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Evaluation of Sanitary and Environmental Impact of Plant Protection Practices in Vineyards of Southwestern France: Organic and Conventional/Integrated Agriculture

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Abstract: The French wine industry is spread across the country and represents 789,000 ha (2023). Over 20% of the plant protection products (PPPs) sold in France are used in viticulture on less than 4% of the French UAA (Utilized Agricultural Area). The share of wine estates with organic farming certification has risen sharply, reaching 9% of French vineyards in 2016. The position occupied by the wine sector on both the national and international scale confirms the need to examine the impacts of different management practices in viticulture on human health and the environment. This study presents an approach to the assessment of plant protection practices in vineyards based on indicators of plant protection pressure and risk. It was carried out on wine-growing farms in the southwest of France, surveyed according to the two farming systems: conventional/integrated and organic. The main objective of this study was to compare the health and environmental impact of the PPPs used in these two farming systems. The impact assessment result of wine-growing plant protection practices shows that some pesticides and molecules used in organic farming, especially those based on copper and sulfur, are more harmful than products used in conventional/integrated farming, in particular to the environment. For this reason, all stakeholders involved in pesticide management should recognize the health and environmental impact of PPPs in order to reduce and to control their toxicity risks to public health and the natural environment.

Keywords: pesticides; risk indicators; vineyards

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1. Introduction

The agriculture industrialization phase between 1950 and 1980 saw the introduction of new technologies in terms of mechanization and the type of inputs used [1]. It marked the beginning of the evolution of practices with a view to increasing the profitability and productivity of farms. The use of chemical fertilizers, plant protection products, genetic development, and monocultures became widespread. Agriculture became intensive and less and less diversified, which led to the emergence of health and environmental concerns a few decades later.

Like most agricultural activities, wine-growing phytosanitary practices have impacts on many environmental systems due to the excessive use of plant protection products (PPPs) [2–4]. Over 20% of the PPPs sold in France are used in viticulture on less than 4% of the French UAA (Utilized Agricultural Area) [5]. The effects of wine-growing practices were also highlighted in the 2004 report of the *Institut Français de l'Environnement* (IFEN, i.e., the French Institute for the Environment), which exposed the presence of pesticides in the surface and groundwater. Indeed, although these practices have made it possible to improve the sanitary quality of crops and produce quality wine, they are the source of diffuse pollution with a cumulative nature, which also has potential health impacts linked to the excessive use of plant protection products. Wine-growing plant protection practices are responsible for the pollution of surface and underground water in two forms: point-source pollution and diffuse pollution [6]. Diffuse water pollution can be significant if treatments with fungicides or pesticides are repeated, especially during rainy episodes following an application or if the topography of the vineyard is conducive to runoff [7]. In addition, active ingredients are easily carried away by runoff to surface water or to groundwater located below the vineyard by infiltration into the fault structure [8,9]. Point-source pollution occurs following errors in the handling of plant protection products or spray applications, such as emptying tank bottoms and discharging rinsing water loaded with chemical residues [10,11].

In addition, imposing vine varieties and using monocultures have a negative impact on animal biodiversity, which is known to depend on plant biodiversity. Indeed, the intensification of wine-growing practices, and particularly the use of plant protection products, leads to an imbalance because it reduces and fragments semi-natural habitats, which degrades biodiversity [12–15].

For several years now, the intensive paradigm that dominates viticulture has been actively called into question [16]. Although wine-growing practices have made it possible to improve the sanitary quality of harvests and to produce quality wine, they have caused damage to the image of wine-growing areas and to the sector. Indeed, the image of wine is strongly linked to its quality, but also to the conditions in which it is produced. The various consequences on human health [17–19] and the environment [20,21] linked to the use of plant protection products are now known. Consequently, the objective is no longer only to produce in large quantities, but also to respect the quality of the products [22,23] and to limit environmental impacts [24,25].

The evolution of viticulture towards more environmentally friendly practices is driven by regulatory and societal pressure [26]. The demand does not only come from consumers but also from other stakeholders involved in wine-growing, such as producers/farms, wine merchants, or cooperatives. In addition to guaranteeing the viability and sustainability of viticulture by protecting ecosystems and consumer health, an improved approach to environmental issues could provide economic value.

Indeed, integrated farming is an approach that considers environmental protection, human health, and animal welfare. It was regulated by the French Ministries of Agriculture and Ecology between 2002 and 2013 through certification but is no longer regulated [27].

Organic farming (AB, i.e., "*Agriculture Biologique*") was created by the Ministry of Agriculture and recognized by the law of 4 July 1980 [28]. Its practices were formalized by the 1994 regulation and aim to respect natural balances by avoiding the use of synthetic chemicals [29].

The same regulations apply throughout the European Union. EU Regulation 2018/848 and its implementing texts specify all the provisions to be complied with (see Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 relating to organic production and labeling of organic products. Consolidated version of 1 January

2022. https://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX:02018R0848-20220101 (accessed on 5 September 2024)). Organic agricultural production activities are based on specific principles such as the preservation and development of the natural fertility of the soil, the minimization of the use of non-renewable resources and external inputs, the preservation of plant health through preventive measures, the use of seeds and animals with greater genetic diversity, a high degree of disease resistance, and high longevity, etc.

The Common Agricultural Policy (CAP) has set up a system of conversion aid for AB. The share of wine estates under the organic farming (AB) certification has risen sharply, reaching 10% of French vineyards in 2018 [30].

The share of this area is greater in viticulture than in agriculture in general, since 6.5% of the French agricultural UAA is certified AB [30]. This organic farming (AB) certification is rapidly spreading in the Occitanie region. Organic viticulture in Occitanie is expanding from one year to the next, both in terms of surface area and in terms of the number of producers under organic certification. Indeed, the Occitanie wine industry covered 28,833 ha in 2020 (36% of the French organic wine industry) and presented notable evolution dynamics [31]. Occitanie and Nouvelle-Aquitaine, in particular, showed the most significant increases in surface area in 2017, with +14% and +11%, respectively [32].

These changes in practices towards more environmentally friendly practices are either part of sustainable development approaches or voluntary private sector initiatives. The stakeholders of this branch of the wine industry are investing in and looking for solutions to improve practices. Indeed, the environmental consequences of agricultural activities have become a major concern for society and for the CAP and environmental policy institutions, which are increasingly encouraging farmers to adopt environmentally friendly practices [33].

By using 20% of the total plant protection products used in French agriculture, even though it only represents 4% of the French agricultural area, viticulture is directly involved in all health and environmental issues [34]. Indeed, it is partly responsible for the pollution of surface and groundwater, but also for the risks to consumer health.

According to the OECD (2001), two families of indicators for pesticides can be distinguished in order to study and manage plant protection products:

- Pesticide pressure/use indicators describe trends in the use of pesticides over time. These types of indicators are the simplest, since they require less information;
- Risk indicators are associated with pesticides that relate to potential polluting pressure. They are characterized by a more complex construction, since they integrate the characteristics of active substances and their toxicities.

Current policies for reducing the use of protection products, such as the Ecophyto 2018 plan, use pressure indicators, including the three main indicators to monitor the evolution of the use of plant protection products in France: the Amount of Active Substances (QSA), the Number of Dose Units (NODU), and the treatment frequency indicator (TFI).

Pressure indicators do not consider the specific characteristics of each plant protection product, such as its behavior in the environment, toxicity to non-target organisms, ecotoxicity to the environment, or the effects on the applicator's health [35]. In the context of a risk study on the use of plant protection products, it is essential to adopt indicators that provide additional information on health and environmental impacts.

In addition to pressure indicators, impact/risk indicators have been developed to allow for the assessment of the environmental and health risks of pesticides. There is a multitude of methods and indicators developed in the literature to study pesticide risks.

Our research work also seeks to assess the risk of diffuse pollution related to plant protection practices in vineyards of southwest France. The main purpose is to assess the toxicity risk linked to plant protection products applied during vineyard plot treatment based on a combination of existing tools [36–39] and to establish a comparison between the risk associated with organic wine-growing and conventional/integrated farms. Through this result, it will be possible to identify the pesticides with the highest risk in order to improve farmers' choices in terms of phytosanitary treatment. This study is an assessment of plant protection practices in viticulture based on indicators of pressure (TFI: treatment frequency indicator) and risk (IRSA: indicator of risk to applicator health; IRTE: indicator of toxicity risk to the environment). Several indicators were developed to assess the impact of pesticides on health and the environment [40–43]. Due to the lack of global indicators to assess the toxicity risk of plant protection practices on health and the environment, the CIHEAM-IAMM team has developed risk indicators (IRSA and IRTE) of pesticide use on health and the environment, allowing for the consideration of the ecotoxicological and toxicological impact of molecules and their physico-chemical properties [38,39]. The results of the indicators are derived from the EToPhy software (2020, APP deposit n°: IDDN.FR.001.090003.000. S.P.2020.000.31500. https://www.dephyto.com/ (accessed on 12 September 2024)) developed by the CIHEAM-IAMM research team [38,44–46]. This approach therefore requires the mobilization of a database of plant protection practices in the vineyards of southwestern France.

Despite the significant role of viticulture in the French agricultural sector, the health and environmental impacts of plant protection practices remain a critical and insufficiently explored issue. Organic farming is often perceived as more sustainable and environmentally friendly. However, its reliance on copper- and sulfur-based products raises questions about its actual environmental impact compared to conventional or integrated farming systems. This study addresses the following research problem: To what extent do organic and conventional/integrated farming systems differ in their health and environmental impacts, and how do specific phytosanitary practices contribute to these outcomes? We hypothesize that organic farming, while reducing certain health risks, may present significant environmental risks due to the use of copper and sulfur. Conversely, we expect conventional/integrated farming to pose higher health risks due to synthetic products but potentially lower environmental risks in specific contexts. By examining these hypotheses, this research aims to provide a nuanced understanding of the trade-offs and inform stakeholders about strategies for sustainable viticulture.

