Field experimental data for crop modeling of wheat growth response to nitrogen fertilizer, elevated CO_2, water stress, and high temperature

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Abstract: Field experimental data of five experiments covering a wide range of growing conditions are assembled for wheat growth and cropping systems modeling. The data include (i) an experiment on interactive effects of elevated CO_2 by water and elevated CO_2 by nitrogen fertilizer application from a Free-Air Carbon Dioxide Enrichment experiment (FACE) at Arizona in USA; (ii) a nitrogen rate fertilizer experiment from three locations and two years in The Netherlands; (iii) water deficit experiments at Lincoln in New Zealand and (iv) at Cunderdin in Australia; and (v) a temperature sensitivity experiment at Obregon in Mexico. Overall, the data sets consist of 65 experimental treatments with more than 1000 observations, with time series of development and growth, soil water and soil nitrogen dynamics, yield and yield components, daily weather, soil characteristics, and cultivar descriptions. These data have been used in various agronomic and crop modeling studies.

Keywords: Wheat, Field experiments, Crop modeling.

1 INTRODUCTION: Field experimental data from main wheat-growing regions with contrasting environments around the world are assembled for wheat growth and cropping systems modeling. Data were obtained from range of experiments conducted in Arizona in the USA, three sites (The Bowing, The Eest and PAGV) in the Netherlands, Cunderdin in West Australia, Lincoln in New Zealand, and Obregon in Mexico. The experimental sites are located in arid, Mediterranean humid continental, temperate maritime, and humid sub-tropical climates.
The data consist of 65 experimental treatments with more than 1000 observations, with time series of development and growth, soil water content and soil nitrogen dynamics, yield and yield components, daily weather, soil characteristics, and cultivar descriptions. Crop management information includes planting date and depth, plant population, fertilizer and irrigation application rates and dates, as well as initial soil water and nitrogen measurements. Agronomic management for the experiments include rain-fed systems with no nitrogen application (sub-optimal practices) and partially to fully irrigated systems with moderate to high nitrogen fertilizer application (optimal practices). Some of the experimental treatments also include interactive effects of elevated atmospheric CO_2 concentration with water and nitrogen supply. Pests, disease and weeds were controlled for all the experiments.
The datasets are representative for low- to high-yielding environments of wheat. The observed grain yield across the various environmental conditions and experimental treatments ranges between 0.9 to 9.9 t/ha (Table 1). The lowest yield was obtained from a dryland Mediterranean climate at Australia. The highest yield was observed in a humid climate at New Zealand.
Assembled data were quality checked and individually and partly published in earlier studies (see Asseng et al., 2004; Asseng et al., 1998; Asseng et al., 2000; Groot and Verberne, 1991; Hunsaker et al., 1996;

Table 1. Summary of experiments and ranges of observed grain yields of wheat across diverse environments and treatments.

Experiments	Location	Number of treatments	Observed yield range (t/ha)
Free-Air Carbon Dioxide Enrichment versus water and nitrogen stress	Arizona, USA	16	4.7 - 9.0
Nitrogen application rate and timing at three locations	The Netherlands	18	4.1 - 8.3
Levels of water deficit with different planting dates	Cunderdin, Australia	18	0.9 - 4.0
Levels and timing of water deficit	Lincoln, New Zealand	7	3.6 - 9.9
Temperature sensitivity	Obregon, Mexico	6	5.4 - 7.8

* observed yield is in air dry weight

Jamieson et al., 1998a; Jamieson and Ewert, 1999; Jamieson et al., 1995; Kimball et al., 1995; Kimball, 2006; Kimball et al., 2002; Ko et al., 2010; Sayre et al., 1997; Wall et al., 2006; Wall and Kimball, 1993).

2 CO_2-WATER-NITROGEN INTERACTION EXPERIMENT - ARIZONA, USA: A Free-Air Carbon Dioxide Enrichment (FACE) experiment was conducted (Kimball et al., 1999; Wall and Kimball, 1993) to study interactive effects of elevated atmospheric CO_2 concentration with water and nitrogen stress on growth, development, and yield of spring wheat cv. Yecora Rojo. The field experiment was carried out during the 1992-1993, 1993-1994, 1995-1996, and 1996-1997 growing seasons (Table 2) at the University of Arizona's Maricopa Agricultural Center, Maricopa (33.06º N, 111.98º W, 361 meters above sea level), located approximately 50 km south of Phoenix, Arizona (Wall et al., 2006). The soil was a Trix clay loam (fine-loamy, mixed hyperthermic Typic Torrifluvents).

