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# Evolution of some pathosystems on wheat and vines

David Gouache, Romain Roche,  
Philippe Pieri et Marie-Odile Bancal

## A Problem and methodology

Plant pests (pathogenic organisms, weeds) are known to have variable effects on crops, depending on variations in year-to-year weather conditions: this has led to numerous studies being based on the relationships between pests and weather, with a view to tactically adjusting pest control practices during the year. It is likely therefore that climate change\* will greatly affect the behaviour of pathogens, and here we intend to study the effects, both theoretical (yield\* loss) and practical (fungicidal treatments and preventative measures) for various pathosystems.

The study presented here is focussed on certain phytopathogenic fungi of wheat and vines. The models used have some notable peculiarities compared with the crop models used to treat the other topics. Here, the models vary greatly in their degree of complexity and in the way they take account of weather/host/pathogen relationships (the so-called "disease triangle").

A first approach to the study of the relationships of the disease triangle is to almost completely ignore the host and only study the effect of weather conditions on the efficiency of infection by the fungus. Classically two weather variables are used: the temperature and the leaf wetness duration\* (the presence of free water on the leaves) (L'Homme and Jimenez, 1992). The former is readily available; it remains to calculate the latter: this is the variable HUMEC, calculated from a micrometeorological model assuming a wheat-type leaf. This variable has the advantage of being able to be expressed as a number of infectious days for a very wide range of pathogens. However the number of infectious days per se is not necessarily adequate to assess the severity of an epidemic. Other phases of the epidemic may also be limiting, or else there may be infectious days which are not harmful to the plant.

To analyse these interactions, it is possible to couple a model of the behaviour of the pathogen with a crop model. This coupling can be made in a more or less integrated way between the biology of the pathogen and that of the plant. The models presented below offer different degrees of integration between disease and plant models. Finally, these models can be accompanied by decision rules for applying treatments. With these models we will therefore study a variable called severity, which is more or less closely linked to yield losses due to the disease, and trends in the frequency of fungicidal treatments. Table 1 describes the pathogens and models studied.





Degree of plant-pathogen integration	- —————> +			
	Leaf wetness duration	Vine Botrytis (cv merlot)	Wheat septoria tritici blotch	Wheat brown rust
Phenomenon studied	Leaf wetness duration	Vine Botrytis (cv merlot)	Wheat septoria tritici blotch	Wheat brown rust
Present importance	Variable influencing nearly all fungi	Very important (quantity and quality)	Most important disease of soft wheat	2 <sup>nd</sup> most important disease of soft wheat
Known impacts of climate* and manner in which it is accounted for in the model	Constitution overwinter inoculum buildup	depends on the previous year's epidemic (and hence its weather) and winter conditions: not taken into account	depends on the rate of multiplication of the fungus in the field. This phase is currently limited by the winter cold, but can also be by the lack of rain and/or humidity; • taken into account for septoria ; • not taken into account for rust.	
	Epidemiological progression* Epidemic progress	T° and hourly rainfall: taken into account	depends on weather conditions (rain, humidity, radiation and T°) with a retarding effect on the appearance of symptoms: taken into account	depends on the coincidence of infectious conditions (rain and T° for septoria; duration of wetness and T° for rust) and emergence of last leaves of the plant, then • for septoria: temperature for the appearance of symptoms: taken into account; • for rust: temperature and physiological status of leaves for the production of spores, and lastly rainfall and wind conditions for spore dispersal: taken into account.
	Expression Yield loss		depends on the frequency of attack of the bunches and the proportion of berries attacked within the bunch	depends on the amount of contamination suffered in the last stages, but also on the lifespan of the uninfected foliage • for septoria: 2 <sup>nd</sup> aspect not taken into account; • for rust: both aspects accounted for
Calculation of the key variable	HUMEC	FREQ: % of bunches attacked and SEV: % of berries infected within bunches	NUISI: % of foliage affected by the disease during the 1 <sup>st</sup> phase of grain-filling by the "area below the curve" technique. This indicator is known to be well related to the severity, but does not take into account differences in canopy growth, due to abiotic factors	NUISI: Yield loss directly calculated
Calculation of fungicide treatments	no	yes	yes	no

Table 1: summary of pathosystems studied and models used.

