The Hot Serial Cereal Experiment for modeling wheat response to temperature: field experiments and AgMIP-Wheat multi-model simulations

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Abstract: The dataset reported here includes the part of a Hot Serial Cereal Experiment (HSC) experiment recently used in the AgMIP-Wheat project to analyze the uncertainty of 30 wheat models and quantify their response to temperature. The HSC experiment was conducted in an open-field in a semiarid environment in the southwest USA. The data reported herein include one hard red spring wheat cultivar (Yecora Rojo) sown approximately every six weeks from December to August for a two-year period for a total of 11 planting dates out of the 15 of the entire HSC experiment. The treatments were chosen to avoid any effects of frost on grain yields. For the late fall, winter, and early spring plantings, temperature free-air controlled enhancement (T-FACE) apparatus utilizing infrared heaters with supplemental irrigation were used to increase air temperature by 1.3°C/2.7°C (day/night) with conditions equivalent to raising air temperature at constant relative humidity (i.e. as expected with global warming) during the whole crop growth cycle. Experimental data include local daily weather data, soil characteristics and initial conditions, detailed crop measurements taken at three growth stages during the growth cycle, and cultivar information. Simulations include both daily in-season and end-of-season results from 30 wheat models.

Keywords: wheat, field experimental data, heat stress, simulations.

1 ORIGINAL PURPOSE: The original purpose of this dataset was to support a model inter-comparison (Asseng et al., 2015) as part of the Agricultural Model Intercomparison and Improvement Project (AGMIP, http://www.agmip.org/; Rosenzweig et al., 2013). The field experimental data were from the Hot Serial Cereal (HSC) experiment carried out by the USDA Arid-Land Agricultural Research Center and the University of Arizona at Maricopa, Arizona to investigate the response of wheat development (White et al., 2011, 2012), gas exchange (Wall et al., 2011), growth, grain yield (Ottman et al., 2012;), canopy temperature and energy balance (Grant et al., 2011; Kimball et al., 2012) to supplemental heating and to seasonal air temperature from varied planting dates. This dataset is a unique source of information for meta-analyses of the impacts on temperature and heat on crop growth and yield and for benchmarking model improvement against a large ensemble of state-of-the-art wheat crop simulation models.

2 FIELD EXPERIMENTS: A full description of the experiment site and of the experiment treatment are found in Wall et al. (2001) and Ottman et al. (2012). The most important information for the plantings and heat treatments used in the AgMIP-Wheat project are summarized below for a comprehensive understanding of the dataset and to allow setting up simulations.

The experimental site was located at the University of Arizona's Maricopa Agricultural Center, Maricopa, Arizona, USA (33°4'N, 111°58'W, 361 m a.s.l.). Maricopa has a semiarid climate with mean annual solar radiation of 21 MJ m^{-2} day^{-1}, a mean annual temperature of 21°C and mean annual precipitation of 164 mm. The soil was a Trix clay loam with low organic matter content described in Post et al. (1988). Wheat crops were sown approximately every six weeks from March 2007 through January 2009. The experimental design was a randomized complete block with three replicates. Seeds were sown at a rate of 288 seeds m^{-2} with a row spacing of 0.19 m to produce a final target plant density of approximately 200 plants m^{-2}. Blocks were strips 11 m wide × 37 m long, allowing three 11 m × 11 m plots per block. A circular (3-m diameter) (Control) plot was identified in the center of each block where plant measurements were taken. On four planting dates, two additional treatments were arranged in each block to yield a 3 × 3 Latin square experimental design, where heated plots were paired with Reference plots. The Heated plots were equipped with infrared heaters arranged to provide uniform warming over a 3-m diameter circular area as described in Kimball et al. (2008) (Figure 1). The

Reference plots were equipped with dummy non-operable heaters to mimic the effect of the infrared heaters on the crop microclimate. In the data reported herein the Control and Reference treatments were pooled (see below).

Figure 1. Photograph of the infrared heater system. In the centre foreground, infrared heaters are arranged in a circle above a wheat crop (Heated plot), and in the background to the left, the dummy non-operable heaters are arranged in a similar configuration (Reference plots).

The crops were irrigated at 100% replacement of potential evapotranspiration to maintain the soil water content at field capacity. Depending on planting date, the total amount of irrigation ranged from 362 to 921 mm. Water was supplied through a surface drip tape irrigation system with drip tapes placed 38 cm between every other row. Heated plots received 8% to 10% more water as a separate supplemental irrigation (except for the first planting on 13 March 2007) to provide a first-order correction for the increased plant-to-air vapor pressure gradient (Kimball, 2005). To guarantee good germination and emergence of the summer planted crops, additional sprinkler irrigation was provided. Soil fertility was managed to avoid nutrient limitations. Fifty to 56 kg N ha^{-1} and 67 kg P_2O_5 ha^{-1} were applied as granular ammonium phosphate at planting, and urea ammonium nitrate was subsequently applied in irrigation water at rates of approximately 50 kg N ha^{-1} per application with up to four applications (at tillering, heading, anthesis and during grain filling) depending on crop requirements.

