Integrated protection and production in viticulture
IOBC/ wprs Bulletin Vol. 67, 2011
pp. 93-100

Modelling and experimenting crop protection decision workflows: some lessons from GrapeMilDeWS research

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Abstract: The political roadmap about pesticides in France is to reduce quantities by 2, "if possible", before 2018. Research is needed to design and evaluate new pest management solutions. A decision workflow system, name GrapemilDeWS was designed, at the plot scale, to handle grapevine powdery and downy mildews. GrapeMilDeWS stipulates throughout the season if and when fungicide sprayings should take place. GrapeMilDeWS has been experimented on a network of plots in different French wine regions. We give some results about the number of sprayings generated by GrapeMilDeWS and the crop protection performance obtained. We discuss methodological aspects such as partnership and data required to test and check such decision system.

Key words: *Plasmopara viticola*, *Erysiphe necator*, decision, workflow

Introduction

The French political roadmap on pesticides („Grenelle de l'environnement", „Ecophyto 2018") is to divide sprayed quantities by 2, "if possible" and before 2018. This emphasizes need for research to design and evaluate new pest management solutions. When it comes to decide about when to protect grapevine against powdery and downy mildews, the framework of "*Protection raisonnée*" constitutes the current basis for French advisers on how to avoid unnecessary treatments. *Protection raisonnée* is related to Integrated Crop Protection in the sense of using indicators and statements – often called „rules" – about how to use these indicators. The current status about *Protection raisonnée* of grapevine against mildews is the following: the information provided to growers is mostly bioclimatic at a micro-region scale; it is mostly used, in France, to reduce spraying in the beginning of the season.

Where and when can we do more with these information and indicators, can we combine risk management and proven tactics to design environmentally efficient crop protection decision systems? This paper contributes to answer these questions and is also a call for building international research collaboration on operational decision systems and models for grapevine.

The authors of this paper study reasoning methods about *when to spray and when not to spray*. More precisely, we design decision systems, which, throughout the season, output decisions based on the current epidemic and bio-climatic inputs. On the track to reduce pesticides use in viticulture, this work is very complementary with work on dose management undertaken by e.g. IFV (Davy, 2007) and Agroscope Changins (Siegfried, 2007), and also on optimisation of the spraying process itself (Gil, 2007).

Previous work

GrapeMilDeWS stands for Grape Mildews Decision Workflow System. GrapeMilDeWS manages the decision making about control of both powdery and downy mildews. It was originally designed and tested in 2005 on 4 experimental plots in the Bordeaux region (Léger, 2008). The original guidelines consisted in 7 stages defined on a phenological timeline, 1 decision array per stage, and a set of indicators, including 3 field observations per year. Then, a model of the decision system was made in the Statecharts language. The Statecharts language (Harel, 1987) describes dynamic processes on the basis of state machines, which react to events, as described in Figure 1. The Statecharts language possesses mechanisms such as hierarchy and concurrency for combining state-machines, which ease the building of models. GrapeMilDeWS was elicited with careful interviews of each expert of the phytopathologists team, and the interviews were made on the basis of successive versions of the statechart diagram (Leger, 2009). The resulting Statechart model was introduced to OILB's grapevine group in 2007 (Léger, 2007). It was successfully checked against actual behavior of experts during the experiments of 2005 & 2006 (Léger, 2008). The model has thus been shown to be consistent with the experts' *„how-to decide"* knowledge on both a declarative and a behavioural basis.

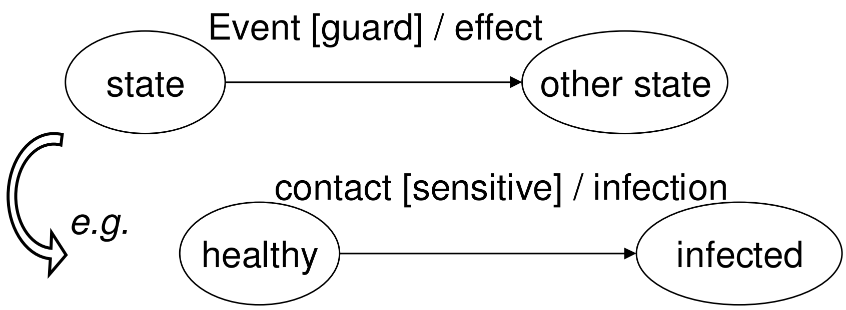

Figure 1: States and events in Statecharts' graphical language.