## B Trends found and explanatory factors

In this part we will deal with the results for the key variables (wetness duration and severity). Where it is relevant to do so, we will break down the different phases of the epidemic to bring to light certain contradictory trends. We will try to relate the trends we find to those of easily-calculated indicators. We also offer some ideas about the uncertainty associated with the work.

### Wetness duration

In this analysis we have focussed on the spring and summer, as it is during these seasons that the largest differentiations are observed in relation to climate change and these are the most significant for the pathogens studied.

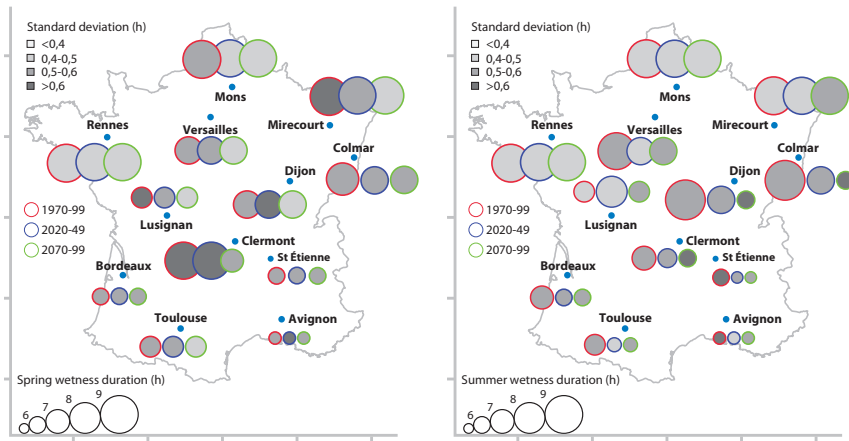


Figure 1: wetness durations (in hours) in spring (left) and summer (right) using the WT\* downscaling method.

In the maps in figure 1, where the mean wetness durations are expressed in hours, one sees very clearly a north-south divide, with wetness durations about 1.5 times higher in the north than in the south. The future trend is towards a slight fall in the spring, which is much more pronounced in summer. The most northerly sites\* (Mons and Mirecourt) and those to the west (Rennes) seem to be exceptions. While the fall in the mean values is small, we see in places a fall in the year-to-year variability (standard deviation) (e.g. Mirecourt, Versailles, Lusignan in spring). Finally, although the values fall in the centre-east, they do not, even for the distant future, (DF\*), reach values as low as those of the most southerly sites for the recent past (RP\*). Climate change will thus reduce the number of days favourable to infection for the two key seasons of spring and summer. However the disease pressure will remain stronger in the future in the north than it currently is in the south.

For most pathogens the wetness duration, effective for infection, is considered in relation to the ambient temperature: for many, the higher the temperature, the shorter is the wetness duration needed for infection (strictly speaking, this is only applicable to diseases with a high optimum temperature such as wheat rust). Yet temperature is one of the main factors likely to be altered by climate change. We have therefore chosen, in the following maps, to show the trend in the number of wet degrees-days\* for the different sites for spring and summer.



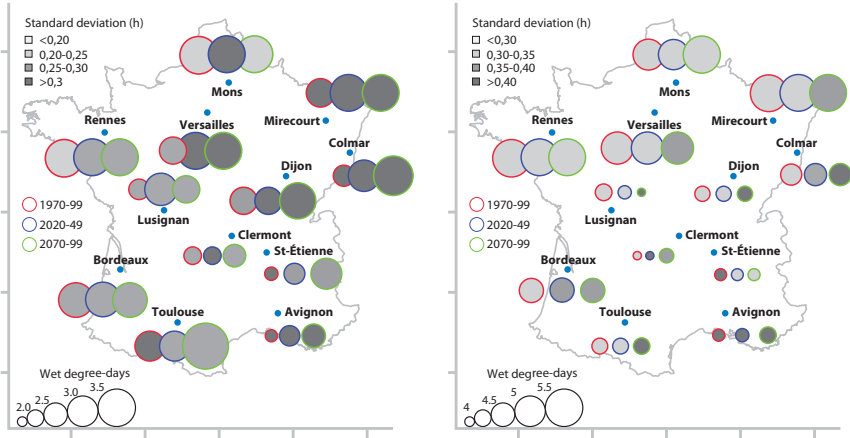


Figure 2: degrees-days of wetness in spring (left) and in summer (right) using the WT downscaling method.

