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Assessing future meteorological stresses for grain maize in France

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ABSTRACT

Recent climate change has already affected maize cropping in France allowing for example earlier sowing dates in southern France and the growth of early season varieties in northern parts of the country. The climate will continue to evolve as discussed in all IPCC reports and there is a need for farmers, seed companies and agricultural cooperative corporations to be able to anticipate those changes. The ambition of our work is to provide them with the means to get ready to adapt by analyzing a) the time evolution of meteorological stresses and certain management practices throughout the crop's growth cycle, b) the impacts of climate-induced changes in calculated sowing dates on those stresses and practices. We have applied the method we developed in a former paper to study the climatic suitability of maize in two contrasted areas of France, Ile-de-France in the North and Midi-Pyrénées in the South. Three climate change scenarios, two climate models and two maize varieties distinct in terms of precocity were used to try and ensure meaningful results. Whatever the scenario, model and variety, maize will be sown earlier than it is currently the case in both regions, especially in Midi-Pyrénées. Whatever the sowing date, rising temperatures in the future will be favorable for late varieties in the current cooler areas, and therefore even farmers in Ile-de-France will be able to grow varieties with a wide range of crop cycle length. However heat and water stress will increase in both regions between flowering and maturity, irrespective of the sowing date and scenario, thereby limiting the possibility to achieve potential yields. In Midi-Pyrénées compromises will need to be found between early sowing to minimize some later stress and increasing risks of frost during emergence, that do not currently exist.

1. Introduction

France is the leading producer of grain maize and the third largest producer of silage maize in Europe (Eurostat, 2014). Grain maize (*Zea mays* L.) is the number one feed crop in this country, the second in terms of cultivated area after wheat, and it covers about 6% of the national agricultural area (Agreste, 2014; Eurostat, 2014). Two main production areas are distinguishable in France with very diverse climate envelops, namely the north-east area representing 18% of the national surface area and 15% of the national production; and the south-west area (Aquitaine, Poitou-Charentes, Midi-Pyrénées), representing 60% of the national surface area and contributing to 60% of the production.

In the future, maize will probably remain an important crop in the French agricultural landscape because of a demand for this crop in the developing world that is expected to double by 2050 (Rosegrant et al., 2009). However, climatic conditions are changing in ranges that are likely to alter maize cropping (Bassu et al., 2014). The expected impacts in Europe from the questionnaires of Olesen et al. (2011) are shorter growth duration in most of the continental, western and Mediterranean areas of Europe, more suitable days for harvest and a decrease of late frost risk along with an increase of heat and water stress risks Europe-wide. In their simulation study of the impacts of climate change on many species in France, Brisson and Levrault (2010) predicted an advancement of the timing of maize flowering leading to the grain filling process during dryer and hotter periods. Finally, several simulation studies in Europe and France predict a negative influence of climate change (mainly temperature increase) on modeled yield despite the positive effect of the increase in CO_2 concentration (Brisson and Levrault, 2010; Bassu et al., 2014; Angulo et al., 2013).

Understanding the periods and the type of meteorological stresses that will affect maize in the future should be of great interest to many stakeholders in agriculture. Indeed, planners, land managers, and plant breeders could use this information to recommend and tailor strategies to improve agriculture performances. A general assessment of future meteorological stresses on maize cropping means considering impacts on phenology (successfully completing the crop cycle), vegetative and reproductive growth, grain quality (sugar or protein content) and the performance of cultural practices.

In a previous study, we developed a generic method to assess the climate suitability for different crop types, based on the sub-annual

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analysis of agroclimatic indicators (Holzkämper et al., 2013) calculated during main phenological periods. We have proposed to call them ecoclimatic indicators (Caubel et al., 2015). The application of the method in past and current climatic conditions proved to be effective in providing quantitative information on the stresses acting on particular plant processes (e.g. heat stress during grain filling) or on the number of days available to carry out cultural practices (e.g. days available for harvest according to risk of waterlogged soil compaction by machinery). The limited amount of required input data further promotes its use in climate change scenarios and on various spatial scales (farm, region, and country) in order to explore future possibilities for agriculture in many areas. This method can be considered as complementary to process-based crop growth models, which take into account the interactions between physiological processes and consider other environmental (e.g. soil properties) or economic factors (Holzkämper et al., 2015).

In this work, we apply this method to assess when and what meteorological stresses will affect future grain maize crops in France, regarding phenology, growth cycle, grain quality and days available to carry out the main cultural practices. We have considered three climate change scenarios, two global climate models, and one method to downscale climate change at the resolution of France to take into account the main sources of uncertainty in climate change studies. The study was performed for two maize varieties that are notable in terms of precocity, and two maize productive regions as study areas: the Ile-de-France and Midi-Pyrénées regions (Fig. 1). The evaluation was performed with a calculated sowing date designed to mimic an adaptation of farmers' behavior to climate change. Consequences on phenology and meteorological stresses helping to decide where and when to sow to improve maize potential suitability will therefore be analyzed and discussed.

