DOI: 10.5937/ISAE25127T

ISAE 2025 - Book of Abstracts
The 7th International Symposium on Agricultural Engineering

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OPTIMIZING THE USE OF PESTICIDES IN PERMANENT PLANTATIONS – LowVolPest

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Abstract. The project proposal envisages a four-year study (2 years' apple orchard and 2 years' vineyard) to investigate the influence of technical and technological factors of pesticide application on the main characteristics of the study: Residues of active pesticide substances in the fruit, occurrence and spread of pests, fruit quality, and deposition and drift of the spray. The technical and technological factors of the application are the spraying rate, the spray concentration and the nozzle type with its sub-factors. The spraying rate is determined according to the TRV method (tree row volume) and a 50% reduction, while the concentration is determined according to the recommended (FIS registration) and its 20 and 40% reduction. According to the technological map for the protection of permanent plantations, two types of nozzles are used for spraying: Standard TR and Air-Injector ITR. The residues of the active substances are determined using the liquid chromatography with mass spectrometer (LC-MS/MS) method in an accredited laboratory, while the quality of the fruit and the occurrence and development of the pests are determined in the Faculty of agrobiotechnical sciences central laboratory. The deposit and spray drift are determined using the spectrophotometric method defined by the ISO 22866:2005 standard. The field trial should provide information on whether it is possible to reduce the application rate and concentration of sprays (low-volume pesticide management) and at the same time improve the quality of the fruit with the same or better

biological effect on the pests. In addition, the improved quality of spraying will reduce drift, which will have an impact on better pest control and the possibility of reducing the number of applications.

Key words: sprayer, pesticide, residues, nozzles, pests, spraying

1. Introduction

This manuscript is presenting a scientific project funded by the EU funds 581 – Recovery and Resilience Mechanism through the NextGenerationEU platform under the national NPOO program. Therefore, the text represents a four-year scientific project starting on 1 October 2025. It explains the reasons for applying for the mentioned project, the main research objectives, the research methodology and the expected research results with the application projection.

The intensity of agricultural production in modern farming systems has the task of achieving a high yield of a certain crop with corresponding quality. Intensity follows modern technological progress, and by utilizing all modern technologies, producers can indeed achieve high yields in all areas of agricultural production. When it comes to the quality of agricultural products, the paradigm becomes much more complicated. The quality of fruits can refer to several factors that we observe, namely: pomological, physiological, morphological, technological, organoleptic, phytosanitary, economic, etc. Of all the types of fruit quality listed, the market and farmers demand excellent results, especially in the economic characteristics, which refer to the classification of the fruit and the categorization in the extra class, which also achieves the highest price (Ministry of Agriculture, NN 114/2008). The first prerequisite for achieving such quality is a product without scab and spotty damage (damage caused by plant diseases), which can completely downgrade the fruit. In order to meet market demands and achieve the desired results, growers have started to apply technological protection maps that provide for even more than 25 pesticide applications during the growing season (this is especially true for apple orchards, which are one of the resources of the project proposal). The protection plan can be viewed at several commercial pages like at “Agroklub” and “Fitopromet”

Based on the above examples, we conclude that these production technologies, the fruits are loaded with residues of pesticide active substances that exceed the permitted MRLs (maximum residue levels) - non-compliance with phytosanitary quality (Elsavier, 2016, Ahmadi, et al., 2024). The MRLs (EU pesticide database) for the individual active substances are set and amended at EU level so that they can be applied by the individual member states. The results of the project proposal are commented on the basis of this database and the applicable Croatian regulations and laws. The described situation is a paradigm of current production technologies in permanent plantations, and the system of regulation and control of pesticide residues in the Republic of Croatia is not sufficiently coordinated (549 samples for the entire Republic of Croatia, Croatian Agency for Agriculture and Food), and very few samples are analyzed for residues of active substances without complete analytical reports being available, both from domestic production and from imports (Ministry of Agriculture, NN 79/2008).

In the Republic of Croatia, there is no comprehensive multidisciplinary scientific research on the above-mentioned topic, and with this project proposal, empirical results will be obtained by copying current technological maps of plant protection into an experimental design, and as one of the research results, residues of active substances in fruits will be determined. From all this it can be concluded that the topic described is current, poorly researched, poorly regulated and associated with very little scientific research from direct production.