Sowing was early to mid-December on clay loam soils. The FACE plots were fumigated with elevated atmospheric CO_2 of 550 ppm throughout the growing season while control plots were kept at ambient atmospheric CO_2 level at approximately 360 ppm.

Experiments during the growing season of 1992-1993 and 1993-1994 included interactive effects of elevated atmospheric CO_2 with limited water supply on wheat growth. Some of the experimental treatments were fully irrigated (wet treatments), and some were partially irrigated (dry treatments). Irrigation water was supplied with a sub-surface drip-tape irrigation system. The 1995-1996 and 1996-1997 experiments included interactive effects of atmospheric CO_2 concentration with nitrogen supply. In addition to elevated CO_2, some treatments received high nitrogen and some received limited nitrogen applications (Table 2). All treatments of the 1995-1996 and 1996-1997 experiments were fully irrigated. Above-ground dry matter, leaf area, grain yield, and yield components were measured at various growth stages of the crop.

Table 2. Summary of a Free-Air Carbon Dioxide Enrichment (FACE) experiment at Arizona, USA

Growing season (years)	Treatments	Sowing (yyyy-mm-dd)	Irrigation (mm)	Nitrogen (kg N/ha)	CO2 (ppm)
1992-1993	A-CO_2-dry	1992-12-15	275	277	360
	A-CO_2-wet	1992-12-15	602	277	360
	E-CO_2-dry	1992-12-15	275	277	550
	E-CO_2-wet	1992-12-15	602	277	550
1993-1994	A-CO_2-dry	1993-12-07	287	261	360
	A-CO_2-wet	1993-12-07	629	261	360
	E-CO_2-dry	1993-12-07	287	261	550
	E-CO_2-wet	1993-12-07	629	261	550

Table 2. Continued

Growing season (years)	**Treatments**	**Sowing** (yyyy-mm-dd)	**Irrigation** (mm)	**Nitrogen** (kg N/ha)	**CO2** (ppm)
1995-1996	A-CO_2-low N	1995-12-15	592	100	360
	A-CO_2-high N	1995-12-15	653	383	360
	E-CO_2-low N	1995-12-15	592	100	550
	E-CO_2-high N	1995-12-15	653	383	550
1996-1997	A-CO_2-low N	1996-12-15	548	138	360
	A-CO_2-high N	1996-12-15	621	451	360
	E-CO_2-low N	1996-12-15	548	195	550
	E-CO_2-high N	1996-12-15	621	421	550

A-CO_2: ambient (normal) CO_2; E-CO_2: elevated CO_2; low N: low nitrogen; high N: high nitrogen;

3 NITROGEN FERTILIZER EXPERIMENT - THE NETHERLANDS: Field experiments with three nitrogen fertilizer application rates (N1, N2, N3) were conducted during the growing seasons of 1982-1983 and 1983-1984 at three locations in The Netherlands (Groot and Verberne, 1991). The field experiments were located at The Bowing (51.95º N, 5.75º E), The Eest (52.62º N, 5.75º E), and PAGV (52.50ºN, 5.50º E). Soil types were silty clay loam at The Bowing and silty loam both at The Eest and PAGV. The original purpose of this experiment was to generate experimental data relevant to testing simulation models for soil nitrogen dynamics, crop growth, and nitrogen uptake (Asseng et al., 2000; Groot and Verberne, 1991). Accordingly, a wheat cv. Arminda was grown with three contrasting levels of nitrogen fertilizer applications, including low (N1), medium (N2), and high (N3) (Table 3). In addition to the fertilizer amount indicated in Table 3, a monthly nitrogen deposition of 4 kg N/ha of ammonium nitrate at the Bouwing and 3 kg N/h for the Eest and PAGV (Asseng et al., 2000) was considered. The experiments consisted of frequently measured above-ground dry matter, grain yield, leaf area, grain nitrogen, crop nitrogen, and soil water contents at various growth stages of the crop.

Table 3. Summary of nitrogen fertilizer applications (N1, N2, N3) experiment at three sites in The Netherlands.

