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Evaluation of the mechanized harvest of grapes with regards to harvest losses and economical aspects

J. Jobbágy, K. Krištof[*], A. Schmidt, M. Križan and O. Urbanovičová

Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Machines and Production Biosystems, Tr.A. Hlinku 2, SK949 76 Nitra, Slovakia
[*]Correspondence: koloman.kristof@uniag.sk

Abstract. The aim of the study was to evaluate the mechanized grape harvest conducted by the trailed harvester. As a criterions was introduced the performance, harvest losses of grapes and economic efficiency from the perspective of its introduction. The calculations consist of total annual and partial unit costs also with regards to indirect costs which are formed by the grape losses during the harvest. Evaluation was conducted on three varieties of grapes. The losses of grapes, total annual and partial unit costs were calculated for selected varieties of grapes and also for whole production area. The mean grape losses for whole production area were determined at 470 kg ha^{-1}, while the greatest portion of these losses (9.7%) was observed in case of Neronet variety. Among other analysed aspect were the efficiency of mechanized harvest introduction by definition of labour costs and the ransom price of grapes in relation with minimum required area. A substantial part of total costs for area 100 ha was formed by direct costs up to 15.24% greater than the indirect costs. The efficiency of machinery introduction into the harvest process was observed at minimum area of 16.92 ha in case of rental mechanized harvest of grapes. In case of mechanized harvest conducted by previously bought trailed grape harvester the value of minimal efficiency was determined at 27.42 ha year^{-1}. As a result then serves an effective utilization of mechanized grape harvest in selected company but it is not limited to it and can be applied on any other scenario.

Key words: grapes, harvest, yields, harvest losses, economic benefits.

INTRODUCTION

Currently, in conditions of Slovakia there are almost 300 various vine production and viticulture organisations (in different form of private production economies) which grown vine grapes and produce vines. According to registration for year 2017, the total area utilized for vine grapes production was calculated at area 17,598 ha (8,873 ha of directly produced vineyards and 11,159 ha managed for vine production and similar purposes), whereas this total area includes also not managed areas (UKSUP, 2016).

Mechanized vine grape harvest is spreading over Slovakia at slow motion in comparison with ratio of its utilization in other European countries (e.g. Italy or France). From the published statistics it is clear that mechanized vine grape harvest is fully utilized at level from 20 to 30% of total area used as vineyards in case of north Italy (Corazzina, 2010). In contrast, in case of Slovakia, mechanized vine grape harvest is established only at 10% of total area utilized to production of vine grapes. The issue of establishment and utilization of mechanization in viticulture is limited due to several specific conditions. As critical criterions for its full establishment was emphasised by several conditions. Mainly, the selection of appropriate location of fields, it's landscaping in particular, since as a main issue which needs to be addressed are following. Subsequently, the employment of support constructions produced as a narrow aluminium pillars along with unified cropped varieties in single rows. In addition, on the fields which are characterised by good level of transverse slope along with employment of the appropriate landscaping techniques allows a non-problematic movement of machinery and therefore it allows the reduction of damaged to cropped vine grapes (Johnson et al., 2003; Jobbágy & Findura, 2013).

The main aim for introduction of mechanized vine grape harvest is to lower the need of manual labour and reduction of annual costs however initial costs needed for introduction of mechanized harvest are quite high (Bates & Morris, 2009; Jobbágy & Findura, 2013; Pezzi & Martelli, 2015). On the other hand, introduction of mechanized vine grape harvest cannot lead to decrease of harvested product quality (Morris, 2007; Pezzi, 2013). As it was stated, spacing of the support pillars should be in range from 4.5 to 8.0 m in accordance to the weight of vine grape crop row and to appropriate leaf area. In addition, the height of used support pillars should not exceed the height 1.8 m due to utilization of mechanization which is limited by this value. Moreover, the support pillars should not be produced from any wooden materials as they usually are (e.g. spruce wood, bamboo). Mainly, due to the caused vibration can easily lead to its damage or destruction and therefore the vine grape harvester mechanisms can be damaged or it may lead to complication of postharvest treatment of harvested products. As another limiting factor is considered the use of the same variety of vine grapes while it allows of the continual harvest of whole row at a single passage of machinery. It is also important to replace withered or other way damaged individual plants by the same variety (Fic, 1973; Žufánek & Zemánek, 1992; Zemánek & Burg, 2003; Walg, 2007; Keller, 2010).

In Europe (e.g. Italy), the trend is in increasing of mechanization of harvest labour in all phases of vine grape production including of its harvest. According to available sources, in latest ten years, the number of machinery used in this field was doubled. Statistics showed (UNIMA, 2013) that in case of Italy operates more than 2,600 vine grape harvesters which mostly (86 to 88%) utilize the horizontal harvest mechanism (horizontal impactors) while majority of this machinery is designed as trailed types (up to 85%). Moreover, 170 to 190 of new self-propelled vine grape harvesters are introduced into viticulture production which are subsequently also utilized by a various adapters designed for other field operation in viticulture production, e.g. pest controls, green and other operations (Pezzi & Balducci, 2012).

In conditions of Slovakia, as well as in other countries, the area for production of vine grapes was increased rapidly at different levels. Majority if this area is, in case of harvest, treated under mechanized harvest which is in year 2017 implicated in more than 10 companies of various types. By introduction of new technologies and machinery, the aim is to decrease final costs on manual labour along with preservation of limit values required for harvest losses and final quality of harvested product.

Due to the faster introduction of grape harvest by grape harvesters the aim of the study was to evaluate the mechanized grape harvest conducted by the trailed harvester. As a criterions was introduced the performance, harvest losses of grapes and economic efficiency from the perspective of its introduction.

MATERIALS AND METHODS

Field conditions

Field measurements were conducted on selected vine grape production company JM Vinárstvo Doľany, Ltd., Slovakia. Vineyards of selected company are situated at southern slopes of Small Carpathians on the area of 115 hectares. In selected company the mechanized vine grape harvest were tested on 3 different varieties of vine grapes, namely: Ruland blue (Pinotnoir), Neronet and Veltliner green (Table 1). Varieties were tested in near locations to the company with average altitude 251 above sea level (48°25'03.5"N, 17°22'59.4"E).

