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Climate change and the wheat crop: the main impacts

Marie-Odile Bancal, Philippe Gate

A Some key elements for the soft wheat crop in France

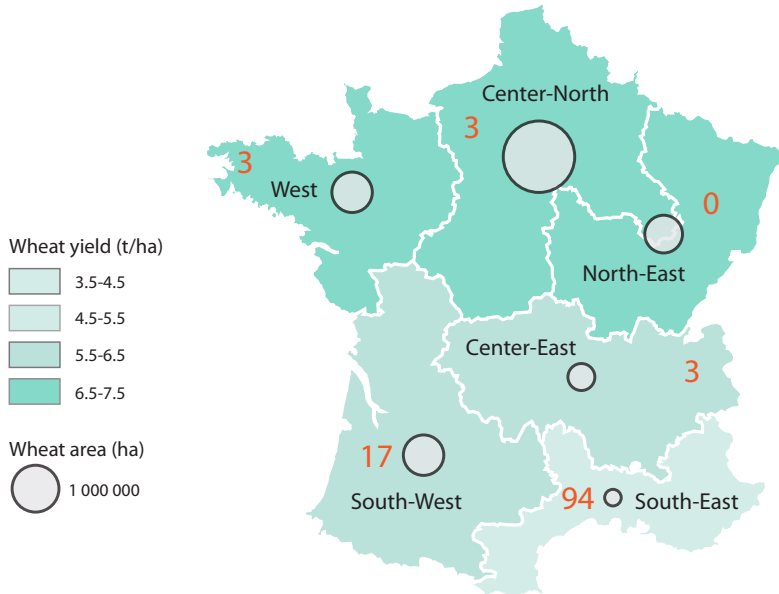


Figure 1: yields and areas sown with wheat in the CLIMATOR regions, with the proportion of durum wheat in red, and mean yields*. Means 2000-2007. Source Agreste.

Occupying about 4.8 million hectares (17% of the UAA), soft wheat is the highest-ranking of French arable crops. Half the area is situated in the centre-north (fig. 1). The mean yields are about 7 t ha^{-1} with a maximum of 7.5 t ha^{-1} in the north-east and a minimum of 3.7 t ha^{-1} in the south-eastern region where it is usually replaced by durum wheat (cf. "And durum wheat?"). Soft wheat is grown for its starch, and an improvement in its protein content is often sought for human and animal feeding. The diversity of industrial outlets with a primary processing (semolina and starch manufacture, milling) and often a secondary one (biscuits and bread) involves precise specifications to reach optimal quality at harvest which are specific for each industrial process.

Wheat is a major crop in arable rotations. Its long life cycle, from October to July, its wide range of sowing dates and its relative tolerance to degraded environments make it an easy crop to grow, exploiting a wide range of environments; its sensitivity to heat and water stress* however limit its expansion into the southern zones. As to diseases, wheat is subject to numerous fungal diseases, both soil-borne (eyespot, take-all) and foliar (mainly Septoria leaf spot, rusts and Fusarium foot rot), which frequently affect yield and the technological, hygienic and nutritional quality of the harvest. It is also sensitive to waterlogging and has high nitrogen requirements.

B Simulation protocol of CLIMATOR

The cultivation of soft wheat has been studied in monoculture with three crop models*, CERES, STICS and PANORAMIX, and several cropping systems* with the STICS model, including a basic irrigated cereal system (MWRW) and two low-input systems (SWSgW) and ORG). Durum wheat was only studied in STICS simulations as part of the MWRW and SWSgW successions.

Sites	12 sites in mainland France including one at high altitude
System	Monoculture (all models) Three successions (STICS): <ul style="list-style-type: none"> • maize-soft wheat-rape-durum wheat (MWRW) • sunflower-durum wheat-sorghum-soft wheat (SWSgW) • peas-soft wheat-2 years of forage grass (ORG)
Management	Recommended management, sowing 10 Oct, 230 kg N ha ⁻¹ in 3 applications Sowing dates: 20 Sept, 1 Oct, 10 Oct, 20 Oct, 10 Nov, 1 Dec Irrigation for the MWRW system to 50% of water requirements (if necessary)
Soils	Soil 1: deep silt soil with a high available water reserve (AWR) (226 mm) and average fertility Soil 2: rendzina with a low AWR (104 mm) and low fertility Soil 3: leached hydromorphic soil with a high AWR (218 mm) and high fertility
Variety	Soissons (early) and Arminde (late) which differ in their earliness at the 1cm ear stage and duration of stem elongation
Model	CERES, PANORAMIX, STICS
Climate	SRES: A1B, ARPÈGE, downscaling: WT, QQ and ANO

C Ecophysiological identity card of wheat in the climate change context

Advantages

Like all C3 plants, soft winter wheat and durum wheat are good for exploiting the increase in CO₂ concentration, with both a stimulation of photosynthesis* and a limitation of transpiration.

