# Recommend and guarantee: testing an insurable treatment protocol for reducing pesticide use in vineyards

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**Abstract: Recommend and guarantee: Testing an insurable treatment protocol for reducing pesticide use in vineyards**

There is considerable uncertainty surrounding the status of sanitary threats to crop production in real time. The ratio between the direct costs of pesticide treatments and the costs associated with yield losses would suggest that risk minimization strategies include treatments that are unnecessary, while this is not known when they are selected, and that therefore cause harm to health and the environment. How can we determine the real proportion of such unnecessary treatments and support the direct economic risk of eliminating them? This article focuses on French wine production, known for its high per-unit-area use of fungicides, to describe the testing of an insurable treatment protocol. This protocol has enabled a 30-55% reduction in the use of fungicides between 2019 and 2022 and is combined with an incentive system for the payment of compensation in the event of losses, complementing the current system for covering climatic risks.

***Keywords:*** *decision support system, living lab, treatment protocol, insurance, vineyards, pesticides*

## 1. Introduction

The phylloxera crisis in the second half of the 19th century led to a drop in French wine production, from 70 to 85 million hectoliters in 1870-75 to fewer than 30 million hectoliters in the 1880s (Pouget 2015). The crisis was overcome by introducing resistant rootstocks from North America. These massive imports (10 billion plants uprooted and replaced) might explain how the fungal agents responsible for the mildew and black rot epidemics that were identified in the course of the 19th century arrived in Europe in the first place (Fontaine et al. 2021). These new epidemics were also responsible for severe crop losses, before chemical control methods were discovered and widely used, such as copper-based Bordeaux mixture and sulfur. The development of synthetic fungicides after the Second World War widened the range of molecules available for combating the development of these diseases.

These fungicides are now used on a massive scale, despite societal demand that they be reduced. A number of their characteristics help us to understand how they are used by winegrowers. These include:

- Their high efficacy, which is close to 100% for the most effective molecules when applied under optimal conditions;
- Low cost: based on references from Gironde in 2012[1], the cost of phytosanitary protection has been estimated to be less than 4% of the cost price of a bottle (Davy 2020). The French *EcoPhyto*

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[1] "*Référentiel technico-économique du vigneron bordelais*". https://gironde.chambre-agriculture.fr/nos-publications/referentiel-du-vigneron/.

plan's target of a 50% reduction in phytosanitary inputs would therefore mean a saving of only a few cents for a winegrower, compared with the risk of losing a substantial part of his bottled harvest;

- The weak correlation between the intensity of their use and yield (compared, to a certain extent, with the application of fertilizers in arable crops, for example): while some treatments prove to be useless, the failure to carry out a single treatment during a period of high fungal pressure can lead to substantial losses. However, as the "*Bulletins de Santé du Végétal"* (Vegetal Health Bulletins) show, forecasts of actual local fungal pressure are characterized by a high degree of uncertainty, linked to the uncertainties of weather forecasts and to agronomic and epidemiological instabilities;
- Their persistence[2] varies from product to product (around seven to eight days for "contact" products that remain on the surface of the plant, and 10 to 14 days for products that penetrate the plant). This period of effectiveness is also dependent on bad weather, again to varying degrees depending on the product (it is estimated, for example, that contact products such as sulfur and copper, which are the only ones authorized in organic farming, are washed away by as little as 20-25 mm of rain), sometimes resulting in the need to repeat treatments at shorter intervals. The withdrawal of marketing authorizations for the most environmentally damaging chemicals, which are often penetrating or systemic, arithmetically leads to a reduction in the average persistence of treatments and therefore a potential increase in the Treatment Frequency Index (TFI);
- Finally, regardless of the type of product used, the most effective treatment is a preventive one that is applied as close as possible to the point of contamination. However, the conservation and maturation conditions of these fungi, which are invisible to the naked eye, are still poorly controlled at plot or even vineyard level.

An effective strategy in the strict sense of minimizing phytosanitary risks, and one which was still widely practiced until the early 2000s before the widespread use of integrated pest management techniques, consisted of protecting the vineyard in its entirety throughout the period of susceptibility. This was performed regardless of the actual level of threat, which was often unknown or only known after the fact. During this period, which extends from budburst (the bursting of buds at the end of winter) to harvest, i.e. 150 to 180 days, this strategy consists of reapplying a product as soon as its remanence period has come to an end or as soon as rainfall levels that could wash away contact products are forecast (making weather forecasts a central instrument in phytosanitary decisions). This mechanically leads to unnecessary treatments, which are not identified as such at the point when they are selected.

