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Quality and efficiency of apple orchard protection affected by sprayer type and application rate

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Abstract

The goal of this work was to evaluate the potential of reduced application rates in apple trees as well as the potential of selective spray applications by using sensor-based tree detection techniques in Serbian fruit production. Their economical and biological effect was evaluated based on the quality and efficiency of the crop protection and techno-economic analysis. Results showed that during suitable weather conditions and with properly adjusted sprayer settings, a reduced application rate of 381 L ha^{-1} gave same quality of crop protection as a medium application rate of 759 L ha^{-1}. A two-year efficiency trial on *Venturia inaequalis* and *Podosphaera leucitricha* infecting apple also showed that there was no significant difference in crop protection results for different types of orchard application techniques and application rates. The techno-economic analysis showed that selective application should be introduced in practice in areas > 3 ha given that the cost of their introduction pays off after 2-3 seasons. Every subsequent season would give a clear economic profit. Besides the economic benefits, selective application technique also has a significant positive ecological effect due to reduction of spray losses and the amount of plant protection products used.

Additional key words: efficiency; techno-economic analysis; application technology; sensor.

Introduction

Apple (*Malus silvestris*) is one of the main fruit crops in Europe production and it is the fourth ranked fruit in the world, right after banana, citrus and melons (www.faostat.fao.org). Apple growing requires substantial capital investment but high returns are possible. Pest management is of particular importance for the maintenance of any type of orchard, especially apple orchards. Today, the most common plant protection measure is the application of chemical plant protection products by using air-assisted sprayers. Pesticides are widely used to control pests and diseases of food crops, which may lead to residues in foodstuffs (Xiang-Ming *et al*., 2008). During the last decade, European countries have launched national initiatives to reduce the use of pesticides. These experiences offer valuable insights for the development of national action plans required by new European legislation on pesticides (Balsari & Marucco, 2011; Barzman & Dachbrodt-Saaydeh, 2011). Due to the strict requirements regarding fruit safety, the economical and environmental aspects of the production and the expansion of land used for fruit growing, questions arise about the justifiability and cost-effectiveness of high application rates. A trend of low application rates has been noticed in many countries over the last few years. Lately, fruit growers have started using low application rates (200 to 500 L ha^{-1}) especially during the initial growth stages. Escola *et al.* (2006) tested three different application rates (400, 800 and 1,600 L ha^{-1}) in two apple orchards during two growing seasons. Spraying

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This work has one Supplementary Table that does not appear in the printed article but that accompanies the paper online.

Abbreviations used: CHS (crop health sensor); CIS (crop identification sensor); I (disease severity); LV (low application rate); MV (medium application rate); TRV (tree row volume); VMD (volumetric medium diameter).

parameters were kept as similar as possible (forward speed, weather conditions, air volume rate, etc...) to provide similar volume median diameters (VMDs) for different application rates. This experiment found no differences in VMD values between different application rates. Cross *et al*. (2001) obtained similar results for apple orchards where three treatment rates were applied during three years.

In Serbia, high application rates (1,000 to 1,500 L ha^{-1} of ground surface) are rare, while medium rates (500 to 1,000 L ha^{-1}) are the most common. In order for the low application rates to be effective, all working parameters should be adjusted and they should operate properly (Sedlar *et al*., 2007). The biggest problem of low application rate is the drift. Bugarin *et al*. (2013) emphasized the necessity of introducing air injection hollow cone nozzles in Serbian practice because of the possibilty to work under unfavorable weather conditions and to reduce the drift.

Solanelles *et al*. (2007) carried out a 3-year long research in apple and pear orchards in Catalonia (Spain). Three different spray application rates (400, 800 and 1,600 L ha^{-1}) were applied in all orchard growth stages with the same droplet size spectrum. The results showed that the lowest application rate was fully effective in the early growth stages. No significant effect of application rate was found in the orchard with two varieties of pear ('Conference' and 'Blanquilla') and one apple variety ('Golden'). The lowest application rate gave the best results in 'Red Chief' apple orchard. They concluded that a wide range of application rates could be used in an orchard treatment and that with unchanged droplet size spectrum, right protection dosage and spray coverage good efficiency can be achieved.