This study is essential because it addresses a significant gap in the existing literature: the lack of a comparative and localized assessment of phytosanitary practices in organic and conventional/integrated farming systems. Previous research has often been limited in geographical scope or focused on broader trends without examining specific farming practices in detail. By focusing on the Gironde department, a key wine-producing region, this study provides a unique perspective that combines methodological rigor with practical relevance. It aims to support stakeholders in adopting more sustainable practices, thus contributing to both scientific understanding and practical solutions in sustainable viticulture.

This article is structured into three main sections (except for the Introduction), each addressing key aspects of the health and environmental impact assessment of plant protection practices in vineyards. The first section introduces the approach used in this assessment, including a presentation of the study area and an analysis of phytosanitary practices in organic and conventional/integrated farming systems. It details the methodological framework, the sample of wine-growing farms surveyed, and the indicators developed to evaluate the impact of these practices. The second section focuses on the analysis of wine-growing phytosanitary practices, comparing them across farming systems and within the Gironde department. This includes descriptive statistical analyses and specific impact assessments of cropping treatments for conventional/integrated and organic farming plots. Finally, the article concludes by summarizing the findings and their implications for sustainable wine-growing practices.

2. Approach to the Health and Environmental Impact Assessment of Plant Protection Practices in Vineyards

2.1. Presentation of the Study Area

In order to study plant protection practices in viticulture and to assess their associated risk level to human health and the environment, various field surveys were carried out to collect information on cropping treatment schedules at the wine-growing plot level. This work was carried out in two departments in southwestern France: Gironde and Hérault (Figure 1).

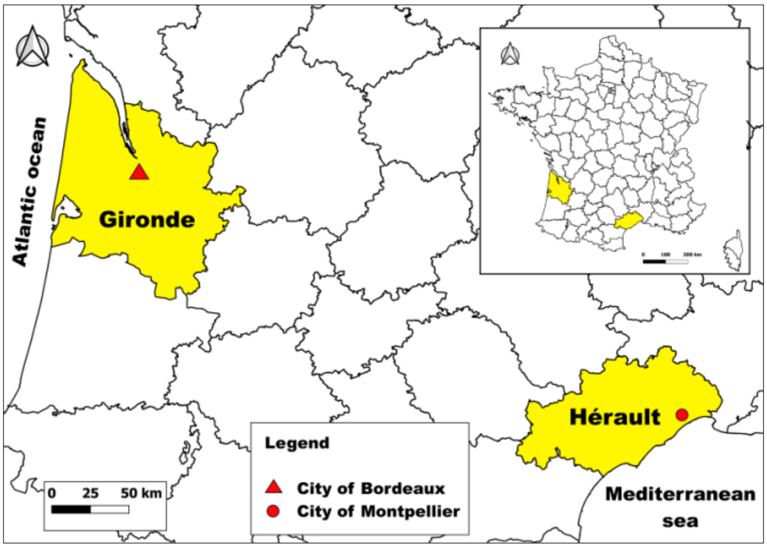


Figure 1. Location of the study area (source: BDD Geofla (https://www.data.gouv.fr/fr/datasets/geofla-r/ (accessed on 18 September 2024)) 2016).

In the Hérault department, the farms surveyed are located across 9 communes in the *Etang de l'Or* watershed, a few kilometers east of Montpellier, and in the commune of Combaillaux (north of Montpellier). In the Gironde department, the farms are located in the experimental catchment area of Marcillac in the Blayais area (north of Bordeaux), a wine-growing region located on the right bank of the Gironde estuary.

The southern and southwestern French departments, especially the Gironde department, offer significant territorial diversity across the Great South-West of France. However, agriculture occupies a large part of each department: nearly half of the department area (Figure 2).

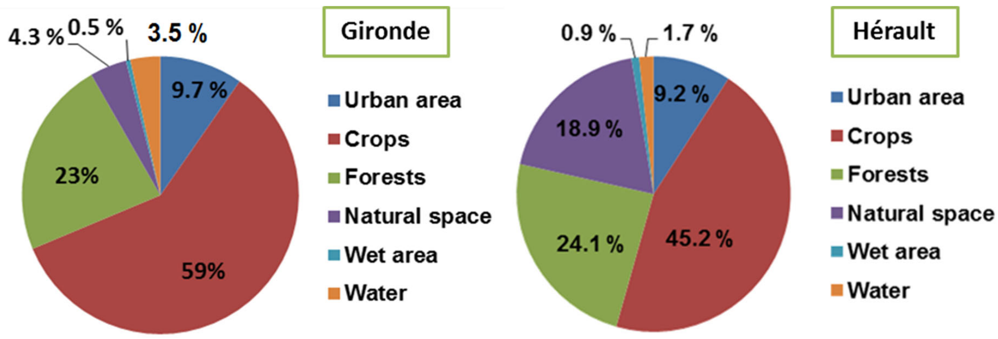


Figure 2. Land use in the Gironde and Hérault departments (source: OSO 2017 data of Theia cnes (https://theia.cnes.fr/atdistrib/rocket/#/search?collection=OSO (accessed on 28 September 2024))).

The Gironde department is dominated by permanent crops, which accounts for its high pesticide consumption [47]. It is ranked as the leading pesticide consumer in France, with over 3400 tons [48]. It is characterized by a strong wine-growing footprint (it is the largest French wine-growing department), and its wine industry extends over 120,120 ha, i.e., almost half of the departmental agricultural area (272,062 ha), of which 13,909 ha are certified organic [49]. Gironde is the country's largest organic wine-growing department, followed by Hérault.

The Hérault department is the second largest wine-growing department in France, with 84,945 ha of vineyards (45% of his UAA) [50]. The share of wine estates under AB organic certification has increased significantly in this department. Organic wine-growing areas cover 12,255 ha [49]. The Occitanie region is the emblem of organic wine in France, as it covers 38% of the French organic wine-growing area [30].

2.2. Approach to Analysis of Wine-Growing Phytosanitary Practices in Organic and Conventional/Integrated Farming Systems

2.2.1. Methodological Approach

Figure 3 below presents the methodological approach to the analysis of plant protection practices in the vineyards of southwestern France. It shows the initial database and its use in the process of calculating the pressure and risk indicators TFI, IRSA, and IRTE [37,38], as well as the analysis of the results obtained according to the organic and conventional/integrated farming systems.

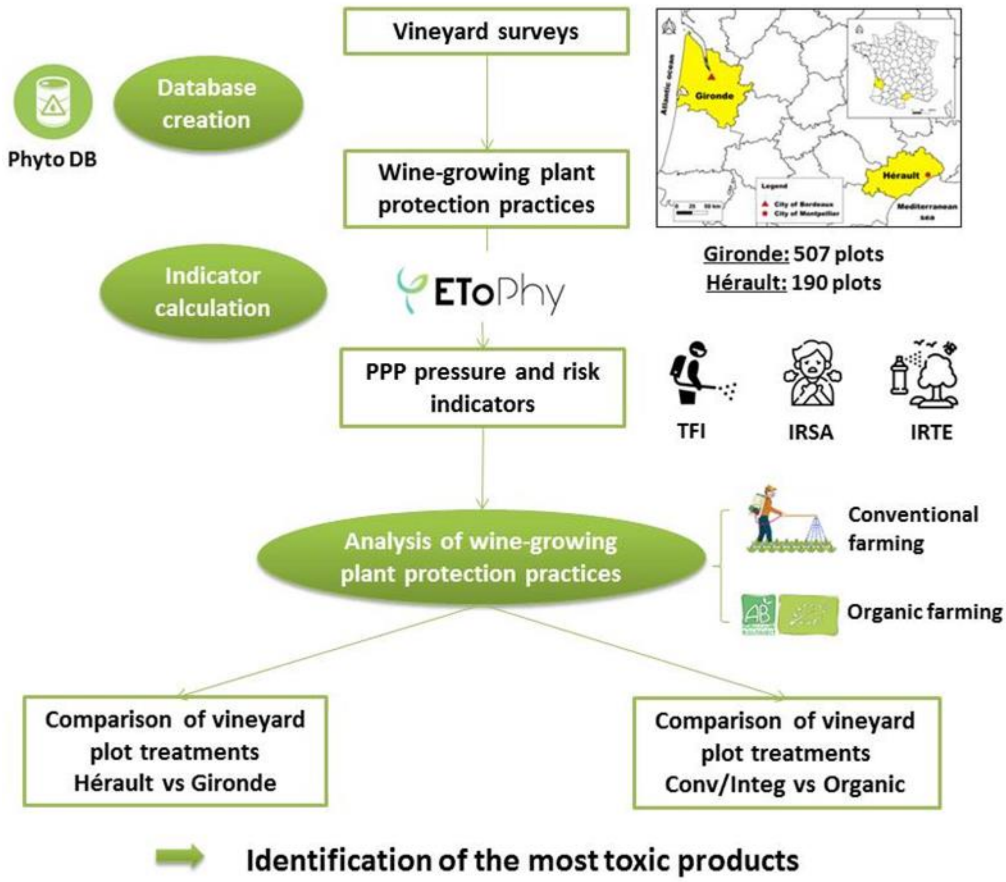


Figure 3. Methodological approach to plant protection practice analysis.

2.2.2. Presentation of the Sample of Wine-Growing Farms Surveyed

Since 2009, the research team at the Mediterranean Agronomic Institute of Montpellier (CIHEAM-IAMM) has been building a database of plant protection practices collected from farmers and agricultural cooperatives in two departments in the south-west of France: Hérault and Gironde. A total of 49 representative wine-growing farms were surveyed during only one year, 2015/2016. In the Gironde department, 507 cropping treatment schedules were collected (which corresponds to the number of plots). These surveys in the Gironde department were carried out in collaboration with INRAE of Bordeaux, ETBX research unit [51,52]. A total of 190 cropping treatment schedules were collected from winegrowers in the Hérault department. The sampling of vineyard plots in this department was carried out within the framework of the Tram research project (Plan Ecophyto 2018) [38,39,44,53]. (The Tram (2010–2014) research project was approved in September 2010 and was funded by ONEMA. Its objectives were to develop a methodology for testing the agro-environmental and technical-economic impact of an integrated reduction in the use of pesticides, taking into account the different levers of action from field level to catchment area level with weightings to take account of environmental specificities. https://ecophytopic.fr/recherche-innovation/concevoir-son-systeme/projet-tram (accessed on 12 September 2024)) These farms in the departments of Gironde and Hérault were divided into conventional/integrated and organic vineyards (Table 1).

