Environmentally Optimised Sprayer – EOS – a software application for comprehensive assessment of environmental safety features of sprayers

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Abstract

Despite technological progress in pesticide application equipment, chemical crop protection continues to contribute to environmental pollution. Water is at risk of contamination with pesticides from point and diffuse sources and could be reduced to a great extent with a better sprayer design. The sprayer manufacturers and pesticide applicators need to take more responsibility for the prevention of water pollution and therefore they have to make environmentally responsible decisions at different stages, from designing to servicing sprayers. The objective of the presented work was to develop an interactive application that would support decisions made by sprayer manufacturers during the production process, and by pesticide applicators when selecting and operating the sprayers. The EOS (Environmentally Optimised Sprayer) is an application evaluating the risk mitigation potential of sprayers based on their technological features, within five risk areas, representing sources of pollution: (i) Inside Contamination; (ii) Outside Contamination; (iii) Filling; (iv) Spray Loss & Drift; (v) Remnants. The evaluator completes the EOS questionnaire by checking for the technical solutions identified in the evaluated sprayer and the result reflects the sprayer quality in terms of potential environmental risk mitigation. The EOS tool also proved its awareness raising facility and educative value when used during training activities and university courses.

Key words: environmental risk, risk mitigation, water protection, E-learning, training

Highlights:

- Decision support tool to evaluate environmental risk mitigation potential of sprayers
- E-learning interactive application with user-friendly software
- Extended help service based on library of explanations, illustrations and references
- Educative and awareness raising function of sprayer evaluation process
- Sprayer evaluation software as a training tool improving knowledge on spray technology

1. Introduction

Agriculture is considered to be a considerable contributor to water pollution caused by entries of nitrates, phosphates and pesticides. Due to improper practices and poor quality of application equipment, pesticides may contaminate water by two main entry routes: (i) point sources - mainly related to the handling of PPP on farmyards, e.g. filling and cleaning of sprayers, and remnant management; (ii) diffuse sources - mainly related to off target deposition of spray due to spray drift and run-off from fields after application. Research results show that point source contributes to more than 50% of total water contamination by pesticides (Müller et al., 2002; Bach et al., 2005). The environmental risk arising from this contamination can be greatly mitigated by upgrading the spray application equipment. The diffuse source contamination of water occurs mainly during spray application and off-target deposition due to adverse weather conditions. Spray drift is one of those threats that can be controlled by spray technology and the operator. Considerable drift reductions are achieved by using low drift nozzles as well as sprayer design and accessories allowing for precision spray application and easy, effective and precise adjustment of application parameters (Nuyttens et al., 2006; Arvidsson et al., 2011). Apart from technical aspects, equally important is high awareness, training and proper behaviour of sprayer operators and careful organization of work along the whole chain of PPP handling. From the above it seems obvious that environmentally friendly sprayers are a key measure to mitigate risk of pesticide contamination and good knowledge of the operator about the application technology and its proper use makes this measure even more effective.

The requirements related to environmental aspects of plant protection equipment and its accessories are defined by European and international standards (EN, ISO). These standards play the rule of guidelines and reflect minimum requirements which should be met (Herbst & Ganzelmeier, 2002) unless they have a status of European harmonised standards, such as: EN-

ISO 4254-1 (EN-ISO, 2013a), EN-ISO 4254-6 (EN-ISO, 2009), or EN-ISO 16119-1-2-3 (EN-ISO, 2013b; EN-ISO, 2013c; EN-ISO, 2013d) in which case it is necessary to follow their requirements in order to comply with the prescriptions of the European Directives (EC/60, 2000; EC/127, 2009; EC/128, 2009). The manufacturers of sprayers should self-certify their products following the harmonized standards. However, most of the standards setting the requirements on spray equipment are not harmonised and considered voluntary. Therefore there is still a big variation in design and level of technological advancement of spray equipment available on the market. These features influence potential environmental risks posed by different sprayers at all stages of sprayer use, from the filling process before application to cleaning operation after the application, to mention only the two most risky stages. The user or the purchaser of a sprayer finds it difficult to tell the difference between sprayers in terms of their risk mitigation potential. In order to help them to make better decisions the environmental linked parameters and mitigation characteristics including options of the considered sprayers needs to be determined .

Decision making in plant protection is supported by applications based on the objective criteria and recognised reference. The range of prognosis models, setting down terms of chemical treatments to control pests and diseases, has been recently complemented by Drift Evaluation Tool (Doruchowski et al, 2013) which assists the applicator to make better decisions about pesticide use from an environmental point of view. This interactive application is a good example of a decision support tool being very useful at tactical level of pesticide use. However, prior to the tactical decisions the strategic ones need to be taken as regards long term planning, including design and selection of sprayers to apply pesticides with the lowest possible potential environmental impact.