Cross *et al*. (2001) tested three different application volumes (medium: 727-769 L ha^{-1}, low: 277-302 L ha^{-1} and extra low: 88-97 L ha^{-1}) in three different orchard size types (large, medium, small) using eight different sizes of Albuz ATR hollow cone nozzles. The VMDs were 159, 156 and 157 µm for the medium, low and extra low volume treatments, respectively. It is very important to chose carefully all working parameters so that VMD and droplets size are as similar as possible for different application rates and treatments.

In order to improve fruit and environmental safety, many authors claim that it is necessary to implement new and sustainable pesticide application techniques which will provide more precise application and minimize the losses to the environment (Solanelles *et al*., 2006; Walklate *et al*., 2006; Gil *et al*., 2007; Marucco *et al*., 2008; Walklate *et al*., 2011). One of the possibilities is to equip orchard sprayers with crop identification sensors (CIS). The presence of a tree is generally detected using ultrasonic or optic sensors (Walklate *et al*., 2002; Jeon *et al*., 2011). Van de Zande *et al*. (2007) describe a disease identification sensor called *crop health sensor* (CHS). Commercial use of the CHS is very rare but it is affordable and efficient. Zijlstra *et al*. (2011) presented state-of-the art monitoring tools and precision application technologies for integrated high-tech crop protection.

Koch & Weisser (2000) measured savings from 10-35% in a 3-7-year old apple orchard and from 35-45% in a 1-year old apple orchard using optical tree detection sensors. By using the same system, a reduction of 45-60% in the application rate was achieved in a 3-year old cherry orchard.

In this study, different apple orchard treatments were performed in order to: (i) evaluate the spray application quality and efficiency for different application rates (low and medium) and techniques (conventional and selective); and (ii) perform a techno-economic analysis of reduced application rate and a selective application technique with a sensor-based tree detection.

Material and methods

In 2009 and 2010, pesticide treatments of the apple orchard owned by the Department of Fruit Growing, Viticulture, Horticulture and Landscape Architecture, Faculty of Agriculture, University of Novi Sad (Serbia), were performed in order to determine the quality and protection efficiency of different spray application techniques and rates. The experiments were carried out as a two-factor factorial experiment and organized as a randomized block design (Ponjican *et al*., 2011): Factor 1- spray application technique (conventional and selective) and Factor 2- application rate expressed in L ha^{-1} of ground surface (medium, MV = 759 L ha^{-1} and low, LV = 381 L ha^{-1}). Each year, 12 pesticide treatments were performed using 12 different fungicides and 10 different insecticides. They were rotated on the same plot.

Two application rates (low and medium) were combined with two spray application techniques (conventional and selective) resulting in four treatments, *i.e.*: I, medium application rate – conventional application; II, low application rate – conventional application; III,

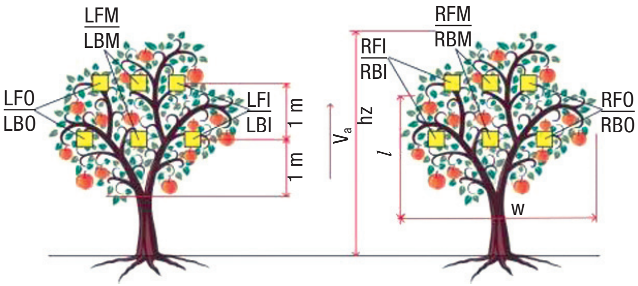

Figure 1. Position of the measuring points and tree dimensions. Nomenclature of the measuring points: first letter (L- left side, R- right side); middle letter (F- leaf face, B- leaf backface); last letter (I- inner part of treetop, M- middle part of treetop, O- outside part of treetop). Nomenclature of tree dimensions: height from the ground (*hz*), the width (*w*) and length (*l*) of the tree. Va: direction of movement of air-assisted sprayer.