The calendar timing of its developmental cycle is generally advantageous for avoiding summer water stress*, and this could be further enhanced by suitable varietal choice. Also, soft wheat has high vernalisation* requirements: to complete its floral development*, it requires a certain number of days when the mean temperature does not exceed 10°C (about 40-80 days according to the varieties and the climate*). These vernalisation requirements depend on the variety and are a component of their earliness. Moreover, to flower, a vernalised wheat must be subjected to a long photoperiod, which gives a certain stability to the duration of the emergence-flowering period in relation to regional temperature regimes and climate change*. Thus the shortening of the growth cycle caused by climatic warming will be limited by these two requirements (vernalisation and long days) of soft wheat.

The beginning of stem elongation (or the 1cm ear stage) is a critical stage as regards low temperatures at the moment when the apex passes from the buffered temperature of the soil to that of the air, and from a vegetative physiology to a reproductive one: the temperature threshold

of -4.5°C for soft wheat is usually lethal for main culms during stem elongation (earlier, during the vegetative phase, one can assume a temperature of -25°C for the freezing threshold of the plants). This ear frost damage mainly affects the main stems which contribute about 50% to the final yield. Consequently, this occurrence of early freezing of the ears is regarded as a major factor in the feasibility* of growing the crop, even though tillering can partially compensate for the losses caused. If, as seems likely, these ear frosts should become rarer with climate change, it is important to reconsider the timing of the sensitive stages in relation to the occurrences of low temperatures. Still in relation to winter physiology, the reduction of waterlogging may also prove to be favourable in certain regions.

Weaknesses

Although soft winter wheat is less sensitive to summer water stress than spring-sown wheat, it is on the other hand very sensitive to heat stress towards the end of growth, which can occur above 28°C : above this threshold, there is an irreversible cessation of the growth of the grains and sometimes even abortion of grains beginning to fill. Also, above 25°C there may be a reduction in grain growth. More generally, one must consider the timing of the critical stages (stem elongation, flowering, grain filling) in relation to the occurrence of high temperatures and/or water stress, because it is these stresses brought about by climate change which could hinder the formation of wheat yield in the future.

Note also that its vernalisation requirements make soft wheat sensitive to an increase in winter temperatures which, above a certain threshold, could become critical for its flowering.



D Impacts of climate change on wheat growing

Impacts on yield and its components

The maps (fig. 2) show the geographical distribution of yield trends and their variability* for an early variety (Soissons) and a late variety (Arminda) of soft wheat, simulated with CERES. Compared with the RP* we see an increase in the yield of the variety Soissons (a mean increase of about 0.7 ± 0.5 t/ha for the NF* and of 1.2 ± 0.8 t/ha for the DF*), mainly in the east of the country. This increase in mean yield is nearly always accompanied by an increase in the variability of yields, indicated by the shade of grey of the circles in figure 2.

Except for certain sites* (Bordeaux, Clermont and Saint-Étienne), the variety Arminda has a lower yield than the early variety (96% of its yield on average for the RP). It also shows a less clear trend towards an increase in yields: of about 2% and 6% for the NF and DF respectively, as against 9% and 14% for the early variety. Hence this all supports the view that for the late variety, the benefit of the increased CO₂ is counterbalanced by the larger effect of stresses.

These results, obtained with the CERES crop model, agree in general with those of PANORAMIX. One should note however one difference with the STICS model which, by taking account of waterlogging, simulates a substantial increase in yield at all the sites towards the west (Rennes, Lusignan, Bordeaux).

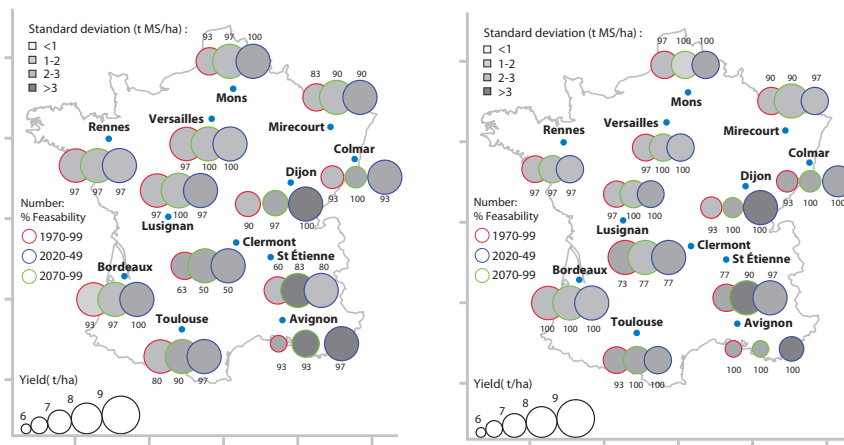


Figure 2: changes in yield (means and variability) and in feasibility (percentage given below the average yield per site) of the soft wheat crop for the early variety Soissons (A) and the late variety Arminda (B). CERES model, soil 1, WT climate.