Table 1. Distribution of the wine-growing farms surveyed by department.

Department	Crop	Number of Farms	Number of Plots	Area (ha)
Gironde	Conv/integrated vineyard	30	467	726.60
	Organic vineyard	9	40	195.83
Hérault	Conv/integrated vineyard	9	180	348.74
	Organic vineyard	1	10	19.82
	Total	49	697	1291

This sampling will be used to assess the health and environmental impact of plant protection agricultural practices using pressure (TFI) and risk (IRSA and IRTE) indicator outcomes from the EToPhy tool on the surveyed wine-growing farms in the Hérault and Gironde departments and according to conventional/integrated and organic farming systems.

2.2.3. Indicators for Assessing the Plant Protection Impact of Wine-Growing Phytosanitary Practices

The assessment of plant protection practices is based on the complementarity between the TFI, IRSA, IRTE, and risk sub-indicators (acute IRSA; chronic IRSA; terrestrial IRTE; bird IRTE; aquatic IRTE), which makes it possible to determine the degree of toxicity of the practices to human health and to the three environmental systems: soil, air, and water [38,39].

- The treatment frequency indicator (TFI): Plant protection pressure varies from one region to another and depends on soil and climatic conditions, agricultural practices, sanitary pressure, and the crops concerned. Because of their large surface area or their particular sensitivity to one or more pest(s), some crops, particularly fruit trees and vines, accumulate a high proportion of the pesticides used. The treatment frequency indicator (TFI) corresponds to the number of registered doses applied to a plot during a crop year. The registered dose is defined as the effective application dose of a product according to the pair (crop/pest).

$$TFI = \frac{\text{applied dose}}{refrence\ dose} \times \frac{treated\ surface}{\text{plot area}} \quad (1)$$

This indicator is calculated at different levels depending on the need for analysis (product, plot, crop, farm, and region) [54]. Consequently, the TFI reflects the intensity of PPPs use and therefore the plant protection pressure exerted at the different levels, and it also describes the dependence of farmers on these products.

- Agri-environmental indicators (IRSA and IRTE): In this study, the choice of parameters was based on the risk indicators IRSA (indicator of risk to applicator health) and IRTE (indicator of toxicity risk to the environment), both calculated using the EToPhy software. These indicators are generic and modular, and they can be calculated at different levels, from plot to farm [38,39,55]. They are subsequently used to analyze the health and environmental risk of plant protection practices by crop. The calculation of IRSA and IRTE indicators is performed for each active ingredient (AI) according to the following equations:

$$IRSA = \text{IRT AI} \times \text{FPf} \times \text{FCP} \quad (2)$$

$$IRTE = (1.75 \times (T + O) + A + M + P + 1)^2 \quad (3)$$

IRSA and IRTE are composite indicators that assess the acute and chronic toxicity of plant protection products by taking into account several critical variables such as the characteristics of the active ingredient (physicochemical and ecotoxicological properties), the commercial preparation (concentration of the active substance, applied dose, . . .), the place of application (full field, greenhouse cultivation, . . .) and the type of crop (market gardening, arboriculture, . . .).

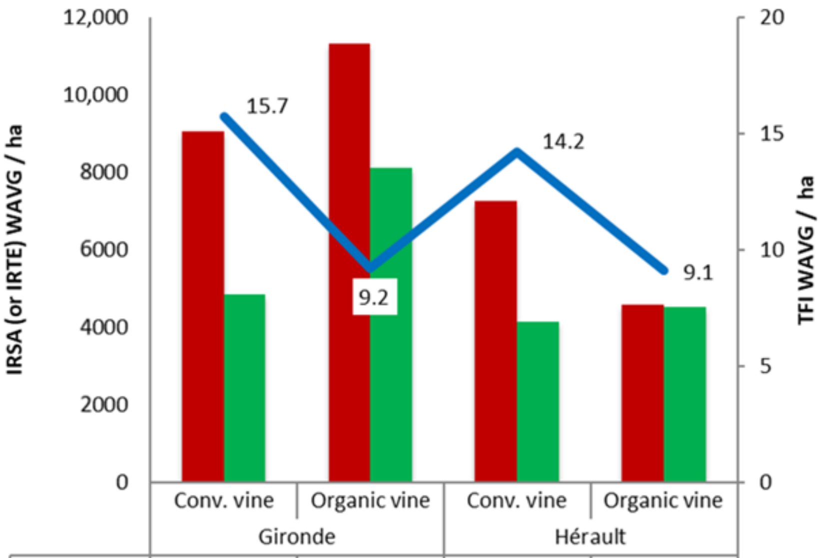
The indicator of risk to applicator health (IRSA) is a scoring indicator. It assesses the acute and chronic toxicities of plant protection products by considering the physicochemical and toxicological properties of active ingredients. Furthermore, this indicator is broken down into sub-indicators: acute toxicity (acute IRSA), which is related to skin and eye irritation, inhalation, etc., and chronic toxicity (chronic IRSA), which represents the risks related to cancer, reproduction, neurotoxicity, and endocrine disruption [38,39,41]. This indicator is based on the calculation of the Toxicity Risk Index (IRT), which takes into consideration the acute and chronic toxicity of active ingredients with their persistence factor (bioaccumulation in living tissues).

The indicator of toxicity risk to the environment (IRTE) assesses the eco-toxicological impacts on non-target living organisms (terrestrial invertebrates, birds, aquatic organisms), as well as the physico-chemical behavior of molecules in the receiving environment (mobility, persistence in the soil, bioaccumulation). Its calculation is based on physicochemical parameters, eco-toxicity, interception factors, drift, runoff, and drainage potential [38,39,41,56]. This indicator is broken down into three sub-indicators: terrestrial IRTE (IRTE T), bird IRTE (IRTE B), and aquatic IRTE (IRTE A). They allow decision-makers and researchers to implement strategies for protecting target organisms, mainly bees and pollinating insects, and reducing toxicity in aquatic environments.

3. Analysis of Wine-Growing Phytosanitary Practices According to Farming Systems

3.1. Overall Analysis of Plant Protection Practices in Vineyards and Comparison Between Departments and Farming Systems

The results of the global analysis of the plant protection practices applied on the surveyed farms in the Gironde and Hérault departments are illustrated in the figure below (Figure 4).



	Gironde Conv. vine	Gironde Organic vine	Hérault Conv. vine	Hérault Organic vine
IRSA/ha	9039	11,305	7243	4589
IRTE/ha	4852	8117	4146	4515
TFI/ha	15.7	9.2	14.2	9.1

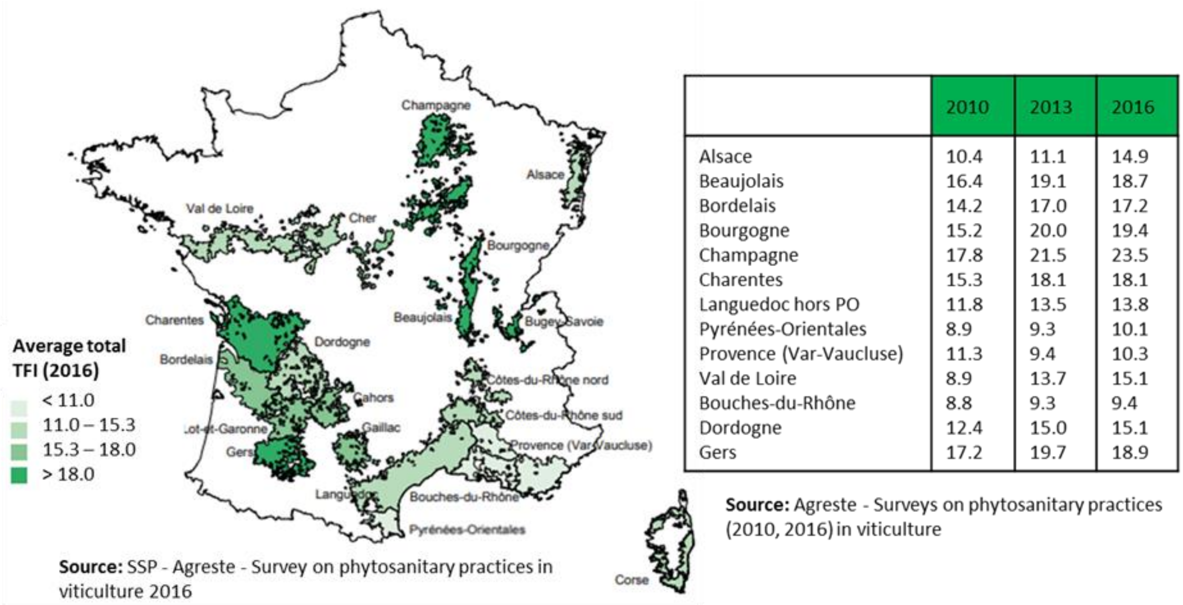
Figure 4. Variability of indicators according to conventional/integrated and organic farming between departments (values expressed as weighted average per hectare).

The graph presents the results of the phytosanitary pressure and risk indicators (TFI, IRSA, and IRTE) in the two departments for conventional/integrated and organic farming systems.

This illustration shows a difference between the two departments in terms of risk. The risk to the applicator's health and to the environment is higher in Gironde than in Hérault. However, it is important to bear in mind that the data collected in the Gironde department only concern one year (2015–2016), which shows that the climate effect is not negligible. This effect acts indirectly on the choice of plant protection products, which changes from a dry year to a wet year, requiring more interventions and more effective products against certain diseases and pests.