The objective of work described in this paper was to develop a decision supporting tool in the form of a web-based application determining the capability of sprayers to minimise risk of pesticide pollution of water. As a consequence, the tool is intended to stimulate research and development of new technology enhancing environmental friendliness of sprayers. The application is to help sprayer manufacturers, advisers and farmers to make better decisions at strategic levels of chemical crop protection. It may also be used as a training and awareness raising tool.

2. Materials and methods

The EOS application was developed within the TOPPS-EOS project (*www.topps-life.org*)and is based on discussion and consultation with a European working group of experts representing research, advisory services as well as the chemical and the machinery industries. The EOS development was a three stage process: (1) identification of potential areas of environmental risk attributed to sprayer design and operation; (2) configuration of EOS content and structure; (3) elaboration of EOS algorithm and software.

2.1. Identification of potential areas of environmental risk

In order to quantify the environmental risk mitigation capability of different sprayer features it was necessary to categorise the features and associate them with certain potential areas of environmental risk, being sources of uncontrolled pesticide loss to the environment. Based on the results of TOPPS project the main risk areas attributed to the sprayer design are pre- and post-treatment operations, such as: filling of sprayer, internal and external cleaning of sprayer and management of remnant spray liquid. According to Roettele et al. (2010) they pose significant potential risk of point source pollution. Among diffuse sources spray drift is another manageable risk area where spraying technology has great risk mitigation potential. The identified risk areas were weighted with a (%) assigned to each of them, which reflected differences between risk areas in terms of their significance. The risk areas and their significance (weights) for field crop sprayers and orchard/vineyard sprayers are shown in Figures 1 and 2 respectively. The rating of risk areas for those two groups of sprayers is different, confirming that field crop sprayers pose higher potential environmental risk due to internal cleaning and remnant management while the potential risks from orchard/vineyard sprayers relate to external cleaning and spray applications generating drift.