Lastly, figure 2 shows an increase in the feasibility of the crop with climate change at all the sites, due to the decline in ear frost risk. This trend is very clear in the east for both varieties. The feasibility, calculated in this way, is very high (>80%) at all the sites except for the high-altitude site of Clermont. This site is also distinguished by the fact that the early variety's feasibility falls from 63% to 50%, suggesting that the developmental shift due to climate change results in a more unfavourable timing of the frost-sensitive stage, whereas for the late variety the feasibility remains the same at about 75%. Due to winter waterlogging, the STICS model simulates low yields at the western sites, which often makes wheat growing unprofitable, even though physiologically feasible, in the NF. Climate change tends to remove this constraint.

Table 1 gives yield projections* for the NF and the DF, site by site, with their level of significance. On average, we see a significant increase in yield of about 0.9 to 1t/ha in the NF and DF respectively, due to the effect of increasing CO₂.

	NF-RP	DF-RP
Avignon	ns	ns
Bordeaux	ns	<i>0.9</i>
Clermont	ns	ns
Colmar	<i>1.1</i>	<i>1.7</i>
Dijon	ns	<i>1.5</i>
Lusignan	ns	ns
Mirecourt	1.9	1.3
Mons	<i>1.0</i>	<i>1.0</i>
Rennes	ns	ns
Saint-Étienne	2.4	2.6
Toulouse	1.3	<i>1.5</i>
Versailles	0.9	<i>0.8</i>
All sites	0.9	1.0

Table 1: changes in wheat yields simulated by CERES (soil 1, climate:WT). The significance of the changes in comparison with the year-to-year variability is denoted thus: **Bold:** $p < 0.01$; *Italics:* $p < 0.05$; Normal: $p < 0.10$; ns: non-significant.



However the response is very variable between sites. Thus, no significant change is predicted for half the sites in the near future (Avignon, Bordeaux, Dijon, Clermont, Lusignan and Rennes) and for a third of the sites in the distant future (Avignon, Clermont, Lusignan and Rennes). For the other sites, the increase in yield is significant and varies from 0.9t/ha at Versailles to 2.4t/ha at Saint-Étienne in the near future and from 0.8t/ha to 2.6t/ha in two thirds of cases in the distant future.

If we now examine the components of yield (fig. 3), we see that 70% and 55% of yield variability is related to that of the number of grains (NG/m²) for the early and late varieties respectively. In both cases and for most of the sites, we find an increase in NG/m² with climate change. This suggests that the water and heat stresses resulting from climate change are not critical during the pre-flowering phases when this component is being formed: the advancement of stages partially limits the occurrence of stress (cf. TIMING section). On the other hand the sites differ as regards grain filling: for a given number of grains one can find differences in the 1000-grain weight (TGW) of up to 20%. Grain filling is more affected by water and heat stress towards the end of life for the late variety, but the longer duration of grain filling combined with the increase in CO₂ buffers these effects. This is illustrated by the concomitant changes in TGW and NG/m² of the two varieties which shows a larger fall in TGW for the late variety for the same NG/m². However it remains clear that the responses to climate change are very site-dependent: for example at Avignon, NG/m² and TGW are always limiting yield, but increase with climate change, whereas conversely at Mirecourt and Mons, with the likely climate during stem elongation improving, it allows the formation of a high NG/m² for the NF, although the conditions at grain filling preclude a maximal TGW.