2. Material and methods

The research and project proposal is designed as a four-year (2 years' apple + 2 years' vineyard) field trial with laboratory completion to obtain empirical results using already established and proven scientific methods. Several working hypotheses can be derived from the research objectives, the title and the expected results, several working hypotheses can be defined:

- The current technological map of permanent crop protection with the recommended concentrations and spraying rates controls the development and spread of pests well, but with active pesticide substance residues above the permitted MRL levels;
- Reducing the spraying rate and the recommended concentration of sprays will also control the pests satisfactorily during the growing season, with the obligation to improve the quality of spraying (different nozzle types and technical settings), but with active substance residues below the MRL levels;
- Fruit quality is better in treatments where lower amounts of pesticides are sprayed (either spraying rates or concentrations);
- The growing season plays an important role in the application of spray application;
- Technical factors in the application of sprays play an important role in the deposition and drift of sprays.

The above working hypotheses will be tested, as already mentioned, in the context of field research, and the experiments will be set up as a standard three-factor design. The first factor is of a technical-technological nature and relates to the *spraying rate (1)*. The application rate is a factor that is adjusted according to the needs of the plantation and its development phase (lower spraying rates are set at the beginning of vegetation) and higher application rates at the end of vegetation. The spraying rate (Tadić, V., 2013) depends primarily on the condition of the leaf area (LAI index) and the leaf density (LAD index). It is usually calculated using the TRV method (tree row volume), which must result in good deposition and surface coverage and minimal air and soil drift of the spray (UW Fruit Programme, Wisconsin Fruit). The most important technical factors that strongly influence the adjustment of the spraying rate are the ISO nozzle number, the operating speed, the operating pressure, the number of nozzles in operation and the row spacing of the plantation. The project plan is planned on two levels – two sub-factors in relation to this factor. The first sub-factor is the spraying norm adjusted according to the procedure described (LAI and LAD) and the second sub-factor is the spraying norm reduced by 50%.

The second factor of the study is the *concentration of the spray (2)*, i.e. the concentration of the active substance of the pesticide in the water (Milton D., Taylor, 2020). This technological factor of the field trial was planned in three levels (three sub-factors), namely: recommended (100%) concentration in relation to the registration of the active substance (FIS system) on the type of plantation in the study (2.1.); 80% concentration in relation to the recommended concentration (2.2.) and 60% concentration (2.3.).

The third factor in the study is the *type of nozzle (3)*. This technical factor (Tadić, V. et al., 2014) was planned in two levels (two sub-factors), namely: standard nozzle TR 80 (3.1.) and air injector nozzle ITR 80 (3.2.). The color of the nozzles, i.e. the ISO number, is adjusted according to the first factor of the trial – the spraying norm, and the nozzle type is the third factor of the study. If the nozzle has the same ISO number but a different type, this primarily relates to the spectrum of droplets produced by the nozzle (Tadić, V. et al., 2024). The TR nozzle produces a smaller droplet spectrum with potentially greater coverage of the treated surface (better biological effect of the active substance) and greater air drift (Figure 1a). The ITR nozzle (Figure 1b) produces droplets with a larger diameter (SVP – mean volume diameter 20-30 larger), which cover the treated surface less well but are less susceptible to drift. Table 1 shows schematic example of conducting research.

Figure 1a TR nozzle

Figure 1b ITR nozzle

Table 1 Research plan

	Apple orchard (2 y.)			Vineyard (2 y.)		
Spraying norm (1) (N_r – l ha^{-1})	TRV (1.1.)	50% TRV (1.2.)		TRV (1.1.)	50% TRV (1.2.)	
Concertation (2) (c - %)	100% (2.1.)	80% (2.2.)	60% (2.3.)	100% (2.1.)	80% (2.2.)	60% (2.3.)
Nozzle type (3) (n)	TR (3.1.)	ITR (3.2.)		TR (3.1.)	ITR (3.2.)	

*vegetation year (4)

The main characteristics of the research, i.e. the measurable parameters that are monitored in the field and later processed in the laboratory, are:

- Residues of active substances in fruits used in the technological map of plantation protection and in the experimental design (all active substances are determined by laboratory analysis);
- Occurrence and development of pests during the growing season and on the fruit (infection indices);
- Fruit characteristics (morphological, pomological, physiological, economic, etc.);
- Deposit of sprays in the plantations;
- Spray application according to ISO 22866:2005.

Pesticide residues (1) as one of the characteristics of the research are determined in the fruits according to the research plan in accredited laboratories that easily determine the residues with their equipment and techniques. Laboratories that determine pesticide residues must have certificates in accordance with HRN EN ISO/IEC 17025:2017 (ISO/IEC 17025:2017; EN ISO/IEC 17025:2017). Using the methods mentioned, these laboratories also find minimal residues of active substances in fruit using two techniques LC-MS/MS and GC-MS/MS and provide data in mg kg-1 of the analyzed fruit with a comparison of the currently valid residues in the EU and the Republic of Croatia (EU pesticide database). The aforementioned standards use the technique of liquid chromatography (Cindrić, M., et al., 2009) with a mass spectrometer (LC-MS/MS) and gas chromatography (GC-MS/MS). These methods can be used to measure over 400 active substances in minimal concentrations.