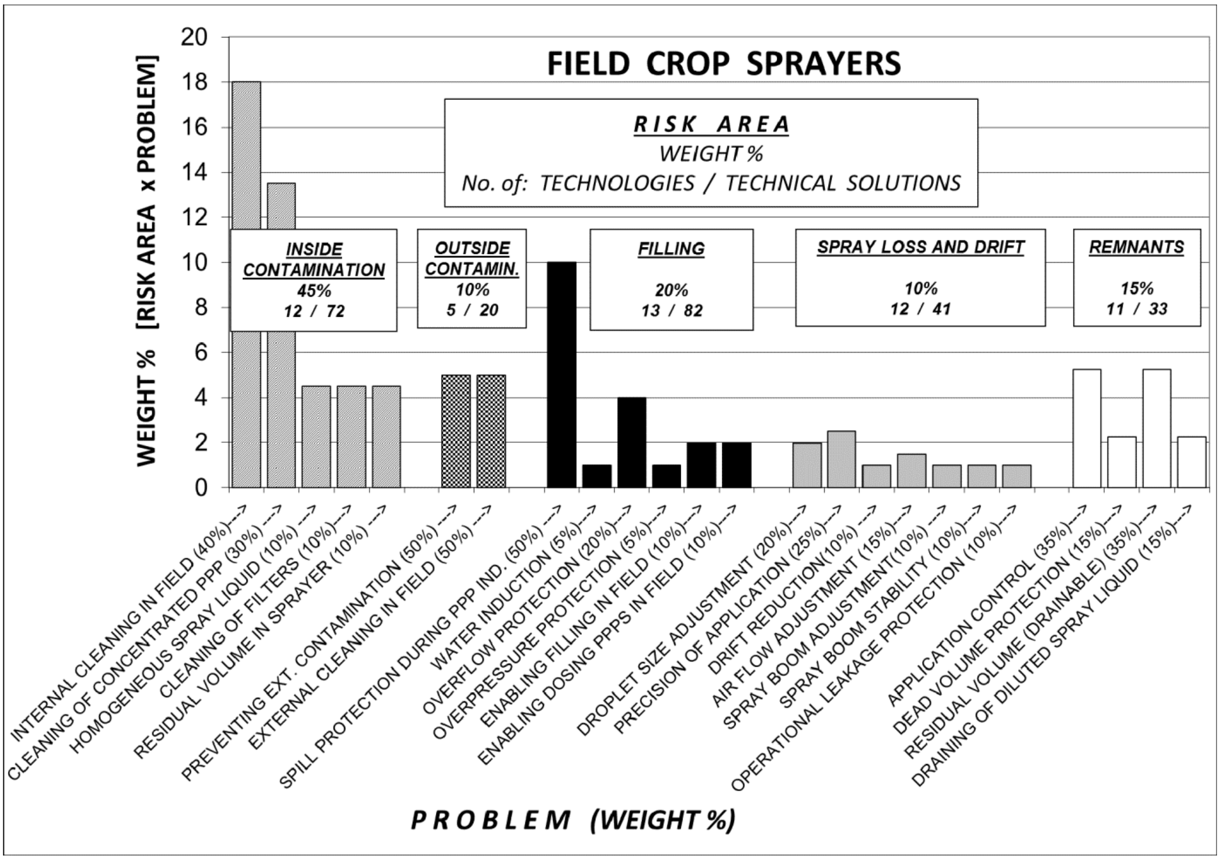

Figure 1. Values of weights [risk area × problem], and number of technologies and technical solutions within risk areas as used by evaluating tool *Environmentally Optimised Sprayer (EOS)* to determine the risk mitigation potential of field crop sprayers

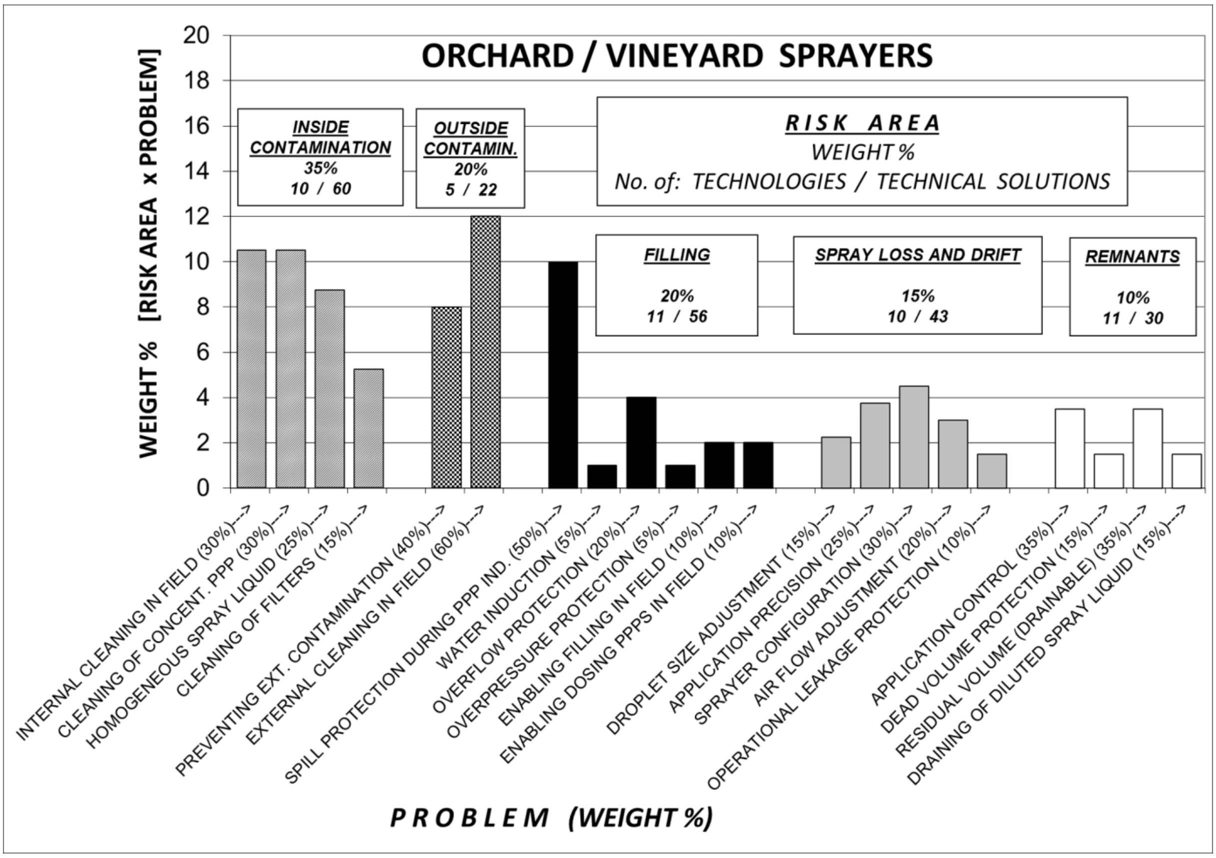

Figure 2. Values of weights [risk area × problem], and number of technologies and technical solutions within risk areas as used by evaluating tool *Environmentally Optimised Sprayer (EOS)* to determine the risk mitigation potential of orchard/vineyard sprayers

