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Wheat response to a wide range of temperatures, as determined from the Hot Serial Cereal (HSC) Experiment

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Abstract: Temperatures are warming on a global scale, a phenomenon that likely will affect future crop productivity. Crop growth models are useful tools to predict the likely effects of these global changes on agricultural productivity and to develop strategies to maximize the benefits and minimize the detriments of such changes. However, few such models have been tested at the higher temperatures expected in the future. Therefore, a “Hot Serial Cereal” experiment was conducted on wheat (*Triticum aestivum* L.), the world’s foremost food and feed crop, in order to obtain a dataset appropriate for testing the high temperature performance of wheat growth models. The wheat (*Cereal*) was planted serially (*Serial*) about every six weeks for over two years at Maricopa, Arizona, USA, which experiences the whole range of temperatures at which plants grow on Earth. In addition, on six planting dates infrared heaters in a T-FACE (temperature free-air controlled enhancement) system (*Hot*) were deployed over one-third of the plots to warm the wheat by additional target 1.5°C during daytime and 3.0°C at night. Achieved average degrees of warming were 1.3 and 2.7°C for day and night. Overall, a dataset covering 27 differently treated wheat crops with three replicates each was obtained covering an air temperature range from -2 to 42°C. Herein, the management, soils, weather, physiology, phenology, growth, yield, quality, and other data are presented.

Keywords: wheat, global warming, temperature, infrared warming, climate change, planting date.

1 OBJECTIVE: The primary objective was to obtain a dataset on the response of wheat to a wide range of temperatures. This was achieved by planting the wheat serially about every six weeks for over two years at Maricopa, Arizona, which experiences temperatures from below freezing to higher than most places on Earth where wheat is grown. In addition, on six of the planting dates, infrared heaters in a temperature free-air controlled enhancement (T-FACE) system were deployed so as to provide a treatment wherein only the crop temperature was varied with respect to reference and control treatments.

2 FIELD EXPERIMENTS: Approximately every six weeks for over two years starting in March, 2007, the bread wheat (*Triticum aestivum* L.) cultivar Yecora Rojo (Qualset et al., 1985) was planted in a Hot Serial Cereal (HSC) experiment conducted at Maricopa, Arizona, USA. There were a total of 15 planting dates For six of the plantings (early fall, midwinter, and spring), infrared heater arrays (T-FACE) were deployed in a Latin square experimental design with three replicates each of Heated plots, Reference plots with dummy heaters (i.e., the same housing as real heaters, but no heating elements), and Control plots with no experimental apparatus. As described by Kimball et al. (2008), the plots were 3 m in diameter, and calibrated infrared thermometers were used to measure canopy temperatures in the Heated and Reference plots. The canopy temperature data were processed by dataloggers, which provided 0-10 V control signals to dimmers, which in turn modulated the output of the heaters {[Model FTE-1000 (1000 W, 240 V, 245 mm long x 60 mm wide)] mounted in reflector housings, so as to maintain the canopy temperatures of the Heated plots at 1.5°C warmer than those of the Reference plots during daytime and 3.0°C warmer at night. Additional experimental details are presented in Wall et al. (2011, 2013), Ottman et al. (2012), White et al. (2011, 2012), and Kimball et al. (2012, 2015, 2016).

Solar radiation, air temperature, and wind speed were measured on a weather mast in the experimental field most of the time starting with the fall, 2007 planting. For times when field mast data were not available, we utilized data from the AZMET weather station (http://ag.arizona.edu/AZMET/) located about 1 km away.

Figure 1. Plot nomenclature diagram for the Hot Serial Cereal Experiment. The H, R, and C designate Heated, Reference (dummy heaters), and Control (no apparatus) plots, respectively, with adjacent numbers indicating replicate number and the underneath numbers being plot numbers. Each S designates a strip of 3 plots (north-south) that were drip irrigated together. Planting dates for the various strips are listed at the top with the sequence numbers in parentheses. For the cases of 19 April, 12 June, and 25 July 2007 plantings, all the plots were C plots. Poor germination in Strip S9 for the 17 September 2007 planting required that Plots C3, H3, and R3 be relocated to nearby Strip S7, and they have been designated as in Strip 7b. Strips S4, S5, and S6 were used for un-heated planting date treatments in 2007, and then in 2008, they were used for two infrared heater experiments. (Updated from Wall et al., 2011).