The massive use of plant protection products characteristic of wine production has been estimated at 13% of national pesticide expenditure for 3-4% of French farmland, with TFIs remaining stable at high levels compared with other crops: 13.5 in 2016 compared with 4.9 for wheat in 2017, for example (Aubertot et al. 2005, Butault et al. 2010, Fouillet et al. 2022, Agreste 2023). However, this use is contributing to the development of other correlated risks that fall into three categories: (i) the downward trend in the effectiveness of certain molecules due to the development of resistant strains of pathogens (Rossi et al. 2021); (ii) the deterioration in the environmental quality of environments; and (iii) damage to the health of vineyard workers and their immediate environment (Raherison-Semjen et al. 2017, Topping, Aldrich and Berny 2020). These risks are expressed over longer time scales than the risk of crop loss and are not necessarily accorded the same significance as the short-term risks linked to crop loss and, consequently, to the economic survival of agricultural businesses in the event of insufficient protection.

[2] Period following application during which the vine is effectively protected.

The search for tools to better characterize actual fungal pressure so as to avoid the application of unnecessary treatments, and thus better manage the multiple associated risks, has become a central preoccupation for growers. But experimenting with them in real conditions brings significant economic risk. Public tools that offer economic incentives or ensure secure pathways therefore seem necessary to support the experimentation that is required as well as to enable more winegrowers to apply the resulting innovations.

The "*Assurance des pertes de récolte contre les maladies de la vigne*" (APREM, Vineyard Diseases Crop Losses Insurance) project is an initiative of the VitiREV program[3] coordinated by the Nouvelle-Aquitaine Region. Its aims are to test the effectiveness of new tools for predicting local fungal pressure under real production conditions and to recommend both treatments and the possibility of insuring against harvest losses brought about through such experiments.

This project was established in 2019 through the involvement of two cooperative wineries, *Vignerons de Tutiac (Gironde) and Vignerons de Buzet (Lot-et-Garonne)* involved as part of one of VitiREV's Living Labs (LL). Over a period of four years (2019 to 2022), an experimental plant protection protocol formulated by the *Institut Français de la Vigne et du vin* (IFV, French Vine and Wine Institute), detailed in the following paragraph, was carried out on several dozen hectares of conventional and organic vineyards.

At the same time, an insurance policy was taken out, underwritten by the Groupama company, to compensate for crop losses attributable to disease (mildew, powdery mildew, black rot) and assessed during the crop year. It covered any protection errors in the experimental phytosanitary protocol, hereafter referred to as the Insurable Treatment Protocol (ITP). Subsidies from VitiREV made it possible to support the cost of insurance premiums, estimated at the start of the project. A steering committee brought together all relevant stakeholders, as well as economic researchers, throughout the 2019-2022 period, from the co-constitution of the project to its analytical monitoring and evaluation.

## 2. Materials and methods: experimental crop loss insurance system

### 2.1. The experimental crop loss insurance scheme

The aim of the APREM project was to test under real production conditions to what extent crop losses caused by minimalist protection programs (in this case, a treatment protocol based on decision-support tools) could be covered by an insurance-type process.

The experiment was conducted from 2019 to 2022 in two cooperative wineries of Tutiac and Buzet, which produce wine on 5,400 ha in Gironde and 1,800 ha in Lot-et-Garonne, respectively (see presentation of the scheme in Table 1). The trial focused on two types of production: conventional protection at the Tutiac winery and conventional and organic protection at the Buzet winery on the region's main grape varieties (Merlot, Cabernet Sauvignon, Cabernet Franc).

[3] VitiREV is an innovation program supported by the "*Conseil Régional de Nouvelle-Aquitaine*" and co-financed by public stakeholders, foremost among them the "*Banque des Territoires*" as part of the "*Territoires d'Innovation programme*", and private stakeholders, including professionals in the regional wine industry. Its aim is to support experimentation and innovation for the agro-ecological transition of vineyards through the use of Living Labs.

**Table 1** Presentation of the APREM experimental set-up

| YEAR APREM PROJECT | APREM SURFACE AREA (HA) | TUTIAC, CONVENTIONAL, MERLOT (HA) | BUZET, CONVENTIONAL, SEVERAL GRAPE VARIETIES | BUZET, BIO, SEVERAL GRAPE VARIETIES |
|---|---|---|---|---|
| **2019** | **68** | 32 | 26 | 10 |
| **2020** | **54** | 18 | 26 | 10 |
| **2021** | **78** | 28 | 26 | 24 |
| **2022** | **101** | 28 | 0 (plots entering organic conversion) | 73 |

On each of the two experimental sites, around 15 Untreated Control Plots (UCPs) were set up to assess the natural disease pressure and the damages caused by non-treatment. The aim of repeating these systems on each of the sites is to assess the natural variability of attacks, which can be very high from one plot to another at the scale of the winery level, and even within the same plot.

These UCP systems are monitored every week during the season, from bud-break to veraison, which marks the end of the grapes' susceptibility to the main diseases. The weekly observations cover the phenological stages and physiological development of the vines, as well as the appearance of disease symptoms (mildew, powdery mildew, black rot) on leaves and bunches and the intensity of destruction of the foliage and the harvest.

### 2.2. The Insurable Treatment Protocol

The Insurable Treatment Protocol (ITP) (Figure 1) is an expert system[4] that combines a number of tools developed by *IFV Bordeaux Nouvelle Aquitaine* (IFV-BNA) since the early 1990s.

