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ENVISPRAY: A Methodology to Evaluate PAE (Pesticide Application Equipment) According to the Environmental Risk

Rubén Collantes [1,2], Ramon Salcedo [1], Enric Armengol [1], Jose F. Schlosser [3] and Emilio Gil [1,*]

[1] Department of Agri-Food Engineering and Biotechnology, Universitat Politècnica de Catalunya, 08860 Castelldefels, Barcelona, Spain; ruben.dario.collantes@upc.edu or rcollantes@lamolina.edu.pe (R.C.); ramon.salcedo@upc.edu (R.S.); enric.armengol.esplugas@upc.edu (E.A.)
[2] Departamento de Mecanización y Energía, Universidad Nacional Agraria La Molina, Lima 15024, Peru
[3] Departamento de Engenharia Rural, Universidade Federal de Santa María, Santa María 97105-900, RS, Brazil; josefernandoschlosser@gmail.com
* Correspondence: emilio.gil@upc.edu; Tel.: +34-935-521-099

Abstract: Pesticide application equipment (PAE) is the last part of the chain during the plant protection process. The use-phase of plant protection products (PPP) has been addressed in two EU Directives: 128/2009/EC and 127/2009/EC. This last one covers all the mandatory technical requirements to be fulfilled by new sprayers prior to their placement in the market. The objective of this research was to develop a potential decision support system (DSS) to evaluate and quantify the degree of implementation of all the required characteristics of new sprayers, including not only the mandatory requirements but also specifications widely described in the corresponding harmonized standard ISO 16119. It includes 10 independent elements of the sprayer, including a list of technical specifications listed in the applied standards ISO 16119 and ISO 16122. The relative influence of every one of the different elements has been quantified based on previous research. The algorithm enables the establishment of an objective relative classification of the sprayers to differentiate among different machines, mainly based on their quantified environmental contamination risk. The DSS can also discriminate among sprayers that should not reach the market due to their non-compliance with any of the mandatory requirements.

Keywords: sustainable use directive; machinery directive; ISO 16119; ISO 16122; boom sprayers; airblast sprayers; environmental risk; sprayer's classification

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1. Introduction

The predominant method for distributing plant protection products (PPP) via pesticide application equipment (PAE) currently relies on hydraulic spraying [1]. The spray system consists of a tank where the PPP is mixed with water and injected through a hydraulic circuit to a set of nozzles [2]. Finally, the resultant liquid is expelled through the nozzles in the form of droplets, thereby materializing the application [3]. For foliar pesticides (the most common type), these resultant droplets are aimed at the treated crop, adapting their trajectory based on whether it is a plant or a tree [4,5].

In the case of vegetable plantations like cereals or legumes, PPP applications employ hydraulic sprayers equipped with horizontal booms [6]. This component stands out as the defining feature of these sprayers, consisting of a sequence of nozzles aligned along a metal boom, varying in length based on the model. Conversely, for tree or 3D crops such as fruit trees and vineyards, air-assisted sprayers are commonly utilized [7]. Mistblowers facilitate PPP application by integrating an air system that aids in product distribution. The generated air directs the spray particles, homogenizes the droplet cloud, and clears leaves and branches, thereby facilitating droplet penetration into deeper sections of the canopy.

These PAEs are very useful, especially in intensive crops, as is the case in Europe, since they enable a large area to be worked in a relatively short time. These sprayers only need a tractor driver for operation. Likewise, they cut down on water usage and have a short enough operating time to address the moment of greatest sensitivity of the disease or pest. This implies a more rational use of agrochemical products, avoiding prevention work and reducing the amount of active material to be used. However, the design of these sprayers is a fundamental factor in avoiding environmental risks due to contamination during treatment [8], especially through airborne spray drift and ground losses [9]. This has forced measures to be adopted by the European institutions.

Publication of two European Directives: Directive 128/2009/EC [10], or the Sustainable Use Directive (SUD), and Directive 127/2009/EC [11], or the Machinery Directive, represented a break-point in the use of PPP. For the first time in Europe, aspects related to the inspection and use of sprayers (explained by the ISO 16122 series [12–14]), as well as the manufacturing requirements for new sprayers (explained by the ISO 16119 [15–19]), were incorporated into official legislation. These directives address environmental and safety factors associated with equipment, focusing on the last part of the crop protection chain.

European manufacturers of sprayers are required to guarantee that their PAE adheres to the legislation's applicable provisions before being introduced to the market or utilized. The European Free Trade Association (EFTA) directed the European Committee for Standardization to formulate a standard for new sprayers. This standard aims to outline the minimum specifications for the different sprayer aspects to comply with the requirements of the Directives. Hence, the ISO 16119 series [15–19] was introduced as a standardized framework, aiding sprayer manufacturers in meeting all obligatory mandates. The aim is to facilitate the effective deposition of PPPs onto a specific target area, minimize unintended dispersion of the liquid outside the application zone, and enhance the utilization and operation of ECPs. The ISO 16119 standard is divided into five parts: (1) general concepts about application machines; (2) environmental requirements for boom sprayers; (3) conditions for airblast sprayers; (4) fixed and semi-mobile sprayers; and (5) aerial spray systems. Even though manufacturers can follow the standard as a reference to enhance their sprayers, its success hinges on the extent of responsibility and consciousness they exhibit in adhering to it. However, solely relying on the standard may not be adequate, considering its potential complexity during implementation. ISO 16119 presents a series of trials that can be time-consuming and require specific materials and facilities, repeatability of the results, and a properly qualified workforce [20].

In order to assist manufacturers, various Member States have taken complementary initiatives to support the development of prototypes and ensure compliance with European regulations. For instance, in Spain, a manual has been published outlining methodologies for normative implementation [21], with a particular emphasis on the horizontal boom and airblast sprayers. This guide, developed by the Agricultural Mechanization Unit of the Technical University of Catalonia (UMA-UPC) at the request of the Spanish Ministry of Agriculture, encompasses strategies to minimize product loss during treatments and specifies the requirements for sprayer cleaning systems, tank conditions, induction hopper capacity, efficiency of agitation systems, and residual product levels in the deposit. Additionally, Spain's Ministry of Agriculture established the Agricultural Machinery National Renewal Plan (RENOVE) to encourage the replacement of obsolete machinery with advanced technology, enabling farmers to operate within the framework of sustainable pesticide use [22]. This initiative mandated manufacturers to subject their machines to certified laboratory tests for inclusion in the plan, thereby promoting adherence to regulations.