Location	**Sowing date** (yyyy-mm-dd)	**Harvest** Year	**N1** (kg N/ha)	**N2** (kg N/ha)	**N3** (kg N/ha)	**Monthly deposition** of N (kg N/ha)
The Bouwing	1982-10-21	1983	0	60	160	4
	1983-10-27	1984	70	170	230	4
The Eest	1982-10-19	1983	0	60	160	3
	1983-10-21	1984	110	150	150	3
PAGV	1982-10-25	1983	80	140	240	3
	1983-10-21	1984	80	180	240	3

4 WATER DEFICIT EXPERIMENT - CUNDERDIN, WESTERN AUSTRALIA: An experiment with three sowing dates resulting in increased water deficit was conducted during the growing season of 1996-1997 at Cunderdin (31.40º S, 117.40º E), Western Australia on clay loam soil (Asseng et al., 2004). Wheat cv. Wilgoyne (early maturing) and Spear (late maturing) were sown on 6 June (sowing 1), 8 July (sowing 2), and 30 July (sowing 3) (Table 4). Sowing 3 was outside the normal sowing window to increase terminal water and temperature stress during grain filling (Asseng et al., 2004). Nitrogen fertilizer was applied at the different sowing dates with rates of 0 or 50 kg N/ha (Table 4). In selected treatments, irrigation water (total of 100 mm) was applied at weekly intervals for 7 weeks prior to anthesis to minimize water deficit.

Above-ground dry matter were measured at various growth stages of the crop. Grain yield was measured at the end of the growing season.

Table 4. Summary of water deficit experiment-Cunderdin, Western Australia

Treatment name	**Sowing date** (yyyy-mm-dd)	**Cultivar**	**Fertilizer** (kg N/ha)	**Irrigation** (mm)
C97s0n1	1997-06-06	Spear	0	0
C97s0n2	1997-07-08	Spear	0	0
C97s50n1	1997-06-06	Spear	50	0
C97s50n2	1997-07-08	Spear	50	0
C97s0i1	1997-06-06	Spear	0	100
C97s0i2	1997-07-08	Spear	0	100
C97s50i1	1997-06-06	Spear	50	100
C97s50i2	1997-07-08	Spear	50	100
C97w0n1	1997-06-06	Wilgoyne	0	0
C97w0n2	1997-07-08	Wilgoyne	0	0
C97w0n3	1997-07-30	Wilgoyne	0	0
C97w50n1	1997-06-06	Wilgoyne	50	0
C97w50n2	1997-07-08	Wilgoyne	50	0
C97w0i1	1997-06-06	Wilgoyne	0	100
C97w0i2	1997-07-08	Wilgoyne	0	100
C97w0i3	1997-07-30	Wilgoyne	0	100
C97w50i1	1997-06-06	Wilgoyne	50	100
C97w50i2	1997-07-08	Wilgoyne	50	100

5 WATER DEFICIT EXPERIMENT - LINCOLN, NEW ZEALAND: A field experiment located at New Zealand Institute of Crop and Food Research experiment station, Lincoln (43.39° S, 172.39° E), was used to examine the effect of water deficit on growth and yield of wheat (Jamieson et al., 1995). Wheat cv. Rongotea was sown on 8 June 1991 in a mobile rain shelter (55 m x 12 m). A mobile rainfall shelter was used to cover the experimental crop during rainfall events. On days without rainfall, the crop was exposed to a normal field environment (Jamieson and Ewert, 1999; Jamieson et al., 1995; Jamieson et al., 1998b). The control treatment was fully irrigated and crops in other treatments were exposed to increasing levels of water stress at different crop growth stages (Table 5). Treatments presented here (1, 3, 5-8, and 11) were selected from the full experimental set described in Jamieson et al. (1995). Authors assessed response of crops to drought stress by exposing the crops to droughts of varying time and duration. The soil was a deep sandy loam (1.6 m) with an available water-holding capacity of 190 mm/m depth. Thirty kg N/ha was applied at sowing, and an additional 150 kg N/ha was applied through irrigation. Above-ground dry matter, leaf area, grain yield and soil water contents were measured at various growth stages of the crop.

Table 5. Irrigation time (dates) and amount (mm) for water deficit experiment - Lincoln, New Zealand

	Treatments						
Irrigation dates (yyyy-mm-dd)	**1** (control) (mm)	**3** (mm)	**5** (mm)	**6** (mm)	**7** (mm)	**8** (mm)	**11** (mm)
1991-06-10	7	7	7	7	7	7	7
1991-08-16	7	7	7	7	7	7	7
1991-08-29	20	20	20	20	20	20	
1991-09-07	12			12	12	12	
1991-09-12	22			22	22	22	
1991-09-19	4			14	14	14	
1991-09-26	7	7	7	7	7	7	7
1991-10-03	27				27	27	
1991-10-10	18				18	18	
1991-10-17	30				30	30	
1991-10-24	42	42				42	
1991-10-31	33	33				33	
1991-11-07	24	24				24	
1991-11-14	28	28					
1991-11-21	37	37					
1991-11-27	51	51					
1991-12-05	36	36					
1991-12-12	38	38					
1991-12-19	35	35	35				
1991-12-26	47	47	47				
1992-01-03	40	40	40				
1992-01-09	41	41	0				
Total irrigation (mm)	606	493	163	89	164	263	21

Note: Selected treatments with contrasting water deficit are presented in this table. Full sets of experimental treatments are presented in Jamieson et al. (1995).