With this approach (fig. 2), because of the temperature increases, the trend is reversed and now shows a slight increase to be expected in the future at certain sites. We do however still observe, although perhaps not so clearly, a certain north-south divide: in spring, only the three sites of Clermont, Saint-Étienne and Avignon stand out, with significantly shorter wetness periods than the others, be it for the recent past (RP\*), the near future (NF\*) or the distant future (DF\*). For the summer only, the four most north-westerly sites stand out, with particularly high values for all the periods. This means that the infection conditions will be, in general, slightly more favourable in spring for diseases with a high optimum temperature. On the other hand in summer they will remain constant.

These trends are generally confirmed by figure 3, showing, for spring at Colmar, the distributions of leaf wetness durations in intervals of 3 hours on the left, and of 1 day-degree on the right. We see a general shift in the distribution of the wetness durations towards lower values in the future, and conversely, a shift in the number of wet degrees-days towards higher values. This result is due to the dominating effect of warming on shortening the durations expressed in hours. However, before drawing conclusions about the effect of climate change on these diseases, one must also take account of the advancement of phenological\* stages of host crops as affected by this same temperature factor, which could partially compensate for this effect of warming by repositioning key phases in cooler periods, in which case the reduction in wetness duration could still be just as large. Finally, the reasoning should include the full infectious cycle of the disease and not just the infection phase on which we have focussed in our interpretation: this is the objective of the following parts, which treat several important diseases in more detail.

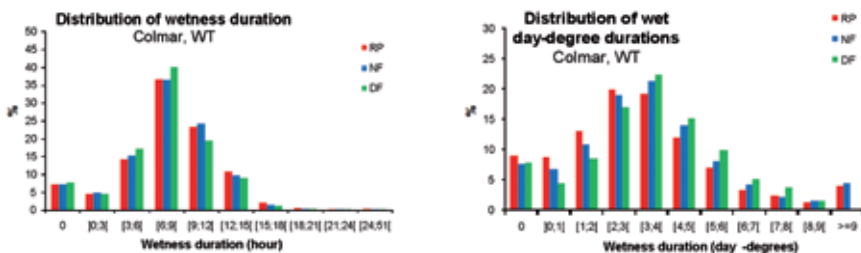
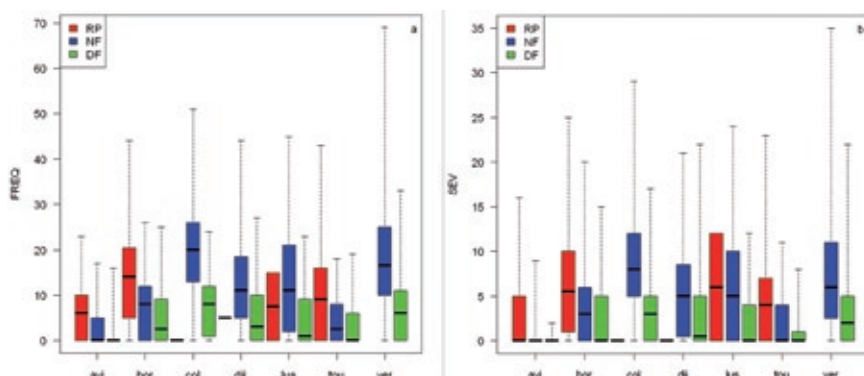


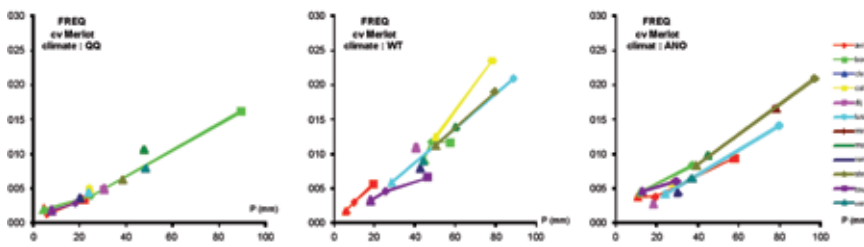
Figure 3: distribution of wetness durations (in 3-hour intervals) (left) and degrees-days of wetness (right) for Colmar, using the WT downscaling method.