Experimenting GrapeMilDeWS in different wine regions

Basics of GrapeMilDeWS: a quick reminder

GrapeMilDeWS is precisely described in the Statecharts language in (Leger, in press). The 7 decision stages are decomposed as follows. Each stage leads to at most one treatment against each of the two diseases. Whenever it is appropriate in a stage, if both diseases have to be treated, the spraying combines products against both diseases in order to limit the workload, consistently with growers' practice. There are three stages before flowering, one from bud break to 5 leaves unfolded (stage 0), a second one starting after a field survey to be performed between 5 and 7 leaves unfolded (stage 1), and the last starting two weeks after, also initiated by a field survey (stage 2). At flowering, the decision stage 3 consists in a unique and mandatory spraying against both diseases. Stage 4 follows and manages fruit set. There is no field survey at this stage, the treatments are decided according to the epidemics levels estimated before flowering, and according to the local downy mildew risk. A third field survey has to be done before stage 5. It allows deciding if it is necessary to protect fruit and leaves before grape closure. The last stage is a mandatory copper treatment at ripening.

GrapeMilDeWS experiment protocol

Since 2008, experiments on GrapeMilDeWS rely on a protocol with a decision procedure written in quasi natural language that was derived from the Statechart model. This protocol gives detailed instructions on how to decide at each stage, and when to move from one stage to the other. It describes the sampling methods for getting epidemic level in the field: number and choosing of vinestocks, leaves, and grapes. It specifies how to record the local risk indicators for the control of downy mildew: bioclimatic info and rain forecasts. It stipulates that the decision path that leads to spraying is part of experimental data and is to be recorded. The protocol naturally includes instructions for the evaluation of protection performance.

Thanks to this protocol, it became possible to extend the experimental network. The extent of this network as of 2009 is described below.

After the 2008 campaign, due to a few cases mentioned in the results section, the first stages (0, 1 & 2) of GrapeMilDeWS were slightly transformed in order to handle more efficiently high and early downy mildew pressure.

The network of experimental plots

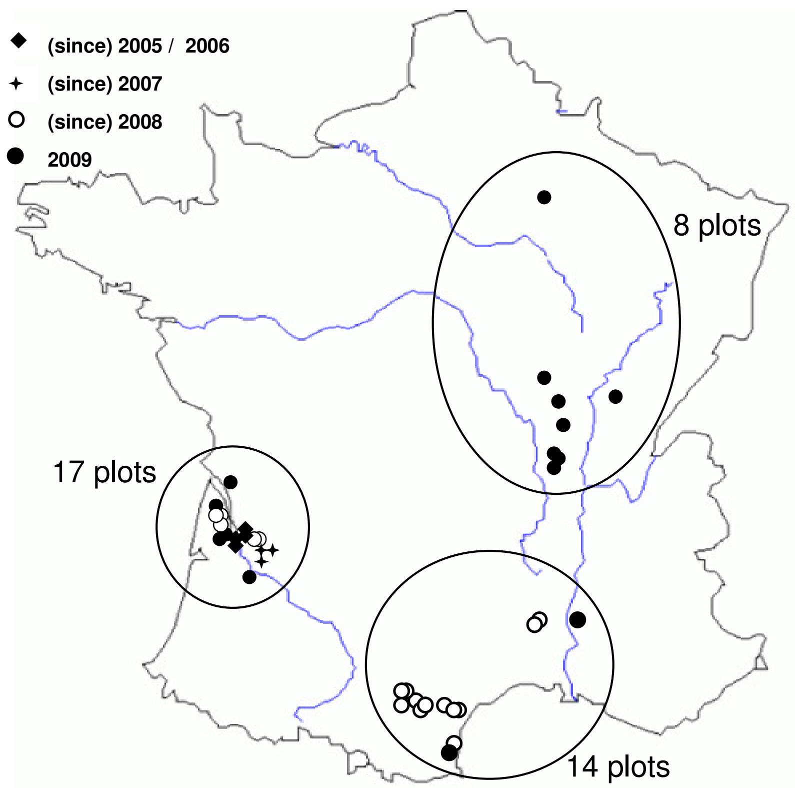

Figure 2: Network of plots were GrapeMilDeWS is tested in France.