2.2. EOS content and structure

The general assumption underlying the structure of EOS is that the risk mitigation potential of the evaluated sprayer is a sum of mitigation potential of technical solutions on the sprayer. The state-of-the-art commercially available solutions used in spray application technology, together with the standard and the basic ones were listed and categorised according to their function. This list of technical solutions constitutes the EOS interface, being subject to a questionnaire used by the user to select the solutions identified on the sprayer under evaluation. Obviously the significance of different technical solutions varies and depends on the significance of functions they carry out and risk areas they belong to, as well as their actual impact on potential risk mitigation. Therefore EOS has been designed as a stepwise structured questionnaire, divided in sections representing different risk areas (step 1): Inside Contamination; Outside Contamination; Filling; Spray Loss & Drift; Remnants. Within each risk area there were identified problems (step 2) to be solved by different technologies (step 3), in some cases evaluated in different aspects (step 4) when the user selects technical solution (step 5) identified on the sprayer. The criteria of steps 1 to 4 were assigned weights (%) reflecting their significance of risk mitigation potential. The technical solutions were rated by scores from 0 to 10 (10 = the best available in class). En example of this stepwise approach to evaluate the actual value of a selected technical solution is shown on Figure 3.

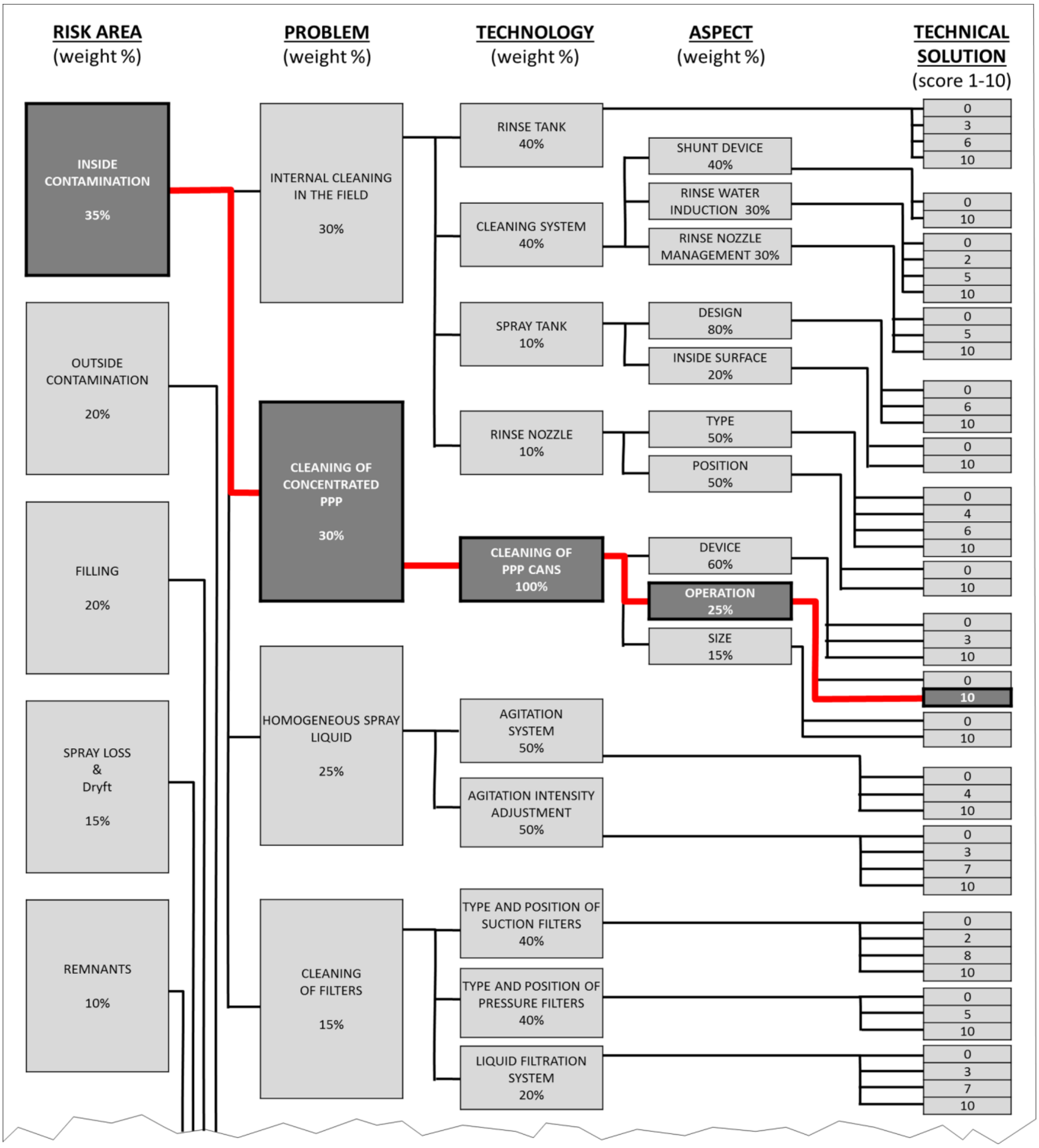

Figure 3. A part of the EOS application structure (orchard/vineyard version) showing the stepwise approach of the tool to determine the actual value (effective score E_T) of a selected technical solution (absolute score = 10), evaluated in aspect: *Operation* (25%), within technology: *Cleaning of PPP Cans* (weight 100%), solving the problem: *Cleaning of Concentrated PPP* (30%), within the risk area: *Inside Contamination* (35%). According to eq. [1]: $E_T = 10 \times 0.25 \times 1.00 \times 0.30 \times 0.35 = 0.2625$.

