RÉPUBLIQUE FRANÇAISE
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INRAE

MIRRORS

EXPLORATORY PROJECT

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Participating INRAE units
EVA
AGAP Institute
ISPA

External partner
LORIA (Lorraine Research Laboratory in Computer Science and its Applications)

Predicting the response of plants subjected to chronic thermal stress

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Context, key challenges and goals

Climate change is leading to more frequent extreme weather events such as heat waves, causing considerable harm to crop yields and harvest quality. Given this situation, improvements to the prediction of plant performance under recurrent thermal stress scenarios are of major interest to the world of agriculture.

The MIRRORS project began with the premise that the cumulative effects of a succession of stressful events on crop performance will not always correspond to the sum of individual responses to each stress. This hypothesis is based on the possible "memory" effects of stress exposure, which can be either negative (where an initial stress event adds to the negative effects of subsequent stress events), or positive (where the initial stress event has a priming effect that reduces the negative effects of subsequent events). Using existing data sets, acquired in the field and under glass for rapeseed and sorghum, MIRRORS set out to explore generic prediction methods and tools to assess the response of plants under chronic thermal stress.

Results

Results for rapeseed

Using large datasets[1] that incorporated crop performance parameters and climate data from 170 trials, the project participants defined eco-climatic indicators which they tested using multivariate regression models. While the models selected by the project do not yet predict perfectly the criteria for crop performance (yield, composition, oil and nitrogen content of the seed), MIRRORS has enabled the teams to demonstrate that the most promising models incorporate interactions between eco-climatic indicators acquired from early growth phases and indicators from late growth phases.

A separate, data-driven, approach using the same datasets sought to identify "motifs" in the form of particular thermal sequences that could explain crop performance. The results highlight the many relationships between eco-climatic indicators and performance variables. For example, the protein content of the seeds during the filling phase was proportionate to the number of hot days (i.e., average temperature over 30°C). Follow-up work on these

[1] Part of PIA Rapsodyn, partner N Nési, IGEPP.

results is needed, drawing on further datasets currently being acquired, with a particular focus on testing the responses of other genotypes and different recurrent thermal stress sequences.

Results for sorghum

The analysis of a dataset covering 109 varieties of sorghum over a period of around twenty years and coupled to meteorological data revealed the negative impact of higher numbers of extreme heat events on the potential yield of sorghum, but no impact from temperature intensity. Yield prediction based on mean temperature (using the Random Forest prediction model) was good, but it improved when temperatures above 25°C were excluded, suggesting once again that the effect of higher temperatures on yield is limited. The addition of variables such as rainfall, wind speed and testing location significantly strengthened modelling performance.

Three experiments under controlled conditions on two sorghum genotypes showed that different chronic thermal stress scenarios (varying in intensity, duration and date) had different impacts on the number, weight and quality of the grain. The likelihood of a "memory effect" was confirmed in some cases. These results confirm that the recurrence of extreme heat events has a greater effect than their intensity.

Perspectives for the future

Funding for 2 new projects to build on MIRRORS findings

The MIRRORS project enabled the creation of an interdisciplinary group of experts in ecophysiology and data processing who work on different predictive modelling approaches to study the effects of chronic thermal stress on crop performance in rapeseed and sorghum wheat. The project produced the preliminary data required to

1. test the robustness of a concept-driven use of the rapeseed model to report on a possible "memory effect"
2. initiate a data mining approach.

These initial results led the teams to expand the existing study on rapeseed and sorghum to include a third crop species – wheat – and to refine the ecophysiological approach employed. To achieve these ends, a further partner, LEPSE (the Montpellier-based Laboratory of Ecophysiology of Plants under Environmental Stress), joined the consortium and the three-year **PARSEMA inter-unit project** "Plant Adaptation to Recurrent Stresses: combining Ecophysiological and Modeling Approaches" began in 2022 (lead partner: AGAP Institute, other participating units: EVA, LEPSE, ISPA).

Meanwhile, limitations in the concept-driven approach soon became apparent, as did the difficulty of identifying and hierarchizing the processes at work in responses to recurrent thermal stresses. The consortium considered it particularly important to identify the signatures produced by an initial stress event that might or might not subsist in plants at the time of a second exposure to stress. Its members therefore sought to expand the project to include the transcriptomic, proteomic and metabolomic scales, obtaining, in 2023, a five-year grant for the **ANR RICOCHET project** "Resilience to recurrent heat stresses in plants", which incorporated these additional scales (lead partner: AGAP Institute, other participating units: EVA, LEPSE, BFP, LORIA).

Publications

- Lethicia Magno Massuia de Almeida, Erwan Corlouer, Anne Laperche, Nathalie Nesi, Alain Mollier, et al. To what extent can ecoclimatic indicators assist crop performance predictions in oilseed rape upon repeated heat stresses? European Journal of Agronomy, 2022, 141, article 126622. ⟨10.1016/j.eja.2022.126622⟩. ⟨hal-03845468⟩

See the full list of publications and papers resulting from the project at https://digitbio.hub.inrae.fr/