Another feature of the study is the *occurrence and progression of pests during the growing season (2)* on fruits and leaves (infection indices). During the growing season, samples are taken from the plantations (fruits and leaves) according to the research treatments and the infection indices are analysed, commented and conclusions are drawn about the impact of each research treatment on the biology of the pests. The disease evaluation indices for apple and grapevine are used for a standardized evaluation of infection intensity under research and field conditions. For the evaluation of diseases such as apple scab *(Venturia inaequalis)*, a scale from 0 to 5 is often used according to EPPO standards, where 0 indicates the absence of symptoms and 5 means very pronounced symptoms with more than 75 % of the leaf area affected. For grapevines, a scale of 0-9 is used for powdery mildew *(Erysiphe necator)* and downy mildew *(Plasmopara viticola)* – according to the OIV (*Organisation Internationale de la Vigne et du Vin* - https://www.oiv.int/node), which rates the intensity of symptoms on leaves and grapes in detail. These scales are particularly useful in trials comparing different spraying strategies, such as differences in frequency, type of fungicide or application of biological preparations. Based on the results of the evaluation, it is possible to quantitatively assess the effectiveness of individual treatments, optimise plant protection and reduce the unnecessary use of plant protection products.

The third research property will be the *quality of the fruit (3)* from the permanent plantations in the research (two years of apples and two years of grapes). The assumptions contained in the working hypotheses and objectives of the research are that the economic/commercial characteristics depend largely on the individual research treatments

(here damage to the fruit is meant - scab/spot/rot). The observation of the morphological characteristics of the fruit (size, shape, colour, hardness, calyx, etc.) will probably not differ greatly between treatments, while the pomological and physiological characteristics will vary greatly depending on the research treatments (Skendrović Babojelić, et al., 2014). As part of the pomological (morphometric) measurements of the apples, it is planned to carry out analyses that include the following: Yield, yield per tree, number of fruits, fruit weight, fruit height and width index, hardness, iodine-starch index and fruit colour according to the CIE LAB system. Analyses of the internal quality of the fruit are also planned: dry matter and acidity as well as spectrophotometric measurement of the vitamin C content, anthocyanins, total phenols and antioxidant activity. In the second part of the research to evaluate grape quality, the project proposal envisages carrying out the following analyses: Yield per vine, average grape mass per vine, sugar content, total acidity, anthocyanin and polyphenol content, antioxidant value, relative density of the must, pH value.

The fourth research property according to the project proposal is *the spray deposit (4)* in the plantation. The spray deposit (Petrović, D. et al., 2019; Petrović, D. et al., 2019) is a technical property of the application and represents a precisely defined concentration of the spray that is applied to a specific part of the canopy. The more evenly the deposition is distributed in the canopy, the better the biological effect of the pesticides and vice versa. The aim is to adjust the technical factors of application in the research plantations in such a way that the highest possible application rate is achieved. However, it can also vary greatly depending on a number of technical factors that are also taken into account in this project proposal (nozzle type, spray concentration and spray volume). The deposition is determined using the spectrophotometry method, whereby samples of different concentrations are collected on filter paper within the plantation. The dye tartrazine (which serves as a tracer, a dye with a precisely determined concentration) produces a spectrophotometric curve at 425 nm. The sampled filter papers were washed with 0.1 l of deionized water. After washing, the solution was pipetted into a quartz cuvette and the wavelength was read in a spectrophotometer. The values obtained were used to calculate the spray deposit (µg cm^{-2}).

Figure 2 Drift and deposit measurement in orchard

The fifth property of the research contained in the project proposal is drift (5). The term drift (Petrović, D., 2018) includes three phenomena: the evaporation of the spray due to high temperature and low humidity and the entrainment of the spray outside the plantation due to the high speed of movement or the high speed of the surrounding wind. We can conclude that drift is the opposite of deposition, i.e. if the spray deposition is weak or very small, then the occurrence of drift is increased. Various scientific sources emphasize and prove that this phenomenon is unavoidable; that in average applications it accounts for 30-40% of the spray volume (Petrović, D., 2018) and that it is the task of adjusting the technical factors of the application to minimize drift as much as possible. The methodology for determining drift is determined by the international standard ISO 22866:2005 (Figure 2) and the filter papers are processed using the same method as for deposition.

As a research feature, this group also includes the *vegetation year (6)*, which is an indicator of the weather conditions that influence the growth, development and spread of pests in the plantation.