Decision support systems (DSSs) can play a pivotal role in agricultural machines too [23], particularly in aiding manufacturers in adhering to regulations and optimizing practices. These systems leverage data analytics, predictive models, and real-time information to provide invaluable insights into various aspects of agricultural operations. Specifically, in the context of complying with European regulations and aiding manufacturers in prototype development, DSSs can streamline decision-making processes. By integrating information on regulatory standards and technological requirements, DSSs empower manufacturers to make informed choices during prototype design and development phases. These systems can offer predictive analysis on the performance of agricultural machinery, ensuring they meet stringent criteria outlined by European laws.

Various existing DSSs primarily assess sprayer design from the operator's viewpoint. One example is the tool based on the indications of the European project TOPPS (Train Operators to Promote Best Management Practices and Sustainability), and with the support of CEMA (European Agricultural Machinery Industry Association) and ECPA (European Crop Protection Association) called 'STEP-WATER' [24]. This initiative aimed to assist farmers in identifying key features in new sprayers or adapting existing ones. STEP-WATER focused on the tank-filling process, the internal and external cleaning systems of the spray tank, waste management, and the reduction of spray losses. This DSS was designed to provide a comprehensive framework for farmers to optimize their sprayer operations, emphasizing sustainability and compliance with good agricultural practices outlined by the project. Other alternatives can be the method presented by Spugnoli and Vieri [25] to expose the risk as a sum of hypothetical negative outcomes on the environment and the farmer, considering different sprayer designs.

There are also regional-level DSSs, such as the one developed by the Institute for Agricultural, Fisheries and Food Research (ILVO) in Belgium. ILVO created a tool called "Spray Technology" [26], aimed at assisting farmers in understanding the factors influencing spraying practices. This tool provided insights into various aspects of spraying, including the type of pesticide used, spray nozzles, working pressure, forward speed, and buffer zones. There are also DSSs specifically focused on sprayers tailored for particular crops, such as vineyard sprayers. EvaSpray Viti [27] presented a tool developed for the sprayer classification regarding off-target loss risk. PERFORMANCE PULVÉ® [28] is for wine growers to improve the use of PPP.

Doruchowski et al. [29] developed an interactive application called EOS (Environmentally Optimized Sprayer) to support manufacturers in decision-making processes during sprayer production and enable PPP applicators to make appropriate selections and use them effectively. The software evaluated sprayers based on their technological features and across five critical areas representing contamination risks: internal and external sprayer pollution, spray-tank filling, losses, and drift caused during spraying operations. EOS functioned as a comprehensive guide, allowing stakeholders to prioritize environmental considerations and optimize sprayer design and usage in alignment with regulatory standards.

At the Spanish level, there is not currently a similar DSS specifically tailored to manufacturers, especially those specializing in boom and airblast sprayers. However, given the importance of such a tool, a valuable addition could be the integration of an evaluation DSS capable of assessing compliance levels with regulations across various components of the sprayers. This tool would serve as a complement to aid manufacturers in ensuring adherence to standards and optimizing their designs for regulatory compliance.

The objective of this research has been the development of a DSS to achieve an objective classification of new sprayers based on the degree of accomplishment of the Machinery Directive (127/2009/EC) concerning environmental and safety aspects, and the corresponding technical requirements specified in the ISO 16119 parts 1, 2, and 3. The platform will serve as an objective tool to establish an environmental classification of sprayers prior to their placement in the market, helping manufacturers comprehend and conform to the established regulations in Europe.

2. Materials and Methods

The ENVISPRAY tool has been developed in collaboration with ANSEMAT, the Spanish National Association of Agricultural, Forestry and Green Spaces Machinery (https://www.ansemat.org/). The process has been divided into three main steps: (1) the identification of the manufacturer's needs to ensure a comprehensive understanding and compliance with European requirements for new sprayers; (2) the development of the algorithm to quantify the environmental risk of the sprayer; and a (3) proposal of objective criteria for classifying sprayers based on EU requirements.

2.1. Identification of Manufacturer's Needs

Since the publication in Europe of the SUD [10], the use-phase of pesticides has been regarded as a pivotal element for the overall success of the process. Among other points, SUD included the mandatory inspection of sprayers in use, a regular and mandatory calibration of the sprayers, and some other important issues affecting sprayers in use. Additionally, the European Parliament also published the amendment of the Machinery Directive [11] which focused its attention on the mandatory technical requirements that should be met by all new sprayers prior to their placement in the European market. The harmonized ISO 16119 series [15–19] includes in detail the whole process and requirements to be fulfilled by all the EU sprayer manufacturers prior to the placement into the market of their respective new equipment. The above-mentioned standard includes a series of technical requirements. Nevertheless, previous research already carried out in this sense demonstrated the difficulties of evaluating airblast sprayers following the ISO standard [20]. The assays were expensive, time-consuming, and complex. A complete application of the standard may require a lot of resources. It makes, in most cases, its practical implementation by medium and small (SME) sprayer manufacturers in Europe difficult or nearly impossible. In this sense, user guides improve the communication and feedback from national representatives on International Standardization Bodies and local manufacturers in order to guarantee a clear and useful information channel.

Two guidelines have been used to identify the manufacturer's needs. The first one is a practical guideline [21] developed by the UMA-UPC research group as a requirement of the Spanish National Association of Agricultural Machinery of Agricultural, Forestry and Green Spaces Machinery (ANSEMAT). This book has clear and practical information, including real examples, in order to help Spanish sprayer manufacturers in the complex process of conforming to ISO 16119. Based on similar principles and objectives, another basic manual for sprayer manufacturers was developed within the EU Twinning Project SR 12IB AG 01. Both guidelines were developed to give practical answers and useful tools to EU sprayer manufacturers, especially those belonging to the SME category, to help them conform to the mandatory requirements established by the European Parliament. Consequently, the main structure of these two guidelines has been used as the main organizational process for the development of the presented DSS for the sprayer's evaluation concerning environmental risk. From the Spanish guideline, it was able to design a template with questions for sprayer manufacturers. This facilitated the presentation of technical inquiries in a manner that is both clear and rigorous based on the requirements of Directive 127/2009/EC [11] in addition to those outlined in ISO 16119 [13–15]. The second document played a crucial role in identifying the key aspects concerning environmental safety. While this manual did not encompass ISO standards for manufacturers, it provided other insights into elements related to the effectiveness of the treatment process.