## Vine Botrytis

The simulation results (only applicable to the merlot variety) expressed as numbers of risk days for increase in the frequency (FREQ: % of berries attacked) and severity (SEV: % of berries infected within bunches) of Botrytis attacks, are shown in figure 4 for the main wine-growing sites (Avignon, Bordeaux, Toulouse, Dijon) and some prospective sites (Lusignan, Versailles, Colmar). They show a clear trend towards a lowering of the infection risk for the traditional wine-growing sites, with a steady trend between RP, NF and DF. These results are barely affected by the downscaling method. For the sites where vines, although not currently grown, could be (success of the crop better than 80%, cf. section ADVANTAGES AND VULNERABILITIES) in the NF or DF, the associated infection risk is very high and very variable: we will return to this point later on.



**Figure 4:** changes in the severity of Botrytis (vine cv. merlot) and its variability (extremes, median, 2<sup>nd</sup> and 8<sup>th</sup> deciles) expressed as number of risk days for frequency FREQ (left) and severity SEV (right) increase (cf. tab.1)



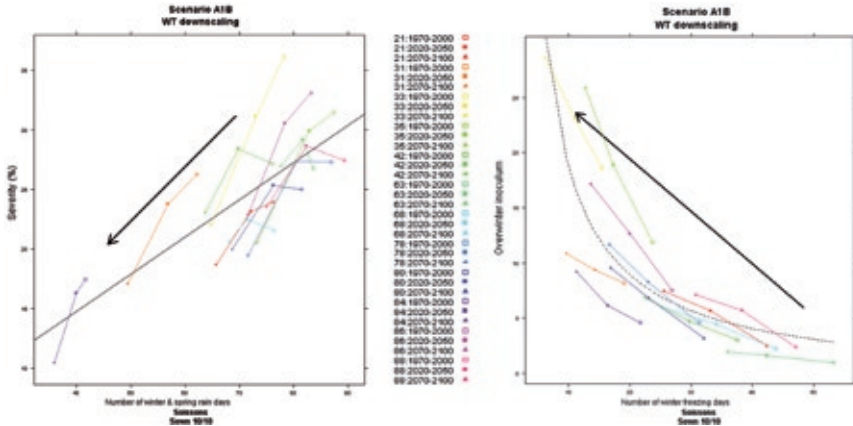
**Figure 5:** relation between the severity of Botrytis on vines (cv. merlot) expressed by the variable FREQ (% of bunches attacked) and rainfall for three downscaling methods.

The predicted variations in the epidemic risk are closely related to variation in rainfall during the period from veraison to maturity (fig. 5). These relationships are almost linear, with a dispersion which depends on the downscaling method (but a large proportion of the observed differences arise from differences in crop feasibility\*), with a slope of about 0.2 risk days per mm of rain. Considered individually, each site follows this relation well: the amount of rainfall during the period from veraison to maturity thus constitutes a very good indicator to evaluate the impact of climate change on the change in infection risk. This indicator appears all the more useful as even the possible future sites fit this relationship, which appears to be of general value.



**Wheat Septoria tritici blotch**

The key trend simulated is to diminishing severity of the disease, of approximately 20% in the DF as compared with the RP (fig. 6 right).



**Figure 6:** changes in the inoculum during winter as a function of the number of days of frost (left) and the severity of septoria as a function of the number of days of rain in winter and in spring (right). The arrows indicate the trend with climate change. WT downscaling method

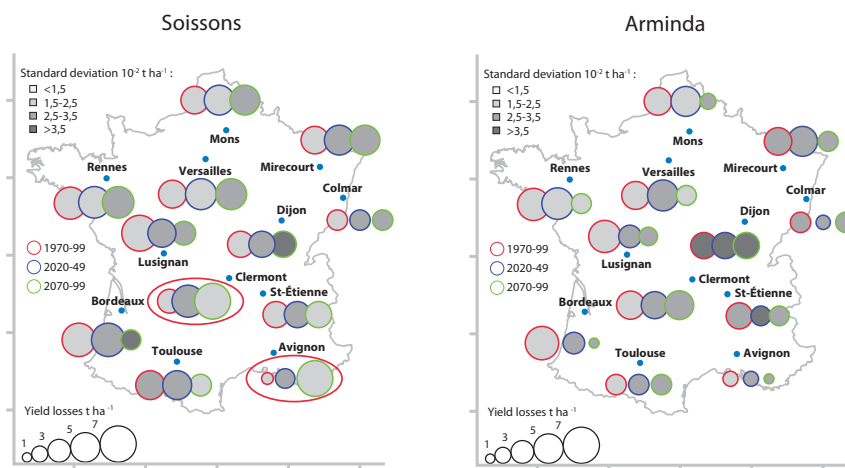
However, this general finding seems rather variable depending on both the geographical sector and especially the downscaling method\* chosen. In fact the trend appears rather gradual with the QQ\* method, whereas with the WT\* method we sometimes see a stagnation or even a slight increase in severity in the NF. The changes are not so clear with the Anomalies downscaling method. This general trend is confirmed when observing the earliness of epidemic onset, which is characterised by the date of the first fungicide spray recommended by the model (see § on treatments): in relation to the plant developmental stages, the epidemic is delayed by 5-10 days.