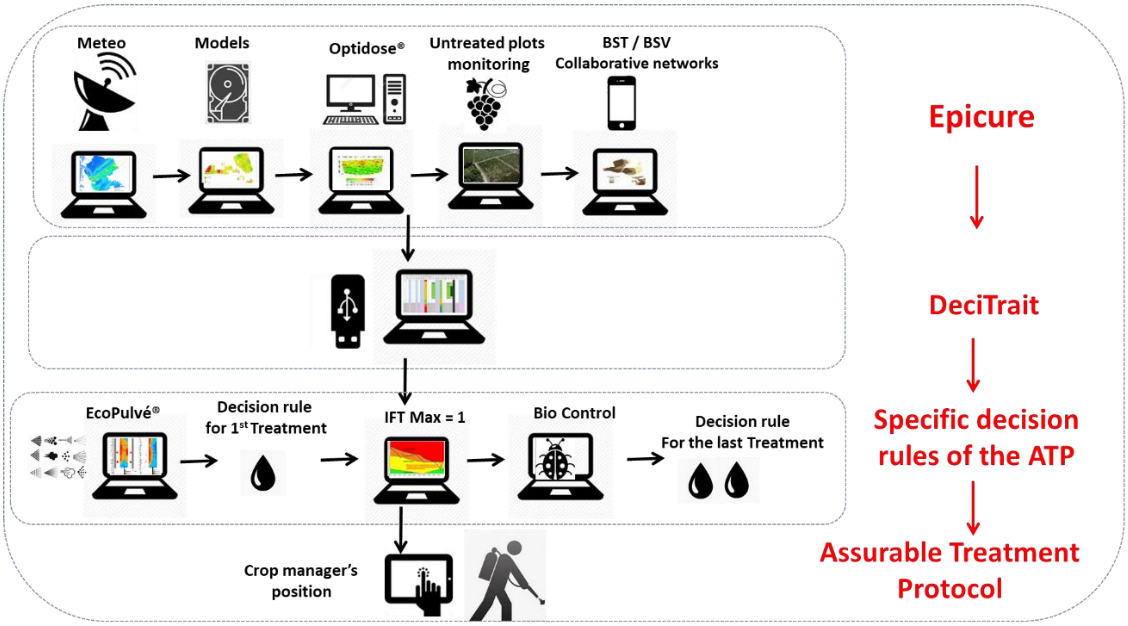


**Figure 1** Architecture of the Insurable Treatment Protocol (ITP)

[4] An expert system is a (computer) tool capable of reproducing the cognitive mechanisms of an expert in a particular field.

Firstly, the Epicure Geographic Information System (GIS) brings together:

- Meteorological data on temperature and rainfall provided by Meteo-France on a kilometer-by-kilometer basis;
- Weather forecasts provided by Meteo-France, using three categories (low, medium and high) for assessing the risk of epidemics over the coming week;
- Models to simulate the development of fungal diseases as a function of weather data;
- Algorithms derived from the Optidose® tool developed in the mid-1990s by IFV to account for the adaptation of plant protection product doses according to the three main factors of natural variation: (1) the epidemic risk (assessed via the *Potentiel Système* models); (2) the vine's stage of sensitivity; and (3) the development of the vegetative biomass;
- Observations from monitoring plots in the Untreated Control Plots (UCP) network;
- Lastly, observations from the Biological Monitoring of the Territory (BMT) networks and participative networks.

All of this information is fed into the DéciTrait Decision Support System (DSS), marketed since the early 2020s, which identifies levels of contamination requiring the application or renewal of treatments and suggests the doses of products that are needed to control the development of epidemics.

As shown in Figure 1, the following decision rules are combined with the DéciTrait DSS to reduce phytosanitary inputs to a minimum and thus form the ITP:

- The EcoPulvé module assesses the performance of the equipment used and offers an additional reduction (0 to 20%) in treatment doses depending on the performance of the hardware configuration used;
- Specific decision rules for determining the first and last treatment have been added in order to shorten the period of active protection as much as possible. In addition to the potential epidemic risk assessed by the models, the appearance of the first symptoms is recorded as triggering the first treatment, while the cessation of treatments is determined by the sanitary state of the plots;
- The climatic conditions conducive to disease differ according to the pathogens: rainy, mild temperature conditions are favourable to downy mildew, while hot, dry conditions are favourable to powdery mildew. These risks are therefore antagonistic and inversely proportional overall. Thus, the "TFIMax=1" rule suggests that in the case of combined treatments in the same pass (targeting two parasites), the TFI for the pass should not exceed 1 (e.g. a downy mildew treatment at 70% of the legal dose can only be supplemented by a powdery mildew treatment at a maximum of 30% of the registered dose). The choice of dominant parasite is determined by Optidose®;
- Finally, given the current level of control over application conditions and the effectiveness of biocontrol products, these are included in the ITP, but only during low-risk periods and outside stages considered as very sensitive for harvesting.