2.2. Algorithm to Quantify the Environmental Risk of Sprayers

Two main groups of sprayers were addressed, covering a large number of sprayers in Europe. Horizontal boom sprayers with or without air assistance (horizontal boom hydraulic sprayers according to the ISO 16119-2 definition [16]) and airblast sprayers (sprayers typically used for bush and trees, according to ISO 16119-3 [17]) were separately managed due their important differences. Consequently, two different (but similar) algorithms have been developed.

The main principle was to collect in a logical order all the requirements established for the sprayers (new sprayers and in-use sprayers) focusing the attention on environmental and safety aspects. The algorithm started considering the mandatory requirements included in the two European Directives, 128/2009/EC and 127/2009/EC [10,11], with special attention to environmental and safety aspects. Additionally, and related to that, the two related harmonized standards (ISO 16122 for sprayers in use [12] and ISO 16119 for new sprayers [15]) have been also included in the algorithm.

For each one of the sprayer types (boom sprayers and airblast sprayers), ten different and independent items (Table 1) have been identified as a common structure for the sprayer's evaluation: spray tank, pump, agitation system, hoses and pipes, filters, spray boom, nozzles, fan, cleaning devices, and instructional handbook. In this first version of the tool, only airblast sprayers were taken into account for airblast sprayers, while only hydraulic boom sprayers without air assistance were considered for boom sprayers. For every one of the identified items, a relative weight in the algorithm (W_E in percentage) has been assigned based on previous works, either focused on the development of similar tools [25–27] or on laboratory results provided by different comparative evaluation processes of different sprayer technologies [30–38]. Because these tools highlight the importance of sprayers (due to the risk of accumulated residues appearing from pesticide treatments), this item was the one that acquired the greatest relevance (20% of the weight in both types of sprayers). The rest of the elements were scored equally at 10%. However, the hydraulic circuitry, due to its complexity, was evaluated by differentiating hoses and pipes, on the one hand, and filters on the other, being assigned 5% each.

Table 1. Values of weights expressed as a percentage for each group of sprayers: boom sprayers and airblast sprayers.

Sprayer Items	Boom Sprayers Weight WE (%)	Airblast Sprayers Weight WE (%)
Spray tank	10	10
Pump	10	10
Agitation system	10	10
Regulation	10	10
Hoses and pipes	5	5
Filters	5	5
Spray boom	10	-
Nozzles	10	10
Fan	-	10
Cleaning devices	20	20
Instructional handbook	10	10

For every one of these ten items, a hierarchical checklist has been developed ranging from mandatory requirements included in the European Directives to additional specifications from the involved international standards. Every single evaluated item has been structured to be tested through a detailed checklist, in order to quantify the degree of accomplishment of the requirements. As shown in Table 2, a total of 19 single requirements provided by the European Directives have been included (one specification for each Directive, except the handbook which was only subject to the Machinery Directive). Additionally, (57) specific technical requirements provided by ISO 16119 [13–17] and (46) requirements established at ISO 16122 [12] complete the whole process. Finally, some elements (19) have been included considering specific requirements from other international standards (ISO 4288 [39], ISO 9357 [40], ISO 13440 [41], ISO 4254-2 [42], ISO 4254-6 [43], and ISO 21278-1 [44]).

Table 2. Number of requirements for boom sprayers and airblast sprayers by every ISO category and Directive.

Sprayer Items	Boom Sprayers				Airblast Sprayers			
	CE 127/128	**ISO 16119**	**ISO 16122**	**ISO Others**	**CE 127/128**	**ISO 16119**	**ISO 16122**	**ISO Others**
Spray tank	2	6	7	10	2	6	7	10
Pump	2	3	3	1	2	3	3	1
Agitation system	2	3	2	-	2	3	2	-
Regulation system	2	8	8	2	2	8	8	2
Hoses and pipes	2	2	2	-	2	2	2	-
Filters	2	5	3	-	2	5	3	-
Spray boom	2	6	11	-	-	-	-	-
Fan	-	-	-	-	2	1	2	-
Nozzles	2	13	9	-	2	8	9	-
Cleaning devices	2	7	2	1	2	7	2	1
Instructional handbook	1	4	-	-	1	4	-	-

Once the relative influence of every single topic (W_E) on the global evaluation of the sprayer was defined, the mathematical process to quantify the assigned value to every one of the items was then established. The composition of each item was determined through a rigorous process, emphasizing the need for an objective and logical approach to measure the specific impact of each topic listed in the checklist. An objective mathematical process was developed in order to quantify the effect of every single item in the total score of the sprayer resulting from the evaluation process. Every single item was assigned with a maximum theoretical score, considering the rest of the items included in the same group. The process allowed the researchers to assign a logical maximum score for every single item within a common topic (for the 10 identified individual topics). For every case, a maximum score was assigned when the sprayer "Accomplishes" the requirement, being assigned the minimum score in case of a "No Accomplishes" situation. The objective assignment of maximum and minimum values was determined based on two aspects. On one hand, it considered all the studies presented on the previously mentioned DSS to rigorously assess, from an environmental perspective, the risk of off-target losses from a sprayer based on the machine's design and its requirements, with special emphasis on the STEP-WATER tool [24]. That was because this methodology has already been evaluated and validated as a useful approach [30]. On the other hand, it took into account the proprietary studies conducted by the UMA-UPC group, following the ISO 16122 [12] and 16119 [15] standards. The robustness of these studies is evident in the manual for Spanish manufacturers or in the evaluation of tests required by ISO 16119 [19,20].

The established process can be described as follows: for every one of the subtopics included in each category, a maximum (*Max*) and a minimum (*Min*) value was assigned (Figure 1). During the evaluation process and based on the accomplishment of the established requirements, a certain value (v_i) was assigned to every independent element. The absolute score value of every topic (AS_x) is then calculated according to Equation (1):

$$AS_x = \frac{\sum_{i=1}^{n} v_i}{n} \times 100 \quad (1)$$

where AS_x is the absolute score (dimensionless) achieved by the topic; v_i is the individual score assigned to every single element included in the topic; and n is the number of elements evaluated in the topic. For example, for the agitation system, there are a total of four organized subtopics: (1) mixing homogeneity; (2) disconnection; (3) product quantity adjustment to reduce foam; and (4) system operability (either hydraulic or mechanical). The first three subtopics refer to Section 5.1.1.5 of ISO 16119-2 [16], while the last aspects refer to Section 4.3 of ISO 16122-2 [13]. In this case, depending on the fulfillment of all the subtopics, the maximum score could be 44. The 16119-2 part [16] was divided into four sections, each carrying 8 points in case of compliance, except for the maximum deviation requirement of 15%, which was assigned 10 points due to its increased significance. Conversely, zero points were assigned in case of non-compliance. The remaining subtopics were considered with 10 points each if the evaluation was positive. In this case, if the score is 36, the absolute score would be 900 (36/4 × 100 = 900). Once the absolute score is calculated, the previously assigned relative weight (W_E) is then applied in order to obtain the relative score (RS_x) following Equation (2):

$$RS_x = AS_x \times W_E \tag{2}$$

where RS_x is the relative score of the intended item; and W_E is the relative weight assigned to the item. In the particular case of an absolute score of 900 for the agitation system, the relative score would be 90 (900 × 0.1 = 90).