2.3. Meaning of risk areas, problems and technologies

Figures1and 2 show the values of combined weights [risk area × problem] as used by the EOS application to determine the risk mitigation potential of field crop sprayers and orchard/vineyard sprayers respectively. These weights reflect the significance of problems in context of relevant risk areas, and in fact they represent potential value of certain technologies capable to solve these problems.

The most significant risk area includes cleaning of sprayers (Inside Contamination + Outside Contamination), which was assessed to account for 55% of the risk mitigation potential of sprayers. The weight values for field crop and orchard/vineyard sprayers are slightly different (Figure 1 vs. Figure 2). Internal cleaning is more important for field crop sprayers because of larger residual volumes of spray solution in the boom and pipes. The results of tests indicate that not only the boom length but also the design and dimensioning of the liquid circuit affect the residual volume. The standard EN 12761 (EN, 2002) accepts a technical residual volume determined by 0.5% tank volume plus 2.0 litre per each meter of spray boom width. The results of the ENTAM test have shown that well designed sprayers achieve 50% lower technical residual volumes (Debear et al., 2008). The technologies minimizing the technical residual volumes have a significant potential to reduce the potential risks of point source pollution.

For orchard sprayers the aspect of outside contamination is more important due to higher deposition of plant protection products (PPP) on the sprayer resulting from spray application with air assisted sprayers or mist blowers. Outside deposits on orchard/vineyard sprayers can reach 0.33to 0.83% of the applied dose (Balsari et al., 2006). It was shown that PPP deposits on the sprayer could be best washed off when the deposits were still wet (Debear et al., 2008). It is therefore recommended to carry out the external cleaning of sprayer in the field. If not fitted, this requires an external cleaning kit attached to the sprayer. Thus, type of accessory as well as solutions preventing external contamination considerably increases the risk mitigation potential of orchard/vineyard sprayers.

Another significant risk area is the Filling of the sprayer. Many field crop sprayers are equipped with induction hoppers. They are efficient mitigation technologies to reduce the potential risk of spillage of concentrated pesticides during the operation of mixing with water and induction to the main tank (10% of risk mitigation potential – weight values on Figures 1 and 2). The TOPPS surveys showed that farmers mainly use level indicators on the spray tanks to control the process of filling the sprayer with water. Such indicators are often not easy to read and research has shown that their precision is not always adequate (Balsari et al., 2006). Technology is available to measure precisely the water volume needed in the tank. The minimizing of residual volumes in the tank post application starts with the correct amount of water being filled to start with.

The Remnants include the volume of spray liquid coming back with the sprayer to the farmyard (residual volumes), as well as diluted PPP released as spills and overflows, or losses during the use or servicing of the sprayer (e.g. change of nozzles, cleaning filters). The better the internal cleaning system and the less residual volume remaining in a sprayer the lower the volume of remnants returning back to the farmyard. The sprayer technology could support minimising the problem of remnants by designing the liquid system components (e.g. filters, operating units, nozzle holders) in a way that no spills occur during servicing, by enabling the complete emptying of sprayer and the collection of remnants and by application control systems ensuring precise use of spray liquid.

Spray Loss & Drift is an area offering big potential for technical improvements, especially in orchard and vine applications. Drift reduction technologies both for field crop and orchard/vineyard sprayers are available and strongly recommended. They include mainly coarse spray nozzles, precise target oriented application and supporting airflow adjustment.

Research conducted with target identification systems and variable rate application is promising and may offer further technological breakthrough. This risk area is more important for orchard/vineyard sprayers due to the way the spray is discharged from the sprayer.

2.4. Algorithm of EOS

The stepwise structure and weighting of EOS categories allowed for calculating the Effective Score of each selected technical solution (E_T) in terms of its risk mitigation potential:

$$E_T = S \times a \times t \times p \times r \qquad [1]$$

where:

S - absolute score of technical solution [0 to 10]

a - weight of aspect [%]

t - weight of technology [%]

p - weight of problem [%]

r - weight of risk area [%]

Thus, the E_T is a product of absolute score of technical solution and the weights of all the categories (criteria) of evaluation process. The Effective Score of Sprayer (E_S) is a sum of Effective Scores of the selected technical solutions:

$$E_S = \sum E_T \qquad [2]$$

The final result of sprayer evaluation is expressed by relative value of EOS index (*EOS*) which is calculated as a ratio of the Effective Score of the Sprayer (E_S) and Effective Score of the environmentally optimised sprayer (E_{EOS}), i.e. score calculated based on maximum rating values of all technologies>>aspects of EOS application. Thus, E_{EOS} is the effective score of a theoretically perfect sprayer from a potential environmental risk mitigation point of view.