The date of drilling the seeds into dry soil is the "nominal" planting date, and the "effective" planting date is defined as the date irrigation water was first applied for seed germination and to fill the soil profile to field capacity, which occurred between one and eight days after the nominal planting date.

Each crop was sampled three times during the growing season for biomass and other crop growth parameters. The stages at sampling were before flag leaf emergence, after heading, and final harvest between physiological maturity and harvest ripe stage. Exceptions to the stages at sampling are the first sampling of the 13 March 2008 planting, which occurred between anthesis and the kernel milky stage, and the 13 February 2008 and 12 January 2009 plantings for which plants were also sampled after tillering. For the sampling times before maturity, dry mass, and nitrogen concentration of stems, green leaves, brown leaves, spikes, and crowns were determined. Leaf area index was calculated from the leaf laminae surface area and green area index was calculated from the sum of leaf, stem, and spike surface area. Grain and total plant yields were adjusted to a 0% moisture basis. Dates of crop emergence, anthesis and physiological maturity and final leaf number were determined as described in White et al. (2011). Figure 2 illustrates the exceptional range of grain yield and temperature in this dataset and the impact of the supplemental temperature treatments on grain yield.

The entire HSC experiment comprised 15 planting dates, but in both years the crop planted in September and October suffered from significant frost damage and were excluded from the model intercomparison study reported by Asseng et al. (2015), which focused on high temperature impacts. These four plantings are not reported here. Experimental data for these plantings and additional measurements for all plantings, including detailed phenological stages, leaf emergence rate (Haun

stage), soil and canopy temperature, vegetation index (NDVI), leaf level gas exchange and water relations, and grain quality data are reported in a separate paper (Kimball et al., 2018).

Maximum and minimum values of daily air temperatures were obtained primarily from a weather station at the experimental field. When temperature data were unavailable, data were obtained from an Arizona Meteorological Network weather station (AZMET; http://ag.arizona.edu/azmet) located 1.2 km from the experiment site and were adjusted to match the on-site station values using a regression procedure. The wind and air temperature sensors were at 2-m height on the field mast, whereas wind was at 3 m and air temperature was at 1.5 m on the AZMET mast. Daily solar radiation, precipitation, mean wind speed and mean dew point temperature were obtained from the AZMET weather station. Seasonal (defined based on observed phenological stages) mean air temperature was calculated from daily air temperature, which was derived from the sum of eight contributions of a cosine variation between maximum and minimum daily air temperatures as described in Weir et al. (1984).

Figure 2. Final grain yield versus mean growing season temperature for the 11 plantings and the four Heat treatments of the HSC experiment reported here. The dashed lines connect the Control and supplemental Heat treatments of the same plantings. Control, average of the Control and Reference treatments; supplemental Heat, infrared warming (T-FACE) treatment. Data are mean ± 1 s.d. for *n* = 3 (for the supplemental Heat treatments and the Control treatments of plantings with no supplemental Heat treatment) to 6 (for the Control treatments of the plantings with supplemental Heat treatments) replicates.
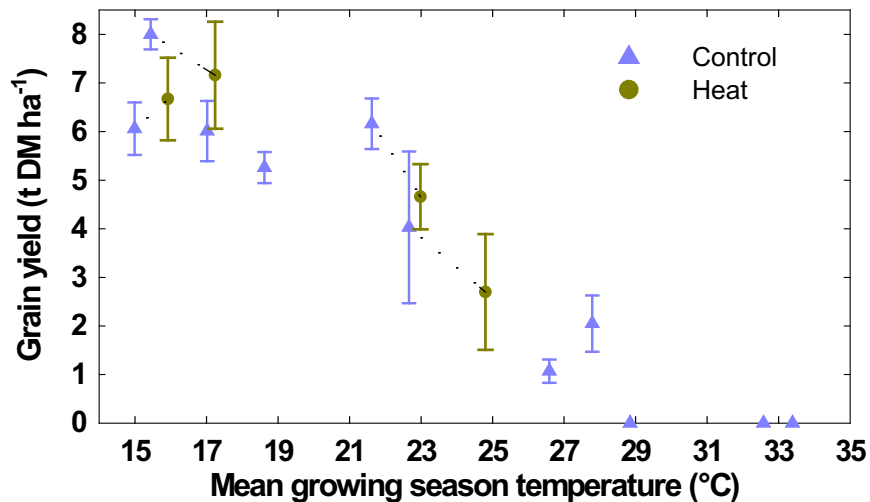
Results for the Reference and Control treatments were similar (Ottman et al. 2012), so they were pooled and named "C". The Heat treatment was named "H". Data are reported as mean and standard deviation. Missing data are indicated by "NA". Missing data correspond either to plant variables that were measured only at specific growth stages (e.g. grains were harvested only after anthesis) and to crops that died early in the growth season because of the summer heat (planting dates between June and August). In the latter case, final grain and chaff yield and nitrogen mass are equal to zero and the other variables are reported as NA.