According to farming systems, the average TFI/ha in organic farming is lower than in conventional/integrated farming (in Gironde, TFI conventional/integrated vine = 15.7; TFI organic vine = 9.2). This explains why farmers tend to decrease the treatment frequency when switching from conventional/integrated to organic farming. By comparing the average TFI/ha values of our sampling with the average TFI values on the different wine-growing areas in France based on surveys of wine-growing phytosanitary practices during the year 2016 calculated and published by Agreste (The Agriculture Ministerial Statistical Department in France) in 2019, we find that the value of TFI in the Bordelais wine-growing area is 17.2 (Figure 5) against a value of 15.7 calculated on our sampling. In the Languedoc wine-growing area, the average TFI/ha according to the Agreste report is 13.8 (Figure 5), against a value of 14.2 in our study (Figure 4). The values are close, which confirms the results of a comparison study [57] which aims to analyze the phytosanitary pressure variability between the different wine-growing areas but without taking into account organic wine-growing practices. Our study complements these results while also emphasizing the comparison between farming systems (conventional/integrated vs. organic).

According to results presented in Figure 4, the risk level is much higher for organic farming in our study sample from the Gironde department. This result shows, firstly, that there is no correlation between treatment frequency and risk. The risk to the applicator's health is not correlated with the TFI of plant protection pressure. Therefore, an increase in the TFI cannot lead to a direct increase in risk. However, this increase is mainly due to the products used and the acute and chronic toxicity degree of the active ingredients chosen by the farmers. Secondly, it can be concluded that even if the plant protection products in organic farming are not used very frequently, they present a significant risk to health and the environment compared to conventional methods in the Gironde department. This is therefore due to poor choices on the part of the farmers, choices based only on the efficiency of the products yet ones which do not take into account their eco-toxicological and toxicological characteristics.



	2010	2013	2016
Alsace	10.4	11.1	14.9
Beaujolais	16.4	19.1	18.7
Bordelais	14.2	17.0	17.2
Bourgogne	15.2	20.0	19.4
Champagne	17.8	21.5	23.5
Charentes	15.3	18.1	18.1
Languedoc hors PO	11.8	13.5	13.8
Pyrénées-Orientales	8.9	9.3	10.1
Provence (Var-Vaucluse)	11.3	9.4	10.3
Val de Loire	8.9	13.7	15.1
Bouches-du-Rhône	8.8	9.3	9.4
Dordogne	12.4	15.0	15.1
Gers	17.2	19.7	18.9

Figure 5. Average total TFI of wine-growing areas in France [57].

In order to test the dependence of the indicators on each other, a correlation analysis was conducted in order to test the shape of the correlation curve between two indicators. This analysis was performed using RStudio software (Version 1.2.5042), with the indicators of risk and phytosanitary pressure values as input data. The graphs below are the output result (Figure 6). This presentation illustrates a scatter plot of indicator values in order to analyze the correlation between phytosanitary pressure and risk indicators.

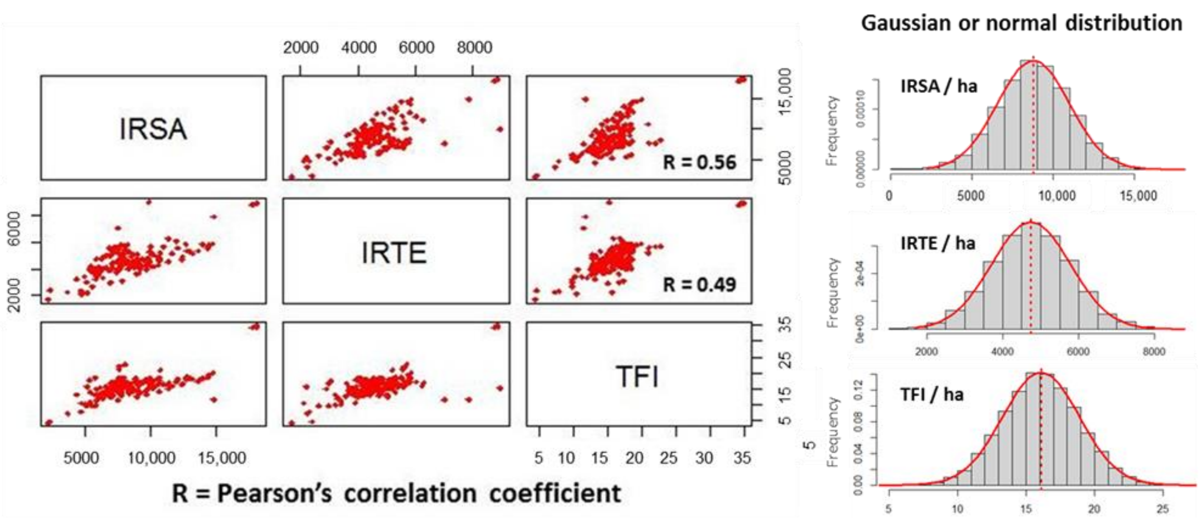
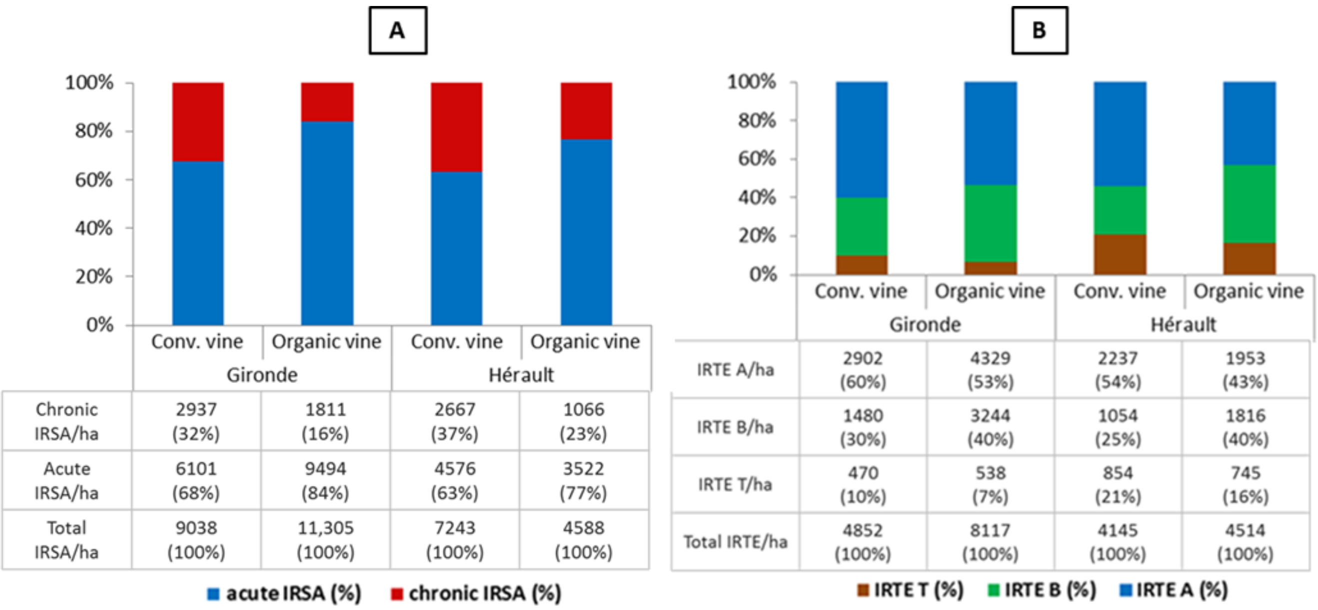


Figure 6. Correlation analysis and Gaussian distribution of phytosanitary pressure and risk indicators.

The scatter plots in the correlation graph between the two risk indicators (IRSA, IRTE) and the TFI barely take on the appearance of a straight line through the origin. Points are distributed randomly. Therefore, the phytosanitary pressure indicator (TFI) is moderately correlated (R value is between 0.4 and 0.6) with the risk indicators IRSA and IRTE. This result shows that the phytosanitary treatment frequency cannot indicate the toxicity expressed by the risk indicators. Even at low frequencies of phytosanitary treatment, the risk indicators appear with very high values. This high toxicity risk is related to the eco-toxicological characteristics of the products and active ingredients and it is not directly linked to the dose and frequency of the applied treatment. This is sometimes the case of products applied at a low dose but which induce a very high toxicity risk. This analysis clearly shows the usefulness of risk and phytosanitary pressure indicators and the complementarity between these indicators in order to provide an exhaustive analysis of the health and environmental impact of agricultural phytosanitary practices to the different stakeholders involved in pesticide management.

An assessment of the toxicity degree of plant protection practices was carried out using sub-indicators (acute and chronic IRSA; terrestrial, bird, and aquatic IRTE) to obtain a deepened analysis of their health and environmental impact (Figure 7). The graph below shows a comparison of the toxicity share between the two wine-growing farming systems (conventional/integrated, conv.; organic) and between the two departments (Gironde, Hérault). The sub-indicators of risk to human health are presented in figure A and the sub-indicators of risk to the environment are presented in figure B. All values were expressed as weighted average per hectare.



	Gironde Conv. vine	Gironde Organic vine	Hérault Conv. vine	Hérault Organic vine
Chronic IRSA/ha	2937 (32%)	1811 (16%)	2667 (37%)	1066 (23%)
Acute IRSA/ha	6101 (68%)	9494 (84%)	4576 (63%)	3522 (77%)
Total IRSA/ha	9038 (100%)	11,305 (100%)	7243 (100%)	4588 (100%)

	Gironde Conv. vine	Gironde Organic vine	Hérault Conv. vine	Hérault Organic vine
IRTE A/ha	2902 (60%)	4329 (53%)	2237 (54%)	1953 (43%)
IRTE B/ha	1480 (30%)	3244 (40%)	1054 (25%)	1816 (40%)
IRTE T/ha	470 (10%)	538 (7%)	854 (21%)	745 (16%)
Total IRTE/ha	4852 (100%)	8117 (100%)	4145 (100%)	4514 (100%)

Figure 7. The toxicity share of plant protection practices between farming systems and between departments ((**A**): share of acute and chronic toxicity; (**B**): share of toxicity on each environmental system).

Regardless of the farming system and department, the share of acute toxicity risk related to plant protection practices is greater than 60% (Figure 7A). Most of the products used on the wine-growing farms surveyed have a health risk that is more acute (risk of irritation and risk due to inhalation, skin, or ingestion exposure) than chronic (carcinogenic, mutagenic, toxic to reproduction, neurotoxic, and endocrine-disruptive).