North	17 Sep. 2007 (5)			10 Mar. 2008 (9) 1 Dec. 2008 (14)			13 Mar. 2007 (1) 2 Jan. 2008 (7) 29 Sep. 2008 (12)					Heated Plantings ← Rep.
	3	2	1	3	2	1	3	2	1			
30 Oct. 2007 (6)				25 Jul. 2007 (4)	12 Jun. 2007 (3)	19 Apr. 2007 (2)				13 Feb. 2008 (8) 27 Oct. 2008 (13)	28 Apr. 2008 (10) 25 Aug 2008 (11) 12 Jan. 2009 (15)	Control Plantings ← Rep. ↓
C1 31	R3 28	H2 25	C1 22	C1 C3 19	C1 H2 16	C1 R1 13	C3 10	R2 7	H1 4	C1 1	C1 -2	1
C2 32	C3 29	R2 26	H1 23	C2 H3 20	C2 R2 17	C2 C1 14	H3 11	C2 8	R1 5	C2 2	C2 -1	2
C3 33	H3 30	C2 27	R1 24	C3 R3 21	C3 C2 18	C3 H1 15	R3 12	H2 9	C1 6	C3 3	C3 0	3
S10	S9 (7b)	S8	S7	S6	S5	S4	S3	S2	S1	S0	ST	Strip ID ←

A bias between air temperatures measured at the field and by AZMET was detected when data from times when both were operating were plotted against each other. Consequently, AZMET data were adjusted to the field condition using a regression equation that had solar radiation and wind speed as covariates.

To ensure that the dataset could be used to evaluate crop growth models, careful records were kept of agronomic operations, such as tillage; planting and emergence dates; amounts, dates, and types of fertilizer applications; and dates and amounts of irrigations. Dual meters were used for the irrigations that were applied via drip tubing. Large initial irrigations were applied after each planting, and then an irrigation management program based on estimated evapotranspiration adjusted by measurements of normalized difference vegetation index (NDVI; Hunsaker et al., 2007) was used to schedule weekly (bi-weekly during mid-winter) replacement of potential evapotranspiration from the un-heated Control plots (with adjustments for rainfall). As suggested by Kimball (2005, 2011), we provided supplemental irrigations to the Heated plots in amounts of about 10% more than corresponding Control plots to minimize the effects of increased leaf to air vapor pressure gradients and thereby make the T-FACE treatment more like global warming with constant relative humidity. Additional sprinkling of the summer-planted crops was done to aid germination and emergence.

Biomass of various above-ground organs was sampled at three intervals per crop, and final grain yield and its components were obtained at maturity (Ottman et al., 2012). Leaf appearance rates and phenology were observed (White et al., 2011, 2012). Reflectance in four wave bands was measured two to five times per week, enabling vegetation indices to be determined (Kimball et al., 2012). Net photosynthesis, stomatal conductance, and plant water status were measured one to two times per crop in Heated and Reference plots (Wall et al., 2011). Soil respiration and soil temperatures were also measured on two planting dates (Wall et al., 2013).

Several quality attributes of mature grains from all planting dates that produced grains and supplemental heat treatments were also measured. Flour total carbon and nitrogen concentrations were determined by the Dumas combustion method (AOAC method no.7.024), and flour total grain protein concentration (AACC method 39–70A; AACC, 1995) and grain hardness (AACC method 39–10; AACC, 1995) were determined by near infrared reflectance spectroscopy (NIRS). The viscosity of non-starch polysaccharides, mainly arabinoxylans, was measured following Bordes et al. (2008). The Chopin Alveograph test was used to assess dough strength, tenacity, extensibility and dough swelling (AFNOR NF ISO 5530-4). The behavior of dough constituents (starch, protein, water) was analyzed by using a Mixolab apparatus (ICC Standard Method No. 173; ICC, 2010). Gliadin classes and glutenin subunits were separated and quantified by reverse-phase high-performance-liquid-chromatography (RP-HPLC) as described in Plessis et al. (2013). Starch granules were extracted following Bancel et al. (2010) and the volume percentages of A- (diameter > 10 µm), B- (2 µm < diameter < 10 µm), and C- (diameter < 2 µm) granules were determined by using a laser beam scattering apparatus (Debiton et al., 2011). The size distribution and radii of glutenin polymers was analyzed by asymmetric flow field-flow fractionation (AF4) coupled with a multi angle laser light scattering (MALLS) detector (Lemelin et al., 2005). Flour starch content was determined as described by Hendriks et al. (2003). The mass percentage, average weight, average molar mass and z-average root-mean-square radii of amylose and amylopectine polymers were analyzed by AF4 coupled with multi-angle light scattering and refractive index detectors (MALS–RI; Chiaramonte et al., 2012).