Figure 2. Carried axial fan air-assisted sprayer AGP 440.

medium application rate – selective application; and IV, low application rate – selective application.

Trials were conducted in a 13-year old 'Idared' apple orchard 1-ha big, which was established on week thickness transplant-base with a slender spindle type training system. It was planted in degraded chernozem soil with 3% humus. The macro relief was flat, while the micro relief was mostly flat with a 10 cm deep depression between the rows. The orchard had a 4 m inter-row distance and 1.6 m distance inside a row. Ten trees were randomly chosen and measured in order to get the average height from the ground (h_z), the height of the treetop (h_g) and the width (w) and length (l) of the tree (Fig. 1). Average h_z was 3.22 m, $h_g = 2.63$ m, w = 1.85 m and l = 1.77 m. Orchard tree row volume (TRV) was 14,800 m^3 ha^{-1}. In the middle of the orchard, there was a 20 m wide empty space which was used for the spatial isolation between the left side of the orchard, treated with the MV, and the right side of the orchard treated with the LV application rates.

Fuel consumption was measured by the volume method using the Pierburg 2911 flowmeter.

Spray application techniques and methods of calibration

Two different spray application techniques were tested, both at MV and LV: (i) a conventional spray application, *i.e.* a mounted axial fan air-assisted sprayer Agromehanika 440 (AGP 440), (ii) a tower sprayer or selective spray application, *i.e.* a trailed cross flow air-assisted tower sprayer Dal Degan Morava 1000 (DDM 1000) with crop identification system.

The mounted axial fan AGP 440 sprayer (Fig. 2) had a 400-L tank volume and a two chamber membrane pump able to deliver a flow rate of 65 L min^{-1} and an operating pressure up to 30 bar. Airflow settings of the axial fan were adjustable by changing the blade angle resulting in an air velocity range from 12 to 32 m s^{-1} at the exit of the fan corresponding with airflow capacity from 16,000 to 50,000 m^3 h^{-1}. The AGP 440 sprayer was equipped with 12 Lechler TR 80-02 hollow cone nozzles (Lechler GmbH, Metzingen, Germany) for the LV and with 12 nozzles type Lechler TR 80-04 for the MV, both producing a medium droplet size spray according to the research done by Nuyttens *et al.* (2007). A complete overview of the spray application parameters can be found in Table 1.

The trailed DDM 1000 air-assisted tower sprayer (Fig. 3a) had a 1,000 L tank volume and a four-chamber pump with a maximal flow rate of 130 L ha^{-1} and a pressure up to 40 bars. The fan capacity could be changed by switching the gearbox on and off. Maxi-

Table 1. Spray application parameters for medium (MV) and low (LV) application rate

Working parameters	MV (759 L ha^{-1})	LV (381 L ha^{-1})
Nozzle type	Lechler TR 80-04	Lechler TR 80-02
No. of nozzles	12	12
Working pressure (bar)	8.0	8.0
Nominal nozzle flow rate (L ha^{-1})	2.53	1.27
PTO speed (rpm)	540	540
Forward speed (km h^{-1})	6.0	6.0
Volumetric air flow (m^3 h^{-1})	50,000	50,000

PTO: power take off.