Average yields of Ruland Blue variety range from 6 to 10 t ha^{-1} (Kraus et al., 2004). The vineyard of this variety was established continuously in years 1997 till 2011 on the area of 3 ha, 13,900 individuals (4,630 individuals per hectare), specifically.

The average yields of Neronet variety range from 7 to 12 t ha^{-1} (Kraus et al., 2004). The vineyard of this variety was established in years 1997 till 2011 on the area of 4 ha, 18,500 individuals (4,630 individuals per hectare).

Average yields of Veltliner Green variety range from 12 t ha^{-1} (at medium height of support) up to 16 t ha^{-1} (at high height of support) (Kraus, 2004). The vineyard of this variety was established in years 1997 till 2011 on the area of 16.1 ha, 74,500 individuals (4,630 individuals per hectare).

Table 1. Characteristics of vineyards

Cultivar	Spacing	Average Harvest, t ha^{-1}	Surface, ha	Number of rootstock, pcs ha^{-1}	Trellis system	Field slope, %	Plant Age, years
Ruland Blue	2.4 × 0.9	6.23	3	4,630	Double Guyot	4	15
Neronet	2.4 × 0.9	7.30	4	4,630	Spur cordon	3	13
Veltliner Green	2.4 × 0.9	9.70	16.1	4,630	Double Guyot	2	14

Grape Harvester

For mechanized vine grape harvest of individual varieties was used the same type of trailed vine grape harvester ERO LS Traction (ERO-Gerätebau, GmbH, Niederkumbd, Germany). The ERO LS Traction (Table 2) grape harvester has a special hydrostatic transmission (the Load Sensing system) that actuates the wheels depending on the pulling force measured at the drawbar. The detachment system is an oscillatory shaker with bow rods on either side of the frame (maximum of ten per side). The grapes are collected by a series of overlapping spring-loaded plates, which carry the grapes on two lateral conveyer belts that unload into two lateral hoppers (3,000 L). The cleaning system is composed of two lateral suction fans at the end of the catching surface and one at the discharge into the hoppers.

Selected vine grape harvester was aggregated with four-wheel drive tractor Lamborghini RF 75 (Lamborghini Trattori, Italy). Such combination allows harvest on slopes at maximum 35% with maximum working speed 6 km h^{-1} (Table 3).

Table 2. Technical parameters of grape harvester ERO LS Traction

Parameter	Value
Height of hopper during emptying, mm	2,600
Dimensions: Length/Width/Height, mm	3,300/2,550/2,650
Minimal space between rows, mm	1,350
Capacity of hopper, m^3	1
Maximum side slope, %	27
Maximum slope, %	35
Minimal power input from tractor, kW	37
Number of striping rods, pcs	2×5

Table 3. Technical parameters of tractor Lamborghini RF 75

Parameter	Value
Cylinders/Displacement, cm^3	4,000
Max. homologated power, kW	54.5
Nominal engine speed, rpm	2,200
Max. torque, Nm	257
Fuel tank capacity, L	55
Torque backup, %	15
Dimensions: Length/Width/Height, mm	3,440/1,460/2,090

Performance of vine grape harvester

The height of the bunch of grapes ranged from 0.8 to 1.35 m, from 0.5 to 1.1 m and from 0.7 to 1.2 m above the ground in case of variety Ruland Blue, Neronet and Veltliner Green, respectively. The harvest mechanism of vine grape harvester consists of 5 wattles in the both sides of it. Therefore, it is able to harvest the whole range of grapes. Working speed, oscillation frequency and amplitude of wattles were set according to previous working experience and the results of preliminary harvest measurements. Post-harvest treatment and separation of harvested vine grapes was conducted by two ventilators at the bottom and single ventilator at the top of the harvest mechanism. The upper ventilator is connected with shredders and finger conveyors. The hopper for harvested vine grapes is equipped by screw separators which are responsible for empting of hopper from the back of vine grape harvester. The effective field capacity of vine grape harvester C_a (ASABE, 2006) was evaluated according to measurements of effective working time during the harvest of all varieties (Eq. (1)).

$$C_a = 0.1 \cdot s \cdot w \cdot E_f, \ (\text{ha h}^{-1}) \quad (1)$$

where C_a – area capacity (ha h^{-1}); s – field speed (km h^{-1}); w – distance between rows (m); E_f – field efficiency, considering the time required for turning and manoeuvring at the ends of the field and for hopper unloading (Srivastava et al., 2006; Pezzi & Martelli, 2015).

In case of all varieties of vine grapes were tested by measurements of effective working time, time needed for turning of machinery at the edges of rows and empting of hopper. Evaluation consists of considering the mean values and standard error (±*SE*).

Field experiments

Evaluation of field experiments of vine grape harvester work quality followed a specific number of steps for all of the tested varieties. From each varieties were selected a specific sections of lines represented by length 10 m. These sections were located in the middle part of rows. These procedures allows avoiding of influence of the results by working conditions of vine grape harvester, working speed and setting of the harvesting height and variety. The results then reflect the evaluation of losses which consist of the losses of grapes left on shrubs and losses caused by the slumping to the ground below vine grape harvester. The methodology of field measurements according to recorded losses of vine grape was done according to standard ISO (1980). The losses of vine grapes left on shrubs was measured by weighting of grape berries without the rest of tassel, leafs and stem on selected part of rows in length of 10 m. For measurement of grape losses by the slumping to ground was done by utilization of foil which was spread on the surface in length of 11 m from both sides of measured row in width 1.2 m. Subsequently, both parts of foils were then connected to avoiding of the slumping outside of measured parts. After the vine grape harvester passage, collected leafs, tassels and stems were removed and left grape berries were weighted. Statistical evaluation was conducted by statistical software Statistica 10 (StatSoft, Inc., Tulsa, USA). For evaluation of the results and analysis of statistically significant differences between mean values was used one-way analysis of variance (*ANOVA*). The results are presented as means ± *SE*. The p value ($p < 0.05$) was used to determine significant differences.