The appendix provides an illustration of the information provided by the ITP during the season.

### 2.3 Description of the insurance contract

Once the treatment protocol had been drawn up and presented to the partner cooperatives, a safety net was designed. This covers the crop losses that would be the direct consequence of the development of three diseases (downy mildew, powdery mildew and black rot), subject to compliance with the ITP and the performance of commonly accepted prophylactic work to minimise the sanitary risk (in particular de-budding, lifting, trimming, weeding under and between the rows). As discussed by the cooperatives and Groupama at the start of the trial, this policy coverage took the form of an extension to the Multi-Risk

Climate (MRC) insurance. Although this meant that the vines first had to be insured against climatic risks (possibly with another insurer), this extension was built on a basis that was more favourable to the producer than the MRC contract subsidised by the public authorities. In particular, unlike the MRC, the reference is not the Olympic average[5], but the maximum yield achieved over the last five years (limited by the maximum yield for the appellation). The deductible was set at 0%, followed by 5%. The insured capital was therefore equal to the insured yield multiplied by the insured price, multiplied by the insured surface area.

Despite the extreme difficulty on the part of the insurer to set the price of an insurance product of this type which relates to a process whose performance has no historical basis, the amount of the insurance premium was set on the basis of the IFV's estimate of the success of the ITP. The contract was facilitated by subsidies from the VitiREV project.

On the plots selected for the experiment, both IFV and insurance company employees subjected the treatment periods to very close technical monitoring. This monitoring is intended to inform and anticipate these first experimental set-ups as much as possible. A yield potential was defined at the start of the campaign, based on the vine's spring development, to serve as a basis for calculating any losses. In the event of the appearance of a disease that could lead to a reduced yield, the cooperative had to quickly notify the insurer (as for the MRC) so that a new yield potential could be calculated. At the end of the year, a final yield was estimated based on samples taken from the bunches in the plot.

## 3. Results

### 3.1. Reduction in TFI

Environmental performance was assessed by comparing the intensity of pesticide use per hectare (measured by the Treatment Frequency Index, TFI) between the insured plots and other plots that are close to the cooperative and share similar characteristics (grape variety, organic or conventional management methods) but do not employ the ITP. Depending on the year, a reduction of between 30% and 55% was achieved (compared with the *Ecophyto* plan's target of a 50% reduction).

Table 2 summarises the average values for total fungicide TFIs (including biocontrol products, including sulphur) observed on the reference plots ("Winery " columns) for the period 2019 to 2022, compared with those obtained via the ITP ("Aprem" columns). Performance in terms of percentage reduction is shown in the "Var(%)" columns[6]. Table 4 in the appendix details the results by plot and without biocontrol products.

[5] Average yield over the last 5 years after excluding the best and worst yields.

[6] In 2022, the island operated in conventional mode at the Buzet site was shut down.

**Table 2** Average total fungicide treatment frequency indices (including biocontrol products) over the period 2019-2022

| | | TFI Tutiac (Conv.) | | | TFI Buzet (Organic) | | | TFI Buzet (Conv.) | | | Average TFI (Tutiac Buzet) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Winery | Aprem | Var(%) | Winery | Aprem | Var(%) | Winery Cellar | Aprem | Var(%) | Winery Cellars | Aprem | Var(%) |
| 2019 | Downy mildew | 7.0 | 3.3 | -53 | 5.8 | 3.6 | -38 | 5.8 | 4.4 | -24 | 6.2 | 3.8 | -39 |
| | Powdery mildew | 4.7 | 2.3 | -51 | 4.1 | 2.9 | -29 | 4.1 | 2.0 | -51 | 4.3 | 2.4 | -44 |
| | **TFI Total** | **11.7** | **5.6** | **-52** | **9.9** | **6.5** | **-34** | **9.9** | **6.4** | **-35** | **10.5** | **6.2** | **-41** |
| 2020 | Downy mildew | 8.4 | 4.0 | -52 | 6.0 | 2.7 | -55 | 6.1 | 3.5 | -43 | 6.8 | 3.4 | -50 |
| | Powdery mildew | 5.1 | 2.2 | -57 | 4.0 | 2.1 | -48 | 2.7 | 1.5 | -44 | 3.9 | 1.9 | -51 |
| | **TFI Total** | **13.5** | **6.2** | **-54** | **10.0** | **4.8** | **-52** | **8.8** | **5.0** | **-43** | **10.8** | **5.3** | **-50** |
| 2021 | Downy mildew | 8.0 | 6.0 | -26 | 6.1 | 3.3 | -46 | 6.1 | 4.4 | -28 | 6.7 | 4.6 | -32 |
| | Powdery mildew | 5.0 | 1.8 | -64 | 3.7 | 2.4 | -35 | 3.7 | 1.2 | -68 | 4.1 | 1.8 | -56 |
| | **TFI Total** | **13.0** | **7.7** | **-40** | **9.8** | **5.7** | **-42** | **9.8** | **5.6** | **-43** | **10.9** | **6.4** | **-42** |
| 2022 | Downy mildew | 6.0 | 2.9 | -52 | 3.9 | 3.9 | -1 | | | | 4.9 | 3.4 | -32 |
| | Powdery mildew | 3.4 | 1.6 | -53 | 2.4 | 2.5 | 1 | | | | 2.9 | 2.0 | -30 |
| | **TFI Total** | **9.4** | **4.5** | **-52** | **6.3** | **6.3** | **0** | | | | **7.9** | **5.4** | **-31** |
| **19 - 22** | Downy mildew | 7.3 | 4.0 | -45 | 5.5 | 3.4 | -38 | 6.0 | 4.1 | -32 | 6.4 | 3.7 | -42 |
| | Powdery mildew | 4.6 | 2.0 | -57 | 3.6 | 2.5 | -31 | 3.5 | 1.6 | -55 | 4.1 | 2.2 | -45 |
| | **TFI Total** | **11.9** | **6.0** | **-50** | **9.0** | **5.8** | **-35** | **9.5** | **5.7** | **-40** | **10.0** | **5.8** | **-42** |