Figure 3. Trailed air-assisted tower sprayer DDM 1000 (A), ultrasonic sensors for crop identification (B) and operating unit (C).

mum fan capacity was 50,000 m^3 h^{-1}. The DDM 1000 sprayer was also equipped with twelve Lechler TR 80-02 nozzles (theoretical VMD = 155 µm) for LV and twelve Lechler TR 80-04 nozzles (theoretical VMD = 215 µm) for MV (Lechler GmbH, Metzingen, Germany). With these settings and in case of a continuous spraying, the LV and MV would correspond to 381 and 759 L ha^{-1}, respectively. As all the nozzles were shut off between the trees, the actual application rates were lower compared with the conventional application technique. After every treatment, the actual application rate was measured based on the residual volume after the spray application. The DDM 1000 cross flow sprayer was equipped with an air tower and ultrasonic sensors (UM30-1_111/5, Sick, Germany). Distance between sensors and nozzles was 2.15 m. According to this and considering a forward speed of 6 km h^{-1} (1.66 m s^{-1}) it was estimated that a delay of sensors detection and nozzles activation would be 1.1 s and nozzles deactivation 1.3 s. Equipping the sprayer with an air-tower produces a horizontal air flow towards the canopy (Endalew *et al*., 2010) with the aim of improving spray deposition and reducing spray drift (Fox *et al*., 1992; Holownicki *et al*., 2000). The ultrasonic sensors were used for tree identification (Fig. 3b). The presence of a tree was signaled to the operating unit (Ecosonar, Spain) which sent the signal for the opening of the electromagnetic valves (Fig. 3c). Ultrasonic sensors have been used for crop identification by Solanalles *et al*. (2006), Gil *et al*. (2007), Chueca *et al*. (2008) and Jeon *et al*. (2011), among others.

Spray deposition

The canopy spray deposition for each of the four application techniques (low/conventional, medium/conventional, low/selective, medium/selective) was measured in three repetitions, which totals to 12 sprayings in 2009. Water sensitive papers (52 mm × 76 mm, Syngenta Crop Protection AG, Basel, Switzerland) were placed on 24 randomly selected trees at six measuring points within each tree. Four measuring points were located in the top of the tree. Two were located in the inner part of the tree. The papers were placed at heights of 1 and 2 m from the branch closest to the ground (Fig. 1).

The water sensitive papers were analyzed by 'Droplets' software designed at the Faculty of Agriculture in Novi Sad. The software was able to select a representative surface area of 1 cm^2. The representative surface was taken instead of total surface beacause of specific program features which could provide more precise information on this representative area than on total area. The spray coverage was calculated within this area. Water sensitive papers have been used before in many studies as a tool for providing a quick and cheap evaluation of spray coverage (Fox *et al*., 2003; Sánchez-Hermosilla & Medina, 2004; Foqué & Nuyttens, 2011a,b).

Biological efficiency

Biological efficiency was determined by analyzing the efficiency of fungicide for suppressing apple scab (*Venturia ineaequalis*) and powdery mildew (*Podosphaera leucotricha*). Biological efficiency of fungicides was assessed twice in both years of the experiments for *V. ineaequalis* on the leaves and the fruits and for *P. leucotricha* on the leaves. As a control treatment, 5 apple trees were not sprayed in both 2009 and 2010. In 2009, efficiency of the four treatments was compared. In 2010, only the LV and MV applications were compared with the conventional application. For each tested application technique and for the control treatment, leaves were collected from 5 randomly selected trees at 5 branches in 4 repetitions. Moreover, 4 wooden boxes with 200 fruits were collected for each spray application technique and for the control treatment. Leaves were picked up 5 days after spraying at the end of June (29.06.2009 and 30.06.2010). Fruits were picked up at the end of September (30.09.2009 and 30.09.2010).

After classifying the collected leaves and apples in one of the five disease classes, the disease severity (I) was calculated according to the formula of Towsend & Heuberger (1943):

$$I(\%) = \frac{\sum(1 \times n_1)+(2\times n_2)+(3\times n_3)+(4\times n_4)+(5\times n_5)}{D\times N}\times 100$$

where n_i = number of leaves/fruits in disease class i, N = total number of leaves/fruits, D = number of classes (5 classes).

Efficiency was calculated according to the Abbott formula (Wenzl, 1948) by comparing the disease severity for different treatments with the disease severity in the control. The experiments of biological efficiency were analyzed in the Laboratory for Pesticides and Biological Research at the Faculty of Agriculture, University Novi Sad.