3 PRIOR WHEAT GROWTH MODELLING ACTIVITIES: The HSC dataset has been utilized in some prior model evaluation and inter-comparison activities. The first was by Grant et al. (2011) who found good agreement of hourly canopy temperatures as well as with grain yields with the *ecosys* model. Kimball et al. (2015) used the data to validate a model predicting the infrared heater requirements needed to conduct T-FACE experiments. However, the largest effort was done by the Wheat Team (http://www.agmip.org/wheat/) of the Agricultural Model Inter-comparison and Improvement Project (AGMIP, Rosenzweig et al., 2013), who did a major inter-comparison study among 30 wheat models with the HSC data (Asseng et al., 2015), as well as predicting likely impacts of global warming on global wheat productivity. The Wheat Team also used the HSC data to improve the accuracy of their responses to high temperature. With 15 of such improved models, Mariorano et al. (2016) showed that both accuracy and precision were indeed improved when tested against several independent datasets from around the world. To evaluate whether simulation of canopy temperature improves the ability of simulate heat stress impacts, nine wheat models were tested against the HSC dataset by Webber et al. (2017). The model output and the HSC data contributing to Asseng et al. (2015) and Maiorano et al. (2017) are presented in a companion paper (Martre et al., 2018).

4 DATA FORMAT AND STRUCTURE: A list of the files in the HSC dataset is given in Table 1. The data from the many crops were assembled and formatted following ICASA Version 2.0 standards (White et al., 2013), and they are presented herein. The names of the variables are explained in companion "key" files.

Table 1. Overview of the main HSC dataset files.

Crop and Soil Management Files	
Crop_management_events.ods	List of planting dates, cultivar information, plant populations, row spacing, planting depth for all 81 of theplanting date and warming treatments and replicate combinations.
Experiment_treatment_site_information.ods	List of all the experimental site characteristics, treatments, and associated weather and soil files for all 81 of the planting date and warming treatments and replicate combinations.
Fertilizer.ods	Tabulation of N and P fertilizer applications
Irrigation.ods	Tabulation of irrigations
Soil_description.ods	Soil classification and characteristics by layer
Soil_initial_conditions.ods	Initial water, NH_4, and NO_3 from a previous study

Table 1. Continued	
Soil_residue.ods	Residue of straw and roots from previous crop
Wheat_variety_information.txt	Characteristics of wheat cultivar Yecora Rojo
Weather, heater, canopy temperature files	
AZ000604.TXT	Daily weather file for the Reference and Control plots. The 0604 indicates the data start in 2006 and there are almost 4 years' worth of data extending past the end of the HSC experiments.
AZ110604.TXT	Special weather file for models that "grow" the crop using air temperature. It was created using AZ000604.TXT as a base and then adding the difference in canopy temperature between the heated and reference plots to TMAX and TMIN. AZ110604 is for heated plot 4, strip S1, 2007-03-13 planting date.
AZ120604.TXT	As above but for heated plot 9, strip S2, 2007-03-13 planting date.
AZ130604.TXT	For heated plot 11, strip S3, 2007-03-13 planting.
AZ270604.TXT	For heated plot 23, strip S7, 2007-09-17 planting.
AZ280604.TXT	For heated plot 25, strip S8, 2007-09-17 planting.
AZ290604.TXT	For heated plot 30, strip S9, 2007-09-17 planting.
AZ310604.TXT	For heated plot 4, strip S1, 2008-01-02 planting.
AZ320604.TXT	For heated plot 9, strip S2, 2008-01-02 planting.
AZ330604.TXT	For heated plot 11, strip S3, 2008-01-02 planting.
AZ440604.TXT	For heated plot 15, strip S4, 2008-03-10 planting.
AZ450604.TXT	For heated plot 16, strip S5, 2008-03-10 planting.
AZ460604.TXT	For heated plot 20, strip S6, 2008-03-10 planting.
AZ510604.TXT	For heated plot 4, strip S1, 2008-09-29 planting.
AZ520604.TXT	For heated plot 9, strip S2, 2008-09-29 planting.
AZ530604.TXT	For heated plot 11, strip S3, 2008-09-29 planting.
AZ640604.TXT	For heated plot 15, strip S4, 2008-12-01 planting.
AZ650604.TXT	For heated plot 16, strip S5, 2008-12-01 planting.
AZ660604.TXT	For heated plot 20, strip S6, 2008-12-01 planting.
ReadMe_Weather_File_Choice.docx	More detailed explanation of which of the several weather files to use for a particular modeling situation.
Weather_Canopy_Temp_Heater_hourly.ods	Hourly weather, canopy temperature, long-wave radiation from heaters
Crop Response Files	
Biomass_Yield_Area_Phenology.ods	Biomass, grain yield, leaf and other area indices, growth stages.
Gas_Exchange_and_Water_Relations.ods	Leaf photosynthesis, stomatal conductance, and leaf water potentials.
NDVI_Canopy_Reflectance.ods	Canopy reflectance and NDVI, which is a measure of greenness.
Grain Quality.ods	Grain nitrogen, protein, starch, and other quality compound concentrations,
Soil_Moisture 2007Mar-2008Jul.ods	Soil water content of selected plots at six depths at 15-min intervals from March 2007 through July 2008.
Soil Moisture 2008Aug-2009May.ods	Soil water content of selected plots at six depths at 15-min intervals from August 2008 through May 2009.