Figure 7B illustrates the impact on non-target organisms in the three environmental systems: water (aquatic IRTE), air (bird IRTE), and soil (terrestrial IRTE). The share of toxicity risk to the aquatic environment and birds represents over 80% of the overall risk, regardless of the farming system.

In order to better understand the risk values calculated according to the two farming systems, it is necessary to analyze the plant protection products used that are responsible for this toxicity, whether to human health or to the environment. The following tables illustrate the products and active ingredients that were used the most in our sample of vineyard plot treatments in Gironde and Hérault, including the active ingredients that present the highest risk to human health and the active ingredients that present the highest risk to the environment (Tables 2 and 3).

Table 2. Classification of Top 5 plant protection products and active ingredients used in the two departments according to TFI and the quantity applied in kg/ha.

Most Used Products (High TFI/ha)				**Most Used Active Ingredients (High AI Quantity/ha)**			
Gironde		**Hérault**		**Gironde**		**Hérault**	
Product	**Active Ingredient**	**Product**	**Active Ingredient**	**Active Ingredient**	**AI Qtity (kg/ha)**	**Active Ingredient**	**AI Qtity (kg/ha)**
Chaoline	Fosetyl-aluminum	Abilis	Triadimenol	Sulphur *	10.0	Sulphur *	10.0
Steward	Indoxacarb	Bouillie bordelaise RSR disperss	Copper sulfate	Potassium bicarbonates *	4.2	Potassium phosphonates *	2.9
Ysayo	Cyazofamid	Kavea DG	Mancozeb	Potassium phosphonates *	3.0	Oryzalin	2.9
Jokari	Acrinathrin	Turkoise	Fenazaquin	Copper sulfate *	3.0	Metiram	2.8
Consist	Trifloxystrobin	Clameur	Alpha-cypermethrin	Metiram *	2.8	Mancozeb	2.6

Fungicide, insecticide, acaricide. * Active ingredient used in organic wine-growing plots.

Table 3. Classification of the Top 5 plant protection products used in the two departments according to risk level.

AIs with Higher Risk to Human Health (High IRSA/ha)				**AIs with Higher Risk to Environment (High IRTE/ha)**			
Gironde		**Hérault**		**Gironde**		**Hérault**	
Active Ingredient	**IRSA/ha**	**Active Ingredient**	**IRSA/ha**	**Active Ingredient**	**IRTE/ha**	**Active Ingredient**	**IRTE/ha**
Diquat *	3880	Copper oxychloride	1768	Diquat *	900	Dimethoate	1469
Fluazinam *	1167	Chlorothalonil	1353	Chlorpyrifos-methyl *	756	Chlorpyrifos	1024
Maneb *	837	Fluazinam	1247	Cyfluthrin	650	Chlorpyrifos-methyl *	711
Alpha-cypermethrin *	820	Chlorpyrifos	879	Sulfur *	506	Copper oxychloride	676
Meptyldinocap *	774	Meptyldinocap *	853	Emamectine Benzoate *	473	Cyfluthrin	652

Fungicide, insecticide, acaricide. * Active ingredient used in organic wine-growing plots.

The plots surveyed in the Gironde department used 171 products (with 74 active ingredients). In the Hérault department, 155 products (with 91 active ingredients) were used in all the analyzed plant protection treatments.

The five products with the highest TFI in the Gironde department are fungicides and insecticides (Table 2). The five products with the highest TFI in the Hérault department are a mix of fungicides, insecticides, and an acaricide. They are totally different from those used in Gironde.

The most used active ingredients (AIs) in both departments are sulfur and potassium phosphonates, with different quantities per hectare (10 kg/ha in the Gironde department;

3.2 kg/ha in the Hérault department). These AIs are used in both conventional and organic wine-growing plots. Overall, the results in this table indicate that most of AIs identified in both departments with high quantities are used in organic farming.

The products that represent the highest risk to human health and the environment are classified in the table above (Table 3). Diquat represents the AI with the highest risk to human health (IRSA/ha = 3880) and the environment (IRTE/ha = 900) in the Gironde department.

The active ingredients used in the Gironde department that represent the highest risk of toxicity to human health and the environment are used in organic farming. Copper oxychloride represents the highest risk to human health in the Hérault department (IRSA/ha = 1768).

3.2. Results of the Analysis of Plant Protection Practices in Wine-Growing Plots in the Gironde Department

3.2.1. Descriptive Statistical Analysis of Plant Protection Practices in Wine-Growing Plots

The descriptive statistical analysis of phytosanitary pressure and risk indicators was carried out using RStudio software (Version 1.2.5042) to define a set of statistical parameters in order to assess the variability in plant protection practices at the wine-growing plot level in the Gironde department. The results are presented for the Gironde department as it has more vineyard plot samples.

This analysis was carried out for each farming system (conventional/integrated and organic farming) separately in order to compare the health and environmental impact of the plant protection practices. Table 4 presents a descriptive analysis of the phytosanitary pressure and risk indicators for plots in conventional/integrated farming.

Table 4. Descriptive statistics of phytosanitary pressure and risk indicators of conventional/integrated wine-growing plots in the Gironde department.

Indicators	Min.	Max.	Median	Mean	STDEV	CV
IRSA/ha	2274	18,097	8346	8786	2206	0.25
IRTE/ha	1693	8983	4737	4745	1038	0.22
Acute IRSA/ha	1463	11,730	5766	5853	1423	0.24
Chronic IRSA/ha	539	6500	2893	2933	974	0.33
IRTE T/ha	0	1494	559	512	278	0.54
IRTE B/ha	304	4383	1415	1439	565	0.39
IRTE A/ha	938	6661	2772	2789	645	0.23
TFI/ha	4.3	34.9	15.9	16.1	2.8	0.17

The results show a wide variability in indicator values between the minimum and the maximum values. The risk indicator for human health ranges from 2274 to 18,097. Likewise, the environmental risk indicator ranges from 1693 to 8983. The treatment frequency indicator ranges from 4.3 to 34.9 (Table 4); we know that the average TFI in the Bordeaux wine-growing area was 17.2 in 2016 [57]. These results represent the toxicity risk and phytosanitary pressure values calculated at the plot scale (weighted per hectare) using the EToPhy software (Version 1.2.5042). Although the treated plots were occupied by the same crop and the same farming system, the indicators are highly variable. This variability can be explained by the great differences in farmers' treatment strategies and their choices of plant protection products.

Table 5 presents a descriptive analysis of phytosanitary pressure and risk indicators for plots in organic farming.

The results show a wide variability in indicator values between the minimum and the maximum values. The risk indicator for human health ranges from 8065 to 14,669, with a mean value of 11,469. Likewise, the environmental risk indicator ranges from 6256 to

10,273, with a mean value of 8227. The treatment frequency indicator ranges from 7.3 to 11.3, with a mean value of 9.3.

Table 5. Descriptive statistics of phytosanitary pressure and risk indicators of organic wine-growing plots in the Gironde department.

Indicators	Min.	Max.	Median	Mean	STDEV	CV
IRSA/ha	8065	14,669	11,048	11,469	3047	0.26
IRTE/ha	6256	10,273	9289	8227	1426	0.17
Acute IRSA/ha	6677	12,920	9403	9839	2848	0.29
Chronic IRSA/ha	1118	3189	1709	1630	329	0.20
IRTE T/ha	0	890	415	294	218	0.74
IRTE B/ha	2265	4509	3678	3567	440	0.12
IRTE A/ha	3242	5684	5111	4343	980	0.22
TFI/ha	7.3	11.3	9.9	9.3	1.0	0.10

In order to better present the distribution of the risk indicators calculated for our sample, we present them using box plots, which represent the most suitable method to display our data (Figure 8). Boxes are drawn with ends at quartiles Q1 and Q3. The statistical median Q2 is represented as a horizontal line in the box; there are as many values above this value as there are below it in the sample (Figure 9).