### 3.2. Protection of vineyards and compensation paid

Over the first three years, the level of protection was generally considered to be satisfactory. Only a few attacks were observed, sometimes locally severe, but the extent of these was limited to very specific areas, such as where vines were close to UCPs or growing on shaded lower slopes. The fourth year, however, saw a sharp drop in yield by around 80% across an area of 20 ha (average yield obtained of 6.6 hl/ha), i.e. a fifth of the total experimental area (Buzet plot managed organically, the catch-up of treatments carried out after the infestation explains the lack of performance on TFI, as can be observed for that year in Table 2).

With a deductible initially set at 0%, compensation was calculated for the few attacks observed, the damage to which was difficult to assess and characterise as genuine crop losses (compared with a loss of potential linked to the climate, for example). At around 5%, these losses resulted in small amounts of compensation of the same order of magnitude as insurance premiums. In subsequent years, it was therefore agreed that the compensation threshold would rise to 5%. In 2021, no damage in excess of the

5% threshold was recorded, so no compensation was paid. The heavy attack in 2022 on the Buzet site, by contrast, resulted in high levels of compensation.

## 4. Discussion and conclusion

### 4.1. Analysis of the ITP's performance in terms of TFI reduction

Table 2 gives an initial view of the absolute performance (level of TFI) and relative performance (comparison with the TFI of reference plots) of the ITP. Another approach is to situate the TFIs obtained within the wider distribution of TFIs recorded in the basin, on the basis of the references given by the triennial vineyard management practices survey, "Pratiques culturales en viticulture" (Ministry of Agriculture (SSP) 2019). To control the effects of vintage, which have a major impact on the variability of TFIs (see for example Agreste (2023)), this comparison is based on data from 2019, when both the ITP experiment began and the Ministry of Agriculture's triennial survey took place. Table 3 shows the total fungicide TFIs (including biocontrol) recorded by decile in 2019.

**Table 3** Distribution of fungicide TFIs in viticulture in Gironde and Lot-et-Garonne in 2019, as recorded in the Cultural Practices surveys

| | CONVENTIONAL VITICULTURE | | ORGANIC VITICULTURE |
|---|---|---|---|
| | Fungicide TFI in Gironde | Fungicide TFI in Lot-et-Garonne | Fungicide TFI in Lot-et-Garonne |
| 1ST DECILE | **8.8** | **8.2** | 3.8 |
| 2ND DECILE | 10.1 | 8.8 | 4.8 |
| 3RD DECILE | 11.2 | 9.3 | 5.5 |
| 4TH DECILE | 12.2 | 10.0 | **6.3** |

The TFI performance obtained by the ITP in 2019 is in the 1st decile of the population of winegrowers surveyed, or well below (5.6 and 6.4 in Gironde and Lot-et-Garonne respectively, compared with 8.8 and 8.2 respectively). In organic viticulture, it is around the 4th decile (6.5 compared with 6.3), i.e. a lower performance, which may be explained by the lower margins of optimization, particularly in relation to the specific nature of the fungicides used in this type of management (contact products, strict preventives), which are more directly affected by the uncertainty of the weather forecast. The ITP's decision rules take account of the sanitary state, meaning that a slip in organic production can lead to a greater number of treatments being required. If there is an error in the strategy of avoiding unnecessary treatments, a catch-up may be greater for organic than for conventional farming. Nevertheless, the risk of an increase in the TFI for organic winegrowers in the event of insurance seems low.

### 4.2. Reasons for the failure of the ITP in 2022 on the Buzet site

While the ITP has achieved extremely satisfactory results for three years running, its failure in 2022 in Buzet raises questions about the robustness of the protocol. It is therefore important to understand the factors that led to insufficient protection of the vineyards, despite the favorable context (fungal pressure in the *Nouvelle Aquitaine* region was generally much lower than in previous years).