[3]

$$EOS = \frac{E_S}{E_{EOS}}\ 100\%$$

Substitution and simplification of the equations [1] to [3] yielded final general formulas being used in the EOS algorithm to calculate EOS Indices of risk areas (EOS_{RA}) [4], and the Total EOS Index of the evaluated sprayer (EOS_{Tot}) [5]:

[4]

$$EOS_{RA} = \left[\frac{1}{n\ S_{max}} \sum_{i=1}^{n} S_i\ a_i\ t_i\ p_i\ r_i\right] 100\%$$

[5]

$$EOS_{Tot} = \left[\frac{1}{N\ S_{max}} \sum_{i=1}^{N} S_i\ a_i\ t_i\ p_i\ r_i\right] 100\%$$

where:

n - number of technologies>>aspects in EOS questionnaire of the respective risk area

N - the total number of technologies>>aspects in EOS questionairre

S_{max} - maximum score of technical solution in EOS questionairre (S_{max}=10)

3. Results and Discussion

3.1. Sprayer evaluation process

Having started the EOS application the user selects one of the nine languages of the textual user interface (DA, DE, EN, ES, FR, IT, NL, PL, SV), and the type of sprayer to evaluate: field crop sprayer or orchard/vineyard sprayer. Then one of the five risk areas must be selected, which results in opening the list of potential problems within the selected risk area. By selecting a problem the list of technologies >> aspects and technical solutions drops down in form of an interactive questionnaire. Among the items in this questionnaire the user selects the technical solutions identified on the sprayer under evaluation by clicking on the relevant check-boxes. Figures 1 and 2 show the number of technologies and proposed technical solutions as options within the risk areas in the questionnaires for field crop and orchard/vineyard sprayers respectively.

As the user progresses by checking for the identified technical solutions within the consecutive technologies, problems and risk areas the EOS Indices of risk areas (EOS_{RA}), calculated according to formula [4], and the Total EOS Index of the evaluated sprayer (EOS_{Tot}), calculated according to formula [5], are displayed on the risk area menu bar (Figure 4) to communicate the current results of the on-going evaluation process. For a user being familiar with spray application technology and using the EOS tool for the first time, it takes around 30 minutes to complete the evaluation of field crop sprayer or orchard/vineyard sprayer respectively. Having completed the evaluation of the sprayer the user clicks on the button "Evaluation Results" to obtain a summary of the evaluation process, showing the final values of EOS_{RA} and EOS_{Tot} (Figure 4).

The EOS application has a help service linked to the library of illustrations, textual information or references (e.g. relevant standards). Most of the items in the interactive questionnaire are followed by the question mark icon. Clicking on the icon activates the help service which opens a window with relevant information. This information is meant for the user to help him understand and properly interpret the technologies, aspects and technical solutions standing behind these phrases of the questionnaire. This, in turn, assists the user to make an appropriate selection of technical solution during the evaluation of sprayers. The EOS help service also has an educative and awareness rising function which should be extensively exploited when the application is used by students and advisors as a training tool, as described in section 3.3.

The user of EOS tool may also download the EOS Quick Guide (6-page basic instruction) and the EOS Handbook (102-page Manual) containing a background and full documentation of EOS application with detailed information on functions and meaning of different sprayer components and accessories, as well as quotes of the relevant standards.

Figure 4. Results of evaluation of risk mitigation potential of a field crop sprayer: EOS Indices for risk areas (EOS_{RA}) calculated according to formula [4], and the Total EOS Index (EOS_{Tot}) calculated according to formula [5].

3.2. Examples of specific sprayer evaluation results

As an example two field crop sprayers with different range of components and accessories were evaluated with EOS application and the results of evaluation were compared (Tab. 1). The Total EOS Index of Sprayer A was 24.3 %, while that of Sprayer B amounted 68.3%. This almost triple difference was due to very low EOS Indices of Inside Contamination and Filling obtained for Sprayer A. These risk areas are very critical and in combination with the critical problems (Internal Cleaning in Field; Cleaning of Concentrated PPP; Spill Protection during PPP Induction) (Figure 1) they account for 10-18% of risk mitigation potential (weight value used in EOS Index calculation). Therefore the Sprayer A with no components solving these problems (induction hopper, rinsing tank, and tank flushing nozzle) was poorly rated in terms of environmental risk mitigation potential. The double difference in EOS Index of remnants was mainly due to lack of boom flushing valve on Sprayer A which solves the problem of Residual Volume (5.5% weight value of combination [risk area × problem] – Figure 1). The difference between the sprayers in EOS Index of Spray Loss & Drift was not so striking even though Sprayer B was superior to Sprayer A by featuring air assistance and low drift nozzles because the risk mitigation potential of this risk area in combination with problem: Drift Reduction is only 1% (Figure 1).