Since the beginning, GrapeMilDeWS is experimented on real size plots. The sprayings are performed with the usual spraying equipment of the farm. The experimental network has grown and diversified. Whereas in 2005, 2006 and 2007, the plots experimented were on research estates, since 2008, the network includes vineyards run by extension services (ES) as well as professional growers. In the later case, the field surveys are done by researchers or ES staff. As can be seen on Figure 2, the network spans over a number of wine producing regions: Bordeaux, Languedoc-Roussillon, Provence, Côtes du Rhône, Burgundy, Jura, Champagne and Cognac. The total number of plots has reached 39 in 2009.

Results

Spraying intensity

As the goal of GrapeMilDeWS is to provide a satisfactory level of crop protection with a few sprayings, we give in table 1 a brief synthetis of results on how many treatments were done on testing plots from 2005 to 2009. The conventional number of sprayings was obtained thanks to surveys.

Table 1. Number of spraying with GrapeMilDeWS compared to conventional practice.

Year (Number of plots) *Location*	Nb of sprayings Downy mildew Median *(min – max)*		Nb of sprayings Powdery mildew Median *(min – max)*	
	GrapeMilDeWS	Conventional	GrapeMilDeWS	Conventional
2005 4 INRA plots *Bordeaux*	4	6 (4-12)	2 (2-4)	5 (3-11)
2006 4 INRA plots *Bordeaux*	4	7 (5-8)	2 (2-3)	6 (3-10)
2007 network 6 plots *Bordeaux*	6 (5-6)	10 (7-15)	2 (2-3)	6 (4-9)
2008 network >12 plots *Bordeaux*	6 (5-6)	10 (7-14)	2	6 (3-13)
(network > 10 plots) *Languedoc Roussillon*	4 (3-5)	-	3 (2-4)	-
2009 16 plots *Bordeaux + Cognac*	5 (4-7)	-	2 (2-4)	-
12 plots *Languedoc Roussillon*	4 (3-6)	-	2 (2-5)	-
7 plots *Beaujolais - Bourgogne - Champagne - Jura*	4 (2-6)	-	2 (2-3)	-

Agronomical performances

On Figure 3, the analysis is related to the hypothesis that severity of diseases on bunches should be kept below 5% for satisfactory protection, since it has been shown for powdery mildew (Calonnec, 2004) that limited contamination do not cause loss of wine quality. The level of severity has to be considered together with the yield, which is given here relatively to a yield objective (e.g. a quota). Most of the plots where GrapeMilDeWS has been tested are meant to produce wine under designation of origin label. In parts ② and ④ on Figure 3, yield is under the objective. These situations can result from disease level, or from other problems such as physiological trouble (flower abortion, millerandage) or hydric stresses. Whatever the cause, the grower's income is then below its expected maximum. Yet as far as GrapeMilDeWS is concerned, only cases situated in part ④, i.e insufficient yield and severity above 5%, are considered as possibly problematic.