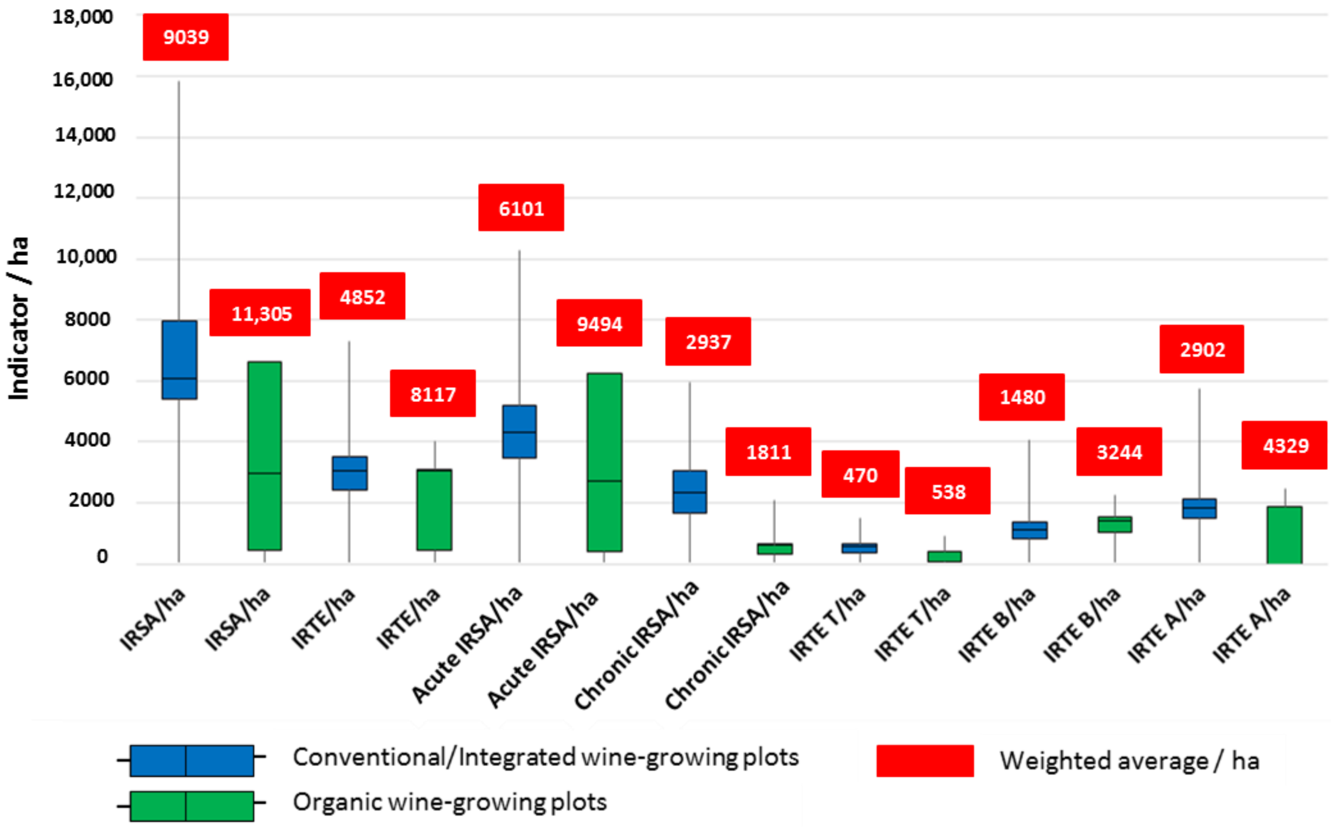


Figure 8. Variability analysis of risk indicators for the surveyed wine-growing plots (conventional/integrated and organic farming).

The graph in Figure 8 shows the variability in the risk indicators and sub-indicators calculated for plots in conventional/integrated and organic farming in the Gironde department. This graph shows more or less symmetrical data, which indicates that the results of the indicators were normally distributed.

The range of the acute IRSA indicator shows good symmetry, with a wide distribution presented by the large difference between the min and max risk values. In contrast, the terrestrial IRTE indicator shows a narrow distribution of values, which indicates that the variability in terrestrial risk toxicity is very low from one cropping treatment schedule to another. The products applied in this farming system (conventional/integrated) present approximately the same level of toxicity.

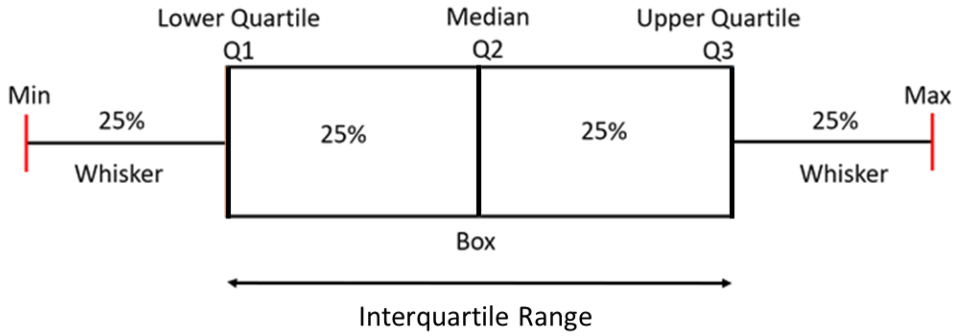


Figure 9. Explanation of the data.

The green boxes show the distribution of the risk indicators and sub-indicators calculated for the organic plots in Gironde (Figure 8). The risk toxicity indicators on the environment show low asymmetry with a narrow distribution. The minimum and maximum risk values are not too far apart, except for acute and human health risk s(acute IRSA and IRSA). So, acute risk represents the indicator with the most variability between minimum and maximum values. Acute risk depends largely on the formulation of the phytosanitary products applied, specifically on the toxicological properties of active ingredients, although the attenuation of human health risk can be achieved by choosing less toxic active ingredients during phytosanitary treatments.

A comparison of the distribution of the two farming systems' risk values shows that the variability within conventional/integrated farming is much higher, as the acute risk indicator varies within a range of 10,000, while that for organic farming does not exceed 6000.

3.2.2. Analysis of the Impact of Cropping Treatments on a Wine-Growing Plot in Conventional/Integrated Farming

This case study of wine-growing plot treatments will allow us to identify the plant protection products used during the cropping season, their treatment frequency, and the toxicity risk level associated with each product. This will be used to select the products that most contribute to the overall risk level for plots.

A conventional/integrated wine-growing plot in the Gironde department was chosen from the group of plots with a medium input of phytosanitary treatments, as it represents values close to the average risk and pressure values (as determined through a cluster analysis of plant protection practices based on pressure and risk indicators as classification criteria). This vineyard plot has an area of 85 ha. On this plot, the farmer chose to treat his vineyard with 22 products (Figure 10 and Table A1 in Appendix A).

The figure shows the risk indicators and the TFI calculated for each product. First of all, it can be noted that there is no correlation between treatment frequency (TFI) and risk (IRSA and IRTE). Fungicide 6 contributes more to risk than to pressure (low TFI), while fungicide 11 has a high TFI and a low level of risk to human health and the environment. The TFI/ha in this plot is low (12.6) if we compare it with the average TFI value for the Bordelais wine-growing area [57].

Six of the products used contribute to more than 50% of the plot's overall risk to human health. These products include five fungicides used against downy mildew and one herbicide. Herbicide 1 is made from ammonium glufosinate, which was withdrawn from the French market by the Anses (French Agency for Food, Environmental, and Occupational

Health and Safety) in 2017 because the risks to human health related to exposure to this product could not be ruled out for the farmers using it as well as for people in the vicinity of the treated areas.

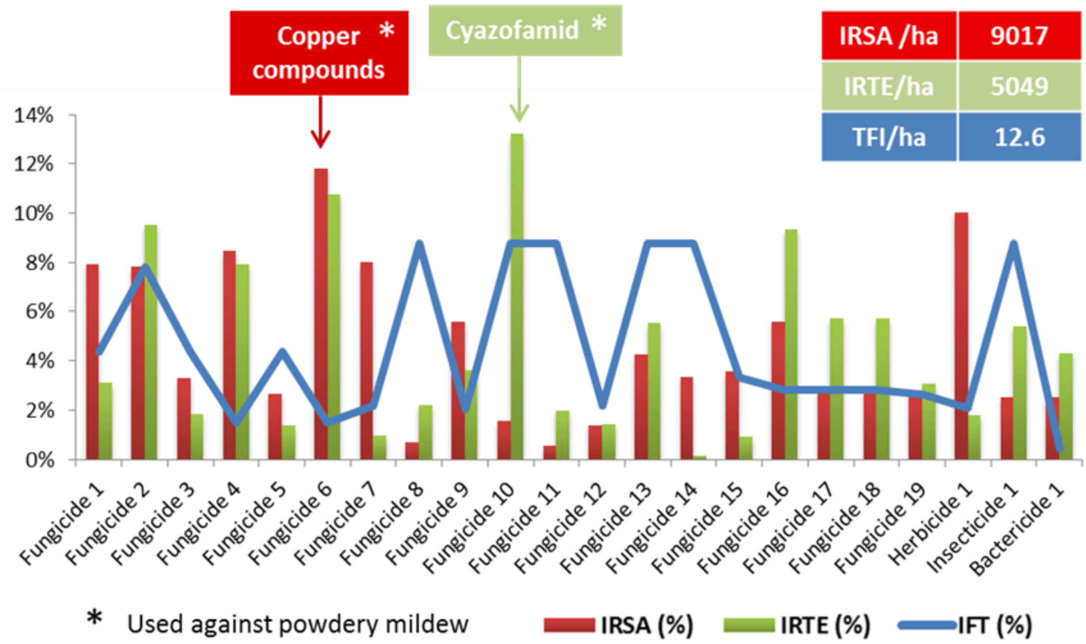


Figure 10. The contribution of the plant protection products applied on a wine-growing plot to risk and plant protection pressure (conventional/integrated farming).

In terms of risk to the environment, we found that four fungicides (fungicides 2, 4, 6, and 10) used against downy mildew contribute the most to environmental risk. Fungicide 10 (active ingredient: Cyazofamide) presents the highest level of environmental risk (14% of the overall plot risk level).

Figure 11 shows the share of acute and chronic toxicity for each product used in the treatment of the wine-growing plot studied in the previous graph (Figure 10). Acute IRSA is equal to 6291 (70% of total IRSA) and chronic IRSA is 2726 (30% of total IRSA). The risk of toxicity to human health on this wine-growing plot mainly involves acute toxicity, which exceeds 50% of the overall toxicity level of all fungicides, except fungicide 7 and 11. On the other hand, the share of toxicity is more chronic rather than acute only in the case of herbicide 1 and insecticide 1. The chronic IRSA of insecticide 1 represents 70% of the overall risk to applicator health; this product generates neurotoxicity, impacts reproduction and organ development, and has endocrine-related effects. In addition, fungicide 7 (active ingredient = Meptyldinocap) and fungicide 11 (active ingredient = Trifloxystrobin) present a high chronic risk.

Breaking down the IRSA into two sub-indicators (acute and chronic IRSA) makes it easier for the farmer to recognize the toxicological characteristics of each product used to avoid products with a high chronic toxicity and to improve pesticide management with a better choice of plant protection products.

Figure 12 presents the share of toxicity risk of each product used for the different environmental systems: air (birds), water (aquatic organisms), and soil (invertebrate terrestrial organisms). The value of aquatic IRTE is equal to 3178 (63% of total IRTE), aerial IRTE is 1674 (33% of total IRTE), and terrestrial IRTE is 197 (4% of total IRTE). We can observe that most of the products have a high aquatic toxicity level, which for some products can represent 100% of their IRTE value, as is the case for fungicides 7 and 8, made with the active ingredients Meptyldinocap and Quinoxyfen.