In seeking to explain this result we examined two phases that exhibit contradictory behaviour. The first, that of the formation of overwinter inoculum, is in fact favoured by climate change: the quantities of inoculum present in the fields at the end of winter are increased. The number of days of frost, a climatic variable mentioned in several studies of septoria (Beest *et al.*, 2009), explains this trend well (fig. 6 right). The winter cold thus becomes much less limiting, but this is counterbalanced by the fact that the following phase, of the progress of the epidemic, becomes increasingly unfavourable to the disease. In fact it seems that the importance of overwinter inoculum as an explanatory factor in the final severity of the disease will diminish. The number of days of rain during winter and spring constitutes a simple explanatory variable for the changes in severity found (Shaw, 1993; Cohan *et al.*, 2006). Departures from this trend could be explained by temperature: the sites whose climate\* is milder by virtue of the oceanic influence are situated above the trend line.



## Wheat brown rust

The following maps (fig. 7) show the changes in absolute yield losses in tons per hectare for an early variety (Soissons) and a late variety (Arminda) of soft winter wheat, simulated for a sowing date of 10 October.



**Figure 7:** changes in yield losses due to brown rust for Soissons (left) and Arminda (right), calculated with the A1B scenario and the WT downscaling method for soil 1.

We essentially find a stagnation or even a reduction in yield losses due to brown rust, the latter trend being more marked for the late variety than for the early one. This varietal difference corresponds to yield differences between early and late varieties; in the same way, losses are less severe for the low-yielding sites and for the late variety. Also, in general, the number of infectious days and the maximum severity are slightly higher for the early variety, and fall in the NF and DF. Nevertheless we see an increase in losses for Soissons at Clermont-Theix and Avignon. For the mountainous site, the mean temperature increase can explain this trend to an increase in the maximum severity of the rust.

The year-to-year variability in losses increases slightly, especially for the early variety. These results agree in general with those obtained for the QQ and ANO\* downscaling methods, with however some divergences for certain sites; for example the ANO downscaling method predicts an increase in yield losses in the future for Versailles and Rennes (but only for the early variety). The results are thus very sensitive to future climatic uncertainty (cf. CLIMATE section and § on uncertainty).

In searching for relationships between climatic indicators and crop behaviour (fig. 8), we find that the simulated yield losses decline with the reduction in rainfall and increase in temperature predicted for the NF and DF. However the correlations with these general climatic variables are weak, because certain sites depart strongly from the trend, in particular Avignon, Clermont-Theix and Colmar, for one or other of the indicators. These site effects disappear when one considers water stress\* as an explanatory variable for yield losses; on average it explains 75% of these losses. Lastly, it is also notable that the variation in yield losses is partly related to that of disease-free yields. However this last result is based more on differences between sites than between periods. In fact the changes between periods are often orthogonal to the trend, showing that the yield projections for healthy crops are not sufficient to diagnose those for the severity of brown rust.