The obtained data were processed by Statistica 10 software package. The application quality and the protection efficiency were analyzed by F-test ANOVA and Duncan's multiple range test. All the tests were performed for the 0.95 confidence intervals.

Results and discussion

Spray application results for different application rates and techniques

Different spray application rates and sprayer types were analyzed based on the spray coverage which was determined after the analysis of water sensitive papers (Table 2). Tower sprayer with 759 L ha^{-1} achieved leaf coverage (64.85%) that was statistically significantly different with respect to other variants. There was statistically significant difference in average coverage between conventional (51.21%) application and tower sprayer (64.85%). Different application rates (MV-759 L ha^{-1} and LV-381 L ha^{-1}) showed no statistically significant difference in leaf coverage for conventional sprayer type, but there were statistically significant differences for tower sprayer (64.85% and 54.53%). No statistically significant difference was observed in the LV of tower sprayer and conventional sprayer type (53.76% and 54.53%).

Analysis of leaf coverage with conventional spraying and MV application, at heights of 1 and 2 m from the branch closest to the ground, showed that there was statistically significant difference between different height zones. At 1-m and 2-m from the branch closest to the ground the coverage of 58.64% and 43.77%, respectively, was recorded.

The LV also demonstrated difference in leaf coverages which was not statistically significant. At 1-m

Table 2. Influence of spray application technique and volume rate on leaf coverage. In brackets, standard deviation

Theoretical application rate	Sprayer type	Leaf coverage at different heights* (%)		Leaf coverage in different tree zones (%)		Average coverage (%)
MV: 759 L ha^{-1}	Conventional	2 m	43.77^{d} (10.65)	Inner	49.19^{b} (10.92)	51.21^{b} (11.08)
		1 m	58.64^{abc} (4.87)	Middle	51.08^{ab} (9.84)	
				Outside	53.36^{ab} (14.91)	
	Selective	2 m	62.27^{ab} (15.53)	Inner	66.30^{ab} (8.69)	64.85^{a} (11.69)
		1 m	67.43^{a} (6.61)	Middle	66.98^{a} (2.43)	
				Outside	61.26^{ab} (19.85)	
LV: 381 L ha^{-1}	Conventional	2 m	48.98^{cd} (5.30)	Inner	57.05^{ab} (5.68)	53.76^{b} (6.59)
		1 m	58.54^{abc} (3.55)	Middle	51.04^{ab} (7.08)	
				Outside	53.19^{ab} (7.22)	
	Selective	2 m	52.44^{bcd} (9.08)	Inner	53.17^{ab} (7.18)	54.53^{b} (7.91)
		1 m	56.62^{abc} (6.69)	Middle	52.15^{ab} (12.00)	
				Outside	58.27^{ab} (2.27)	

* From the branch closest to the ground. Treatments (in columns) were compared using the Duncan´s multiple range test with a significance threshold of 5%.

and 2-m from the branch closest to the ground the coverage was 58.54% and 48.98%, respectively.

Use of tower sprayer did not show statistically significant differences in leaf coverage at different heights. The treatment with LV and MV at 1-m height from the branch closest to the ground gave higher leaf coverage (67.43% and 56.62%, respectively) in comparison to the upper part of treetop (62.27% and 52.44%, respectively), but there were no statistically significant differences.

Analysis of leaf coverage was done in different parts of treetop according to the measuring points shown in Fig. 1. There was no statistically significant difference in leaf coverage in the different tree zones.

Biological efficiency results in 2009 and 2010

In 2009, the two application rates with conventional technique gave statistically significant differences in the disease severity (I) of *V. inaequalis* leaves (MV: 1.94% and LV: 4.46%) (Table 3). The tower sprayer with LV gave significantly better bio-efficiency (I = 1.99%) compared to the conventional technique (I = 4.46%). With MV, no significant differences between both techniques were found. All techniques significantly reduced the disease severity of *V. inaequalis* on leaves which was I = 22.66% in the control. In general, efficiency was high, ranging from 80 to 92%.