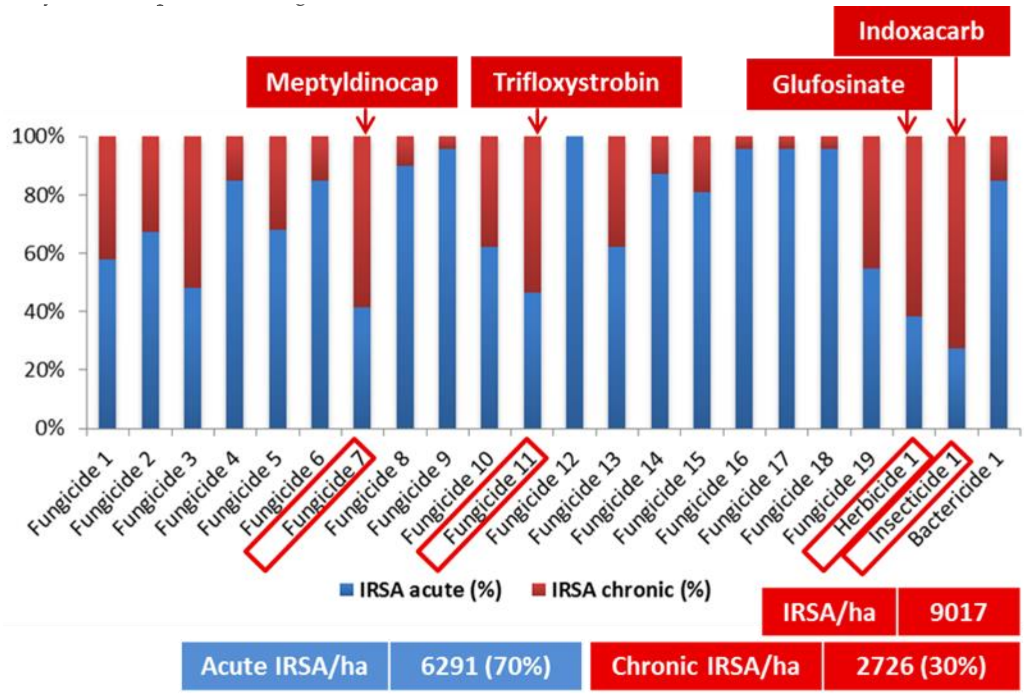


Figure 11. The contribution of the plant protection products used on the conventional/integrated wine-growing plot to acute and chronic toxicity.

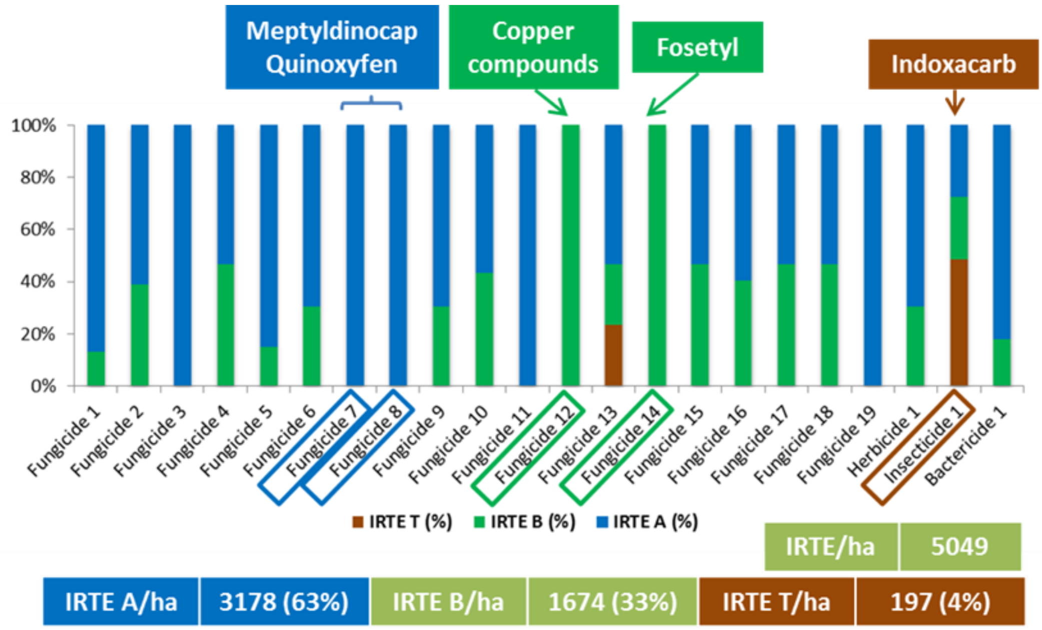


Figure 12. The contribution of the plant protection products used on the conventional/integrated wine-growing plot to toxicity risk for each environmental system.

Fungicide 12 (active ingredient = copper compounds) and fungicide 14 (active ingredient = Fosetyl) represent the highest risk for air. Fungicide 12 is copper-based which gives us an indication of the toxicity of copper-based products to the air environment, in particular birds.

Despite the low risk to the terrestrial environment of all the products used, air toxicity represents more than 50% of the total IRTE for insecticide 1 (active ingredient = Indoxacarb). It is a toxic product for bees that must be used outside the flowering stage.

3.2.3. Analysis of the Impact of Cropping Treatments on a Wine-Growing Plot in Organic Farming

In this part, we will present the results of the plant protection treatment of an organic wine-growing plot in the Gironde department. The plot was chosen from a group of plots which represents the average indicator values for organic farming (as determined through a cluster analysis of plant protection practices based on pressure and risk indicators as classification criteria). The area of this plot is 3.59 ha. On this plot, the farmer used five plant protection products, which are all sulfur- and copper-based fungicides (Figure 13 and Table A2 in Appendix A).

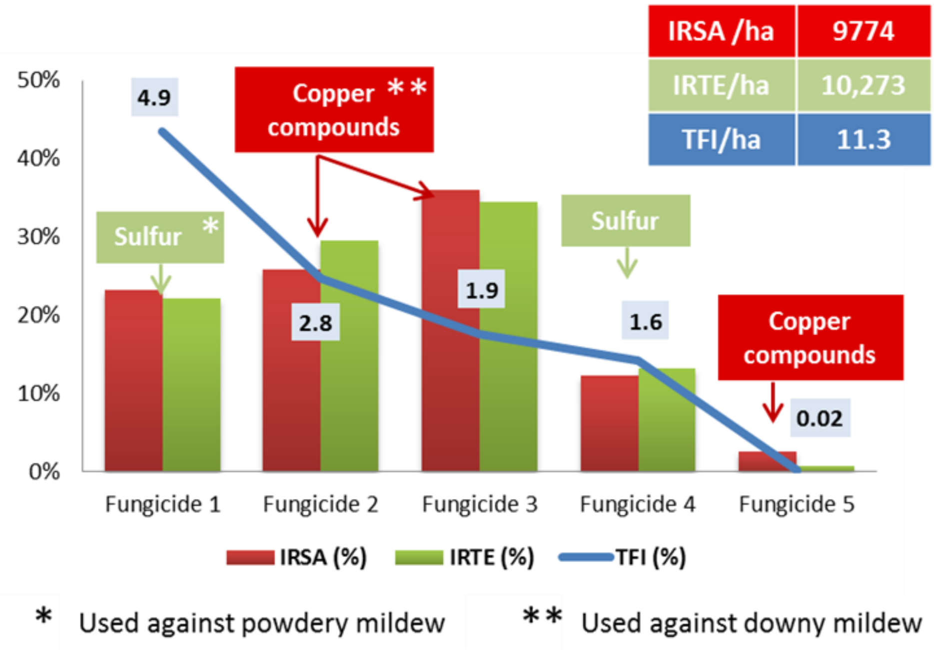


Figure 13. The contribution of the plant protection products applied on the wine-growing plot (organic farming) to risk and plant protection pressure.

These illustrations show the risk indicators and the TFI calculated for each product used in this wine-growing plot. The values of the phytosanitary pressure (TFI) and risk (IRSA and IRTE) indicators do not show a correlation relationship, as in the case of the previously studied conventional/integrated farming plot. Indeed, the decrease in toxicity risk is not associated with a reduction in treatment frequency (TFI), as shown by the comparison between fungicides 1 and 3.

All of the fungicides used in this plot are based on sulfur or copper and thus present a risk to human health and to the environment, particularly fungicides 1, 2, and 3 (Figure 13).

Fungicide 2 and fungicide 3 contribute the most to human health and environmental risk. Nevertheless, they are not used with the highest TFI. These two fungicides are based on the same active ingredient, “copper compounds” made of copper, and used against downy mildew.

Fungicide 1, made of 80% sulfur, is used with the highest TFI (4.9) to control powdery mildew.

Figure 14 presents the share of acute and chronic toxicity for each product used in the treatment of the organic wine-growing plot. IRSA per hectare is equal to 9774; acute IRSA represents the most significant share, with 83% at the plot level. A more detailed analysis shows that the share of toxicity varies from one product to another. Fungicide 2 and fungicide 5 (copper-based) represent more than 70% of the chronic risk to overall human health risk. This type of risk is related to long-term effects such as neurotoxicity, reproduction, and endocrine effects. These two fungicides are used against downy mildew. However, fungicides 1 and 4 (sulfur-based) present a high acute toxicity risk related to short-term effects such as skin and eye irritation and respiratory tract impact via inhalation.

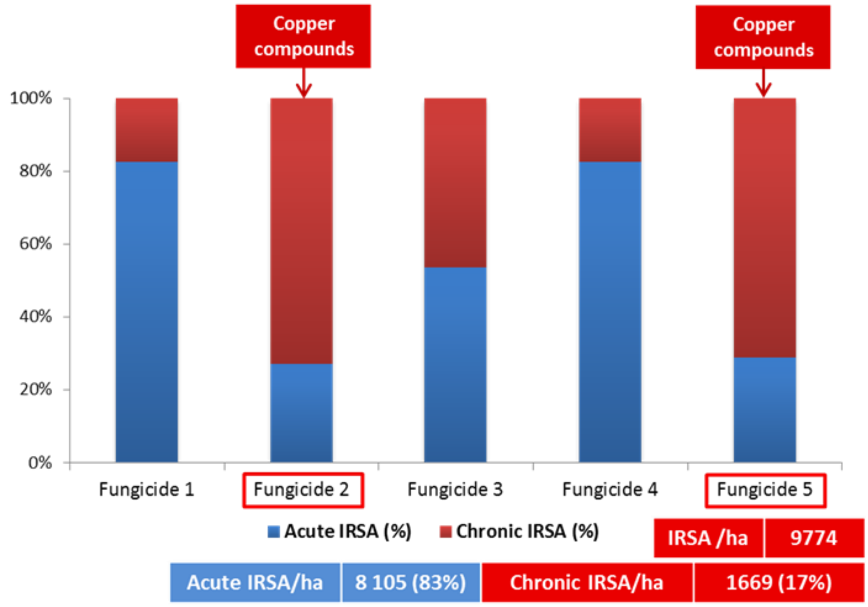


Figure 14. The contribution of the plant protection products used on the organic wine-growing plot to acute and chronic toxicity.