3 SIMULATION OF FIELD EXPERIMENTS: The fifteen treatments described above were simulated by 30 wheat models (see Supplementary of Asseng et al., 2015). Simulations were carried out using standardized protocols and several steps of calibration. The simulation results reported here are for the full calibration step for which modelers had access to most of the experimental data reported here. For the simulations, the nominal planting dates were used. Some models were executed with water and nitrogen unlimited options. Fifteen of these 30 wheat models also participated in a model improvement exercise (Maiorano et al., 2017), where the HSC dataset was used for model improvement. For these fifteen models, simulation results are given for both the original and improved versions.

Table 1. Overview of the main dataset tables. All files are provided in space (weather data) or tabulation (all others) delimited text format. The crop management husbandry parameters, soil description and initial conditions are also provided in Microsoft Excel xml format used in the AgMIP project.

File name	Content
AZXX0306.wth	Space delimited file of weather data. XX is the planting/treatment code.
HSC_AgMIP_measurement_key.txt	Tabulation delimited file with the name, definition, and units of the measured variables with ICASA standard and conversion factor
HSC_AgMIP_measurments_ave_sd.txt	Tabulation delimited file of all available crop measurements (means and standard deviations)
HSC_AgMIP_site_soil_crop_management.xml	Xml (Microsoft Excel 2003) file with crop management, cultivar description, site description and initial conditions
HSC_AgMIP_model names.txt	Tabulation delimited file with the full name, version, and two-letter code of the 30 wheat models
HSC_AgMIP_ simulation_key.txt	Tabulation delimited file with the name, definition, and units of the simulated variables with ICASA standard and conversion factor
HSC_AgMIP_summary_simulations.txt	Tabulation delimited file of the summary model outputs
HSC_AgMIP_daily_simulations.txt	Tabulation delimited file of the summary model outputs

Model outputs include emerged leaf number (Haun stage), anthesis date, maturity date, grain dry mass and nitrogen yields, total above-ground biomass and nitrogen, leaf area index, number of grains per square meter, grain protein concentration, cumulative evapotranspiration, and cumulative transpiration. Not all models simulated all variables. Variables not simulated are indicated by "NA". Simulation results are reported for each individual model and for the multi-model ensemble median (e.median).

For the four plantings with Heat treatments, the three replicates of the Control and Heat treatments were simulated. The model inputs for the replicates differed only for the temperature and amount of irrigation. As no differences were observed between the replicates (as in the experimental data) in the data reported here, they were pooled. For the plantings without Heat treatments, only one replicate per planting was simulated. None of the Reference plots were simulated.

The experimental data presented here were also used in a modeling study of AgMIP-Wheat where canopy temperature models were evaluated for nine of the 30 wheat models used in Asseng et al. (2015) (Webber et al., 2016) and in an earlier study where energy balance and canopy temperature simulated by the wheat model *ecosys* were evaluated (Grant et al., 2011). Measured canopy temperature and energy balance data were reported in Kimball et al. (2018).

4 DATA FORMAT AND STRUCTURE: An overview of the main dataset tables is given in Table 1. Experimental (mean and standard deviation of crop measurements) and simulation (model output) data are provided in tab-delimited text files. The names of the variables (key) are explained in companion text files with their correspondence and conversion factors in the International Consortium for Agricultural Systems Applications standard - also known as the ICASA standard: http://research.agmip.org/display/dev/ICASA+Master+Variable+List.

Model input (cultivar information and crop management), soil description and initial conditions for simulation set up are provided in a Microsoft Excel book in xml format following the AgMIP format for model input and in tabulation delimited text files. Daily weather data (global solar radiation, daily maximum and minimum temperature, rainfall, wind run, dew point temperature, vapor pressure, relative humidity) are provided in the ICASA format in space delimited text files.

DISCLAIMER
$ The views or positions expressed in this publication do not necessarily represent in legal terms the official position of the European Food Safety Authority (EFSA). EFSA assumes no responsibility or liability for any errors or inaccuracies that may appear

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