3. Expected results

The main objectives of the project proposal include research into the effects of agricultural techniques (different types of nozzles) and crop protection technology (different concentrations and spray volumes) on the main characteristics of the study: residues of active substances in the fruit, protective effect on the occurrence and progression of pests, fruit characteristics and on the deposition and drift of pesticides. By varying the above factors in the field study, it will be possible to find out which treatment has the best effect on pests with residues below the authorized levels while ensuring satisfactory fruit quality, i.e. the possibility of reducing the standard and dosage of pesticides (low pesticide management) with the same or better biological effect on pests and a reduction in pesticide residues in the fruit over two years in two permanent plantations. For each plantation, pesticide deposition and drift will be analyzed in relation to the technical factors of the project proposal and, as the vegetation progresses in the second year, conclusions will be drawn about the influence of the growing season on the above-mentioned characteristics. According to the stated research objectives of the project proposal and the working hypotheses, it is realistic to expect some measurable indicators that will fulfill/disprove the working hypotheses. The project proposal contains several measurable research indicators that are expected to more or less confirm the working hypotheses, as follows:

(1) The current technological map for the protection of permanent crops with the recommended concentrations and spray rates controls the development and spread of pests well, but with active pesticides residues above the permitted MRL levels. Pest control with a 20% reduction in concentration and the same or lower spray rates will achieve the same biological effect as the recommended treatments with an efficiency of 70-80% - verified by fruit quality, residues of active substances and pest control indices;

(2) A reduction in spray volume will also result in satisfactory pest control during the

growing season, with a commitment to improve the quality of spray application (different nozzle types and technical settings), with active ingredient residues below MRLs. Pesticide residues in the fruit of permanent crops are expected to be reduced by 40-60% due to the use of technology with a 50% reduction in spray volume - which will be verified by fruit quality, residues of active substances and pest control indices;

(3) Better fruit quality is expected for treatments where lower pesticide application rates or concentrations are used. The physiological characteristics of the fruit are expected to be 10-20% better in treatments with reduced spray concentrations and spray volumes.

(4) Technical factors of spray application play an important role in the deposition and drift of sprays. Nozzles that produce a smaller droplet spectrum achieve greater coverage of the treated area and better control of pests (30-40%). In addition, the use of ITR nozzles with air injection is expected to reduce drift by 20-40 % with the same deposition compared to a standard ITR nozzle;

(5) The influence of the growing season on the results of the main research properties is expected (15-25%).

4. Conclusion

The aim of the research is to obtain empirical results in field research on the effectiveness of various factors influencing the complex process of plant protection. This topic has never been studied in the Republic of Croatia in a multidisciplinary agronomic approach, in which various knowledge from the fields of agricultural engineering (mechanization), production technology and plant protection in the narrower sense should be complemented and combined. It has already been established that the plant protection process is extremely complex, whereby only one of the application factors can have a positive or negative effect on the effectiveness of the spraying and the residues of the pesticide active substance. However, some of the most important factors that have a greater influence on the effectiveness of plant protection should be listed: the type of machine (sprayer) at application; the type of nozzles at application; the concentration of the spray; the spraying rate; pesticide grace period; the number of applications during the growing season; the physical and chemical properties of the spray; the agricultural crop in the study; the weather conditions at direct application; the weather conditions during the growing season between years; the pest biology; the deposition of the spray; the drift of the spray.

The complexity of factors in the plant protection process is evident from the above list and this project proposal and field research will cover most of these factors. The aim of the project proposal is therefore to investigate the interdependence of the main characteristics of crop protection on spray efficacy, pesticides residues in fruit, fruit quality, pest control and pest incidence, and spray deposition and drift, i.e. to apply the principles of using the technology of reduced dosage and concentration of pesticide active ingredients (low volume pesticide management) – FAO 2022.

The main objectives of this project proposal relate to the proposed field research under real time conditions (Real Time Research):

- Determination of the influence of technology (agricultural machinery with different types of nozzles) on: Pesticide residues in the fruits of permanent crops; occurrence and development of pests during the growing season, fruit characteristics (morphological, pomological, physiological and economic) and spray deposition and drift;
- Determination of the influence of the protection technology in permanent crops (reduced spraying volumes and reduced spray concentrations) on: Pesticide residues in fruits of permanent crops; occurrence and development of pests during the growing season, fruit characteristics (morphological, pomological, physiological and economic) and spray deposition and drift;
- Determination of the influence of the vegetation period on the above-mentioned characteristics;
- To gain insights into the possibility of reducing the standard and dosage of sprays (low pesticide management) with the same or better biological effect on pests and lower pesticide residues in fruit over two years in two permanent plantations.

Acknowledgment

Research is funded by the *EU funds* 581-UNIOS-17– *Recovery and Resilience Mechanism through the NextGenerationEU* platform under the national *NPOO program* with *University of Josip Juraj Strossmayer in Osijek*, Croatia by name: *Optimizing the use of pesticides in permanent plantations – LowVolPest.*

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