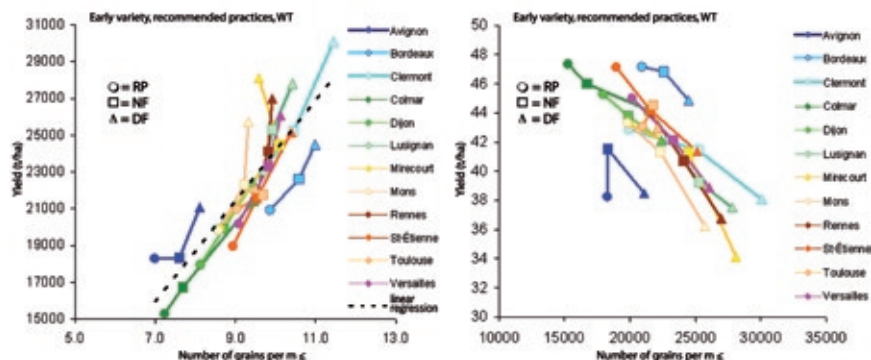
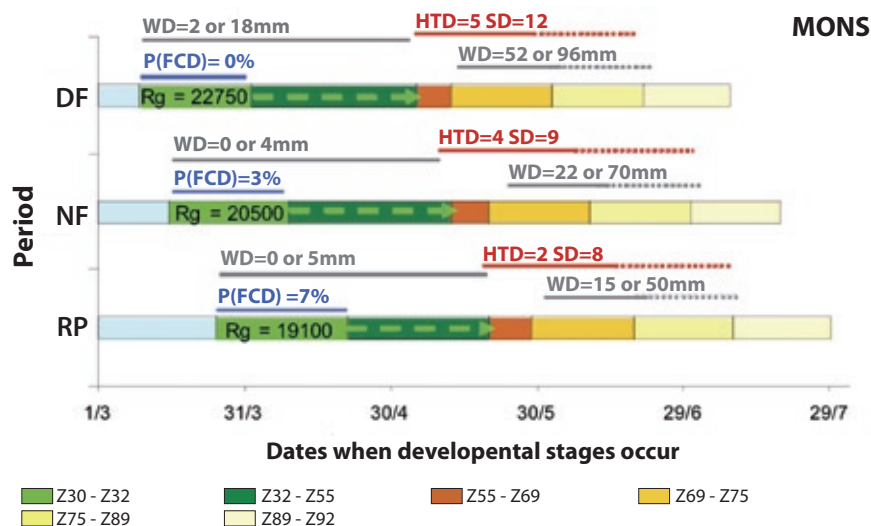


Figure 3: yield formation for an early variety (Soissons). Left, relation between yield and NG/m² and, right, the relationship between components for all sites. ●: RP, ■: NF, ▲: DF.

Impacts on the lifespan, the flowering date, and associated stresses

Figure 4 illustrates, for the Mons site, the impact of climate change on the phenology of an early variety (PANORAMIX model) and its consequences for the occurrence of stress at critical phases in wheat growth: risks of frost at the start of stem elongation, water stress during stem elongation and grain filling, and finally, high temperatures (Tmax > 25°C) around flowering and during grain filling.



P(FCD) = frequency of years with frost during stem elongation
WD = water deficit (mm) if soil AWR is 193 or 104 mm during stem elongation (on left) and during grain filling (on right)
HTD = number of days with Tmax > 25°C from heading to milk grain developmental stages
SD = number of heat stress days during grain filling
Rg = cumulative global radiation during stem elongation in MJcm²

Figure 4: changes in phenology of wheat cv. Soissons with climate change and the associated climatic risks for the Mons site (PANORAMIX, WT, soil 1 for all, sowing date 10/10).

Because of warming, flowering is brought forward at Mons by 9 and 17 days and the whole life cycle is shortened by 10 and 20 days in the near and distant future respectively. These trends are the same for all the sites with developmental shifts which are generally larger in the north than in the south (cf. TIMING section). For wheat the “advancement” effect is greater than that of “shortening of grain filling”, which moderates the yield loss. However these “simple” phenological shifts are also accompanied by increased occurrence of stress towards the end of growth: a doubling of the number of hot days around flowering, affecting the potential NG/m² formed before flowering (also increased because of the improvement in growing conditions during stem elongation), an increase of 50-100% in the number of heat stress days during grain filling, and lastly a doubling or more of the water deficit during grain filling in the distant future, reaching 40-100mm depending on the soil type. This is in agreement with the reductions in simulated TGW in the near and distant future. The water deficit during stem elongation also increases, to reach significant values (up to 18mm on a soil with a low AWR*) in the distant future. These increases in the mean water deficit are accompanied by large increases in the extreme values.

Finally, climate change is not simply synonymous with deterioration in the conditions for wheat production. In fact, in addition to the increase in CO₂ which, depending on the model used, should compensate for the shortening of growth cycles, the frequency of ear frosts falls or remains unchanged while the incident radiation during stem elongation tends to increase. It is these factors which explain the increase in NG/m² mentioned earlier. We also find fewer problems of excessive water.