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REFERENCES

AACC, Chemists. Approved method of the AACC. Saint Paul, MN USA American Association of Cereal Chemists, Approved methods of the AACC, ninth ed., 1995 The American Association of Cereal Chemistry, St Paul, MN.

Asseng, S., F. Ewert, P. Martre, R. P. Rotter, D. B. Lobell, D. Cammarano, B. A. Kimball, M. J. Ottman, G. W. Wall, J. W. White, M. P. Reynolds, P. D. Alderman, P. V. V. Prasad, P. K. Aggarwal, J. Anothai, B. Basso, C. Biernath, A. J. Challinor, G. De Sanctis, J. Doltra, E. Fereres, M. Garcia-Vila, S. Gayler, G. Hoogenboom, L. A. Hunt, R. C. Izaurralde, M. Jabloun, C. D. Jones, K. C. Kersebaum, A. K. Koehler, C. Muller, S. Naresh Kumar, C. Nendel, G. O/'Leary, J. E. Olesen, T. Palosuo, E. Priesack, E. Eyshi Rezaei, A. C. Ruane, M. A. Semenov, I. Shcherbak, C. Stockle, P. Stratonovitch, T. Streck, I. Supit, F. Tao, P. J. Thorburn, K. Waha, E. Wang, D. Wallach, J. Wolf, Z. Zhao and Y. Zhu. 2015. "Rising Temperatures Reduce Global Wheat Production." Nature Climate Change 5(2):143-47. doi: 10.1038/nclimate2470.

Bancel, E., H. Rogniaux, C. Debiton, C. Chambon, G. Branlard. 2010. "Extraction and Proteome Analysis of Starch Granule-Associated Proteins in Mature Wheat Kernel (*Triticum aestivum* L.). Journal of Proteome Research 9(6): 3299-3310. doi: 10.1021/pr9010525.

Bordes, J., G. Branlard, F. X. Oury, G. Charmet and F. Balfourier. 2008. "Agronomic Characteristics, Grain Quality and Flour Rheology of 372 Bread Wheats in a Worldwide Core Collection." *Journal of Cereal Science* 48(3):569-79. doi:10.1016/j.jcs.2008.05.005.

Debiton, C., M. Merlino, C. Chambon, E. Bancel, M. Decourteix, V. Planchot, G. Branlard. 2011. "Analyses of Albumins, Globulins and Amphiphilic Proteins by Proteomic Approach Give New Insights on Waxy Wheat Starch Metabolism." Journal of Cereal Science 53(2): 160-169. doi: 10.1016/j.jcs.2010.11.001.

Grant, R. F., B. A. Kimball, M. M. Conley, J. W. White, G. W. Wall and M. J. Ottman. 2011. "Controlled Warming Effects on Wheat Growth and Yield: Field Measurements and Modeling." *Agronomy Journal* 103(6):1742-54. doi: 10.2134/agronj2011.0158.

Hendriks, J. H. M., A. Kolbe, Y. Gibon, M. Stitt and P. Geigenberger. 2003. "ADP-Glucose Pyrophosphorylase Is Activated by Posttranslational Redox-Modification in Response to Light and to Sugars in Leaves of Arabidopsis and Other Plant Species." Plant Physiology 133(2):838-49. doi: 10.1104/pp.103.024513.

Hunsaker, D. J., G. J. Fitzgerald, A. N. French, T. R. Clarke, M. J. Ottman, and P. J. Pinter Jr. 2007. "Wheat irrigation management using multispectral crop coefficients: I. crop evapotranspiration prediction." Transactions of the ASABE 50(6):2017-2033. doi: 10.13031/2013.24105.