Costs on vine grape harvest

Evaluation of costs on vine grape harvest was calculated with reflection of fixed and variable costs on vine grape harvester and those caused by the harvest (non-direct costs). While the study was focuses on evaluation of work quality of trailed vine grape harvester, the final costs needs to reflect also the cost of tractor which was used for aggregation. Therefore, fixed costs on tractor then consists of costs on amortization, interests, insurances and garaging (ASABE, 2005, 2006; Ďuďák, 2016; Prístavka et al., 2017). Table 3 show the input parameters for determination of specific cost items which are valid in conditions of Slovakia.

Total direct costs on vine grape harvest

$$ {}_{r}N_{mC} = {}_{r}N_{mT} + {}_{r}N_{mZ} + {}_{r}N_{o} + {}_{r}N_{e} + {}_{r}N_{zp}\,, \quad (€\ year^{-1}) \qquad (2) $$

where ${}_{r}N_{mT}$ – direct costs on tractor (€ year^{-1}); ${}_{r}N_{mZ}$ – direct costs on vine grape harvester (€ year^{-1}); ${}_{r}N_{e}$ – annual costs on energy (€ year^{-1}); ${}_{r}N_{o}$ – annual costs on repairs of machinery (€ year^{-1}); ${}_{r}N_{zp}$ – annual costs on manual labour (€ year^{-1}).

Constant (fixed) costs

$$ {}_{r}N_{k} = {}_{r}N_{a} + {}_{r}N_{zu} + {}_{r}N_{cd} + {}_{r}N_{p} + {}_{r}N_{g}\,, \quad (€\ year^{-1}) \qquad (3) $$

where ${}_{r}N_{a}$ – annual costs on amortization (€ year^{-1}); ${}_{r}N_{zu}$ – annual costs on capitalization of equity and loan interest (€ year^{-1}); ${}_{r}N_{cd}$ – annual costs on road tax (€ year^{-1}); ${}_{r}N_{p}$ – annual costs on mandatory insurance (€ year^{-1}); ${}_{r}N_{np}$ – annual costs on voluntary insurance (€ year^{-1}); ${}_{r}N_{g}$ – annual costs on garaging (€ year^{-1}).

Annual costs on amortization

$$ {}_{r}N_{a} = \frac{C_s \cdot a}{100}\,, \quad (€\ year^{-1}) \qquad (4) $$

where C_s – purchase (input) cost of machinery (€ year^{-1}); a – depreciation rate, it is depreciation percentage for the selected period of use and depreciation strategy.

Annual costs on capitalization of equity and loan interest

$$ {}_{r}N_{zu} = \frac{(C_S + C_Z) \cdot z}{200} \text{ , (€ year}^{-1}\text{)} \quad (5) $$

where C_s – purchase (input) cost of machinery (€ $year^{-1}$); z – interest rates on deposits (%); C_z – residual price of machinery (€ $year^{-1}$).

Annual costs on insurances and taxes

$$ {}_{r}N_{s} = (L + 1) \cdot (B + 1) \cdot {}_{r}N_{gm2} \text{ , (€ year}^{-1}\text{)} \quad (6) $$

where L – length of machinery (m); B – width of machinery (m); ${}_{r}N_{gm2}$ – costs on 1 m^2 of area for garaging per year (€ m^{-2} $year^{-1}$).

Variable annual costs then consist of costs on repairs of machinery, energy and manual labour.

Annual costs on repairs of machinery

$$ {}_{r}N_{o} = RF_1 \cdot Cz \cdot (1 + i)^{n} \cdot \left(\frac{h}{1000}\right)^{RF_2} \text{ , (€ year}^{-1}\text{)} \quad (7) $$

where RF_1 and RF_2 – coefficients of machinery repairs (wide range dependent on type and reliability of machinery) defined by ASABE Standards); Cs – purchase (input) cost of machinery (€ $year^{-1}$); i – average inflation; n – age of machinery (years).

Annual costs on energy

$$ {}_{r}N_{e} = Q \cdot C_e \cdot {}_{r}W \cdot 1.1 \text{ , (€ year}^{-1}\text{)} \quad (8) $$

where Q – consumption of energy (L ha^{-1}); C_e – cost of energy (€ L^{-1}); ${}_{r}W$ – annual utilization of machinery (ha $year^{-1}$).

Annual utilization of vine grape harvester (machinery) was observed at value 300 hours. In selected company was harvested by this machinery about 100 ha from total area. Daily working shift was from 7 to 8 hours during the whole vine grape harvest season (35 days). Costs on garaging of machinery was calculate as 6 € m^{-2}. The depreciation period time for vine grape harvester and tractor is usually set to 4 years. In our case it means that the costs on depreciation rate in observed year was not considered due to the age of machinery. For determination of annual costs on capitalization of equity and loan interest was used average value for interests 5.0%. Variable annual costs (repairs of machinery, energy and manual labour) were then determined according to standards (ASABE, 2011) and following Ďuďák, 2016. Average fuel consumption was monitored during the all measurements and then converted on consumption for specific area. Average consumption of oil per hour was calculated considering its price 4.10 € L^{-1}. Salary of vine grape harvester operator was considered 3.10 € without deductions. The price of fuel (diesel) was in the year of study at level 1.34 € L^{-1}.

Annual costs on manual labour

$$ {}_{r}N_{zpm} = {}_{h}N_{zp} \cdot 1.352 \cdot \frac{{}_{r}W}{C_a} \text{ , (€ year}^{-1}\text{)} \quad (9) $$

where ${}_{h}N_{zp}$ – salary of operator per hour (€ h^{-1}); ${}_{r}W$ – annual utilization of machinery (ha $year^{-1}$); C_a – effective field capacity (ha h^{-1}).