Water sufficiency for wheat

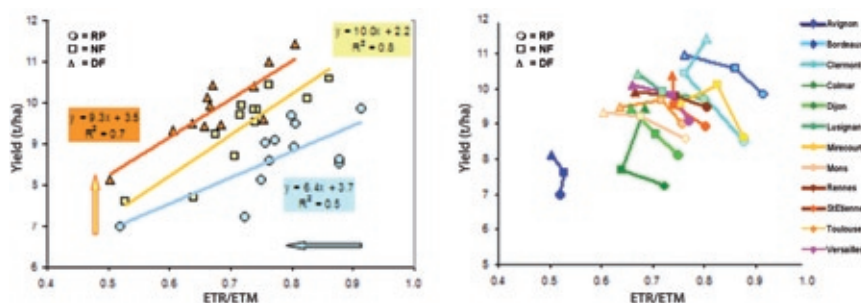


Figure 5: response of yield (a: left) of soft wheat to the variation in water sufficiency caused by climate change and variability due to the site (b: right). ●: RP*, ■: NF*, ▲: DF*.

Despite the advancement of developmental stages, the reduction in rainfall leads to a decline in water sufficiency (cf. WATER section) which is indicated by the blue arrow in figure 5a representing the change in ETR/ETRM* for most sites and the early variety Soissons. Also, the slope of the relations in figure 5a indicates that yield will respond more to this parameter in the future: we calculate that 60-80% of yield variations between sites is due to water sufficiency. On the other hand there is a positive effect: for the same level of water sufficiency, the yield increases in the NF and even more in the DF because of the beneficial effect of CO₂. Although less marked, we see the same thing for the late variety. However we should remain cautious about these conclusions as there is a large interaction between the effect of water sufficiency, the period and the site (fig. 5b): although most of the sites will experience increasing water stress with climate change, it may remain stable (as at Avignon) or even return to its reference value in the distant future after falling in the near future (at Colmar, Clermont, Saint-Étienne). This last effect is explained by the antitranspirant effect of CO₂.

Wheat diseases

At present the two commonest and most harmful leaf diseases of wheat (cf. HEALTH section), septoria leaf spot, predominant in the north of the Paris basin and near the Atlantic coast, and brown rust, a rampant disease in the south and south-west, are responsible for large yield losses. A reduction in their destructiveness of 20% and 15% on average in the case of septoria and brown rust respectively, is simulated for the DF. Although their biology is very different, the decline in the impact of both these diseases is due to the reduction in rainfall and the water sufficiency of the crop, and of course the yield increase with high CO₂.

These effects result from two contradictory behavioural processes in the context of climate change. On the one hand the primary inoculum seems to be favoured in the NF and DF by the reduction in frequency of winter frosts (cf. HEALTH section) for septoria, and probably this is also the case for brown rust. On the other hand the number of days of infection and the maximum severity of the rust tends to decline, particularly in the DF. Septoria develops at later developmental stages, generally ending up with less damage. We should point out however that adaptation of the pathogenic fungi to climate change is not taken into account and so the risks are probably underestimated.

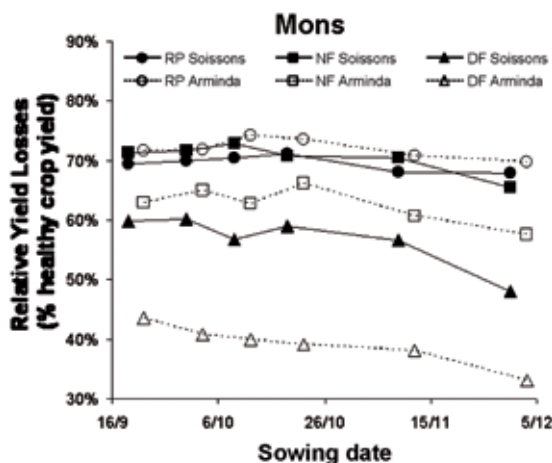


Figure 6: changes in harmfulness of brown rust (yield losses as % of healthy yield; CERES) with the variety, the sowing dates and the periods of interest (RP, NF and DF).

The choice of a combination of variety and sowing date is also a way of limiting disease damage. Thus figure 6 shows the advantage of late varieties in damage limitation, especially in the DF; similarly, and in agreement with current observations, late sowing dates also reduce damage. These data suggest the existence of ways of limiting future losses, even if the pathogen populations adapt. Also, as the sowing date affects both the yield potential (fig. 8) and the amount of damage, an optimum should be sought for each site.

And durum wheat?

Rarer than soft wheat, durum wheat represents only 1.4% of the French UAA, and 80% of it is grown in the south-eastern and south-western regions (fig. 1). The mean yield is 4.7t/ha with a maximum yield of 6.2t/ha in the centre-north and a minimum of 3.2t/ha in the south-east. The main outlet for durum wheat is for human food (couscous and pastry) with 65% exported. The quality requirements (technological and hygienic) are becoming stricter and stricter for export, in particular to north Africa. Nevertheless we find French growing areas and yields will remain unchanged. An increase in good quality yields is a major aim of the industry. In particular, the choice of variety is crucial in the control of fungal diseases.