6 RISING TEMPERATURE EFFECT - OBREGON, MEXICO: Fully irrigated and fertilized wheat cv. Yecora70 was grown during the years 1989-1990 to 1994-1995 on clay loam soil at Obregon (27.33° N, 109.09° W) in Mexico (Sayre et al., 1997). The original purpose of this study was to compare yield progress of semidwarf wheat cultivars over a six year period in northwest Mexico (Sayre et al., 1997). During this period, mean recorded in-season temperature increased by more than 1°C (Asseng et al., 2004). Sowing was from late November to early December (Table 6). Prior to sowing, a summer green manure crop (20 kg N/ha) was incorporated by cultivation to reduce nutrient deficiency. Superphosphate (26 kg N/ha), urea (150 kg N/ha), and chicken manure (150 kg N/ha) were broadcasted at sowing. Irrigation water was supplied at 30% depletion of available water. Above-ground dry matter and grain yield were measured at the end of the crop growing season. Time series (in season) data was not measured for these experiments.

Table 6. Sowing dates and growing season mean temperature during the 1989-1990 to 1994-1995 period at Obregon, Mexico.

Sowing date (yyyy-mm-dd)	**Average daily maximum temperature** (^oC)	**Average daily minimum temperature** (^oC)	**Average daily mean temperature** (^oC)
1989-12-12	26.4	9.1	17.8
1990-12-04	26.5	10.3	18.4
1991-12-06	25.5	11.3	18.4
1992-11-26	26.7	11.0	18.9
1993-12-01	27.2	10.1	18.7
1994-12-01	27.0	10.5	18.8

7 GUIDELINES FOR DATA USE: Details of crop management, weather, soil, and measured crop data are provided in AgMIP format (Rosenzweig et al., 2013). Table 7 includes input and measured data file names for each experiment location. The data is grouped into four main folders. Soil properties and daily weather data are provided in folders named *soil data and weather data,* respectively. Crop management input data such as soil initial conditions, sowing dates, sowing depth, plant population, cultivars, irrigation, and fertilizer rates are provided in a folder named *soil-crop management*. Measured data on wheat growth and development including phenology, above-ground biomass, yield and yield components during the growing season (times series), as well as information at the end of the growing season (summary) are provided in a folder named *experimental data*. All data are in text files (tab delimited). A “read me text file” is included for abbreviations and variable definitions as part of the dataset.

Table 7. File names of experimental data.

Location	**Input files**			**Field measured data***
	Weather	**Soil**	**Management**	
USA, Arizona	MARA.WTH, MARB.WTH	MA.SOL	Crop management_USA.txt	Experimental data_USA.txt
The Netherlands				
The Bouwing	BOUW.WTH	BO.SOL	Crop management_Netherlands.txt	Experimental data_Netherlands.txt
The Eest	EEST.WTH	EE.SOL		
Pagv	PAGV.WTH	PA.SOL		
Australia, Cunderdin	AUST.WTH	AU.SOL	Crop management_Australia.txt	Experimental data_Australia.txt
New Zealand, Lincoln	NEWZ.WTH	NE.SOL	Crop management_New Zealand.txt	Experimental data_New Zealand.txt
Mexico, Obregon	MEXI.WTH	ME.SOL	Crop management_Mexico.txt	Experimental data_Mexico.txt

*Note that weight related field measured data such as the above ground biomass and grain yield are provided in dry weight basis.

REFERENCES

Asseng S., Jamieson P.D., Kimball B., Pinter P., Sayre K., Bowden J.W., Howden S.M. (2004) Simulated wheat growth affected by rising temperature, increased water deficit and elevated atmospheric CO2. Field Crops Research 85:85-102. doi: 10.1016/s0378-4290(03)00154-0.

Asseng S., Keating B.A., Fillery I.R.P., Gregory P.J., Bowden J.W., Turner N.C., Palta J.A., Abrecht D.G. (1998) Performance of the APSIM-wheat model in Western Australia. Field Crops Research 57:163-179. doi: 10.1016/s0378-4290(97)00117-2.