2. Materials and methods

This study was conducted in two climatically contrasted regions, Ile-de-France in the northern part of the country (Lat. 48.2°N to 49.3°N, Lon. 1.2° to 3.8°E) and Midi-Pyrénées in the south-west France (Lat. 43.14°N to 44.96°N, Lon. -0.09°E to 3.14°E; Fig. 1). Ile-de-France is characterized by a quite homogeneous degraded oceanic climate, according to the classification and nomenclature developed by Joly et al. (2010); Joly's class hereafter: mean annual temperature of ~11 °C, with ~8–14 days/year with temperature below −5 °C; annual cumulated rainfall is below 700 mm, quite evenly distributed throughout the year although slightly lower during summer time. Midi-Pyrénées experiences a relatively large gradient of Joly's climate classes: altered Oceanic, semi-continental and alpine climates coexist in the region. Climate is on average considerably warmer (≥13 °C) than in Ile-de-France, and there are many days with a temperature exceeding 25 °C while almost none with temperature below −5 °C; the amount of rainfall is about the same as in Ile-de-France but with a marked seasonal cycle (summer dry season) and a smaller number of rainy days. Insolation is quite larger than in Ile-de-France. Midi-Pyrénées is already a major irrigated maize producer, while Ile-de-France has only recently become an area for irrigated short season maize, due to recent climate warming together with technical and breeding progress.

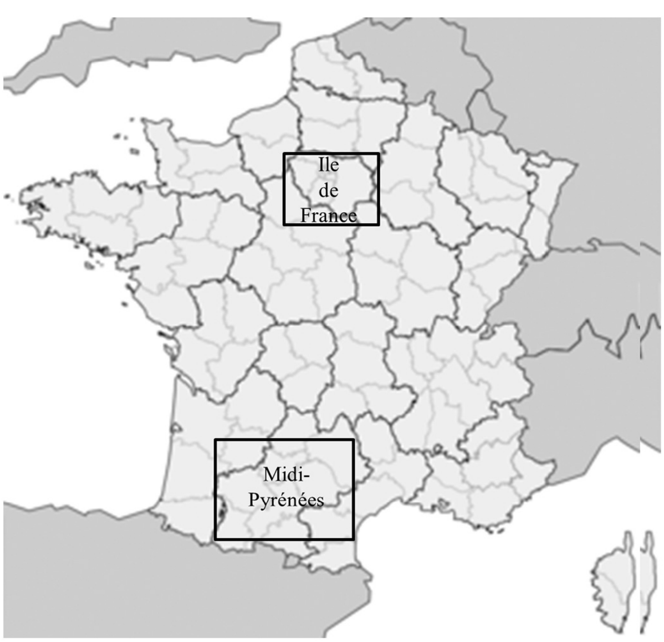

Fig. 1. The two studied areas of France.

2.1. Input data

Historical series of daily climatic data (rainfall, maximal temperature, minimal temperature, mean temperature, solar radiation, and wind speed) in both areas were retrieved from the SAFRAN historical reanalysis, which covers France at 8 × 8 km resolution for the 1950–2011 period (Vidal et al., 2009). Future changes in the 2012–2100 period have been obtained at the same spatial resolution using downscaled and bias-corrected climate changes from the fourth Intergovernmental Panel on Climate Change (Change, 2007) climate simulations. The downscaling and bias-corrected method was developed by Pagé et al. (2009) and applied to the global climate models CNCM and ARPEGE (Gibelin and Deque, 2003). We considered three IPCC SRES (Special Report on Emissions Scenarios) i.e., A1B, B1 and A2, hereafter called climate change scenarios. However, only the climate change scenario A1B was used in the case of the CNCM global climate model. A1B represents a balanced scenario corresponding to atmospheric concentrations of 541 ppm by 2046–2065 and increasing to 674 ppm by 2081–2100. It is the closest to the current Representative Concentration Pathway 6 (RCP 6) (Moss et al., 2010). The climate change scenario B1 is more optimistic and is close to the current RCP 4.5, whereas the climate change scenario A2 is more pessimistic and is close to the current RCP 8.5 (Knutti and Sedlacek, 2013). In our study, changes in the future were analyzed by focusing on 3 climatic periods: 2010–2039, 2040–2069, and 2070–2099, while the historical reference is: 1980–2009.

All our calculations were carried out for two distinct varieties in terms of precocity in order to evaluate the impacts of climate change on short and long-cycle maize varieties: Meribel and dkc5783 (hereafter referred to as early and late varieties respectively, Brisson and Levrault, 2010). From the sowing dates calculated between 1950 and 2100, we computed the calendar dates of the crop phenological cycle for both varieties by using a growing degree day model with a base temperature equal to 6 °C (Bloc and Gouet, 1978; Derieux and Bonhomme, 1990). The sums of degree days characterizing the phenological phases of the two varieties are presented in Table 1.

Daily soil water content (SWC, in g/g) data between 1950 and 2100 for the three climate change scenarios were obtained from the soil

Table 1
Sums in degree days characterizing the phenological phases of both varieties. The corresponding Zadoks scale stages are given in brackets.

Phenological phases	Sum in degree days for Meribel (early variety)	Sum in degree days for dkc 5783 (late variety)
From sowing (Z0) to emergence (Z10)	80	80
From emergence (Z10) to 8-leaves stage (Z30)	240	240
From 8-leaves stage (Z30) to flowering (Z65)	585	805
From flowering Z65) to physiological maturity (Z85)	600	750

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