Direct cost per unit ${}_{j}N_{mC}$ in conjunction with the period and strategy of depreciation (utilization) then can be calculated by below equation.

$$ {}_{r}N_{jC} = \frac{{}_{r}N_{mC}}{{}_{r}W} \text{ , } (\text{€ ha}^{-1}) \qquad (10) $$

where ${}_{r}N_{mC}$ – total direct annual costs (€ year^{-1}); ${}_{r}W$ – annual utilization of machinery (ha year^{-1}).

For the purpose of efficiency evaluation of vine grape harvester utilization was considered three types of parameters. Firstly, the obtained results during the measurements of different varieties of vine grapes. Secondly, by the costs which were generated by organization where the harvest was utilized. Thirdly, by the costs of services generated by other companies in form of outsourcing (Table 4). For this kind of evaluation it requires consideration of different potential areas of vineyards and estimation of maximum life period of vine grape harvester at 15 years. Economical evaluation was then expanded also with evaluation of minimum area treated as vineyards in subsequent differentiation of costs on manual labour which ranged from 2 to 14 € h^{-1} not considering VAT.

Table 4. Machinery cost parameters

Parameter	Units	Trailed vine grape harvester	Tractor
Purchase price	Eur	60,000	45,000
Estimated life	h	3,000	10,000
Annual use	h	300	600
Remaining value*	%	25	25
Depreciation	Year	-	-
Insurance and housing	€	50.49	85,13
Dimensions of machinery	m × m	3.3 × 2.55	3.44 × 1.46
Repair factor	RF_1	0.11	0.02
	RF_2	1.80	1.35

* based on purchase price of machinery.

Total costs were then considered also in case of utilization of manual vine grape harvest within the scope of the same vineyard areas while the selected company do not use mechanized harvest only at all of their vineyards. Total cost on manual labour (salary of workers with insurances) were the considered as 3 € h^{-1}. However, in case of manual harvest, the losses from harvest were considered at zero level while this type of harvest is characterised by minimal losses (Johann et al., 2010). At the basis of our research the time period was used in accordance of harvest needed for vineyard area 102 h ha^{-1}.

RESULTS AND DISCUSSION

Harvester working capacity

From the obtained results on vine grape harvester working capacity, total yields and subsequently recorded losses from harvest the significant differences were observed. Total yields were significantly dependent on variety of vine grape up to value 10 t ha^{-1}. In case of variety Ruland Blue it was 6.23 ± 0.34 t ha^{-1} (sugar content 23.2 NM), Neronet

7.30 ± 0.46 t ha^{-1} (sugar content 24°NM) and Veltliner Green 9.7 ± 0.50 t ha^{-1} (sugar content 21.5°NM) presented in form *mean* ± *SE*.

In evaluation of performance parameters the significant differences were observed i all harvested varieties as well. Working speed of harvester and frequency of wattle oscillations were dependent on thickening of the plant and the time of grape harvest (degree of maturation). The time needed for turning of machinery and emptying of harvester hopper were partially affected by specifically used machinery (type of machinery – self-propelled or trailed). However, at the first place, it is highly dependent on experience and skills of machinery operator and land conditions of vineyards. On the other hand, when the water content of vine grapes are at lower levels (degree of maturation and previous precipitations), the grape berries were better situated in grape tassels. Therefore the frequency of oscillations needs to be increased to the greater values. It means that the every single variety of vine grape and specific year weather conditions are also main driving factors which affect the operability and utilization of machinery and its working settings. Similar results and conclusions can be found in other studies (Bavaresco et al., 2008; Pezzi & Caprara, 2009; Caprara & Pezzi, 2011; Pezzi, 2011; Clingeleffer, 2013; Novák & Burg, 2013; Pezzi & Martelli, 2015).

In the evaluation of 3 varieties of vine grapes it was observed that the harvest with the lowest need of oscillation frequency were for variety Neronet. During the observation of times needed for turning of machinery and empting of harvester hopper there were found out very low differences where the lowest values of these times were observed for variety Ruland Blue. In evaluation of effective field capacity of vine grape harvester for different varieties there were observed only slight differences while the maximum was observed at level 6.4% in comparison of variety Neronet with Veltliner green. In evaluation of material field capacity in relation with yields of selected varieties it can be concluded that the highest yields was observed in case of variety Veltliner Green (about 36.11% higher in comparison to Ruland Blue). In contrast, evaluation of manual harvest by the same person and all of the varieties in conjunctions with density of the plant and size of the grape tassels were observed interested values which are shown in Table 5. From these results it can be concluded that utilization of the manual harvest in comparison with utilization of mechanization requires employment of dozens of workers to be concurrent to mechanized harvest while field capacity of vine grape harvester is immeasurably higher.

Table 5. Operating characteristics of vine grape harvesters (*mean* ± *SE*)

Characteristic	Units	Variety		
		cv. Ruland Blue	cv. Neronet	cv. Veltliner Green
Field speed	km h^{-1}	2.2 ± 0.1	2.1 ± 0.1	1.9 ± 0.1
Turning time	s	82 ± 1.4	90 ± 1.8	103 ± 2.1
Unloading time	s	113 ± 1.4	112 ± 1.7	115 ± 1.8
Frequency of oscillation	beats min^{-1}	550	525	580
Field efficiency, E_f	-	0.61 ± 0.00	0.65 ± 0.00	0.69 ± 0.00
Effective field capacity, C_a	ha h^{-1}	0.32 ± 0.00	0.33 ± 0.00	0.31 ± 0.00
Material field capacity	t h^{-1}	1.98 ± 0.14	2.45 ± 0.16	3.11 ± 0.22
Field Capacity (manual harvest)	10^{-3} ha h^{-1}	2.12	2.22	2.01

Evaluation of effective field capacity was the main aim of the study conducted by Pezzi & Martelli (2015) with focus on cultivar variety cv. Trebbiano. In the study it was reported at value 0.34 ha h^{-1}. It was concluded that the differences may be obvious, however, utilization of smooth and flat vineyards in combination with used tractor Tractor CNH T5060 aggregated with the same vine grape harvester ERO LS Traction was the main difference driving parameter (Pezzi & Martelli, 2015). I comparison with our results, the lower values about 5.88% in average for all of the tested varieties of vine grapes harvested were observed. In other study, conducted by Zemánek & Burg (2005), was used the same trailed vine grape harvester ERO LS Traction aggregated with tractor Zetor 7311 and effective field capacity was reported at value 0.24 ha h^{-1} (harvested variety was Lemberger). It represents about 29.4% lower values in comparison with our results. These differences may be caused by lower manoeuvrability of used machine aggregation combined with specifications of harvested variety.