More extensive observations on practical use of EOS tool by farm managers were carried out in 2011, in 20 vineyards of Northern and Central Italy. The managers were supported by the personnel of the University of Torino when evaluating the sprayers used on their farms. On average, for the 20 sprayers, the EOS Indices for five risk areas were all below 50%, regarded to be a threshold of environmental friendliness of crop protection equipment. This threshold in the risk area: Outside Contamination was met by 13% of the examined sprayers, in the risk area: Remnants also by 13% of the sprayers, and in the risk area: Spray Loss & Drift by 33% of the sprayers. The lowest EOS Indices were obtained for two risk areas: Outside Contamination and Filling. The first was due to lack of external cleaning kits, such as clean water source, hoses with brushes, lances or other accessories that allow removal of the chemical deposit from the external surface of the sprayers in the field. The technologies responsible for filling of sprayers were poorly scored mainly due to lack of appropriate liquid level indicators and flow-meters to measure the exact amount of water entered into the main tank. The highest Total EOS Index among all 20 sprayers amounted 68% which is considered to be a “sufficient” level. According to the feedback from the users of the EOS application it was found to be a useful tool providing valuable information, however, somehow difficult to manage by farmers alone due to a high level of specificity of technical solutions to be selected during the evaluation process.

Table 1. Components and accessories of two field crop sprayers, and the results of evaluation performed by EOS tool

Components and accessories	
SPRAYER A	***SPRAYER B***
Polyethylene tank 1000 l Diaphragm pump Filters: suction + pressure Operating unit: manual Spray boom 12 m : fixed Nozzles: standard	Polyethylene tank 1000 l + 10% over-volume Diaphragm pump + Return valve Filters: suction + self-cleaning Operating unit: electric control Spray boom 12 m: trapeze suspension Nozzles: standard + low-drift + venturi + Spray computer + Induction hopper + Filling device + Rinsing tank + Tank flushing nozzle + Air-assistance + Boom flush valves

Results of evaluation			
SPRAYER A		***SPRAYER B***	
Risk Area	*EOS Index*	*Risk Area*	*EOS Index*
Inside Contamination	17.4%	Inside Contamination	75.3%
Outside Contamination	30.0%	Outside Contamination	51.0%
Filling	14.7%	Filling	54.4%
Spray Loss & Drift	53.2%	Spray Loss & Drift	87.0%
Remnants	34.7%	Remnants	65.0%
TOTAL	**24.3%**	**TOTAL**	**68.3%**

3.3. Proposed use of EOS

The use of EOS software is open. It is available on: *http://www.topps-eos.org/.* The EOS application is an information and training tool not only for spray application experts but also for agricultural engineering students. It provides a reference for the evaluation of the environmental friendliness of sprayers, and delivers facts and arguments that may be very useful during the trainings activities for advisors, farmers and stakeholders. The possible stakeholders are authorities or water companies when deciding on programs of pesticide use training and water protection and could result by incentivising environmentally optimised sprayers.

A good example of use of the EOS application as a training tool was the training campaign aiming at implementation of rules of sustainable use of pesticides (objectives of Directive 2009/128/EC) which were carried out in Spain, by Polytechnic University of Catalonia (UPC) in cooperation with Syngenta Iberia. During more than 25 training courses delivered in the years 2010-2013 over 1200 advisors and sprayer operators were trained using the EOS application to learn about better spray application technology. When using the EOS tool alongside sprayers the trainees were able to go into depth on sprayer details, and by that they improved their knowledge on technologies used in crop protection equipment and different alternative technical solutions to minimize potential environmental pollution during all the operations of the sprayer. At the same time they improved their awareness on the potential environmental risk posed by pesticide application, as well as pre- and post-application operations, and the influence of available technology on potential risk mitigation.

The EOS application was also used for high education purposes at Spanish universities. During the practical sessions of courses conducted at the agricultural engineering faculties more than 100 students used EOS software to achieve an understanding and improve comprehension of technological aspects of pesticide application in the environmental risk context. In most cases this interactive education tool increased the interest of students, stimulated vibrant discussions and provoked interesting feed-back.

The EOS can also be used by the sprayer purchasers to help them ask the right questions before they make a final decision based on the potential environmental risk mitigation and cost benefit.