Figure 15 presents each product's share of toxicity risk to the different environmental systems: air (birds), water (aquatic organisms), and soil (invertebrate terrestrial organisms). The value of aquatic IRTE is equal to 5684 (55% of total IRTE), aerial IRTE is 5509 (44% of total IRTE), and terrestrial IRTE is 80 (1% of total IRTE). Copper-based products (fungicide 2, 3, and 5) are almost as toxic to air and aquatic environments as fungicide 2 and fungicide 5. Fungicide 3 contributes the most to aquatic toxicity risk, with more than 60% of the total IRTE. It is made of 35% copper and it is used against downy mildew.

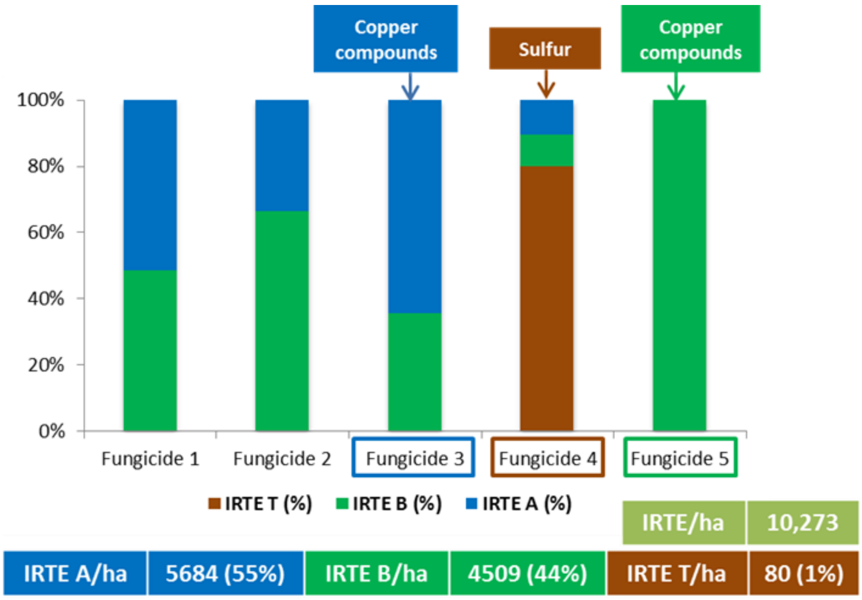


Figure 15. The contribution of the plant protection products used on the organic wine-growing plot to toxicity risk for each environmental system.

A deeper analysis of the environmental impact of plant protection products using sub-indicators can help land management authorities to develop biodiversity protection plans for the fauna and flora and to manage toxicity to natural environments, especially aquatic ones. Moreover, according to the soil type and plot location in relation to watercourses, risk levels can be weighted and more appropriate and targeted action plans can be drawn up in order to limit the impact of some plant protection products that are potentially harmful to human health and the environment.

Figures 12 and 15 illustrate the contribution of each product used to the toxicity risk for different environmental systems: air (birds), water (aquatic organisms), and soil (terrestrial invertebrates), in both conventional/integrated and organic farming systems.

Comparing Figures 12 and 15, 22 products were applied on the conventional vineyard plot, and only 5 products were used on the organic vineyard plot. However, the environmental toxicity risk of the pesticides used on the organic vineyard plot is higher compared to those used on the conventional/integrated vineyard plot (IRTE/ha for organic farming = 10,273; IRTE/ha for conventional/integrated farming = 5049). In contrast, the toxicity risk to applicator health is similar between phytosanitary practices in conventional/integrated and organic vineyards (Figures 11 and 14).

This difference mainly arises from the composition and formulation of the phytosanitary products used. In organic farming, most of the plant protection products are based on sulfur and copper (Appendix A, Tables A1 and A2). Consequently, these substances have a negative impact on aquatic, terrestrial, and aerial environments [58,59] and, in some cases, can be more toxic to living organisms than the substances used in conventional/integrated farming (Figure 15). This observation contradicts the common perception that plant protection products used in organic farming are free from risks to human health and the environment.

As a result, this analysis of the toxicity risk of plant protection products, based on various risk (sub-)indicators (IRSA, IRTE, acute IRSA, chronic IRSA, IRTE A, IRTE B, and IRTE T), helps farmers improve decision-making and choose active ingredients according to their physicochemical characteristics as well as their toxicological and eco-toxicological properties. In both conventional or organic farming, there are several approved products and sub-stances against a given pest or disease. However, farmers typically lack information on the toxicological and eco-toxicological properties needed to identify the substance or product that is least toxic to human health and the environment.

This strategy for improving plant protection practices aims to reduce the impact of pesticides on the environment and human health while designing sustainable farming systems with low inputs, combined with other alternative practices such as biological control and the use of natural pest control methods or environmentally friendly substances.

4. Conclusions

This work demonstrates the value of risk indicators such as IRSA, IRTE, and the treatment frequency indicator (TFI) as essential decision support tools for assessing and managing plant protection practices at the plot level. These indicators help farmers make informed choices to minimize the risks associated with plant protection products (PPPs) that pose significant threats to human health and the environment. By utilizing these tools, farmers can select better alternatives to high-risk products, thus contributing to more sustainable agricultural practices.

Through our analysis, we identified a novel approach for managing the selection of plant protection products based on their potential impact on human health and various environmental components, including air, soil, and water. This study highlights that the risk associated with plant protection practices is primarily determined by the formulation of the products used, with the active ingredient playing a key role. This finding underscores that the risk level is contingent upon the specific molecule applied, rather than the farming system employed.

The variability between farming systems (conventional/integrated and organic) in terms of toxicity risk to both human health and the environment arises from differences in the toxicity profiles of the products used. Conventional farming relies on synthetic products, while organic farming uses naturally derived substances, which, despite being deemed less harmful, still present significant toxicity risks. In organic farming, the high application rates of certain products, particularly sulfur- and copper-based compounds, contribute to environmental toxicity, especially when applied in large quantities. In contrast, the human health risks associated with organic products tend to be more acute and less chronic compared to conventional products.

This study also reveals how assessing the toxicity of different molecules used by farmers can improve the management of phytosanitary treatments at the plot level. The results of this analysis can help refine the monitoring efforts of chemical concentrations in rivers conducted by water agencies in France. By identifying the most commonly used molecules, it is possible to predict which of them are likely to be found in higher concentrations in water sources.

However, this study is not without limitations. The analysis was conducted at the plot level and focused on specific farming systems within a defined geographic area. A broader, territorial-scale approach, such as mapping phytosanitary pressures at the watershed level, would allow for more comprehensive monitoring of the impact of plant protection practices across larger areas. This approach could provide critical insights into the cumulative risks associated with high-intensity agricultural areas and inform future management practices at a regional scale.

Future studies should extend this work to explore the long-term effects of specific plant protection practices on both human health and the environment. A more extensive analysis at a territorial or watershed level, incorporating diverse agricultural landscapes, would allow for a better understanding of the spatial distribution of phytosanitary risks. Furthermore, investigating alternative pest management strategies, such as Integrated Pest Management (IPM), could provide valuable insights into reducing the dependency on high-risk products while maintaining agricultural productivity.

Author Contributions: All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by C.G., O.M., P.L.G., and J.-P.B. The first draft of the manuscript was written by C.G. and all authors commented on previous versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that they have no competing interests.

Appendix A

Table A1. List of plant protection products used on a wine-growing plot (conventional/integrated farming).

Category	Name of Product	Active Ingredient [60]
Fungicide 1	AMALFI	Benalaxyl + Folpet
Fungicide 2	AMALINE FLOW	Copper compounds + Zoxamide
Fungicide 3	FIANAKY	Tebuconazole
Fungicide 4	FUNGURAN OH	Copper (II) hydroxide
Fungicide 5	GRIP TOP	Dimethomorph + Metiram
Fungicide 6	HELIOCUIVRE	Copper (II) hydroxide
Fungicide 7	KARATHANE 3D	Meptyldinocap
Fungicide 8	LEGEND	Quinoxyfen
Fungicide 9	MICROTHIOL SP LIQ	Sulfur
Fungicide 10	MILDICUT	Cyazofamid
Fungicide 11	NATCHEZ	Trifloxystrobin
Fungicide 12	NORDOX 75 WG	Copper (I) oxide
Fungicide 13	PROSPER	Spiroxamine
Fungicide 14	SERVAL	Fosetyl
Fungicide 15	SILLAGE	Fosetyl
Fungicide 16	SOUFREBE DG	Sulfur
Fungicide 17	SULFOJET DF	Sulfur
Fungicide 18	TRILOG	Sulfur
Fungicide 19	TSAR	Myclobutanil + quinoxyfen
Herbicide 1	BASTA F1	Glufosinate
Insecticide 1	STEWARD	Indoxacarb
Bactericide 1	COPERNICO HI BIO WG	Copper (II) hydroxide

Table A2. List of plant protection products used on a wine-growing plot (organic farming).

Category	Name of Product	Active Ingredient [60]
Fungicide 1	AMODE DF	Sulfur
Fungicide 2	BOUILLIE BORDELAISE RSR DISPERSS	Copper sulfate
Fungicide 3	KOCIDE 35 DF (ANCIEN)	Copper (II) hydroxide
Fungicide 4	PENNTHIOL	Sulfur
Fungicide 5	STYROCUIVRE DF	Copper oxychloride

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