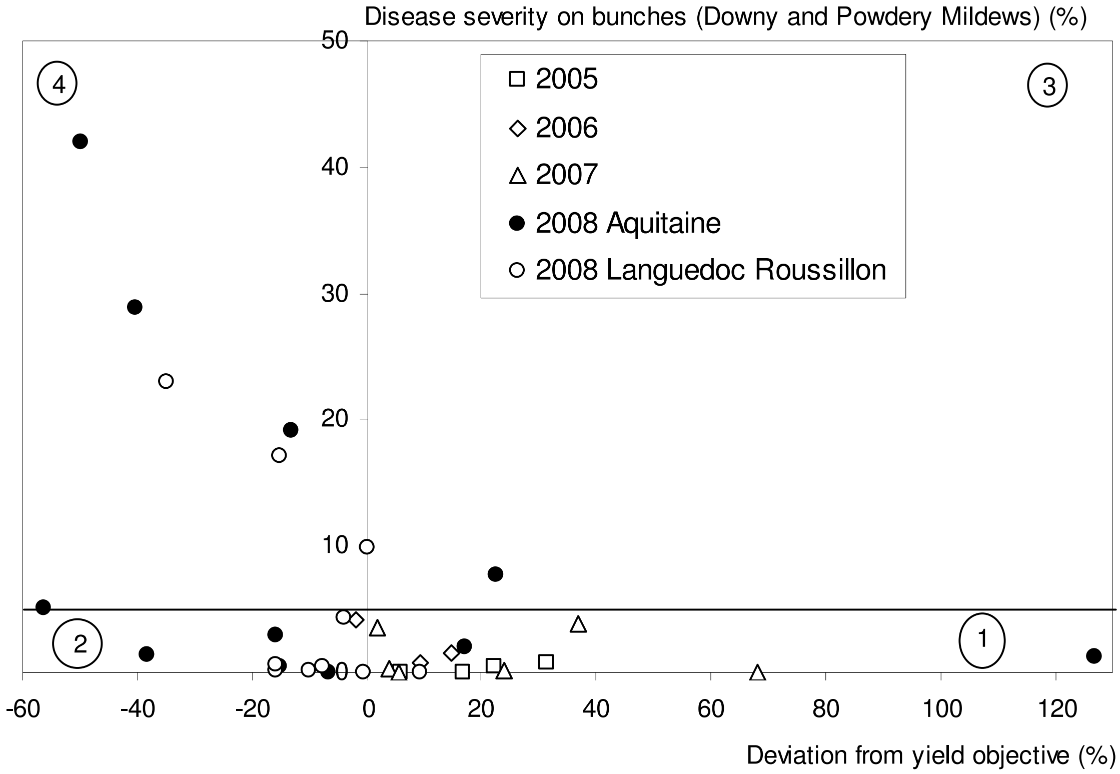

Figure 3. Disease severity on bunches and deviation from yield objective 2005-2008.

The analysis of these cases in 2008 led to modifications of stages 0 and 1. Before 2009, a field survey had to be done before the first treatment, would it be within stage 0 or within stage 1. However, in the Bordeaux region, the BBCH phenological stage 15 (5 leaves unfolded) occurs beginning of May. Bank holidays occurred close to week-ends and make it difficult to schedule human resources for a field survey before a possibly contaminating rainfall. Therefore it may be difficult to schedule a spraying when downy mildew epidemics start fast and remain invisible because of the delay between contamination and expression of symptoms which was what happened in 2008, near Bordeaux. When regional risk is estimated high, it is then important that GrapeMilDeWS gives the possibility to schedule a first treatment against downy mildew during stage 0, without doing a preliminary field survey, and before the field survey that precedes stage 1. The protocole was modified from 2009 on, so as to account for this conclusion.

Discussion: What does the decision workflow approach change for? Experimenting decision strategies

Decision workflow versus pre-scheduled spraying

A decision workflow acting on a pathosystem produces a decision that changes according to inputs (variables, events) and workflow state, state which is the consequence of a sequence of past events. This is very different from a pre-schedule spraying, as happens for example in phytosanitary products homologation tests. With the decision workflow, the epidemiological facts that are accumulated during experiments are attached to the decision path, which includes timed traces of indicators, estimated phenology, and the decisions for scheduling treatments. The notion of decision path for experiments is illustrated in Figure 4.

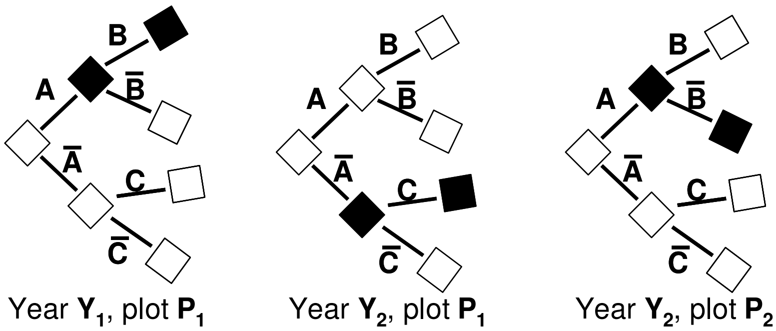

Figure 4. Decision path for different test cases (a case is a year and a plot).