ICC, 2010. "Whole Meal and Flour from *T. aestivum* – Determination of Rheological Behavior as a Function of Mixing and Temperature Increase". Standard Methods of the International Association for Cereal Chemistry No. 173. International Association for Cereal Science and Technology, Vienna. url: https://www.icc.or.at/standard_methods/173

Kimball, B. A. 2005. "Theory and Performance of an Infrared Heater for Ecosystem Warming." *Global Change Biology* 11(11):2041-56. doi: 10.1111/j.1365-2486.2005.1028.x.

Kimball, Bruce A. 2011. "Comment on the Comment by Amthor Et Al. On "Appropriate Experimental Ecosystem Warming Methods" by Aronson and Mcnulty." *Agricultural and Forest Meteorology* 151(3):420-24. doi: 10.1016/j.agrformet.2010.11.013.

Kimball, B. A., M. M. Conley, S. Wang, X. Lin, C. Luo, J. Morgan and D. Smith. 2007. "Infrared Heater Arrays for Warming Ecosystem Field Plots." *Global Change Biology* 14(2):309-20. doi: 10.1111/j.1365-2486.2007.01486.x.

Kimball, B. A., J. W. White, G. W. Wall and M. J. Ottman. 2012. "Infrared-Warmed and Unwarmed Wheat Vegetation Indices Coalesce Using Canopy-Temperature–Based Growing Degree Days." *Agronomy Journal* 104(1):114-18. doi: 10.2134/agronj2011.0144.

Kimball, B. A., J. W. White, G. W. Wall, and M. J. Ottman. 2016. "Wheat responses to a wide range of temperatures: The Hot Serial Cereal Experiment." In J. L Hatfield and D. Fleisher (eds.), *Improving Modeling Tools to Assess Climate Change Effects on Crop Response*. In L.R. Ahuja (Series ed.), *Advances in Agricultural Systems Modeling*, Vol. 7, American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA. 1-12.

Kimball, B. A., J. W. White, M. J. Ottman, G. W. Wall, C. J. Bernacchi, J. Morgan and D. P. Smith. 2015. "Predicting Canopy Temperatures and Infrared Heater Energy Requirements for Warming Field Plots." *Agronomy Journal* 107(1):129. doi: 10.2134/agronj14.0109.

Lemelin, E., T. Aussenac, F. Violleau, L. Salvo and V. Lein. 2005. "Impact of Cultivar and Environment on Size Characteristics of Wheat Proteins Using Asymmetrical Flow Field-Flow Fractionation and Multi-Angle Laser Light Scattering." *Cereal Chemistry* 82(1):28-33. doi: 10.1094/CC-82-0028.

Maiorano, A., P. Martre, S. Asseng, F. Ewert, C. Müller, R. P. Rötter, A. C. Ruane, M. A. Semenov, D. Wallach, E. Wang, P. D. Alderman, B. T. Kassie, C. Biernath, B. Basso, D. Camarrano, A. J. Challinor, J. Doltra, B. Dumont, E. Eyshi Rezaei, S. Gayler, K. C. Kersebaum, B. A. Kimball, A.-K. Koehler, B. Liu, G. J. O'Leary, J. E. Olesen, M. J. Ottman, E. Priesack, M. P. Reynolds, P. Stratonovitch, T. Streck, P. J. Thorburn, K. Waha, G. W. Wall, J. W. White, Z. Zhao and Y. Zhu. 2017. "Crop Model Improvements Reduce Multi-Model Ensembles High Temperature Impact Uncertainties." Field Crops Research 202(0):5-20, doi: 10.1016/j.fcr.2016.05.001.

Martre P., B. A. Kimball, M. J. Ottman, G. W. Wall, J. W. White, S. Asseng, F. Ewert, D. Cammarano, A. Maiorano, P. K. Aggarwal, J. Anothai, B. Basso, C. Biernath, A. J. Challinor, G. De Sanctis, J. Doltra, B. Dumont, E. Fereres, M. Garcia-Vila, S. Gayler, G. Hoogenboom, L. A. Hunt, R. C. Izaurralde, M. Jabloun, C. D. Jones, B. T. Kassie, K. C. Kersebaum, A. K. Koehler, C. Müller, S. Naresh Kumar, B. Liu, D. B. Lobell, C. Nendel, G. O'Leary, J. E. Olesen, T. Palosuo, E. Priesack, E. Eyshi Rezaei, D. Ripoche, R. P. Rötter, M. A. Semenov, C. Stöckle, P. Stratonovitch, T. Streck, I. Supit, F. Tao, P. Thorburn, K. Waha, E. Wang, J. Wolf, Z. Zhao, and Y. Zhu. 2018. "The Hot Serial Cereal Experiment for modeling wheat response to temperature: field experiments and AgMIP-Wheat multi-model simulations.", *Open Data Journal for Agricultural Research* 4:28-34, doi: 10.18174/odjar.v4i0.15830.