Compared with soft winter wheat, durum wheat has lower requirements for vernalisation, making it less vulnerable to increases in winter temperatures. On the other hand the plants freeze at higher temperatures (-16°C). Although durum wheat is more sensitive to high temperatures (heat stress) than soft wheat, its shorter grain-filling period offers it better avoidance* possibilities. It has greater tolerance to water deficit due to stomatal closure at lower water potentials than for soft wheat, a capacity to extract soil water beyond the permanent wilting point, and also because of a lower leaf area index counterbalanced by an ability of the ears to carry out net photosynthesis. These properties explain why it is grown in the south of France.

Comparison of the yield changes for soft and durum wheat for the SWSgW succession.

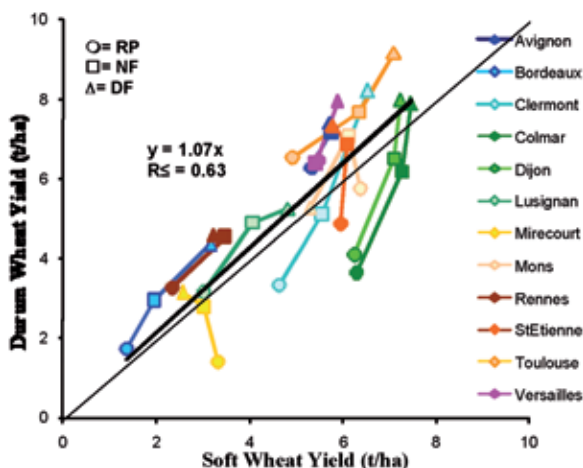


Figure 7: comparison of durum wheat yield (Acalou) with that of soft wheat (Soissons) in a durum wheat-sunflower-soft wheat-sorghum succession with the STICS model.

We see the same trend towards a yield increase with climate change for both species. Figure 7 compares the yield changes for durum wheat (cv. Acalou) and soft wheat (cv. Soissons) for each site. Although in general the durum wheat yield remains lower than that of soft wheat, we can see that at certain sites the two crops tend to converge in the NF. Hence on average climate change seems to benefit durum wheat more than soft wheat (attested by the slope of the regression line being greater than 1), which is in keeping with their respective physiological responses to water and heat stress. With a shorter lifespan, in particular for the grain-filling phase, the avoidance of high summer temperatures will be accentuated in durum wheat. Its lower leaf area index* and better capacity for extracting soil water will allow it to satisfy its water needs more easily.

E Adaptation of varieties and practices faced with climate change

The varietal response, by the timing of the growth cycle in relation to the climatic stresses, is an important lever for adapting cultural practices* to climate change. The sowing date in interaction with the variety is a second readily available means, provided that soil tillage and sowing are feasible (cf. TIMING section).

For each period, we find a significant advantage to the earliest sowings, from 5% to 25% depending on the sites, for the current period, which is within the range of variation normally observed. Figure 8a shows an example of the response of yields to sowing date as % of the yield calculated for the current period and the earliest sowing date. The yield falls with the delay in the sowing date, especially so the earlier the variety. This effect is more than compensated for in the NF and DF by the advancement of stages and the increase in CO_2 for sowing dates from 20 September till

10 November. On the other hand the sowing of 1st December results in lower or equal yields to those calculated for the RP with the same sowing date. Of the stress indicators shown previously (fig. 4), the water deficit around stem elongation increases dramatically beyond 18mm in the DF for the latest sowing dates, and with a variability which diminishes by half (fig. 8b).

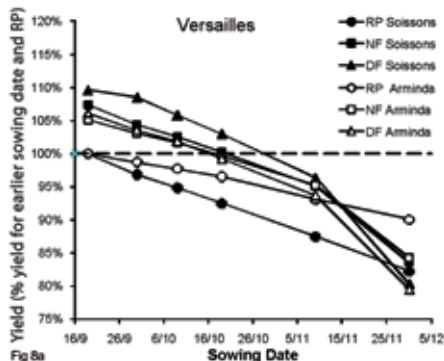


Figure 8a: effect of sowing date on changes in wheat yield with climate change for the Versailles site (CERES, soil 1, climate WT).