The spray manufacturers can use the EOS application as a solid basis for information focusing on environmental aspects when designing new sprayers. Starting with the right development focus is likely to result in more environmentally friendly equipment, and not necessarily at higher cost.

In the years to come the EOS tool may also be used to provide manufacturers, who have their sprayers tested according to the common methodology of the ENTAM network (European Network for Testing of Agricultural Machines - *www.entam.net*), with useful information about the environmental friendliness of their products. The findings of EOS evaluation conducted by the ENTAM testing stations will only have informative character and will be communicated only to the sprayer manufacturers. However, through a self-evaluation of sprayers with EOS tool the manufacturers themselves may instantly identify and eliminate weak points of their equipment at the design stage of the production process.

4. Conclusions

The EOS software application evaluates the capabilities of sprayers in terms of the potential mitigation of the risks of water pollution from point and diffuse sources. Being a user-friendly interactive evaluation tool, with a rich help library it has a high educative value that can be used by advisory services to raise awareness with pesticide users on the environmental impact of pesticide application technology. It may also support activities of other target groups, such as sprayer manufacturers, agricultural machinery dealers, plant protection industry, trainers and pesticide users themselves.

EOS is a dynamic tool, which needs to follow the new developments and innovations of the sprayer technologies, and update its contents and evaluation parameters. Overtime, EOS will be an indicator of the progress in sprayer design and technology from an environmental protection point of view.

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6. Literature

Arvidsson, T., Bergström, L., Kreuger, J. 2011. Spray drift as influenced by meteorological and technical factors. Pest Manag. Sci. 67 (5), 586-598.

Bach, M., Röpke, B. and Frede, H-G. 2005. Pesticides in rivers – Assessment of source apportionment in thePesticides in rivers – Assessment of source apportionment in the context ofWFD; European Water Management Online, Official Publication of the EuropeanWater Association (EWA) *http://www.ewa-online.eu/tl_files/_media/content/documents_pdf/Publications/E-WAter/documents/66_2005_02l.pdf*

Balsari P., Marucco P. Oggero, G. 2006 External contamination of sprayers in vineyard. Aspects of Applied Biology 77 Vol. 1, 215-221.

Debaer, C., Springael, D., Ryckeboer, J., Spanoghe, P., Balsari, P., Taylor, W.T. and Jaeken, P. 2008. Volumes of residual of sprayers and their International Standards :impact on farm water treatment systems. Proc. International advances in pesticide application, 2008, 193 -199.

Doruchowski, G., Roettele, M., Herbst, A. and Balsari, P. 2013. Drift evaluation tool to raise awareness and support training on the sustainable use of pesticides by drift mitigation. Computers and Electronics in Agriculture 97, 27–34.

EC/60 (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Of. J. EU, 22.12.2000, L 327/1.

EC/127 (2009).Directive 2009/127/EC of the European Parliament and of the Council of 21 October 2009 amending Directive 2006/42/EC with regard to machinery for pesticide application. Of. J. EU, 25.11.2009, L 310/29.

EC/128 (2009). Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides. Of. J. EU, 24.11.2009, L 309/71.

EN 12761-2: 2002. Agricultural and forestry machinery - Sprayers and liquid fertilizer distributors; Environmental protection - Part 2: Field crop sprayers

Herbst, A. & Ganzelmeier, H. (2002). International Standards and their Impact on Pesticide Application. Aspects of Applied Biology 66: 1-8.

ISO 4254-1:2013a. Agricultural machinery - Safety - Part 1: General requirements

ISO 4254-6:2009. Agricultural machinery - Safety - Part 6: Sprayers and liquid fertilizer distributors

ISO 16119-1:2013b. Agricultural and forestry machinery -- Environmental requirements for sprayers -- Part 1: General

ISO 16119-2:2013c. Agricultural and forestry machinery -- Environmental requirements for sprayers -- Part 2: Horizontal boom sprayers

ISO 16119-3:2013d. Agricultural and forestry machinery -- Environmental requirements for sprayers -- Part 3: Sprayers for bush and tree crops

Müller, K., Bach, M., Hartmann, H., Spiteller, M., Frede, H.G., 2002. Point and non-point source pesticide contamination in the Zwester Ohm Catchment (Germany). J. Environm. Quality, 31(1), 309-318.

Nuyttens, D., De Schampheleire, M., Steurbaut, W., Baetens, K., Verboven, P., Nicolaï, B., Ramon, H., Sonck, B. 2006. Experimental study of factors influencing the risk of drift from field sprayers, Part 2: Spray application technique. Asp. Appl. Biol. 77(2), 331-339.

Roettele, M., Balsari, P., Doruchowski, G., Petersen, P.H. 2010. Sprayer development needs more focus on mitigation of environmental risks arising from point source water pollution.International advances in pesticide application, Aspect of Applied Biology 99, 357-368.