Asseng S., van Keulen H., Stol W. (2000) Performance and application of the APSIM Nwheat model in the Netherlands. European Journal of Agronomy 12:37-54. doi: 10.1016/s1161-0301(99)00044-1.

Rosenzweig, C., Jones, J.W., Hatfield, J.L., Ruane, A.C., Boote, K.J., Thorburn, P.J., Antle, J.M., Nelson, G.C., Porter, C.H., Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G.A., Winter, J.M., 2013. The Agricultural Model Intercomparison and Improvement Project (AgMIP): protocols and pilot studies. Agricultural Forest Meteorology. 170, 166-182. doi: 10.1016/j.agrformet.2012.09.011

Groot J.J.R., Verberne E.L.J. (1991) Response of wheat to nitrogen fertilization: a data set to validate simulation models for nitrogen dynamics in crop and soil. Fertilizer Research 27:349-383. doi: 10.1007/BF01051140.

Hunsaker D., Kimball B., Pinter P., LaMorte R., Wall G. (1996) Carbon dioxide enrichment and irrigation effects on wheat evapotranspiration and water use efficiency. Transactions of the Asae 39:1345-1355.

Jamieson P., Porter J., Goudriaan J., Ritchie J., van Keulen H., Stol W. (1998a) A comparison of the models AFRCWHEAT2, CERES-wheat, Sirius, SUCROS2 and SWHEAT with measurements from wheat grown under drought. Field Crops Research 55:23-44. doi: 10.1016/S0378-4290(97)00060-9.

Jamieson P.D., Ewert F. (1999) The role of roots in controlling soil water extraction during drought: an analysis by simulation. Field Crops Res. 60:267-280. doi: 10.1016/S0378-4290(98)00144-0

Jamieson P.D., R.J. M., G.S. F. (1995) Drought influences on grain yield of barley, wheat and maize. New Zealand Journal of Crop and Horticultural Science 23:55-66. doi: 10.1080/01140671.1995.9513868

Jamieson P.D., Semenov M.A., Brooking I.R., Francis G.S. (1998b) Sirius: a mechanistic model of wheat response to environmental variation. European Journal of Agronomy 8:161-179. doi: 10.1016/S1161-0301(98)00020-3.

Kimball B., LaMorte R., Pinter P., Wall G., Hunsaker D., Adamsen F., Leavitt S., Thompson T., Matthias A., Brooks T. (1999) Free-air CO2 enrichment and soil nitrogen effects on energy balance and evapotranspiration of wheat. Water Resources Research 35:1179-1190. doi: 10.1029/1998WR900115.

Kimball B., Pinter P., Garcia R., LaMorte R., Wall G., Hunsaker D., Wechsung G., Wechsung F., Kartschall T. (1995) Productivity and water use of wheat under free-air CO2 enrichment. Global Change Biology 1:429-442. doi: 10.1111/j.1365-2486.1995.tb00041.x.

Kimball B.A. (2006) The effects of free-air CO2 enrichment of cotton, wheat, and sorghum. Ecological Studies 187:47-70. doi: 10.1007/3-540-31237-4_3.

Kimball B.A., Kobayashi K., Bindi M. (2002) Responses of agricultural crops to free-air CO2 enrichment. Advances in Agronomy, Vol 77 77:293-368. doi: 10.1016/s0065-2113(02)77017-x.

Ko J., Ahuja L., Kimball B., Anapalli S., Ma L., Green T., Ruane A., Wall G., Pinter P., Bader D. (2010) Simulation of free air CO2 enriched wheat growth and interactions with water, nitrogen, and temperature. Agricultural and Forest Meteorology 150:1331-1346. doi: 10.1016/j.agrformet.2010.06.004.

Sayre K., Rajaram S., Fischer R. (1997) Yield potential progress in short bread wheats in northwest Mexico. Crop Science 37:36-42. doi: 10.2135/cropsci1997.0011183X003700010006x

Wall G., Garcia R., Kimball B., Hunsaker D., Pinter P., Long S., Osborne C., Hendrix D., Wechsung F., Wechsung G., Leavitt S., LaMorte R., Idso S. (2006) Interactive effects of elevated carbon dioxide and drought on wheat. Agronomy Journal 98:354-381. doi: 10.2134/agronj2004.0089.

Wall G.W., Kimball B.A. (1993) Biological databases derived from FACE. In: Schulze, E.D., Mooney, H.A. (Eds.), design and execution of experiments on CO2 enrichment. Commission of the European communities, dissemination of scientific and technical knowledge unit, Brussels. pp. 329-352.