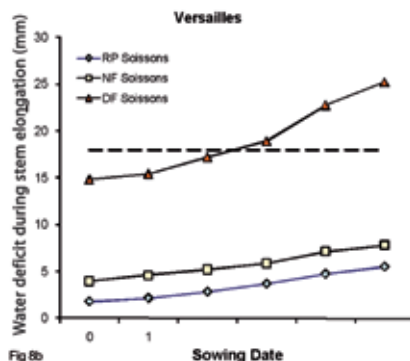


Figure 8b: effect of sowing date on changes in the water deficit of wheat during stem elongation with climate change for the Versailles site (PANORAMIX, soil 1, climate WT).

The same changes with climate change and sowing date are found for the other sites, but with very variable range between sites: small for Bordeaux, Lusignan, Mons, Rennes and Toulouse, a similar one at Versailles, Mirecourt, Saint-Étienne and Dijon, and finally a large one for Avignon, Clermont and Colmar. Finally, a study carried out independently on the optimisation of emergence conditions has shown, for the sites of Colmar and Toulouse, that sowing too early would impair the establishment of the stand because of the increasingly dry conditions in early autumn. All this suggests that a combination of variety and sowing date could be chosen for each site so as to avoid early stress (at emergence) and late stress (during grain filling) which would assure a yield level at least as good as at present.

The comparison of different cropping systems including wheat (fig. 9) shows no significant difference between the systems. We should bear in mind, however, that since these simulations do not take account of biotic limitations, the yield of monoculture wheat is no doubt overestimated.

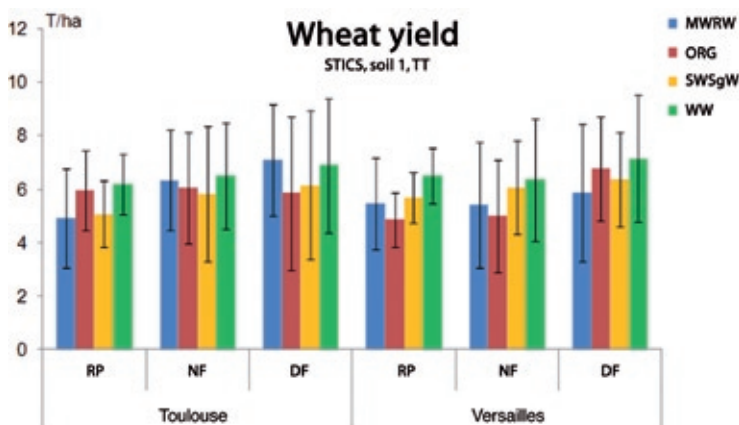


Figure 9: comparison of various cropping systems for wheat yield at Toulouse and Versailles.

One can see in figure 9 the increase in variability which accompanies the increase in yields in the future. One also sees that supplementary irrigation of the MWRW system, which was hardly worthwhile in the RP, will be clearly more profitable in the future, with water stress becoming as severe as, if not worse than, the nitrogen stress. The latter varies with the form of fertilisation (organic or mineral), but also with the previous crop (i.e. whether it is leguminous, and the period between crops). We see that “organic” wheat is not favoured by climate change (cf. ORGANIC FARMING section).

F Uncertainty associated with the simulations carried out

The section UNCERTAINTY and VARIABILITY analyses the causes of the yield variation in wheat. Here are its main conclusions.

As regards the climate, the variability created by the models of general circulation is of the same order as that created by the downscaling methods for a given SRES scenario: these methods differ mainly in their prediction of the variability of the future climate, which has quite a big effect on yield, whose simulation is based on a large number of phenomena which have a threshold or are discrete, including, in particular, the occurrence of developmental stages.

The second source of uncertainty arises from the different formalisms used in the crop models. In the case of wheat, the dynamic crop models STICS and CERES, although they differ quantitatively in their output* variables (yield etc.), predict the same changes, both in magnitude and variability. Conversely the static model PANORAMIX, although based on diagnostic variables including the effects of weather, does not simulate the same changes or the same variability (cf. YIELD and MODELS sections). We should add that, aside from the modelling approach used, failure to take account of certain processes (the nitrogen balance for PANORAMIX, excess water for CERES and PANORAMIX) partly explains the differences in behaviour between the models.

The variability generated by the simulation options constitutes the third source of uncertainty. Of the three factors analysed for Toulouse and Colmar (heat stress or not, CO₂ or not, and photosynthesis calculated by a mechanistic model [Farquhar] or a more empirical one), only the CO₂ had a quantitative effect on the model outputs. This result leads us to include the effect of CO₂ on yield in all the models (cf. MODELS section). However, it is probable that the choice of an early variety tends to minimise the heat stress.