Ottman, M. J., B. A. Kimball, J. W. White and G. W. Wall. 2012. "Wheat Growth Response to Increased Temperature from Varied Planting Dates and Supplemental Infrared Heating." *Agronomy Journal* 104(1):7-16. doi: 10.2134/agronj2011.0212.

Plessis, A., C. Ravel, J. Bordes, F. Balfourier and P. Martre. 2013. "Association Study of Wheat Grain Protein Composition Reveals That Gliadin and Glutenin Composition Are Trans-Regulated by Different Chromosome Regions." *Journal of Experimental Botany* 64(12):3627-44. doi: 10.1093/jxb/ert188.

Post, D. F., C. Mack, P. D. Camp and A.S. Suliman. 1988. "Mapping and Characterization of the Soils on the University of Arizona Maricopa Agricultural Center." Pp. 49-60 in *18th Proceedings of Hydrology and Water Resources of the Southwest, Arizona–Nevada Academy of Science.*: Arizona-Nevada Academy of Science. hdl: 10150/296419

Qualset, C. O., H. E. Vogt and N. E. Borlaug. 1985. "Registration of 'Yecora Rojo' Wheat." *Crop Science* 25:1130. doi: 10.2135/cropsci1985.0011183X002500060069x.

Rosenzweig, C., J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. Thorburn, J. M. Antle, G. C. Nelson, C. Porter, S. Janssen, S. Asseng, B. Basso, F. Ewert, D. Wallach, G. Baigorria and J. M. Winter. 2013. "The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and Pilot Studies." *Agricultural and Forest Meteorology* 170(15):166-82. doi: 10.1016/j.agrformet.2012.09.011.

Webber, H., P. Martre, S. Asseng, B. Kimball, J. White, M. Ottman, G. W. Wall, G. De Sanctis, J. D., R. Grant, B. Kassie, A. Maiorano, J. E. Olesen, D. Ripoche, E. Eyshi Rezaei, M. A. Semenov, P. Stratonovitch and F. Ewert. 2017. "Canopy Temperature for Simulation of Heat Stress in Irrigated Wheat in a Semi-Arid Environment: A Multi-Model Comparison." *Field Crops Research* 202(0):21-35. doi: 10.1016/j.fcr.2015.10.009.

Wall, G. W., B. A. Kimball, J. W. White and M. J. Ottman. 2011. "Gas Exchange and Water Relations of Spring Wheat under Full-Season Infrared Warming." *Global Change Biology* 17(6):2113-33. doi: 10.1111/j.1365-2486.2011.02399.x.

Wall, Gerard W., Jean E. T. McLain, Bruce A. Kimball, Jeffrey W. White, Michael J. Ottman and Richard L. Garcia. 2013. "Infrared Warming Affects Intrarow Soil Carbon Dioxide Efflux During Vegetative Growth of Spring Wheat." *Agronomy Journal* 105(3):607. doi: 10.2134/agronj2012.0356.

White, J.W., L.A. Hunt, K.J. Boote, J.W. Jones, J. Koo, S. Kim, C.H. Porter, P.W. Wilkens and G. Hoogenboom. 2013. "Integrated Description of Agricultural Field Experiments and Production: The Icasa Version 2.0 Data Standards." *Computers and Electronics in Agriculture* 96(0):1-12. doi: 10.1016/j.compag.2013.04.003.

White, J. W., B. A. Kimball, G. W. Wall, M. J. Ottman and L. A. Hunt. 2011. "Responses of Time of Anthesis and Maturity to Sowing Dates and Infrared Warming in Spring Wheat." *Field Crops Research* 124(2):213-22. doi: 10.1016/j.fcr.2011.06.020.

White, J. W., B. A. Kimball, G. W. Wall and M. J. Ottman. 2012. "Cardinal Temperatures for Wheat Leaf Appearance as Assessed from Varied Sowing Dates and Infrared Warming." *Field Crops Research* 137(0):213-20. doi: 10.1016/j.fcr.2012.08.013.