Harvest Losses

In the frame of research activities there were observed total losses of harvested vine grapes caused by vine grape harvester and was divided into two groups. Firstly to the losses due to slumping through the harvest mechanism on the ground and observed at level of 3% from the total harvested volume. Secondly, to the losses due to omissions of harvest where grapes were left on grape plants and observed at level 7%. From the results it is possible to conclude that variety Neronet has a greater ability to stick on the grape plants and has a greater resistance against grape tassels to be harvester by vine grape harvester mechanisms. Therefore, increased attention should be paid to careful settings of harvester mechanisms as well as utilization of greater values of oscillation frequencies should be adopted. On the other hand, it can be concluded that the total harvest losses were not excided 10%. These values are acceptable for mechanized harvest of vine grapes. The greatest observed harvest losses were observed specifically in variety Neronet (9.72%). In case manual harvest of vine grapes it was hardly to observe any losses while precision of labour workers were in case of experimental measurement naturally increased. Therefore, losses by letting grape tassels on grape plants was at absolute minimum and losses by slumping was neutralized by picking up all grape tassels even in case of their falling on to the ground.

The observed vine grape variety, Ruland Blue is variety designed mainly for high height of support and its yields range from 7 to 12 t ha^{-1} (Hubáček & Míša, 1996; Pospíšilová, 2005). In our study, the variety was grown at medium height of support and the average yields were observed as 6.23 t ha^{-1} with observed total losses about 152.64 kg ha^{-1}. The differences among the individual measurements of losses due to letting of vine grapes on grape plants demonstrated greater deviations. It was mainly caused by the areas where the grapes were clamped on the grape plants. However, harvest mechanism of vine grape harvester does not provide any lowest limits for its settings according to lowest height. Therefore, adjustment of harvest mechanism should be recommended and carefully conducted in case of every single harvested variety.

As another tested variety was used Veltliner Green. The maturation of grapes for this variety is characterized as very late. The variety is designed to be grown at higher and medium height of support and it is characterised by high yields where the value of 12 t ha^{-1} of grapes are not unusual (Kraus et al., 2004). These values are easy achievable in high height support. However, in our case it was grown at medium height support which is suitable for grape plants itself however not so suitable for utilization of mechanized harvest. Therefore, yields of this variety was observed only at 9.70 t ha^{-1} , and subsequently, average losses of vine grapes was measured at level 548.05 kg ha^{-1}. In comparison with previous variety (Ruland Blue) were the losses increased by 3.2%. According to fact that the harvest itself was performed during the appropriate term the losses were still quite high. In this case it means that those two factors appear to be among most important affecting variables. The first negative factor was the situation of grape tassels on grape plants and its proximity to supporting pillars. An omission in harvest of these vine grapes or its parts was therefore caused by the phenomenon that the oscillation frequencies of harvest mechanism were near the pillars reduced. This reduction was caused by prevention of damage caused to the support system and the harvest mechanism itself. As a second factor which was responsible for increase in losses were slight damage done on support system. Specifically, the upper mast was relaxed by harvest mechanism which is not unusual in case of mechanized harvest however in case of such a good yielding variety it means the great decrease of grape height position. This phenomenon negatively affected the harvest and results by increase of harvest losses due to slumping through harvest mechanism.

Observed variety Neronet is characterised by dense foliage along with earlier term of maturation. It is suitable to be grown in combination with medium and high height of support system however in case of harvest in later maturation the berries are easily dispatched from grape tassels to the ground (Webb et al., 2011). Tested variety in our study has the average yield at level 7.30 t ha^{-1} while average harvest losses were observed as 709.52 kg ha^{-1}. This variety has showed the greater percentage of harvest losses which was caused by three main factors. As the first negative factor can be mentioned the very late harvest time which was conducted in second half of October due to weather conditions. These conditions do not allow utilization of the earlier dates for the harvest. As the second negative factor has to be mentioned was non-ideal distribution of vine grapes at grape plants and their proximity to support pillars. As the third factor were observed the same phenomenon as in previous harvested variety where the main mast was relaxed. Therefore the weight of single grape tassels caused its easier falling and it's slumping through the harvest mechanism.

The issues and problems connected with quality of harvested products which is caused by mechanized vine grape harvest are linked with mechanical damage cased on berries. It is manifested mainly by the release of the mast. Delay in harvest time period and post harvest treatment, in some cases also by the increased temperatures, is responsible for direct increase of harvest losses by his release of must (Caprara & Pezzi, 2011).

The issue of evaluation of harvest losses in case of vine grapes are also addressed by other researchers. For example, Zemánek & Burg (2003) has reported, in case of grape variety Saint Laurent and utilization of the same trailed vine grape harvester ERO LS – Traction, the total losses at level 7.90%. These losses were divided into two groups. Losses defined as non-harvested was recorded as 2.6% and losses caused by slumping of the grapes through the harvest mechanism into the ground were 5.3%. In case of variety Lemberger the losses by slumping through the harvest mechanism was observed as 3.9% and losses by non-harvesting of grapes was 1.8% which means that total losses were calculated at level 5.7%. As contrast there was used another variant of vine grapes and different machinery, namely self-propelled vine grape harvester NEW HOLLAND

– BRAUD SB 58. In this case the total losses were calculated as 5.5% from which 0.6% were characterised as losses caused by slumping of the grapes through harvester mechanism and the rest (4.9%) as non-harvested losses (Zemánek & Burg, 2003).