Recording decision paths along with data from the field and the weather from a wide range of cases across regions and test years, allows us to systematically explore the decision workflow and link its behaviour to agronomical results. For instance, we can check which decision paths have been taken so far, and which have not. We thus identify which parts of the decision system have been tested and according to which conditions. For example, in Figure 4, one can identify that the path $\overline{\mathbf{A}}.\overline{\mathbf{C}}$ has not been tested. A decision system is analogous to a computer program in this regard. Computer scientists and engineers are well aware that systematic testing is a tedious but necessary activity for the sake of users' safety (e.g. embedded electronics of cars) or users' activity (e.g. personal computer programs). Model-checking are formal methods for performing such systematic verification procedures, and assess behavioural properties of systems (Müller-Olm, 1999; ten Teije, 2006).

Interdisciplinary research

Choosing operational concerns as a subject of study – such as how to decide treatments according to epidemics, wheather forecasts, and resources available – required and fostered interdisciplinary research. The research about GrapeMilDeWS is done within projects which blend phytopathology, agronomy, automation, computer science, economics and management. Because it is very difficult to simulate downy and powdery epidemics at the plot scale, the most convenient way to validate the technical performance of a decision system is to test it, in many different situations and for several years. This means that the research on such decision systems requires the creation of experiment networks with extension services and growers. This is what we did. As a result, the transfer to development and the accumulation of knowledge for further research are happening simultaneously.

GrapeMilDeWS has been designed to be generic and functional in a variety of situations and regions. What will be made available to the growers in different regions may be a set of local adaptations, or even completely new designs that will take into account facts demonstrated by GrapeMilDeWS. For example, it has been made clear that the lower susceptibility of grapes to powdery mildew disease after pea-size can be used to skip treatments from the beginning of berry touch in case of low epidemics.

Handling risk with low fungicide input is a new territory for grapevine growers. We believe that the job of a farmer, who is not a phytopathologist and has many things to do to run his estate, is not to explore this territory on its own. It should fall on the side of research and development to design and test prescriptive solutions that are «safe routes» in the search space of crop protection decision and make it possible to reach the production target with little fungicide input. This applied and interdisciplinary research needs to be conducted in close relation with the professional community.

Conclusion

We have learnt from GrapeMilDeWS experiment how the pathosystem behaves under low input in different regions and we have improved the design of GrapeMilDeWS. We have run large field experiments without usual blocks and repetitions, still the accumulation of cases allows to consolidate scientifically sound knowledge.

What extension workers have been learning is that some level of disease can be accepted. They have seen a number of cases from 2007 to 2009 which showed that it is sometimes possible to limit powdery mildew treatments to two sprayings, even on “sensitive” cultivars (like Chardonnay, Gamay,…,). GrapeMilDeWS has been designed and experimented at the plot scale. At this scale, extension workers have experienced that low input strategies are technically feasible, and have handled the decision workflow, followed a specific observation protocol and interpreted the decision variables.

What growers participating to this research have been learning is that (i) some disease can be tolerated without economical loss and going out of business and that fungicides may be reduced significantly (repeatedly >40% less treatments). They have seen scientifically sound research work made in large fields (fields in the network are >0.5ha) and gained confidence in the possibility to control disease risk.

Further experiments will be conducted at the plot scale. Besides, future research should investigate several points such as decision at the farm scale, optimisation of sampling in different plots of an estate, enhanced modelling formalisms to account for anticipation and revision of anticipated decisions to follow evolution of bioclimatic forecasts, model-checking of decision systems.

Acknowledgements

This work has been carried out with the financial support of the French National Research Agency (ANR) under the “Programme Agriculture et Développement Durable”, project “ANR-05-PADD-001, Vin et Environnement” and is now supported by A2PV program of French Agricultural Ministry, project “SyDéRéT”.

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