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The International Heat Stress Genotype Experiment for modeling wheat response to heat: field experiments and AgMIP-Wheat multi-model simulations

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Abstract: The data set contains a portion of the International Heat Stress Genotype Experiment (IHSGE) data used in the AgMIP-Wheat project to analyze the uncertainty of 30 wheat crop models and quantify the impact of heat on global wheat yield productivity. It includes two spring wheat cultivars grown during two consecutive winter cropping cycles at hot, irrigated, and low latitude sites in Mexico (Ciudad Obregon and Tlaltizapan), Egypt (Aswan), India (Dharwar), the Sudan (Wad Medani), and Bangladesh (Dinajpur). Experiments in Mexico included normal (November-December) and late (January-March) sowing dates. Data include local daily weather data, soil characteristics and initial soil conditions, crop measurements (anthesis and maturity dates, anthesis and final total above ground biomass, final grain yields and yields components), 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 data set was to support model intercomparisons and improvements (Asseng et al., 2015; Maiorano et al., 2017) as part of the Agricultural Model Intercomparison and Improvement Project (AGMIP, http://www.agmip.org/; Rosenzweig et al., 2013). The field experimental data were selected from the four-year International Heat Stress Genotype Experiment (IHSGE) to cover the full range of temperature of the global network of field experiments. The IHSGE was carried out as part of a collaboration between CIMMYT and key national agricultural research system partners in warm wheat growing environments to identify important physiological traits that have value as predictors of wheat yield at high temperatures (Reynolds et al. 1994b).

Table 1. Location and characteristics of the six sites of the IHSGE experiments selected for the AgMIP-Wheat study on heat. Growth cycle duration, average daily mean temperatures, number of days with daily maximum air temperature (T_{max}) > 31°C, and heat thermal time are averages across the growth cycle for the two growing seasons and two varieties.

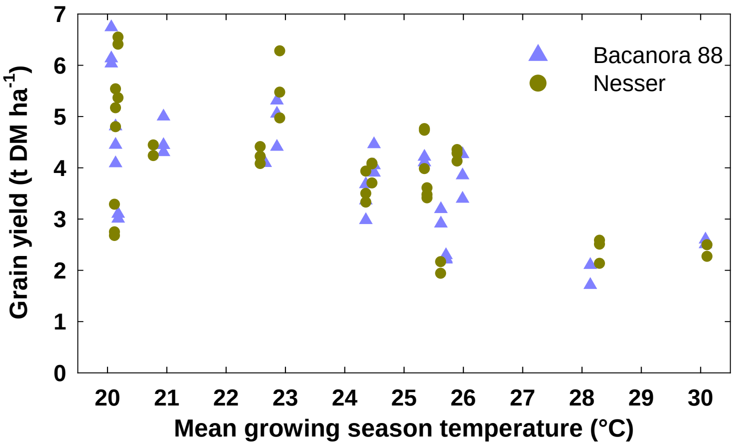
Country	Site name	Coordinates	Elevation (m)	Sowing month	Days from crop emergence to maturity	Type of heat stress	Average daily mean temperature (°C)		Number of days with T_{max} > 31°C	Heat thermal time (°Cdays) [a]
							Sowing to anthesis	Anthesis to maturity		
Mexico	Obregon	27°N 109°W	38	Nov/Jan-Mar	118/92	Hot, dry	20/22.7	23.3/26.4	41/66	112/279
Mexico	Tlaltizapan	18°N 99°W	940	Dec/Feb-Mar	102/84	Hot, dry	22.7/23.8	26.4/27.6	66/88	279/313
Egypt	Aswan	24°N 32°E	200	Dec	123	Hot, dry	16.8	24.1	29	155
India	Dharwar	16°N 76°E	638	Dec	85	Hot, dry	23.8	27.1	56	157
Sudan	Wad Medani	14°N 33°E	411	Nov	94	Very hot, dry	24.5	24.2	74	267
Bangladesh	Dinajpur	25°N 88°E	29	Dec	109	Hot, humid	18.4	25.8	28	97

[a] Heat thermal time was calculated by summing T_{max} above 31°C between crop emergence and maturity.

2 FIELD EXPERIMENTS: Experimental locations were selected based on a classification of air temperature and relative humidity during the wheat growing cycle. “Hot” and “very hot” locations were defined as having mean temperatures above 17.5 and 22.5°C, respectively, during the coolest month. “Dry” and “humid” locations were defined as having mean vapor pressure deficits above and below 1.0 kPa, respectively. The present data set includes data from six of the original 12 locations that were selected to represent a large range of temperatures (Table 1). At Obregon (first year only) and Tlaltizapán (both years), Mexico normal and late sowing dates were used to provide contrasting temperature regimes at the same location. Of the 16 cultivars originally included in the first two-years of the IHSGE, two (Bacanora 88 and Nesser) were selected for the AgMIP-Wheat model intercomparison. Bacanora 88 is a high-yielding Mexican cultivar (Sayre et al., 1997) and Nesser is considered heat and drought tolerant (Okuyama et al., 2005). Both cultivars have low photoperiod sensitivity and low vernalization requirements. Crop growth cycle durations ranged from 80 to 127 days. Mean temperature for the crop growth cycle ranged between 20.1°C and 30.1°C, and grain yield from 1.9 ± 0.28 to 6.3 ± 0.38 t DM ha^{-1} (Fig. 1).