In general, the suppression of *P. leucitricha* on leaves showed much better bio- efficiency of tower sprayer technique than the conventional technique. At MV, significantly better results were found for the tower sprayer (0.97%) compared with the conventional one (5.40%). For the conventional application, there was no effect of application rate. For the tower sprayer, MV gave the best results. Again, efficiency results were high ranging from 87% to 98% with a disease intensity of 41.29% in the control.

At the same time tower sprayer with MV achieved statistically significant difference in leaf coverage (64.85%) when compared to other variants. The results obtained in this project confirmed the importance of influence of leaf coverage to disease severity. Future research should be focused on determining whether the results obtained by selective application (coverage-biological efficiency) are due to the selective application itself or type of a sprayer.

Probably the positive effects of selective application techniques were not only achieved by the selective application itself, but also by the vertical orientation of the nozzles and air flow in the DDM 1000 air-assisted sprayer.

In suppressing *V. inaequalis* on fruits, no significant effects of application technique and spray application rate were found. The disease pressure was generally high (49.82%) and the different applications were not able to offer an acceptable bio- efficiency with disease pressures in the range from 17%-20%, corresponding to the efficacies from 60% to 66%.

Table 3 also presents the 2010 results. Certain differences and similarities between the two years were observed. In 2010 there was no statistically significant effect of application rate on bio-efficiency in suppression of *V. inaequalis* on leaves (MV: 19.24%, and LV: 25.61%) nor in the suppression of *P. leucitricha* on leaves. The disease pressure of *V. inaequalis* on leaves was much higher in 2010 (50.66% in the control) compared with 2009 (22.66% in the control), while the opposite was found for *P. leucitricha* on leaves (15.69% in 2010, 41.29% in 2009). Also in the suppression of *V. inaequalis* on fruits no significant effect of application rate was observed.

Comparison of both years shows that the same results were obtained for the suppression of apple scab (*V. inaequalis*) on leaves and fruits and that there were no statistically significant differences between the LV and MV.

By comparing the disease severity of *V. inaequalis* and *P. leucitricha* in 2010, with the results from 2009, it could be concluded that the intensity of *V. inaequalis* and *P. leucitricha* was considerably higher in 2010 due to higher amount of precipitation during the vegetation period which was favorable for the development of this pathogen (Suppl. Table 1 [pdf online]).

From the aspect of protection against *V. inaequalis* and *P. leucitricha*, the year 2010 was the hardest one because of higher precipitation resulting in clearly lower protection efficiency results. Suppl. Table 1 [pdf online] shows average daily temperatures and amount of precipitation in the period when the apple fruit was the most sensitive to this disease which is from the flowering stage until it reaches the size of a nut. The total amount of precipitation in 2009 and 2010 was 174 mm and 335.3 mm, respectively.

In general, by comparing the efficiency between conventional and tower air-assisted sprayer, it can be concluded that the tower sprayer always gives better results, although not always statistically significant,

Table 3. Efficiency of different spray applications to remove *Venturia inaequalis* and *Podosphaera leucitricha* on leaves and *V. inaequalis* on fruits (2009 and 2010). In brackets, standard deviation