Mechanised grape harvest and its effect on harvest losses were addressed also in conditions of Italy by Pezzi & Martelli (2005). The same vine grape harvester was utilised (ERO LS Traction) however aggregated with tractor CNH T5060. As observation variety were used Trebbiano with recorded total harvest losses of 6.4%, which consist of undetected grape (4.2%) and grapes on the ground of 2.2% (Pezzi & Martelli, 2005).

According to some other researchers, mechanized harvest of grapes is firstly dependent on technical parameters of grape harvester and secondly on physiological properties of harvested vine grapes (variety). It was concluded that irregular distribution of single grape tassels on individual grape plants, maturity of grape berries and density of foliage has a greater influence on subsequently recorded harvest losses than the type of supporting system or operating mode of vine grape harvester. It was also reported that supporting pillars has a great effect on quality of harvest along with negative increase in harvest losses (Novák & Burg, 2013).

Table 6. Harvest losses, % of production, cv. Ruland Blue, Neronet and Veltliner Green (*mean* ± *SE*)

Cultivar (Variety)	Undetached Grape	Grapes on the ground	Total
Ruland Blue	0.48 ± 0.05	1.97 ± 0.11	2.45 ± 0.15
Neronet	6.74 ± 0.87	2.98 ± 0.10	9.72 ± 0.97
Veltliner Green	3.68 ± 0.93	1.97 ± 0.15	5.65 ± 0.96

Moreover, analysis of the results in our study shows the dependence of harvest losses on tested variety of vine grape. It was observed that the highest values of harvest losses was recorded for variety Neronet with decreasing trend in case of Ruland Blue and Veltliner Green (Table 6).

Harvesting costs

In calculation of cost units was total utilization of machinery assembly (tractor and vine grape harvester) set at level 300 ha where the utilization of those machinery in other type of use, e.g. providing services, was not considered. Total annual costs on whole vineyards area (100 ha) by employment of mechanized harvest was calculated as 7,611.11 €, therefore total cost per hour are 25.37 € h^{-1}. In evaluation of harvest costs defined for different varieties the value of harvest costs were significantly higher. In case of Ruland Blue variety it was 315.27 € h^{-1}, 246.32 € h^{-1} and 65.67 € h^{-1} in case of Neronet and Veltliner Green, respectively. From the results is can be concluded that by increasing of the area treated by mechanized vine grape harvest is able to decrease the costs on harvest per hour unit even to level where the costs meets the basic values for utilization of harvest provided in form of services. (ca 200 € h^{-1}). Given that, in conditions of Slovakia, there are not so many vine grape harvesters available on the market. Moreover the price of those services is not given by any platform or agency. The prices of this kind of services was obtained from the companies which posses vine grapes harvesters in their machinery park and they were calculated as 200 € h^{-1} in case of trailed harvester and 400 € ha^{-1} in case of self-propelled harvester. Table 7 shows the total annual costs which are divided onto fixed (costs on amortization, equity interest, road tax, insurances and costs for garaging) and variable (cost of repairs of machinery, energy and manual labour) costs. All of the cost units were showed for single varieties as well as for total area of vineyards where the mechanized harvest were employed Table 8). Costs on amortization were considered as zero due to utilization of machinery with a higher age and road tax on this type of machinery is not given in case of Slovakia. A great share of costs was then represented by costs on equity interests from the total fixed costs (up to 95%). In evaluation of variable costs the greatest share was formed by costs on fuel (diesel) in dependence on grape varieties and lower vineyard areas however in case of considering the whole vineyard area treated by mechanized vine grape harvest (100 ha) it was formed by costs on machinery repairs (Table 7).

Table 7. Total (fixed and variable) annual costs on mechanized harvest of vine grapes

Items costs	Units	Vineyards, varieties			
		Ruland Blue	Neronet	Veltliner Green	Total
Area	ha	3	4	16.10	100
Costs of amortization, ${}_rN_a$	€ year^{-1}	0.00	0.00	0.00	0.00
Costs of interest on capital, ${}_rN_z$	€ year^{-1}	2,625.00	2,625.00	2,625.00	2,625.00
Costs of vehicle tax, ${}_rN_{cd}$	€ year^{-1}	0.00	0.00	0.00	0.00
Costs of insurance for damage, ${}_rN_p$	€ year^{-1}	55.00	55.00	55.00	55.00
Costs of optional insurance, ${}_rN_{np}$	€ year^{-1}	0.00	0.00	0.00	0.00
Costs of garaging, ${}_rN_g$	€ year^{-1}	80.62	80.62	80.62	80.62
Total fixed costs, ${}_rN_k$	€ year^{-1}	2,760.62	2,760.62	2,760.62	2,760.62
Costs of repairs and maintenance, ${}_rN_o$	€ year^{-1}	4.58	6.88	73.81	1,816.84
Costs of fuel, ${}_rN_e$	€ year^{-1}	151.14	167.36	363.55	1,723.90
Costs of live labour, ${}_rN_{zp}$	€ year^{-1}	39.29	50.80	217.67	1,309.75
Total variable costs, ${}_rN_v$	€ year^{-1}	195.01	225.04	655.02	4,850.49
Total annual costs, ${}_rN_{mC}$	€ year^{-1}	2,955.63	2,985.66	3,415.65	7,611.11

Table 8. Total (fixed and variable) unit costs on mechanized harvest of vine grapes

