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Introduction

Breeders have always been trying to find genotypes adapted to target environment which has been essential to recent developments in crop yield improvement. However, they are challenged for (1) adaptation across the target population of environments (TPE; i.e. the set of environments in which cultivars can be grown within the geographical area targeted by a breeding program) (Comstock, 1977) and (2) adaptation to specific types of environments within the TPE (Löffler et al., 2005; Dreccer et al., 2007). Numerous methodologies have been developed to characterize the complete TPE which use soil and climate data (e.g. Hodson and White, 2007), integrated traits like yield or anthesis date (e.g. Hernandez-Segundo et al., 2009), and stress indices simulated by crop models (e.g. Chenu et al., 2013). Considering the cost limitation of conducting the characterization of trial networks based on check-variety performance, crop models offer a more comprehensive environmental sampling and can account for genotype × environment (GxE) interactions and allow more detailed interpretation of GxE interactions (Chenu et al., 2011).

The main objective of this study is to produce typologies of drought and heat stresses confronted by wheat across Europe. The goals are to (1) characterize the typology of the drought and heat stresses scenarios occurring in TPEs, (2) analyze the frequency of the main environment types (ETs across Europe over a long period), (3) analyze GxE interactions, and (4) analyze changes in drought and heat stress scenarios and modifications of the TPE landscape due to recent climate change.

Materials and Methods

A grid-based (25×25 km) analysis of drought and heat stress scenarios for wheat was carried out at the European level using indices calculated by the *SiriusQuality*2 wheat crop model (http://www1.clermont.inra.fr/siriusquality). Weather, soil and agronomic data were obtained from various sources, including the JRC Agri4Cast Data Portal and AgroPheno database, the Harmonized World Soil Database (HWSD), the European Soil Database (ESDBv2.0). The parameterizations of flowering and harvest times for widely grown European wheat cultivars were selected for each NUTS2 (Nomenclature of Territorial Units for Statistics) region by comparing simulated phenological stages with that reported in the AgroPheno database at the grid level. A framework was developed which enables to extract required input data, run the simulations, extract the target outputs and perform statistical analyses.

Model performance were assessed by comparing simulated grain yield aggregated at NUTS2 level with grain yield reported in the EuroStat database. Besides water deficit indices based on a supply-demand approach and heat stress indices based on cumulative days with a maximum daily temperature above a threshold value during critical growth periods, we derived an integrated stress index that decompose the effect of water deficit, above optimum temperature for wheat growth, and nitrogen deficit and their interactions on daily biomass accumulation. All indices were calculated daily to determine their level and frequency of occurrence and the developmental stage at which they apply. A global clustering approach was used to reduce the TPE to a limited number of ETs. The frequency of stress patterns were assessed at various spatial scales and the main stress scenarios (i.e. ETs) were identified.

Results and Discussion

A typology of drought and heat stresses scenarios and their frequency of occurrence at various spatial and temporal scales were obtained. This typology should be the basis for the analysis of what are the key environmental variables for describing drought and heat stresses to be included in G×E studies, and for analyzing the putative impact of adaptive traits in different ETs.

Conclusions

An ensemble of grid-based crop simulations were used to study the relative importance of drought and heat stresses (and their interactions) to the performance of wheat across Europe. The proposed approach to consider the independent and combined impacts of drought, heat and nitrogen stresses is an innovative way to study the relative importance of stresses of various nature to crop performance in different environments.

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