Theoretical application rate	Sprayer tipe	Disease severity of *V. inaequalis* on leaves		Disease severity of *P. leucitricha* on leaves		Disease severity of *V. inaequalis* on fruits	
		I (%)	Efficiency (%)	I (%)	Efficiency (%)	I (%)	Efficiency (%)
Year 2009							
MV: 759 L ha^{-1}	Conventional	1.94^c (1.17)	91.40	5.40^b (2.23)	86.92	19.81^b (6.68)	60.24
	Selective	1.73^c (1.47)	92.36	0.97^c (1.02)	97.65	16.65^b (4.27)	66.58
LV: 381 L ha^{-1}	Conventional	4.46^b (1.63)	80.32	5.27^b (2.41)	87.24	17.92^b (2.81)	64.03
	Selective	1.99^c (0.54)	91.21	3.15^{bc} (1.50)	92.37	17.81^b (3.63)	64.25
Control		22.66^a (1.07)		41.29^a (2.99)		49.82^a (5.95)	
Year 2010							
MV: 759 L ha^{-1}	Conventional	19.24^b (0.49)	62.02	10.94^b (2.02)	30.27	41.96^b (11.53)	51.82
LV: 381 L ha^{-1}	Conventional	25.61^b (8.13)	49.44	12.41^b (0.93)	20.90	39.30^b (10.13)	54.84
Control		50.66^a (2.71)		15.69^a (1.01)		87.10^a (6.71)	

Treatments (in columns) were compared using the Duncan´s multiple range test with a significance threshold of 5%.

compared with the conventional technique. Except in one particular case (suppression of *V. inaequalis* on leaves in 2009), the use of lower application rate did not affect the efficiency results compared with the MV. Since both air-assisted sprayers were calibrated and tested prior to their use and their working parameters were the same, it was clear that better results were achieved with the tower sprayer air-assisted sprayer 'DDM 1000' because of the vertical tower layout of nozzles combined with well adjusted working parameters. This was confirmed by the analysis of water sensitive papers positioned in different tree zones. It was most probably the circular nozzle layout of the 'AGP 440' air-assisted sprayer which caused the inferior results.

Techno-economic analysis of selective spray application technique and reduced application rate

A techno-economic analysis of apple plantation treatments was performed to determine the cost-effectiveness and work savings of those treatments. Considerable saving was achieved by the selective application. Table 4 shows that application rate was reduced by 5.34% using selective application, which means that the actual rate was 360.65 L ha^{-1} instead of the expected rate of 381 L ha^{-1} in case of treatment with LV. In case of MV the actual rate was 718.47 L ha^{-1} instead of theoretical 759 L ha^{-1}. The actual rate of conventional application was 5.04% bigger than theore-

Table 4. Losses and savings of conventional and selective application per one treatment

Application rate	Losses and savings of conventional and selective application (%)		Actual application rate (L ha^{-1})		Actual output (ha)	
	Losses of CA	Savings of SA	CA	SA	CA	SA
LV: 381 L ha^{-1}	5.04	5.34	400.20	360.65	2.48	2.72
MV: 759 L ha^{-1}	5.04	5.34	797.25	718.47	1.20	1.36

CA: conventional application. SA: selective application.

tical (400.20 L ha^{-1} and 797.25 L ha^{-1}) due to the losses caused by the untimely turning of the air-assisted sprayer at the end of the pass. This means that savings of 5.34% were made by selective application and losses of 5.04% with conventional application gave a reduction of 10.38% of the application rate. This reduction given by selective application was realised by shutting off the nozzles in between the trees without jeopardising the deposition in the trees and the bio-efficiency of the treatment. Since the financial aspect is very important for every production, including the agricultural production, the achieved liquid savings of 10.38% should be considered for their financial profit.

The treatment price of €25 ha^{-1} (pesticide price not included) is based on the official pricelist of 'Cooperative Union of Serbia' which means that €2-3 ha^{-1} per treatment will be saved. If the average saving is estimated at €2.5 ha^{-1}, multiplied with the number of treatments, total savings in treatment costs will be around €30 ha^{-1}.

The price of pesticides used in this experiment was €60 per treatment or €720 for the entire season. The selective application provided savings of €6.2 ha^{-1} per treatment or €74.7 for the entire season. Therefore, a total of €104.7 was saved by the selective application in the older apple orchard.