All data were collected on experimental plots consisting of eight rows, 15 cm apart and 6-m long, arranged in α-lattice designs with three replicates. All experiments were well-watered and -fertilized with temperature being the most important variable. Seeding rate was approximately 120 kg ha^{-1} at all sites, while the specific amount of N and P fertilizer applied and the irrigation varied from site to site. No irrigation or fertilizer data are available. Details of these factors, as well as information on soil type and weather necessary to run a wheat crop model are reported herewith.

Figure 1. Final grain yield versus mean growing season temperature for six locations, two growth cycles, and two cultivars of the IHSGE experiment reported here. Data are for individual plots with 2 to 3 replicated plots for each cultivar / site / year / sowing date combination.



Mean of crop measurements have been reported in tabular format in CIMMYT internal reports (Reynolds et al., 1992, 1994a), with the exception of the experiment in Egypt, which has not been previously reported and it is here reported for the first year of the IHSGE. Measured crop variables include crop emergence date, anthesis date, maturity date, anthesis and final total above ground biomass, grain yield, plant number per square meter, spikes per square meter, grains per square meter, final average single grain dry mass, and plant height. In the first year, maturity dates for the late sown treatments for both cultivars at Obregon, Mexico were not available and were estimated as the average growing degree-days from anthesis to maturity of all other treatments. Similarly, anthesis date for Bacanora 88 in Egypt was not available and was estimated as the average growing degree-days from crop emergence to anthesis of all other treatments. Biomass harvests at anthesis were made on a single date for the whole experiment. Missing data are indicated by “NA”.

Correlations between replicates overall and the distribution within each cultivar across replicates were calculated. In cases where the cultivar x replicate effect was high and two replicates were much closer to each other than the third, the outlying replicate was excluded. Data are reported as mean and standard deviation. Figure 1 illustrates the range of yield and mean growing season temperature. 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).

3 SIMULATION OF FIELD EXPERIMENTS: Simulations for the 28 locations/years/sowing dates/cultivars combinations were carried out by 30 wheat model (see Supplementary of Asseng et al., 2015). Fifteen of these 30 wheat models also participated in a crop model improvement study (Maiorano et al., 2017) where the IHSGE data set was used as a validation data set (blind). For these 15 models, simulation results are given for both the original and the improved versions.

Model outputs include crop emergence date, anthesis date, maturity date, and grain number per square meter. They also include outputs of in-season time series and end-of-the-season for total above ground and grain biomass, leaf area index, 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).

Simulations were carried out using a standardized protocol and one step of calibration. All sowing dates, anthesis and maturity dates, soil type characteristics and weather data were supplied to the modelers to simulate the experiments. Other crop measurements were provided to the modelers for Obregon, Mexico only. Detailed soil information were not available for each individual experiment. Therefore, as water and nitrogen were managed to limit any stress effect, a unique set of soil parameters and initial conditions was used to simulate all 11 year/location/sowing date combinations. Some models used an unlimited water and nitrogen mode for simulating these experiments. Weather data were obtained from the AgMIP climate forcing data set based on the NASA Modern-Era Retrospective Analysis for Research and Applications (AgMERRA; Ruane et al., 2015):
http://data.giss.nasa.gov/impacts/agmipcf/agmerra/

4 DATA FORMAT, STRUCTURE, AND AVAILABILITY: An overview of the main tables from the data set is given in Table 2. 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 (ICASA) standard (White et al., 2013):
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 air temperature, rainfall, wind run, dew point temperature, vapor pressure, and relative humidity) are provided in the ICASA format in space delimited text files. All text files are UTF-8 encoded.

All data are available in Harvard Dataverse data repository (https://dataverse.harvard.edu/) with the identifiers “doi:10.7910/DVN/ECSFZG”.

Table 2. Overview of the main data set tables. All files are provided in space (weather data) or tabulation (all others) delimited text format. The crop management husbandry parameters, the soil description and initial conditions are also provided in the Microsoft Excel xml format used in AgMIP.

Table name	Content
XXXX0001.WTH	Space delimited file of weather data. XXXX is the site name.
ISGHE_AgMIP_measurement_key.txt	Name, definition, and units of the measured variables with ICASA standard and conversion factor
ISGHE_AgMIP_measurments_ave_sd.txt	Tab delimited file of all available crop measurements (means and standard deviations)
ISGHE_AgMIP_site_soil_crop_management.xml	XML (Microsoft Excel 2003) file with crop management, cultivar description, site description and initial conditions
ISGHE_AgMIP_model names.txt	Tab delimited file with the full name, version, and two-letter code of the 30 wheat models
ISGHE_AgMIP_ simulation_key.txt	Name, definition, and units of the simulated variables with ICASA standard and conversion factor
ISGHE_AgMIP_summary_simulations.txt	Tab delimited file of the summary model outputs
ISGHE_AgMIP_daily_simulations.txt	Tab delimited file of the summary model outputs

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