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Future crop production threatened by extreme heat

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Perspective

Future crop production threatened by extreme heat

Stefan Siebert and
Frank Ewert

*Institute of Crop Science and
Resource Conservation,
University of Bonn,
Katzenburgweg 5, D-53115
Bonn, Germany
E-mail:
s.siebert@uni-bonn.de*

Abstract

Heat is considered to be a major stress limiting crop growth and yields. While important findings on the impact of heat on crop yield have been made based on experiments in controlled environments, little is known about the effects under field conditions at larger scales. The study of Deryng *et al* (2014 Global crop yield response to extreme heat stress under multiple climate change futures *Environ. Res. Lett.* 9 034011), analysing the impact of heat stress on maize, spring wheat and soya bean under climate change, represents an important contribution to this emerging research field. Uncertainties in the occurrence of heat stress under field conditions, plant responses to heat and appropriate adaptation measures still need further investigation.

Climate change impacts on crop production are complex and diverse. Their assessment is challenging as the impacts result from a variety of biotic and abiotic stressors (and their interactions), diverse crop responses to stress, as well as farmers' management adaptations made in response to changing socio-economic and climatic conditions [2]. Further, farmers' adaptations produce their own feedbacks on the climate system, e.g. by changing resource use or greenhouse gas emissions. Process based crop models are often used in these assessments because they consider relevant crop growth processes and the complex interactions among these in response to climate change. As opposed to empirical or statistical analyses, process based models can be used to explain the reasons behind observed or simulated changes [3–5]. Initial attempts to model the impacts of climate change on crops largely focused on long-term changes and slow processes like crop phenology and drought impacts. Modelling crop response to extreme events like heat waves is receiving increasing levels of attention and is now a particular research focus for crop modelling [6].

The recent article in Environmental Research Letters by Deryng *et al* [1] makes an important contribution and advances the current understanding of potential climate change impacts on crop yield by exploring the combined effects of heat stress around anthesis and changing CO₂ concentrations globally for three crops with very different sensitivity to heat stress and CO₂ concentration. It advances recent studies on global heat stress impacts [7, 8] by considering 72 climate change projections spanning a wide range of possible CO₂ concentrations and corresponding climate changes. The model accounts for adaptation by changing sowing dates. The combination of positive effects of increasing CO₂ concentration and negative effects of increased heat stress resulted in distinct spatial patterns with a trend to increasing yield in temperate climate and decreasing yield at lower latitudes. Spring wheat benefited in most regions from climate change whereas maize yield declined in the major growing regions. The uncertainty in impacts caused by the different climate projections was particularly large for soya beans; it remains unclear whether the considered factors will cause an increase or decrease in mean soya bean yield at a global scale.



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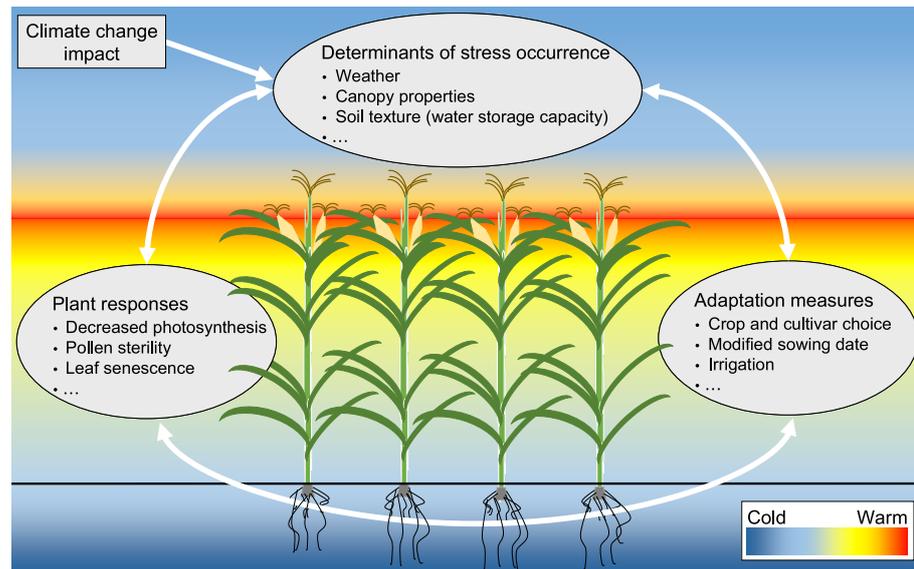


Figure 1. Schematic illustration of links between climate change, heat stress occurrence, plant responses to heat stress and farmer’s adaptation measures.

While acknowledging the research progress on heat stress impacts on crop yield made by Deryng *et al* [1], we also point to uncertainties in heat stress impact modelling and deficiencies in current knowledge. The *occurrence of heat stress* is determined by canopy temperature which is again mainly determined by weather conditions, canopy properties and soil moisture. Canopy temperature can deviate substantially from air temperature outside the canopy [9] or from the effective daily temperature used in the current study by Deryng *et al* [1] or other large scale studies [7, 8, 10] to quantify heat stress on crops (figure 1). Additionally, temperatures typically surpass critical thresholds for only a few hours in the afternoon while flowers typically open in the morning. To our knowledge, the effect of the potential mismatch between the time of flowering and that of daily temperature maximum has not been systematically investigated.

High temperatures affect crops in different ways and cause decreased photosynthesis, leaf senescence, decreased pollen production and pollen viability, seed abortion, and consequently lower grain number and grain weight [11–14]. However, critical temperature thresholds and sensitivities vary between crops, cultivars and phenological development stages [15] resulting in different *plant responses*. The cultivar diversity and heterogeneity in sowing dates observed under real field conditions [16–18] is still not reflected in large scale heat stress assessments.

The uncertainty in simulated effects of heat stress and CO₂ on crop yield caused by different possible climate futures is considerable and well captured in the current study by Deryng *et al* [1]. However, recent crop model comparison studies found that differences in simulated crop yields were larger across different crop models than differences across climate projections [19]. Model uncertainty was particularly high for crop responses to temperature change. To reflect this uncertainty, multi-model ensemble studies have been proposed [19, 20] and deserve more attention in the future.

Climate change assessments typically refer to long time periods whereas farmers often respond very flexibly to changing climatic or socio-economic conditions. Therefore *adaptation measures* should be considered in climate impact assessments with different modelling approach [2]. However, including adaptation in assessment modelling is not trivial. Cultivar choice and changing

sowing dates were considered in the study of Deryng *et al* [1] by optimizing crop phenology but not with regard to changing sensitivity to heat or other stressors. Additional adaptation measures are also possible, e.g. surface cooling by irrigation [21–23] or changing crop types [24]. The latter will also be driven by economic development and market integration suggesting changes in crop shares can be expected when the climatic suitability for specific crops changes considerably [25]. Other factors may also constrain the adaptive capacity of farmers. For perennial crops, the option to adapt to climate change by adjusting crop phenology and cultivar properties is limited to the time of planting. In contrast, in many of regions affected by heat stress, crops can be harvested more than once per year [26]. In these multi-cropping areas, farmers may try to optimize the productivity of the whole crop rotation [27] with assessments limited to specific crops potentially causing misleading results.

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