Table 4 also shows how the selective application with LV provided the covering of an area that was 2,400 m^2 larger when compared to conventional application, whereby the MV covered 1.36 ha instead of 1.20 ha which was achieved by the conventional application.

The analysis of fuel consumption showed that 7.5% less fuel was used with selective application and LV compared to the conventional application which fuel consumption was 7.25 L ha^{-1} (Table 5). Selective application and MV reduced the fuel consumption by 10.2%. If the consumption was analyzed from the aspect of time unit, the savings would amount 16.6% for LV and 19.65% for MV (3.46 and 4.17 L h^{-1} respectively) with respect to the conventional application because 4.15 L h^{-1} and 5.19 L h^{-1} were used per working hour. Based on the price of diesel fuel it could be concluded that the reduced fuel consumption using the selective techniques led to savings of €0.6 ha^{-1} for LV, and €0.8 ha^{-1} for MV.

Considering the previously mentioned savings of €8.7 ha^{-1} achieved per one treatment by the selective application, as well as the fuel consumption saving, it can be concluded that MV and LV applications rates provide savings of €9.3 and €9.5 per treatment, respectively. The total benefit for all 12 treatments would range from €111 ha^{-1} to €114 ha^{-1}.

Since the installation cost of these sensors is minimum (€1,000), this type of investment will be cost-effective for the land area of 1-ha after 9 seasons. In Serbia, land areas ranging from 3 to 5 ha are typically covered with large number of orchards which are, in case of apple orchards, treated 15 or more times. With regard to the previously mentioned, it can be concluded that the selective application would bring profit after 2-3 seasons. Each following season would generate profit from both economical and ecological aspects. Ecological aspects should be particularly emphasized since the environmental protection cannot be valued financially.

In summary, comparative analysis of all spray applications showed that, in general, there was no significant effect of spray application rate on the spray results. Only for the tower sprayer (selective application technique) higher coverage was observed with higher application rate. With LV, there were no significant differences between the coverage with conventional and selective techniques. With MV, the tower sprayer had significantly higher coverage values in comparison to the conventional technique. By comparing the biological efficiency results of conventional AGP 440 and selective DDM 1000 air-assisted sprayer with vertical tower, it can be concluded that the vertical tower in combination with selective application tech-

Table 5. Fuel consumption with conventional and selective application per treatment

Application rate	Fuel consumption				Fuel cost			
	(L ha^{-1})		(L h^{-1})		(€ ha^{-1})		(€ h^{-1})	
	CA	SA	CA	SA	CA	SA	CA	SA
LV: 381 L ha^{-1}	7.25	6.70	4.15	3.46	8.04	7.43	4.60	3.84
MV: 759 L ha^{-1}	7.25	6.51	5.19	4.17	8.04	7.23	5.75	4.62

CA: conventional application. SA: selective application.

niques always gives better results, although they are not always statistically significant when compared to conventional technique. Except in one particular case (suppression of *V. inaequalis* on leaves in 2009), the use of lower application rate did not affect the bio-efficiency results when compared to the MV. The techno-economic analysis of the apple orchard treatments showed that, when compared to the conventional technique, the selective application technique provided savings of €9.3 ha^{-1} per treatment with LV and €9.5 ha^{-1} per treatment with MV. The total benefit of all 12 treatments ranged from €111 ha^{-1} to €114 ha^{-1}. Since the installation costs of these sensors are at least €1,000, this type of investment can be returned after nine seasons for a land area of 1-ha. Maintenance of these sensors is not expensive, but nine seasons payback is a long time. Apple orchards are mostly established on land areas from 3-ha to 5-ha and they are often treated 15 times or more. With regard to the previously mentioned the treatment of apple orchard with selective application will bring profit after 2-3 seasons. It is also very important to mention some other benefits provided by selective application, such as the fact that more hectares can be covered with one tank, different types of application rates are possible depending on the tree growth stage and size, the drift is decreased, and considerably reduced consumption of pesticides is possible.

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