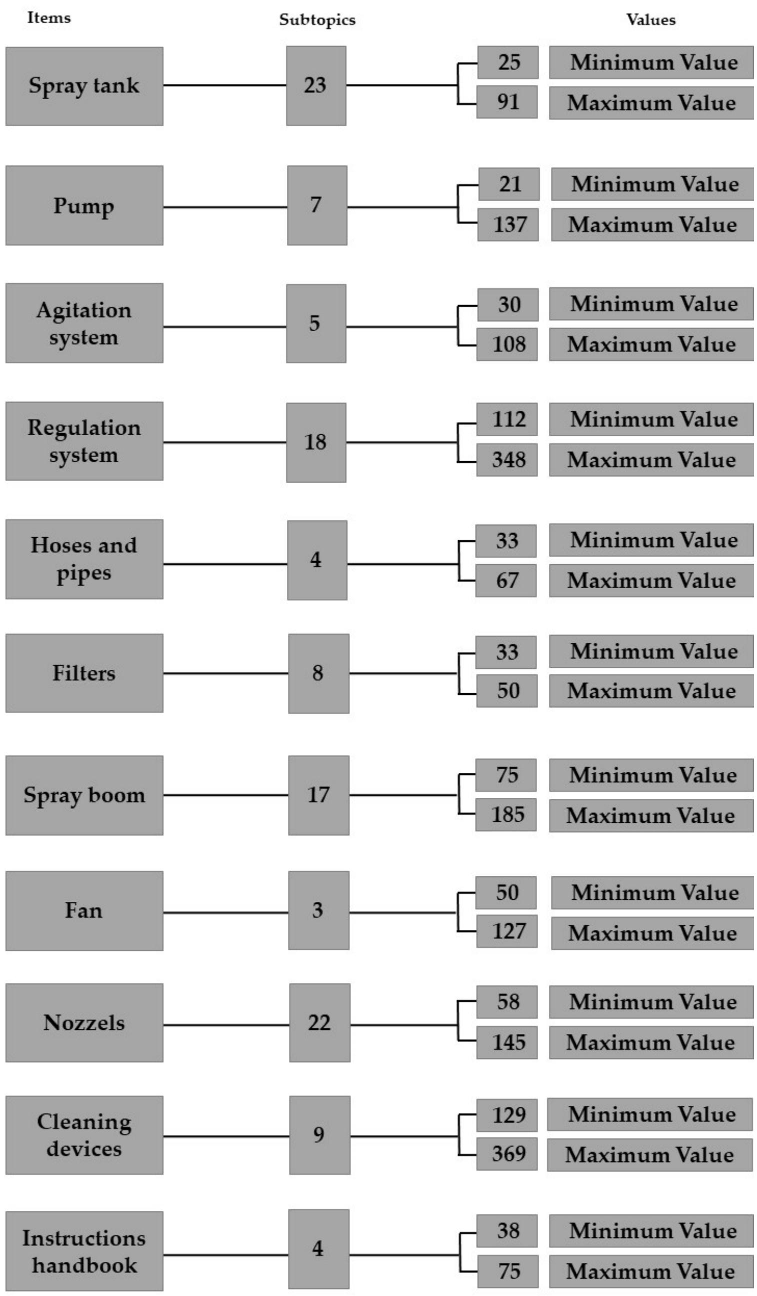

Figure 1. Structure of the ENVISPRAY tool (boom sprayers and airblast sprayers), indicating how the requirements are to be assessed step by step. The number of requirements and the maximum and minimum values obtained in the evaluation are indicated.

2.3. Criteria for Classification of Sprayers according to Their Environmental Risk

Once the relative score (RS_x) has been calculated for a certain evaluated sprayer, the software uses this value to assign one of the five defined categories (Figure 2) ranging from A as an excellent sprayer with a minimum risk of environmental contamination to E when the evaluated sprayer doesn't comply with some of the minimum and mandatory requirements established in the European Directive. This classification model has been based on previous developments, such as the EvaSpray Viti tool, developed by Cheraiet et al., 2023 [25], for sprayer classification according to the risk of drift; the Performance Pulvé, developed by Codis et al., 2023 [26]; the EOS—Environmental Optimized Sprayer, developed by Doruchowski et al., 2014 [27]; or the Operational Risk Assessment methodology developed by Spugnoli and Vieri, 1998 [23].

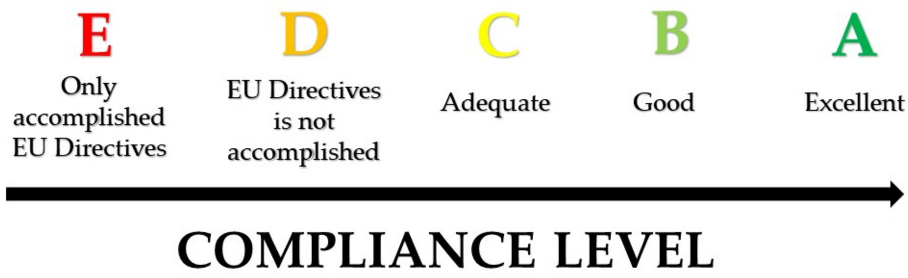

Figure 2. Classification categories for environmental risk were established for both sprayer groups.

The mathematical methodology to establish this classification was based on the minimum (min_i) and maximum (max_i) scores assigned to every single element included in all the ten individual topics. Based on these two extreme values, the maximum (Max_x) and the minimum (Min_x) values to be achieved by every individual topic were calculated as shown in Equations (3) and (4):

$$Max_x = \frac{\sum_{i=1}^{n} max_i}{n} \times 100 \times W_E \quad (3)$$

$$Min_x = \frac{\sum_{i=1}^{n} min_i}{n} \times 100 \times W_E \quad (4)$$

The relative score (RS_x) is then compared with the Max_x and Min_x to assign the corresponding letter for the classification of the topic. The established classification (Table 3) was based on the following criteria: A (Excellent) when the evaluated topic raises an $RS_x \geq 80\%\ Max_x$; B (Good) for $RS_x \geq 60\%\ Max_x$ and $RS_x < 80\%\ Max_x$; C (Adequate) when $RS_x < 60\%\ Max_x$; D (Minimum accomplishment) if $RS_x < Min_x$, but all the mandatory requirements of EU directives are accomplished; and E (Not accepted) when any of the mandatory requirements of EU Directive is not accomplished.