#### *4.2.1. The course of the campaign*

In mid-June, sanitary assessments recorded very little downy mildew: an average of only 3% of leaves on all the untreated controls showed symptoms of downy mildew and 0.3% of bunches were affected by the disease. Fifteen days later, the proportion of leaves affected by downy mildew rose very slightly to 3.4%. Yet there was an explosion in the number of bunches affected (44%) and an average level of crop destruction in excess of 20% for all grape varieties (Cabernet Sauvignon, Cabernet Franc and Merlot), reaching 100% in the case of Merlot, with crop destruction varying from 70 to 90% depending on the plot.

The attack was therefore particularly brutal and virulent on the Merlot grape varieties on the experimental site. A similar level of attack was also observed among many growers at the Buzet winery.

#### *4.2.2. The crucial importance of rainfall*

The rainfall detected by Meteo-France is the result of a combination between the radar signal which locates the rain cells and the weather stations of the Meteo-France network which calibrate this signal to give a quantification of rainfall over a grid of 1 km on a side, i.e. over 100 ha. While, overall, there is a strong correlation between this rainfall per kilometer and the rainfall of a weather station, there may be significant variations in certain specific climatic events. In order to improve local risk assessment, the ITP makes it possible to adjust Meteo-France's rainfall estimate using actual rainfall recorded on site. On 15 May 2022, Meteo-France reported a rainfall of 13.1 mm. This rainfall was corrected by a value of 8.6mm recorded at the local weather station. This correction, which was justified in principle on the basis of the local record, greatly reduced the assessment of the modelled risk on the following days, leading to the prescription of copper doses that were too low for June. Later analysis of the course of events in the absence of this adjustment shows that this correction was sufficient to change the model's assessment of risk from high to low. The dosages of the treatments applied between 3 and 23 June were therefore too low compared with the strategy that should have been applied in the absence of the downward correction with local rainfall (the dose was then increased from the end of June in order to limit the spread of damage).

This phenomenon, which caused a lot of damage in 2022, was not observed in any of the other three years during which the experiment was conducted. This finding highlights the hyper-sensitivity of the system, partly linked to the precision of the weather data to within a few tens of meters, and to its insufficient mesh size. Multi-year experimentation under real production conditions over relatively large areas reveals extremely variable crop losses between vintages and sites. Even within each site, very strong variations in attacks can be observed at plot level, depending on the grape variety, physiological stage, soil type, topography and exposure. Our current knowledge does not allow us to correctly identify the dynamic interactions between these different factors and it reveals our difficulties in reliably predicting the onset of epidemics, the appearance of symptoms and the dynamics of their progression at the level of the vineyard. To guard against this, a new rule of thumb has been devised for the continued course of the ITP test, whereby the weather can only be corrected if local readings are higher than those given by Meteo-France.

### 4.3. The effects of differentiated management of climatic and sanitary risks

Lastly, the experiment also highlighted the difficulties involved in establishing the causality of losses for the insurer, which, like the MRC, requires an expert appraisal. In addition to the technical difficulties involved in observing damage and estimating initial yield potential, sanitary and climatic risks are partly correlated (bad weather, for example, can make it technically impossible to protect against disease).

The two different levels of cover proposed for each of the two risks (complying with the MRC's conditions for the climatic risk and more favorable for the health guarantee) also made it more difficult to calculate compensation.

Further work is needed to design a simplified and inclusive form of cover that takes account of the overall risk born by the winegrower. This should involve regulatory arrangements (or derogations in the first experimental trials) so as not to deprive the winegrowers involved of the subsidies associated with the MRC when the contract is modified. This approach would represent both a concrete proposal for supporting agro-ecological transition and a means to cease assessing the causality of losses; this, in turn, would enable insurers and winegrowers to move towards index-based formats, so long as it is possible to rely on objective measurements of the yields obtained.

## 5. Conclusion: critical points for health insurance in viticulture

The APREM experiment shows that the DéciTrait tool, as used in the ITP, can lead to a significant reduction in TFI for a large proportion of winegrowers. In particular, we have highlighted: (i) a retrospective estimate of the extent to which these treatments can be considered unnecessary in traditional vineyard management, around a significant value varying from 30 to 60% depending on the year; and (ii) the critical points, both technical and regulatory, for implementing a treatment protocol aimed at saving on inputs. Combining a Decision Support System with a risk-pooling scheme can be attractive to winegrowers insofar as the insurance cover secures their income, particularly in the first few years of adopting the ITP, when imperfections in implementation may be observed.

It is nevertheless important to stress that the performance of the ITP remains fragile and relies on very detailed monitoring of the state of the vines, as the failure of 2022 amply demonstrates. The ITP must be adjusted so as to select the measure leading to the most secure treatment strategy in the event of a discrepancy between official weather data and data from local rain gauges. The optimization enabled by the tool implies sensitivity to the measurements, which makes frequent monitoring all the more necessary.