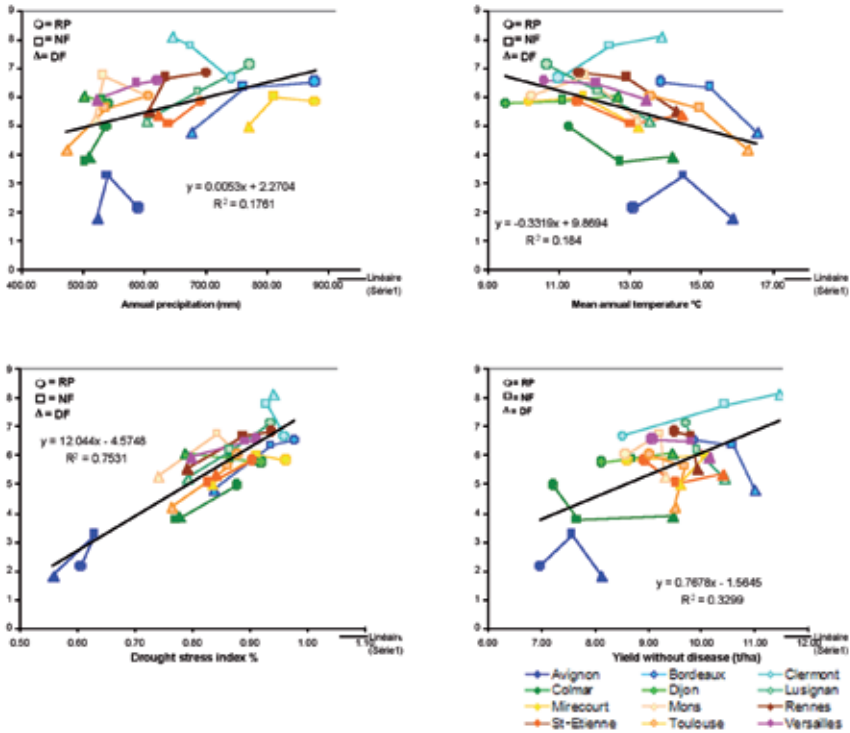
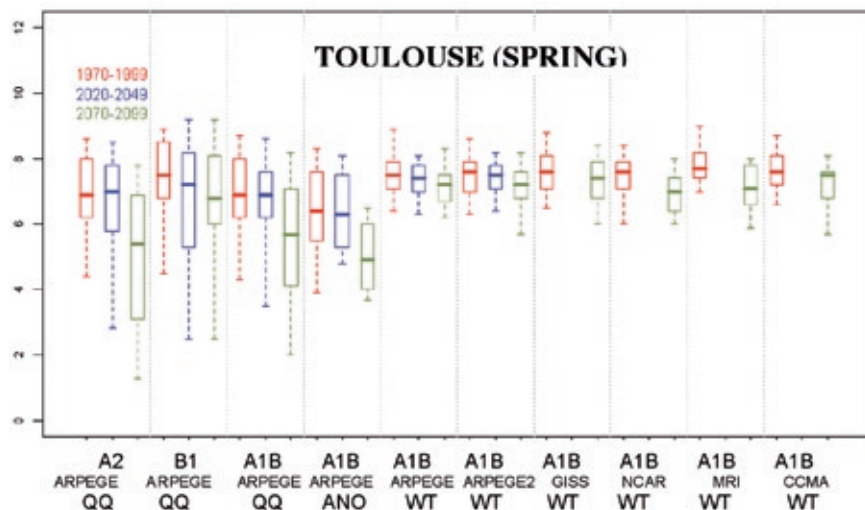


Figure 8: relation between simulated yield loss (t/ha) and direct or indirect indicators of climate change: P (mm), T (°C), water sufficiency (ETR/ETM) and the yield of disease-free crops (t/ha).

### C The uncertainties found

A peculiarity of the models used here is their often non-linear character, the interaction between temperature and rainfall, and the importance of occurrences (rainfall, infectious episodes) rather than their accumulated values. This suggests that weather variability is particularly important. However this is not estimated in the same way between downscaling methods. When one looks at the effect of these downscaling methods over all the series of weather records used for wetness duration (e.g. Toulouse in spring: fig. 9), one notices two very different forms of behaviour: one group, formed by the scenarios downscaled with the QQ and ANO methods, which show a very large year-to-year variability, and another, containing the scenarios downscaled by the WT method and with a distinctly smaller year-to-year variability. The trend of decline of leaf wetness duration due to climate change is in the same direction for both groups, but much stronger for the first (the predicted trends are on average twice as high).



**Figure 9:** variability of wetting at Toulouse in spring as a function of climatic uncertainty represented by either the SRES\* scenarios, the climate models, or the downscaling methods (cf. CLIMATE and UNCERTAINTY AND VARIABILITY). The five values for the boxes represent the minimum and maximum values, the 2nd and 8th deciles, and the median in the centre.

For septoria also, it is the WT downscaling method which behaves differently from the others, with a stagnation phase or even a slight increase in the disease in the NF, whereas the other methods suggest a more gradual decline in the disease. However for the relation between severity and number of days of rain, it is the ANO method which gives the least favourable results. The case of Botrytis is rather different. For this pathosystem, studied on the variety merlot, the uncertainty in the results is largely due to the uncertainty as to the feasibility of growing this variety.