Table 3. Classification of the different items of the sprayers according to the environmental risk based on the achieved RS_x [1]. Data compared with the value of Min_x and Max_x established for minimum relative score and maximum relative score, respectively.

Category	Relative Score (*RSx*)	Description
A	$RS_x \geq 80\%\ \mathrm{Max_x}$	Excellent
B	$60\%\ Max_x \leq RS_x < 80\%\ Max_x$	Good
C	$RS_x < 60\%\ Max_x$	Adequate
D	$RS_x < Min_x$	Only accomplish EU Directive
E	-	EU Directive is not accomplished

[1] RS_x: Relative score as the accumulative achieved value of all the topics included on every single item.

Once every single item of the sprayer has been evaluated and classified, the system assigns an average classification of the whole sprayer, based on the results obtained for every single item. According to that, Table 4 shows the proposed criteria to assign a specific category to the whole sprayer based on the results of every one of the 10 evaluated single items.

Table 4. Classification of sprayers according to the results obtained during the evaluation of the 10 individual items.

Category	Results of Individual Evaluation of Items (n = 10)	Description
A	All items scoring A	No risk of contamination
B	All items scoring A or B	Low risk of contamination
C	Any of the items scoring C	Moderate risk of contamination
D	Any of the items scoring D	Minimum quality
E	Any of the items scoring E	Not allowed to reach the market

2.4. Sprayers Models for Assessing Environmental Risk

To validate the ENVISPRAY tool, three manufacturers located in the region of (Spain) were selected. These manufacturers were: SAHER (Saher, Barcelona, Spain) AMP SPRAYERS (AMP SPRAYERS, Girona, Spain), and TEYME (TEYME Tecnología Agrícola, S.L.U., Lleida, Spain) who participated with three models of airblast sprayers and one model of a boom sprayer.

The manufacturer SAHER (Barcelona, Spain) introduced a Vortex Viña 2000 airblast sprayer (Figure 3). This model was designed for vineyard applications. It was equipped with 18 nozzle holders and an axial fan. The following description is a list of the elements subject to evaluation for the corresponding sprayer:

- Spray tank: The spray tank is made of polyethylene, with a nominal volume of 2000 L and a maximum total volume of 2200 L. It was equipped with two opening lids with a pressure compensator for the supply of the mixture of PPP with water. The manufacturer indicated that the presence of a second lid is to allow a better view of the inside of the spray tank. During the evaluation of this element, it was found that the only requirement that was not met was with reference to the surface roughness or value depth of roughness.
- Pump: The sprayer is equipped with a high-pressure diaphragm pump, which specifications indicate a maximum pressure of 50 bar (5000 kPa) and 142.6 L/min of flow rate. The pump complied with all design and manufacturing requirements that minimize losses and mainly with the flow requirement necessary for the spraying application.
- Agitation system: The sprayer has an agitation system composed of two mixers that operate hydraulically by the Venturi effect. Each of these mixers has a filter that ensures correct operation. The good functioning of the homogenization of the mixture inside the tank was checked.
- Regulation system: In this part of the evaluation, the sprayer has adequate means for the adjustment and calibration of the application volume. The pressure regulation devices and operating and stop controls worked correctly. The pressure gauge complied with the characteristics established by the standard in terms of size, diameter, scale, and accuracy. The requirements that the sprayer did not meet are related to the modification of the treatment conditions, to the performance of successive regulations of the application volume, and to the deviations of the volume applied.
- Hoses and pipes: During the evaluation of the sprayer, no leaks, spills, or any deformation were detected at the connections. The hose has a service pressure of 80 bar (8000 kPa) and a bending radius of 40 mm.
- Filters: The orchard model evaluated has one suction filter and two impulsion filters. Both types of filters are properly marked and during operation showed no leaks or losses.
- Nozzles: The nozzles were properly marked, with individual shut-off devices and in properly protected moldings. They allow interchangeability with models of different

flow rates, according to the need for treatment, in addition to the installation of anti-drift nozzles.

- Fan: The fan is an 820 mm diameter propeller type with 9 blades and adjustable with 2 volumetric flow rates of 31,948 and 39,200 m^3/h and with a 2-speed multiplier. The airflow produced by the fan is symmetrical on the right and left sides. It complied with the disconnection and regulation requirements and has elements that control the drift.
- Cleaning devices: The sprayer is equipped with a water tank for washing the sprayer (150 L) and a clean water tank for the operator (20 L). Both tanks are independent and comply with the volume required by the standard. The inside of the spray tank has two rotating nozzles (cleaning robot) that allow the cleaning of the internal walls. It has an induction hopper, which, in turn, has a closed-circuit device that allows cleaning of the PPP containers.
- Instructional handbook: When reviewing the contents of the instructional handbook, it contains information on the description of the sprayer; calibration; safety; responsible use of PPP; maintenance; a list of problems, causes, and solutions; and types of accessories. However, information stipulated by the standard, such as diluting the residual volume of the tank, the procedure for collecting liquid from the filters, and the type of PPP that can be used with the sprayer, is not mentioned.

Figure 3. SAHER: Vortex Viña 2000 model.

The manufacturer AMP SPRAYERS (Girona, Spain) introduced the A2000 airblast sprayer (Figure 4), with 48 nozzle holders. The air system was formed by two axial fans. This model was designed for use in pome tree plantations. The elements assessed for the corresponding sprayer were as follows:

- Spray tank: The tank is made of polyethylene, with a nominal volume is 2000 L and a total volume of 2170 L. It is equipped with a lid featuring a pressure compensator and a tank connection element. Additionally, it has an induction hopper that functioned properly. However, the tank did not comply with the information regarding the depth of the surface roughness.
- Pump: The sprayer is equipped with a diaphragm pump, whose specifications indicate a flow rate of 125 L/min. The pump met all the requirements for inspection, residue, and the ability to minimize losses, and it mainly satisfies the flow-rate requirement needed for the application.
- Agitation system: The sprayer features an agitation system composed of three mixers that operate hydraulically by the Venturi effect. Each of these mixers has a filter

to ensure proper functioning. The system was able to guarantee a homogeneous concentration of the mixture.