Items costs	Units	Vineyards, varieties			
		Ruland Blue	Neronet	Veltliner Green	Total
Area	ha	3	4	16.10	100
Costs of amortization, ${}_jN_a$	€ ha^{-1}	0.00	0.00	0.00	0.00
Costs of interest on capital, ${}_jN_z$	€ ha^{-1}	875.00	656.25	163.04	26.25
Costs of vehicle tax, ${}_jN_{cd}$	€ ha^{-1}	0.00	0.00	0.00	0.00
Costs of insurance for damage, ${}_jN_p$	€ ha^{-1}	18.33	13.75	3.42	0.55
Costs of optional insurance, ${}_jN_{np}$	€ ha^{-1}	0.00	0.00	0.00	0.00
Costs of garaging, ${}_jN_g$	€ ha^{-1}	26.87	20.16	5.01	0.81
Total fixed costs, ${}_jN_k$	€ ha^{-1}	920.21	690.16	171.47	27.61
Costs of repairs and maintenance, ${}_jN_o$	€ ha^{-1}	1.53	1.72	4.58	18.17
Costs of fuel, ${}_jN_e$	€ ha^{-1}	50.38	41.84	22.58	17.24
Costs of live labour, ${}_jN_{zp}$	€ ha^{-1}	13.10	12.70	13.52	13.10
Total variable costs, ${}_jN_v$	€ ha^{-1}	65.00	56.26	40.68	48.50
Total annual costs, ${}_jN_{mC}$	€ ha^{-1}	985.21	746.42	212.15	76.11

Graphical evaluation of the results of total unit costs on mechanized harvest in relationship with different levels of annual utilization of machinery shows the decreasing trend (Fig. 1). These relations present the results of individual varieties of grapes (Ruland Blue, Neronet and Veltliner Green), for all vineyards which was treated by mechanized harvest in contrast with costs in case of utilization of manual harvest. As another indicator of economic benefits were selected definition of the turning points where the mechanized harvest becomes cheaper than manual harvest from the point of costs view. It was calculated at 16.91 ha year^{-1} in average for total area of vineyards 100 ha.

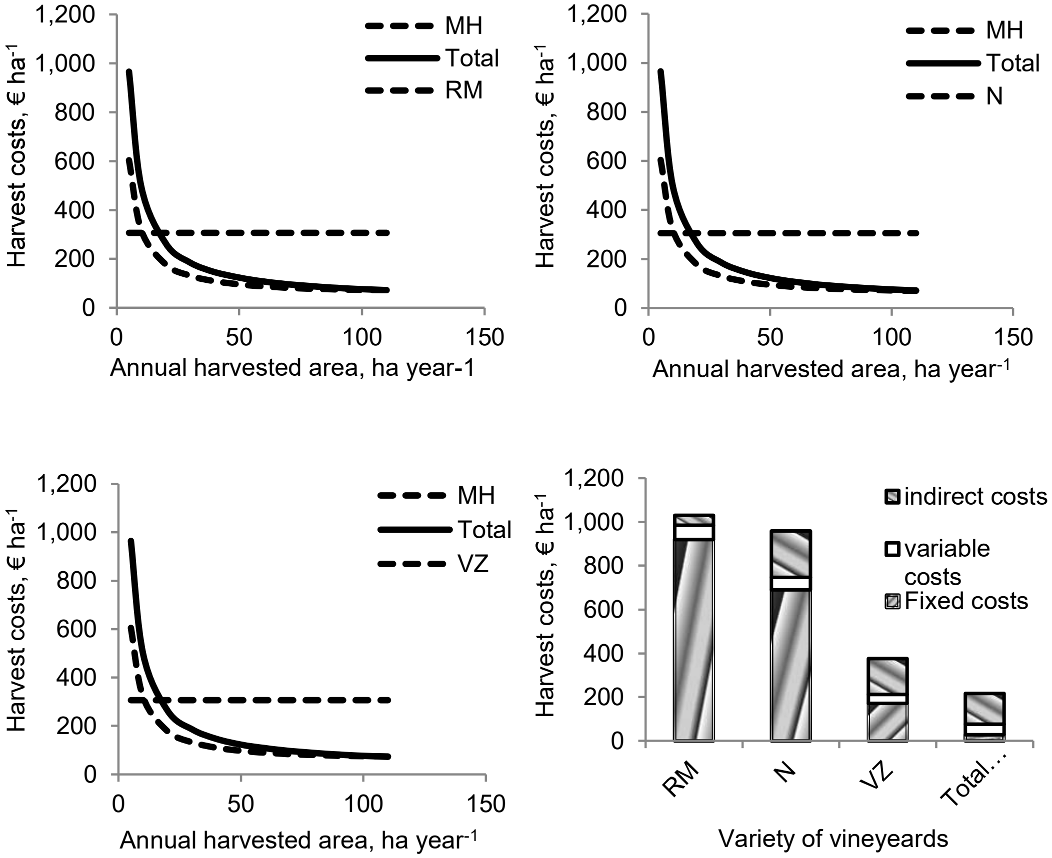

Figure 1. Harvesting costs with harvested area, individual varieties and all vineyards (MH – manual harvesting; Total – all vineyards, mechanized harvest; RM – Ruland Blue; N – Neronet; VZ – Veltliner Green).

Indirect costs, caused by the measured total losses on yields should be then imputed into direct costs. In determination of indirect costs were considered average purchase price of vine grapes (market value) in time of harvest 0.30 € kg^{-1} with VAT. In our study, the total harvest losses were observed at maximum of 9.72% (in case of Neronet variety). Economical evaluation then reveal that the relevant results with regards on total losses from yields are at level 45.79 € ha^{-1} (Ruland Blue variety), 212.86 € ha^{-1} (Neronet variety) and 164.42 € ha^{-1} (Veltliner Green variety). Graphical evaluation of the results of indirect costs divided onto fixed and variable costs and showed at Fig. 1. The direct costs of mechanized vine grape harvest on the total area of vineyards of 100 ha were characterised by the higher effect of indirect costs (in average) in comparison with direct costs about 15.24%, specifically.

In evaluation of total costs on vine grape harvest were the results highly dependent on individual country conditions where in many cases there are various changes in input units for calculation of fixed but as well as variable components (e.g. years of depreciation, costs on insurances, road taxes, cost on garaging, costs on machinery repairs, costs of fuel and costs on manual labour). However, the highest important role in calculation of costs are forming by direct costs (price of machinery or machines assembly) and indirect costs which are caused by harvest losses on yields (Demaldè & Spezia, 2006; Tudisca et. al, 2013; Pezzi & Martelli, 2015).