A cost-benefit analysis remains difficult to perform at this stage, given that the significant costs of monitoring and advising on this trial are hardly representative of a model where this practice would be rolled out across a wider area. The insurer bears a significant risk in offering this new system for which very little data exists and for which it is therefore particularly difficult to calculate the cost of insurance premiums. Better diversification of risks, continued implementation of trial data and support from public tools systems are, however, means to ensure a long-term commitment from insurers.

Insofar as the reduction in the use of fungicides meets a public objective, we could indeed envisage a form of support for green insurance (in the same form as climate insurance), at least initially. Implementing this insurance over a number of years would provide even more data on the risks incurred, therefore enabling the ITP to be fine-adjusted further.

**Ethics**
The authors declare that the experiments were carried out in compliance with the applicable national regulations.

**Declaration on the availability of data and models**
The data supporting the results presented in this article are available on request from the author of the article.

**Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.**
The authors used artificial intelligence in translating this article from French to English.

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**Authors' contributions**
Marc Raynal: coordination of the APREM experiment.
Christian Debord: management of treatment protocol modelling systems.
All: monitoring and analysis of the APREM experiment.
Marc Raynal, Cécile Aubert and Yann Raineau: writing the article.

**Declaration of interest**
The authors declare that they do not work for, advise, own shares in or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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**APPENDIX**

Figure 2 illustrates the season-by-season use of the DéciTrait AOD for Merlot under conventional control at the Buzet site in 2021.

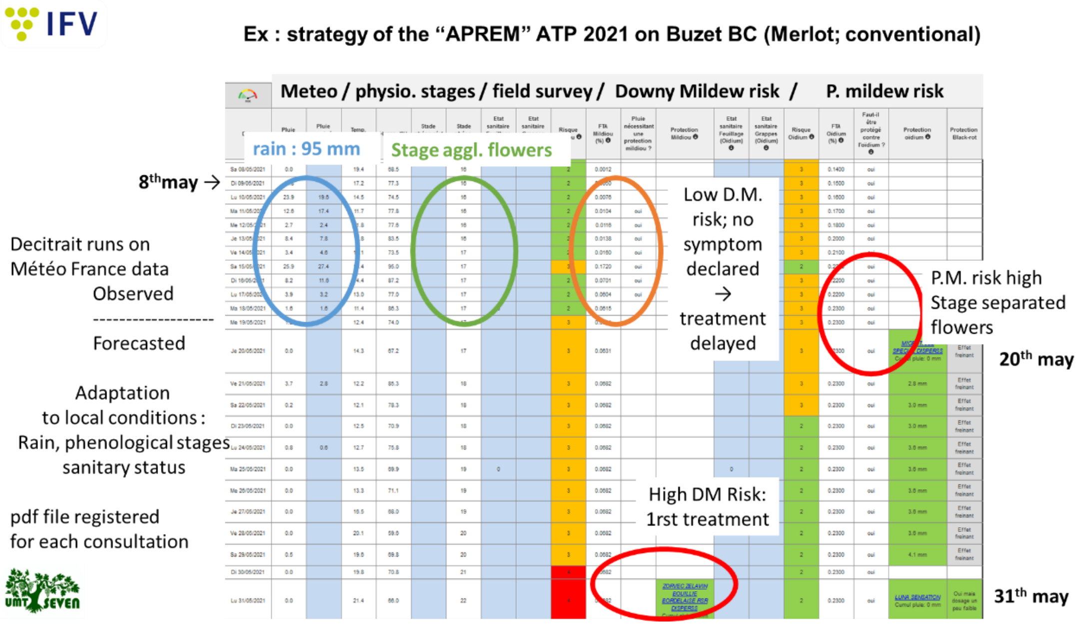


**Figure 2** Illustration of a dashboard from the DeciTrait DSS during 2021 season

Each line of the spreadsheet corresponds to a calendar day. The upstream data contain indicators calculated from past observed weather data. The downstream data correspond to changes in these indicators as a function of weather forecasts. The columns provide information on the various indicators, from left to right:

- Rainfall measured by the Meteo-France “Antilope” data on a 1 km² grid;
- Rainfall, possibly corrected from a local weather station;
- Average daily temperature and humidity;
- The phenological stage modelled by calculating cumulative temperatures;
- Any recalibration of the phenological stage entered by the operator on the basis of field observations;
- The sanitary state of the foliage and bunches as recorded by the technician or winegrower (scale from 0 to 5).

The following columns detail the risk levels for mildew and powdery mildew:

- The epidemic risk is determined by the Potential State of Infection (EPI) of the parasite, ranging from green (low risk) to red (widespread high risk);
- The theoretical frequency of attack (TFA) given as a percentage, which is an indicator of the development of contamination in the absence of treatment;
- Indication of the need for treatment in the event of rain (Yes / No);
- The date on which the treatment was applied and the type of product used;
- Indication of the product's period of action, taking into account its mode of action (persistence) and wash-off by rain (cumulative rainfall recorded since the date of treatment).