- Regulation system: The sprayer lacked the means to adjust and calibrate the application volume. However, the pressure regulation devices and operating and stop controls worked correctly. The pressure gauge met the standard's characteristics in terms of size, diameter, scale, and accuracy. The requirements in this aspect were related to the modification of the treatment conditions, successive regulations of the application volume, and deviations of the volume applied.
- Hoses and pipes: This item presented a good appearance without damage and deterioration. During the sprayer evaluation, no drips or spills were detected at the connections.
- Filters: The evaluated sprayer model features a suction filter and only one impulsion filter. Both types of filters were properly marked and showed no leaks or losses during operation. The filters appeared in good condition, were easily accessible, and proved to be easy to clean.
- Nozzles: The nozzles were properly marked, with individual shut-off devices, and housed in adequately protected moldings. They allow interchangeability with models of different flow rates and enable the installation of anti-drift nozzles.
- Fan: The sprayers have 2 fans with a diameter of 800 mm diameter. They complied with disconnection and regulation requirements and featured the necessary elements to control drift.
- Cleaning devices: The sprayer is equipped with a sprayer wash tank (120 L) and an operator wash tank (12 L), both separate. However, the operator wash tank does not meet the required minimum volume of 15 L. The inside of the spray tank has two rotating nozzles that facilitate cleaning of the internal walls. It also includes an induction hopper, which, in turn, has a device with a closed circuit for cleaning PPP containers.
- Instructional handbook: Upon reviewing the contents of this item, it was found to contain information on the sprayer's components, startup, and maintenance aspects. However, it lacks specific information stipulated by the standard.

Figure 4. AMP Sprayers: A2000 model.

The manufacturer AMP SPRAYERS (Girona, Spain) also introduced a boom spray system model, the Pulmatic 3000 (Figure 5), with 40 hydraulic nozzles along the horizontal boom. The main characteristics of the parts examined were as follows:

- Spray tank: The tank is made of polyethylene, with a nominal volume of 3000 L and a total volume of 3200 L. It is equipped with a lid featuring a pressure compensator and a tank connector. It also has an induction hopper that functions properly. However, the tank does not comply with the information regarding the depth of the surface roughness.

- Pump: The sprayer is equipped with a diaphragm pump, whose specifications indicate a flow rate of 249 L/min. The pump meets all the requirements for inspection, residue, and capacity to minimize losses, and primarily fulfills the flow-rate requirement needed for the application.
- Agitation system: The sprayer has an agitation system consisting of two hydraulically operated mixers. Each of these mixers has a filter to ensure its operation. The system was able to guarantee a homogeneous concentration of the mixture.
- Regulation system: This sprayer lacked the means to calibrate the application volume. However, the pressure regulation devices and operating and stop controls functioned correctly. The pressure gauge complied with the standard in terms of size, diameter, scale, and accuracy. The requirements that this item did not meet pertained to the modification of treatment conditions, successive regulations of the application volume, and deviations of the applied volume.
- Hoses and pipes: This item presented a good appearance, and during the evaluation, no leaks or spills were detected at the connections.
- Filters: The sprayer model evaluated has a suction filter and line filters in the boom sections. Both filters were properly marked and showed no leaks or losses during spraying. The filters looked good and demonstrated ease of cleaning.
- Nozzles: The nozzles were properly marked, with individual shut-off devices and in properly protected moldings. The sprayer allows interchangeability with models of different flow rates and the installation of anti-drift nozzles.
- Spray boom: This item exhibited an adequate design for uniformity of application, complying with the maximum width of sections for a working width of less than 24 m. It had a proper height adjustment system but lacked a contact detection system. The boom demonstrated stability and alignment, adhering to the orientation and spacing requirements for the nozzles, as well as ensuring the correct functioning of the damping and slope compensation. Additionally, it features a nozzle protection system.
- Cleaning devices: The boom sprayer is equipped with a tank for washing the sprayer (300 L) and a tank for washing the operator (15 L). Both tanks are independent. The spray tank has two rotating nozzles that clean the internal walls. It has an induction hopper, which, in turn, has a device with a closed circuit that allows the cleaning of the PPP containers.
- Instructional handbook: When reviewing the contents of this item, it contains information on the boom sprayer components, its start-up, and its maintenance aspects; however, it does not contain specific information indicated in the standard.

Figure 5. AMP Sprayers: Pulmatic 3000 model.

The manufacturer TEYME introduced a 2000 EOLO GTE10 airblast sprayer (TEYME Tecnología Agrícola, Lleida, Spain) (Figure 6), with 68 nozzle holders and a 1000 mm diameter fan, formed by the following:

- Spray tank: The tank is made of polyethylene, with a nominal volume is 2000 L and a total volume of 2100 L. It is equipped with a lid featuring a pressure compensator and a tank connection element. Additionally, it has an induction hopper that worked properly. However, this model failed to provide information on the depth of the surface roughness.
- Pump: The sprayer is equipped with a diaphragm pump, with specifications indicating a flow rate of 185 L/min. The pump met all inspection, residue, and capacity requirements, minimizing losses.
- Agitation system: The sprayer features an agitation system consisting of three hydraulically operated mixers. They are located at the front and on each side of the tank interior. The third mixer has the function of agitating the bottom of the tank and was tested during operation. The system complied with guaranteeing a homogeneous concentration of the mixture.
- Regulation system: The sprayer has the means to adjust and calibrate the application volume. The pressure regulation devices and operating and stop controls functioned correctly. The pressure gauge complied with the characteristics established by the standard in terms of size, diameter, scale, and accuracy. However, this item did not comply with the modification of the treatment conditions, the successive regulations of the application volume, and the deviations of the applied volume.
- Hoses and pipes: This item showed no damage or deterioration, and no leaks or spills were detected in the spraying circuit.
- Filters: The evaluated sprayer model has one suction filter and two impulsion filters properly located and easily accessible. Both types of filters were properly marked and did not leak or show any signs of leakage during operation.
- Nozzles: The nozzles were properly marked, equipped with individual shut-off devices, and housed in adequately protected moldings. Nozzle models are interchangeable with different flow rates and allow the installation of anti-drift nozzles.
- Fan: This item complies with the requirements of independent disconnection of the sprayer and airflow regulation. It has the necessary elements that control drift.
- Cleaning devices: The sprayer is equipped with a tank for washing the sprayer (200 L) and a tank for washing the operator (16 L). Both tanks are independent. The inside of the spray tank has two cleaning devices for the internal walls. It also has an induction hopper, which, in turn, has a device with a closed circuit that allows the cleaning of the PPP containers.
- Instructional handbook: Upon reviewing the contents of this item, it was found to contain information on the general description of the sprayer, how to use it, and how to start it up. However, it does not contain the information stipulated in the standard.

