further research in Romania on such matters in order to assess how the safety concerns are approached by the managers of harvesting companies and forest workers.
3. Wood recovery during tree felling is an important issue. However, our study shows that the procedures used in the field for making conventional undercuts may only lead to small improvements in terms of wood recovery rates. In the studied conditions, one could gain only 0.9 to 2.5 m^3 when felling each 100 mean trees. This should represent an additional reason to actually use the recommended practices.
4. During the field study, no accidents took place and only few trees landed in unplanned directions. However, the figures concerning the related occupational accidents in Romania should constitute a warning by which to enhance the use of proper tree felling techniques.

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