In the example shown in Figure 2, DéciTrait recorded a sequence of 95 mm of rain from 8 May onwards, during the period from the very sensitive "agglomerated flower buds" to "separated flower buds" physiological stages. The risk of a mildew epidemic is low, but DéciTrait recommends applying a treatment from 11 May (a "yes" indicating the need for protection appears in the "Rainfall requiring mildew protection" column). In the absence of downy mildew symptoms reported on the experimental site and given the low risk at this stage, the application of the first treatment is postponed until 31 May, given the evolution towards a medium and then high epidemic risk.

Conversely, for an average powdery mildew risk at the beginning of May and the arrival of the sensitive "separated flower buds" stage, the first powdery mildew treatment is triggered on 20 May. This treatment covers the vines until 29 May. The powdery mildew protection was repeated on 31 May with the first downy mildew treatment.

Figure 3 shows evolutions of the incidence of bunches affected by downy mildew (blue curve) and of the severity of the crop destruction (red curve) from 2019 to 2022 for each of the experimental sites.

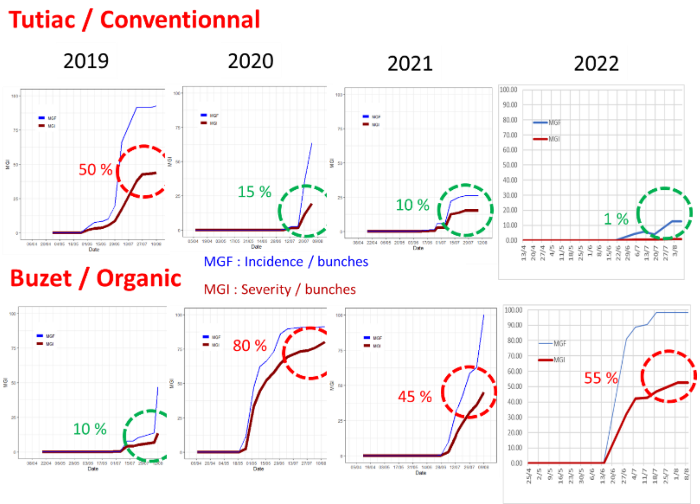


**Figure 3** Development of downy mildew on bunches of grapes in Untreated Control Zones (TNT)

These trend curves represent the average of the assessments made on all controls at each site. The circles indicate the final level of destruction observed at the end of the season (green: low; red: high):

- in 2019, destruction by downy mildew was high in the Tutiac controls (50%) but low in the Buzet controls (10%);
- In 2020, this difference was reversed, with a very high level of destruction at the Buzet site (80%) and a low level at the Tutiac site (15%);
- in 2021, the downy mildew attack remained low-level on the Tutiac site (10%) and severe on the Buzet site (45%);
- in 2022, a year of very low downy mildew pressure over the vast majority of the New Aquitaine vineyard, downy mildew was virtually non-existent at the Tutiac site (1%), but very severe at the Buzet site (55%).

Figure 3 illustrates the extremely variable crop losses between vintages and between sites. Within each site, there can be just as great a variation in attacks at plot level, depending on the grape variety, physiological stage, soil type, topography and exposure, etc. Our current knowledge does not allow us to correctly identify the dynamic interactions between these different factors; it also reveals our difficulties in reliably predicting the onset of epidemics, the appearance of symptoms and the dynamics of their progression at the level of the vineyard.

**Table 4** Total and biocontrol TFIs from the APREM protocol, broken down by plot

| | *CAVE COOP* | | | | *Buzet* | | | | | *Tutiac* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PARCEL | A | B | C | D | E | F | G | H | I | J |
| | MODE | Bio | Bio | Bio | Bio | Bio | Conv | Conv | Conv | Conv | Conv |
| | CEPAGE | cabernet sauvignon | merlot | cabernet sauvignon | merlot | cabernet franc | multi-varietal | merlot | merlot | merlot | merlot |
| | AREA (ha) | 7.0 | 3.0 | 25.6 | 21.9 | 25.4 | 26.0 | 7.7 | 10.6 | 13.5 | 9.6 |
| *2019* | TFI APREM | 6.5 | 6.6 | | | | 6.4 | 5.6 | 6.7 | 6.7 | |
| | of which biocontrol TFI | 2.9 | 2.9 | | | | 1.8 | 0.5 | 0.3 | 0.3 | |
| *2020* | TFI APREM | 4.7 | 5.0 | | | | 5.0 | 6.6 | 6.0 | | |
| | of which biocontrol TFI | 2.0 | 2.3 | | | | 0.4 | 2.0 | 1.7 | | |
| *2021* | TFI APREM | 5.6 | 6.1 | | | | 5.6 | 7.9 | 9.5 | | 6.7 |
| | of which biocontrol TFI | 2.3 | 2.8 | | | | 2.3 | 1.5 | 1.5 | | 2.3 |
| *2022* | TFI APREM | | | 6.0 | 6.1 | 6.9 | | 3.9 | 4.6 | | 4.9 |
| | of which biocontrol TFI | | | 2.3 | 2.4 | 2.7 | | 0.2 | 1.0 | | 1.0 |