Table 5 below shows the comparison of the sprayer models introduced for manufacturers.

Table 5. Comparison of the design features among the sprayer models introduced by the manufacturers.

Manufacturers	Saher	AMP Sprayers		Teyme
Model	**Vortex Viña 2000**	**A2000**	**Pulmatic 3000**	**2000 EOLO GTE10**
Sprayer	Airblast	Airblast	Horizontal boom	Airblast
Crop type	Vineyard	Apple	Crops	Vineyard
Volume tank (L)	2000	2000	3000	2000
Number of fans	1	2	-	1
Diameter of fan	820 mm	800 mm	-	1000 mm
Number of nozzles	18	48	40	68

Figure 6. TEYME: 2000 EOLO GTE10 model.

3. Results and Discussion

3.1. Vortex Airblast Sprayer

This machine obtained a C rating on the ENVISPRAY scale considering the contents of the instructional handbook, while the items of agitation, regulation system, fan, and cleaning devices were assessed with a rating of B, indicating a low risk of contamination. The highest ratings (A) were achieved for the spray tank, pump, hoses and pipes, filters, and nozzles, demonstrating no risk of contamination. In the general classification, this orchard sprayer model received a rating of B. The results are shown in Table 6, and Figure 7 shows the classification according to the environmental risk.

Table 6. Evaluation results of the Vortex Viña 2000 airblast sprayer.

Items	Points	Evaluation Results
Spray tank	79	A
Pump	137	A
Agitation system	82	B
Regulation system	240	B
Hoses and pipes	67	A
Filters	50	A
Nozzles	122	A
Fan	100	B
Cleaning devices	229	B
Instructional handbook	38	C

3.2. A2000 Airblast Sprayer

The sprayer model received the lowest rating (C) in the instructional handbook item. The agitation, regulation system, nozzles, fan, and cleaning devices were evaluated with a rating of B, indicating a low risk of contamination. The highest rating (A) was given to the spray tank, pump, hoses and pipes, and filters, signifying no risk of contamination. Overall, this sprayer model received a B rating in the general classification. The results are shown in Table 7, and Figure 8 shows the classification according to the environmental risk.

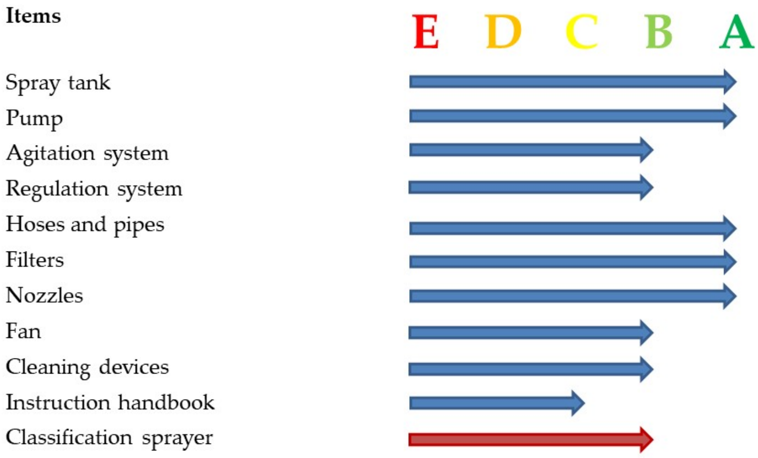

Figure 7. Classification of sprayer Vortex Viña 2000 according to the environmental risk.

Table 7. Evaluation results of the A2000 airblast sprayer.

Items	Points	Evaluation Results
Spray tank	74	A
Pump	137	A
Agitation system	82	B
Regulation system	232	B
Hoses and pipes	67	A
Filters	50	A
Nozzles	115	B
Fan	100	B
Cleaning devices	229	B
Instructional handbook	38	C

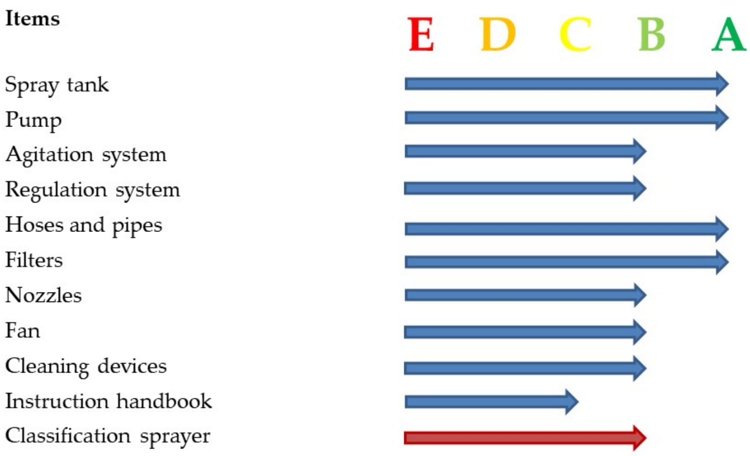

Figure 8. Classification of sprayer A2000 according to the environmental risk.

3.3. Pulmatic Horizontal Boom Sprayer

The equipment got a score of C in the content of the instructional handbook. The items of agitation, regulation system, nozzles, and cleaning devices were evaluated with a rating of B, indicating a low risk of contamination. The best ratings (A) were for the spray tank, pump, hoses and pipes, filters, and spray boom, indicating no risk of contamination. In the general classification, the sprayer model received a rating of B. The results are shown in Table 8, and Figure 9 shows the classification according to the environmental risk.

Table 8. Evaluation results of the Pulmatic 3000 boom sprayer.