Lastly, the variability generated by the different practices is analysed and compared with climate change in the case of the two crop models (CERES and PANORAMIX) for the NF (because of the small effect of CO₂). In general the yield variability calculated by CERES is about 1.5 times that calculated by PANORAMIX. This is because CERES takes account of ear frost damage and nitrogen nutrition and explains why the year-to-year variability constitutes half of the total variability for this model. According to PANORAMIX, the effects of site, variety, soil and sowing date are greater than those of climate change. According to CERES, only the soil effect exceeds that of climate change. In spite of this big difference between the models, our results suggest that the choice of soils and varieties in combination with the sowing date is a way to at least limit the risks from climate change.



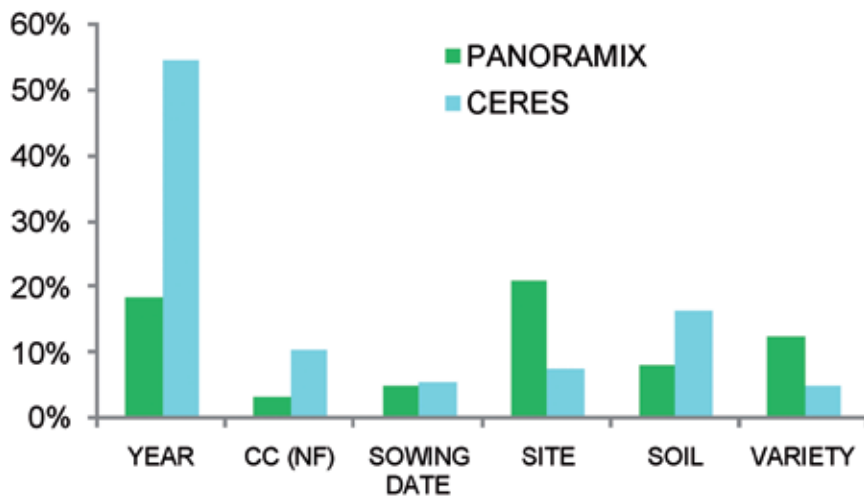


Figure 10: proportion of the variance of yield attributed to various source depending on the model.



What you need to remember

- ✓ For wheat, a crop with a long lifespan, moderately sensitive to summer water stress, the increase in temperature results in an advancement of the developmental stages and a shortening of the life cycle which limits some of the stresses: ear frost, water stress during stem elongation on a deep soil, shortening of stem elongation without affecting the available radiation. This set of advantages tends to allow an increase in the number of grains per m² for a large number of sites. Also, fungal diseases tend to decline in the near and distant future (cf. HEALTH section). In fact the general reduction in rainfall and hours of leaf wetness would tend to reduce the infection potential and the dispersal of the current main diseases, despite the temperature increase. Coupled with the reduction in excess winter water, this improvement in disease likelihood makes it possible to envisage more wheat growing near the Atlantic seaboard.
- ✓ However, although the advancement of stages allows some avoidance of late stresses during grain filling, the water sufficiency of the crop declines with climate change and the risks of heat stress increase in the northerly zones. Although these harmful effects of climate change are often compensated for by the increase in CO₂, the increase in the year-to-year variability suggests a prudent approach and the search for alternative solutions. Among these we should mention the possibility of amplifying the avoidance effect by bringing forward the sowing date or the choice of early varieties, provided that sowing can be done in soil which is moist enough to allow rapid emergence and crop establishment. The risk of ear frost constitutes another limitation to early sowing or growing wheat at high altitudes.
- ✓ Finally, the number of available days* to sow the crop increases with climate change in the different regions, which suggests greater flexibility in managing successions.



What needs further study ...

- ✓ The CLIMATOR project has approached the possible effect of climate change on crops in various ways. Apart from the uncertainty associated with the models, already mentioned above, several uncertainties arise from our lack of knowledge about ecophysiological mechanisms to understand the effects of climate change. For example the quantitative laws for the actions of extreme events (e.g. high temperatures) are often poorly understood and confused with other abiotic stresses. Similarly, the occurrence of rainfall and its variability over time influences the disease risk (through effect thresholds), and the efficacy of different practices (e.g. the efficiency of nitrogen applications, inter alia).
- ✓ The choice of recommended practices and of soils standardised for all the regions does not allow us to really tackle the improvement of wheat quality in the future, while the predicted yield increase could be accompanied, on average, by a reduction in wheat protein content; here again, the regional aspect and spatial distribution will only really be able to be approached by taking account of soil variability between regions and by adapting practices to the local yield potential.
- ✓ Finally, a better knowledge of the adaptation of physiological mechanisms to climate change, both from the point of view of the plant and from that of its enemies and friends (soil-borne or aerial), will also be necessary to plan realistically for the future.

To find out more ...

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