Break-even analysis

The possibilities of exploitation of mechanized vine grape harvest in contrast with utilization of manual harvest are showed in Fig. 2 (left). In case of increasing of costs on manual labour and by calculation of unit costs on mechanized harvest and manual harvest results is decreasing trend of area of vineyards which needs to be treated. The performance in manual harvest were observed at value 9.8×10^{-3} ha h^{-1}, while the average price of manual labour in our conditions can be calculated on level of 306 € ha^{-1}. The efficiency of investment into a new machinery (vine grape harvester) are then represented by minimal annual machinery utilization at level of 16.92 ha $year^{-1}$. If the calculation includes also indirect costs on mechanized harvest (in case of grape price 0.3 € kg^{-1}) the minimum area of vineyards which need to be treated by mechanized harvest will be increased at level 34.5 ha $year^{-1}$. According to indicated prizes of mechanized harvest (rent of machinery) and services for purchase of own vine grape harvester with economic benefits it needs to be treated 27.42 ha $year^{-1}$ of vineyards. In case of areas (vineyards), which are below those mentioned above the mechanized harvest and its utilization, is more beneficial to be obtained in form of services (Tisseyre et al., 2007).

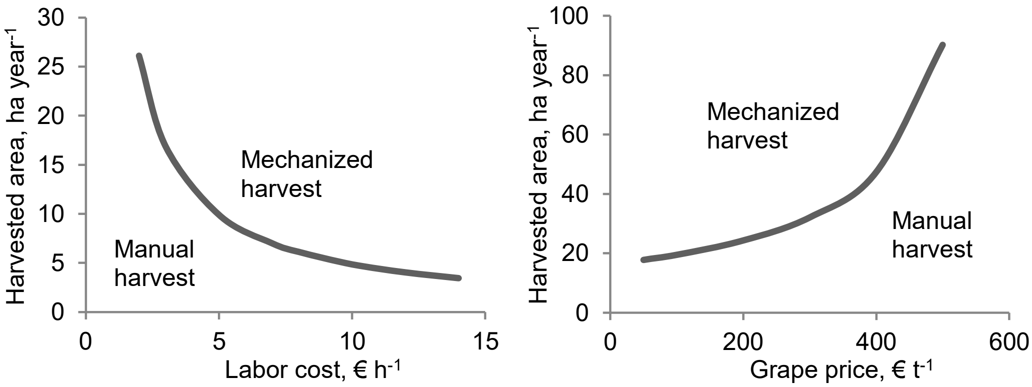

Figure 2. Break–even analysis under different combinations of harvested area and labour cost and grape price (left), break-even areas under different combinations of harvested area and grape price (right).

The evaluation of machinery utilization and exploitation by the changes in grape prizes in relationship with change in direct and indirect unit costs showed the significant differences. By increasing of grape price the minimum area grows exponentially (Fig. 2, right). In case of average vineyard areas (for all varieties) the increase in prize of grapes results in more often utilization of manual harvest where are considered harvest losses by slumping to the ground and non-harvested on grape plants as zero.

The cost-effectiveness of mechanized harvest compared to manual harvest is obtained on small areas (7 to 14 ha) in both situations. Analysis of the cost-effectiveness between mechanized and manual harvest cannot exclude other aspects that are not easily quantifiable. Among the favours of manual harvest is the more intact product, which leads to fewer problems in the successive phases of delivery to the winery and winemaking companies. An aspect against manual harvest in the region is a shortage of labour, which causes problems in the organization of field works and delivery of the grapes (Letaief et al., 2008; Pezzi, 2011; Pezzi & Martelli, 2015).

The mechanized harvest can be effectively employed at minimum area of 16.92 ha according to our results. However if indirect costs are included into calculation and considering the prize of grapes (market prize) at level of 300 € t^{-1} the minimum area which needs to be treated by mechanized harvest is increased to 34.5 ha $year^{-1}$. By comparison of obtained results which defines the costs on rent of machinery in form of services the minimum treated area which will be needed for purchasing of own machinery will be at minimum of 27.42 ha $year^{-1}$.

CONCLUSIONS

The aim of the study was to evaluate the quality of mechanized vine grape harvest expressed firstly by total losses caused by harvest itself and secondly by total costs on mechanized harvest involving three varieties of vine grapes. Although, the manual harvest is defined by absolute minimum values of harvest the losses caused by mechanized harvest was observed in average 470.07 kg ha^{-1} for the whole treated area of vineyards. Higher losses for variety Neronet was affected by non-ideal distribution of grape tassels with close proximity to support pillars and also by the improper hanging of individual grape stems which can be also affected by lower quality of used hanging material. In economical evaluation of mechanized harvest of vine grapes it was showed that cost-effective way of mechanized harvest is achievable however increased harvest losses has to be considered as it was described in our study. Many companies and individuals in the field of viticulture starting to employ mechanized vine grape harvest however it is usually supported by consideration and utilization of greater areas of vineyards as it was defined in this study (16.92 ha $year^{-1}$). The evaluation and following specification of the turning point revealed that cost-effective utilization of mechanized harvest is achievable in comparison with manual harvest in different levels of costs on manual labour on one side and market prize of vine grapes on second side. As the greatest benefit of mechanized grape harvest is the time period needed for harvest itself but also regarding to decrease of work quality and increase in costs of hourly rate. However this phenomenon's combined leads to decrease of unit costs in both direct and indirect type. From the perspective of Slovakia and overview of commonly utilized machinery in viticulture can be concluded that greatest portion of mechanized harvest is done by trailed types of vine grape harvesters however in case of small vineyard holders (area from 5–10 ha) it is mostly application of manual harvest. The consideration and decisions for selection of appropriate harvest technology was provided at the basis of proposed hypothesis of various labour costs and prizes of vine grapes. Those were determined as driving factors for economical evaluation. In the study was also pointed out that there is effect of indirect costs, harvest losses and other factors highly affect the affectivity of mechanized grape harvest however those can be decreased by specific changes in machinery settings.

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