The diagnostic relationships described above based on agroclimatic indicators help to account for some of this climatic uncertainty.

## D Practical consequences

### Fungicidal treatments

#### Vine Botrytis

The numbers of fungicidal treatments simulated by the model are close to current practice (0-2) but they vary widely (fig. 10). For the thirty-year means, the predictable trend is consistent with that of the risk, i.e. a fall in the number of treatments for the sites where merlot is already grown, especially the fairly humid ones, such as Bordeaux. For sites that could be converted to merlot, planting on these new lands will take place at the cost of using a large quantity of fungicide, casting doubt on its feasibility (cf. ADVANTAGES and VULNERABILITIES and VINES).

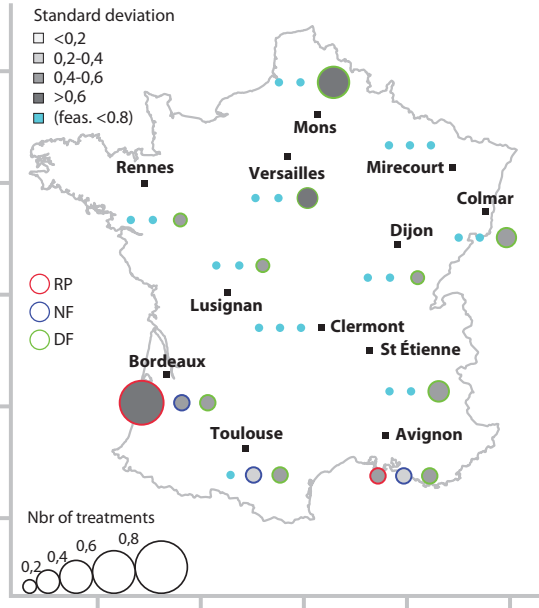


Figure 10: number of treatments required against vine Botrytis (cv. merlot, QQ downscaling method).

### Wheat Septoria

Together with the reduction in severity, we see a trend towards a reduction in anti-septoria fungicide treatments (fig. 11). The variations observed between sites and weather patterns are fully in line with those observed for the severity variable.

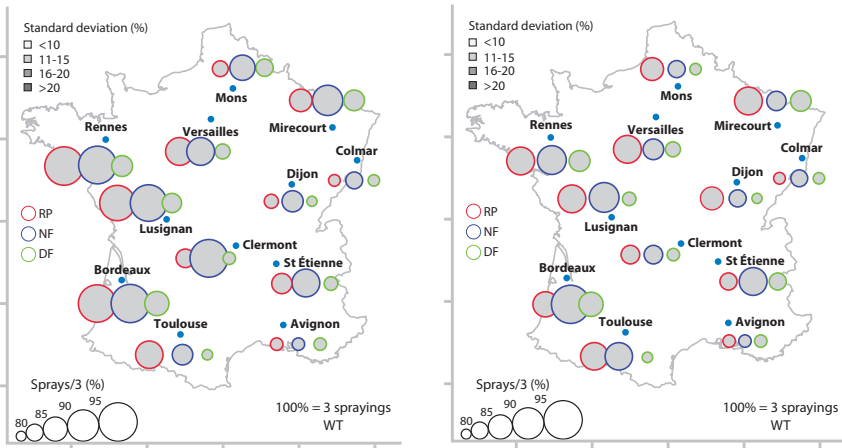


Figure 11: probability of carrying out the 1<sup>st</sup> anti-septoria treatment on wheat (cv. Soissons), WT downscaling method on left and QQ on right.

In terms of implementation, the dates of the first treatment are significantly earlier, by about 15-20 days, between the present and future periods, with quite a steady trend. This apparent “advancement” should however be compared with the advancement of phenological stages: in fact, the advancement of crop stages is greater than that of the disease. This makes sense for two reasons. Firstly, the rate of development\* of the plant depends only on the temperature, whereas that of the disease is limited by both temperature and leaf wetness. Secondly, Lovell *et al.* (2004), by studying the latency time of septoria, showed that this disease possessed a speed advantage when temperatures are cooler. Furthermore, we see, across both sites and time periods, that the earlier the growth stages, the later is the disease onset in relation to them. Compared with these two effects, the effect of varietal earliness is negligible.