Items	Points	Evaluation Results
Spray tank	79	A
Pump	137	A
Agitation system	82	B
Regulation system	232	B
Hoses and pipes	67	A
Filters	50	A
Nozzles	115	B
Spray boom	174	A
Cleaning devices	229	B
Instructional handbook	38	C

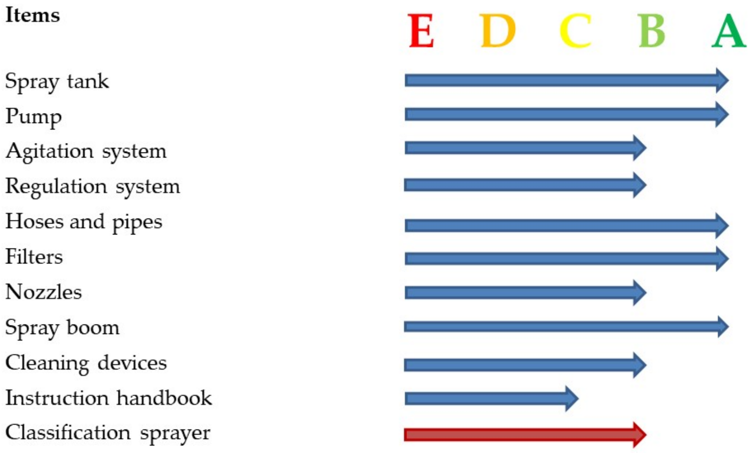

Figure 9. Classification of sprayer Pulmatic 3000 according to the environmental risk.

3.4. EOLO G10 Airblast Sprayer

The orchard sprayer received a C rating in the content of the instructional handbook. The regulation system and fan were evaluated with a rating of B, indicating a low risk of contamination. The best ratings (A) were given in the spray tank, pump, hoses and pipes, filters, nozzles, and cleaning, signifying no risk of contamination. In the general classification, the sprayer model received a rating of A. The results are shown in Table 9, and Figure 10 shows the classification according to the environmental risk.

Table 9. Evaluation results of EOLO 2000 GTE10 airblast sprayer.

Items	Points	Evaluation Results
Spray tank	79	A
Pump	137	A
Agitation system	98	A
Regulation system	225	B
Hoses and pipes	67	A
Filters	50	A
Nozzles	119	A
Fan	100	B
Cleaning devices	303	A
Instructional handbook	38	C

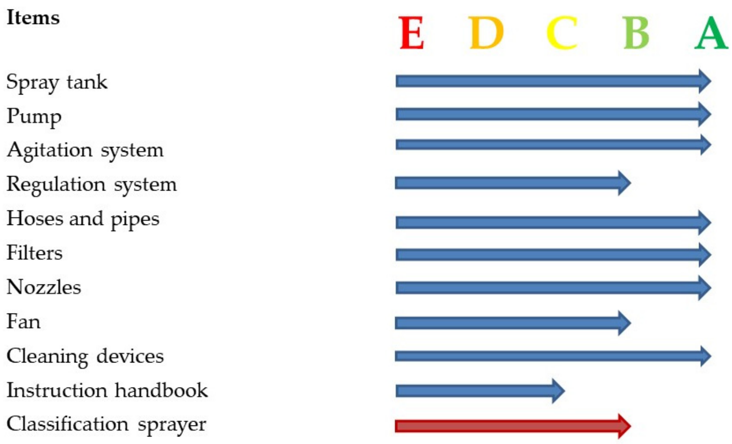

Figure 10. Classification of sprayer EOLO 2000 GTE10 according the environmental risk.

While the results enable an assessment of the degree of compliance with standard requirements, it is also possible to compare them with other DSSs. For instance, when evaluating the same sprayers (Vortex Viña 2000, A2000, and Pulmatic 3000) using the STEP-WATER online tool, which considers aspects such as tank filling, external and internal waste management, and reduction of spray losses, the overall configuration of the three sprayers complies with regulatory requirements. However, it is recommended to incorporate necessary technologies related to internal and external cleaning to ensure compliance with current regulations. According to our evaluation tool, the same sprayers receive an overall classification of B, indicating a low risk of environmental contamination, making them suitable for market placement and field use. In the case of checking the 2000 EOLO GTE10 sprayer using the same STEP-WATER evaluation system, it complies with current regulations but requires improvement in certain technological aspects and the inclusion of relevant details in the instruction manual. Our evaluation tool highlights the absence of necessary information in the user guide, which is essential for guiding operators before, during, and after phytosanitary application. Finally, Table 10 below shows the general classification of the sprayers, their shortcomings, and recommendations to the manufacturers.

Table 10. Results of all sprayers of general evaluation performed by the ENVISPRAY tool with shortcomings and recommendations for each manufacturer.

Manufacturer	**SAHER**	**AMP SPRAYERS**		**TEYME**
Sprayer type Model Classification sprayer	Airblast sprayer Vortex Viña 2000 B	Airblast sprayer A2000 B	Boom sprayer Pulmatic 3000 B	Airblast sprayer 2000 EOLO GTE10 A
Shortcomings	There is no information available regarding the roughness depth of the spray tank. The instructional handbook does not provide information in accordance with clauses 5 and 6 of ISO 16119 2–3.			
Recommendations	Enhance the clarity and comprehensiveness of the instructional handbook, particularly regarding technical specifications and operational procedures. Improve the design or materials used in the spray tank to reduce residue buildup and enhance cleanliness. Ensure that the sprayer system facilitates easy adjustment and regulation of volume per hectare for optimal application. Conduct regular maintenance checks on the operator's wash tank to ensure it meets required standards and volumes. Continuously monitor and assess overall sprayer performance to identify areas for improvement in design, functionality, or efficiency.			

4. Conclusions

Various DSSs are available with specific focuses, such as assessing sprayer design or addressing the needs of specific crops. An example is STEP-WATER, which concentrates on optimizing sprayer operations for sustainability and compliance with agricultural practices by evaluating aspects like tank filling, cleaning systems, waste management, and spray-loss reduction. This tool is a valuable resource for farmers, aiding in the identification of key features in new sprayers or adapting existing ones. Additionally, there are crop-specific DSSs, such as EvaSpray Viti for vineyard sprayers and PERFORMANCE PULVÉ® for wine growers, aiming to classify sprayers based on off-target loss risk and enhance the use of plant protection products, respectively. These specialized DSSs provide targeted assistance in optimizing sprayer performance within specific agricultural contexts.

The ENVISPRAY tool serves as a comprehensive assessment tool for agricultural sprayers, specifically focusing on evaluating environmental contamination risks in accordance with ISO standards and Directives 127/EC and 128/EC. It has demonstrated practicality and functionality in thoroughly assessing key elements of agricultural sprayers by assessing different commercial airblast sprayers as well as horizontal boom spray systems. This tool proves instrumental for manufacturers and distributors of agricultural machinery, providing valuable insights to enhance the components of application equipment. By aligning with the performance requirements of agricultural applications, ENVISPRAY plays a crucial role in driving improvements in the design and functionality of agricultural sprayers, contributing to more sustainable and environmentally conscious practices in the agriculture sector.

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