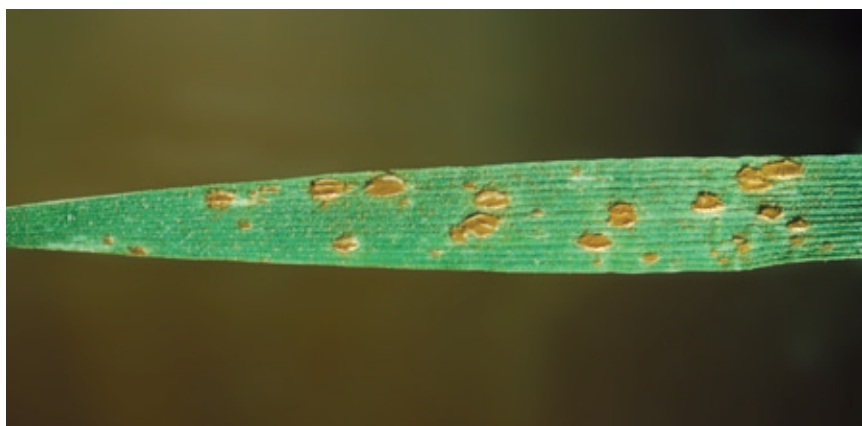
We also tried, using very simple indicators such as rain events around recommended spraying dates, to assess whether sprayings in favourable application conditions would be likely to be compromised: no trend appeared in this respect, but a systematic and multicriteria study is needed here.

### Effect of prophylactic practices

The simulations for septoria and brown rust were made for a wide range of sowing dates. This enabled us to evaluate the impact of climate change on a non-chemical method of control, i.e. deferred sowing. Late sowings are known to limit the overwinter inoculum pressure for both these diseases, which thus have less time to multiply during this phase. For both diseases, we see reduced severity with late sowing.

In the case of brown rust, this decrease is more marked for the early variety and for the RP. The variability in response between sites is large: we can distinguish sites where the yield loss declines slightly and continuously with the sowing date (Avignon and Colmar) and with little variation due to climate change, and other sites (Bordeaux, Lusignan, Toulouse –three sites currently among the most subject to the disease at present– and Mons), where climate change leads to a much clearer reduction in losses, especially for the late variety.

This approach must be combined with the maintenance of a viable economic yield, bearing in mind that the yield also falls with later sowing, but that the increase in ambient CO<sub>2</sub> allows a higher yield potential to be reached (cf. TIMING and WHEAT sections).



### What you need to remember

- ✓ In general, for all the simulated pathosystems, the impression which emerges is that of a lowering of the pressure from fungal diseases. However this assertion needs to be qualified a little.
- ✓ Wetness duration, a common variable to many pathosystems (far beyond the three studied here), falls. However the variable “wet degrees-days”, theoretically more appropriate for diseases with a high optimum temperature such as brown rust of wheat, increases slightly. For vines, the pressure from Botrytis falls at the sites in the south where the modelled variety is already feasible now, but at the sites where this variety will become feasible in future, the Botrytis pressure will be very high. Finally, for septoria, there is uncertainty about the variation in the near future.
- ✓ Note that the results are subject to climatic uncertainty, mainly associated with the downscaling method. Lastly, one must remember that for each pathosystem, we have been able to identify synthetic variables, simpler to calculate, which seem to be well related to the projected trends. However, these relationships are so far specific to each pathosystem.



### What needs further study ...

- ✓ Several aspects of the work done here would be worth further study. A limitation for the Botrytis and brown rust pathosystems is the failure to take account of the impact of climate change on inoculum overwintering. Yet it is likely that these effects may be strong. For vines, it would have been interesting to study several varieties, especially those adapted to the most northerly wine-growing areas.
- ✓ More general limitations can be mentioned. Note, for example, that the effects of CO<sub>2</sub> on the pathogens are not considered, although several studies suggest that it may reduce the severity of diseases. Also, there is the fact that these studies were carried out on one pathogen at a time, yet climate change might, in a given place, modify the relative importance of pathogens, or even cause new ones to appear. Finally, this work does not take account of possible adaptations\* of populations of pathogens to climate change: for example we have recently seen the establishment, in Australia, of a new race of yellow rust, better adapted to hot conditions (Millus *et al.*, 2009).





### To find out more ...

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