Modelling adaptation of wheat cultivars to increasing temperatures and heat stress

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Introduction

Climate change is expected to lead to yield reductions in cereals due to effects on both growth duration and physiological processes affecting both assimilation and translocation of carbon and nitrogen metabolites to grains. However, some of these negative effects may be alleviated through plant breeding.

Experiments

A pot experiment with selected spring wheat varieties exposed to post-anthesis heat stress (35 °C for 5 days) showed that the major factor affecting variety differences in heat tolerance was related to effects on green leaf area duration after heat stress. A field experiment with the same selected spring wheat varieties showed large differences between the varieties in crop development and in biomass.

Modelling

The data were used to calibrate the FASSET and Sirius crop models using a sequenced calibration procedure. Both models simulated crop growth and yield well. A sensitivity analysis for both models with increasing temperature showed declining yields for both models with higher rates of yield reduction at temperature increases above 3°C.

Results

The models agreed on the pattern of yield decline between cultivars, with larger yield reductions being related to earliness. The variation in effects of post-anthesis heat stress between varieties was primarily related to effects on green leaf area duration, which in crop modelling calls for higher focus on simulation of leaf area under high temperature stress conditions.

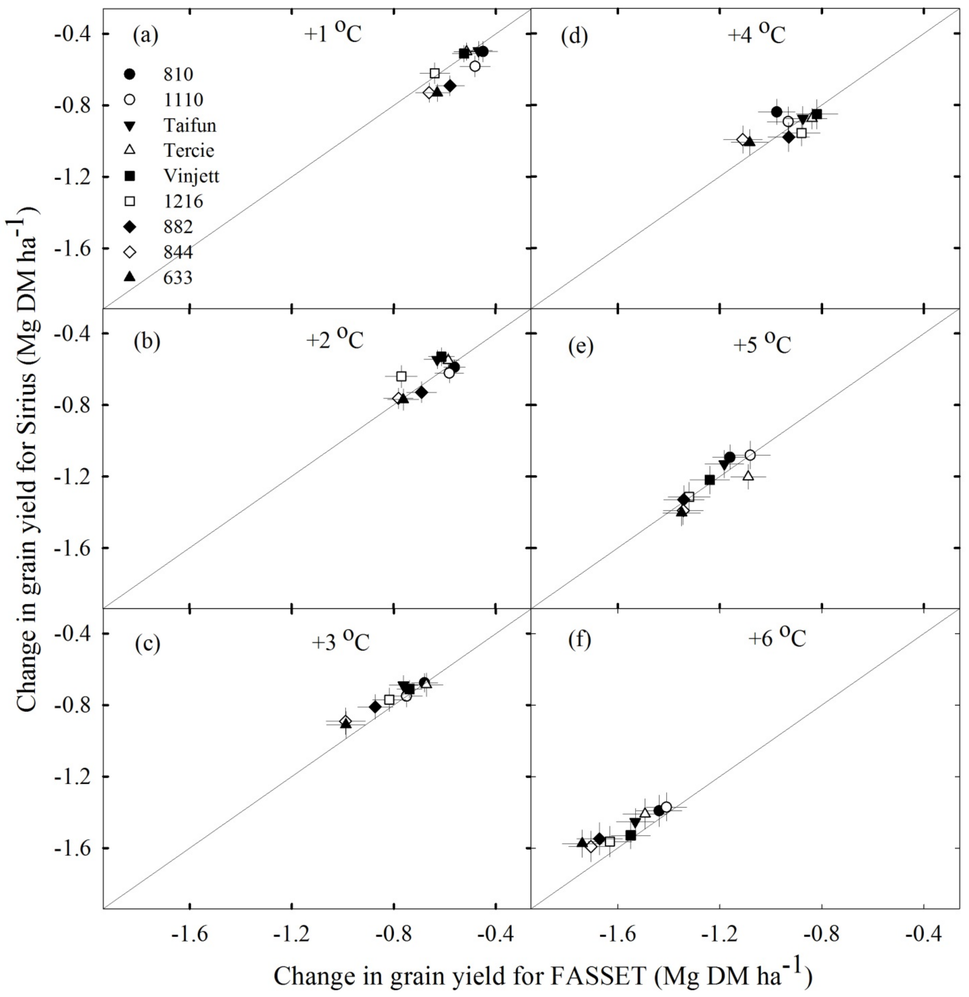
Cultivars grown (dates refer to field experiment)

Cultivar number	Cultivar name	Source	Country of origin	Emergence (GS10)	Stem elongation (GS31)	Anthesis (GS65)	Maturity (GS92)
810	N/A	IPK	Afghanistan	29/04	28/05	21/06	15/08
1110	Kloka WM1353	IPK	Germany	30/04	29/05	25/06	16/08
Taifun	Taifun	NGB	Denmark	01/05	31/05	26/06	17/08
Tercie	Tercie	NGB	Denmark	02/05	01/06	27/06	15/08
Vinjett	Vinjett	NGB	Denmark	03/05	31/05	28/06	17/08
1216	N/A	IPK	Slovakia	04/05	31/05	28/06	17/08
882	N/A	IPK	Romania	05/05	01/06	03/07	30/08
844	N/A	IPK	Afghanistan	06/05	06/06	07/07	04/09
633	Hörnings Grüne Dame	IPK	Germany	07/05	08/06	10/07	06/09

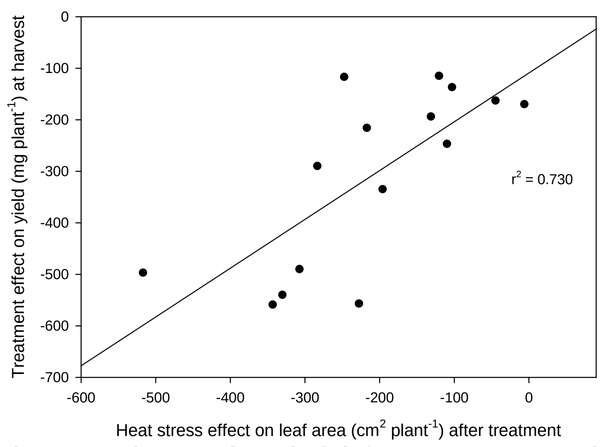
Crop model parameters

FASSET	Description	Standard	810	1110	Taifun	Tercie	Vinjett	1216	882	844	633
TS0	Emergence temperature sum (°Cd)	125	129	129	129	129	129	129	129	129	129
TS1	Temperature sum for anthesis (°Cd)	445	450	458	462	468	471	471	522	551	555
TS2	Temperature sum for end grain fill (°Cd)	310	443	458	461	459	482	490	505	511	535
TS3	Temperature sum for ripeness (°Cd)	200	200	200	200	200	200	200	200	200	200
DS_Flagligule	DS scale for start of flag ligule (BBCH 39)	1.00	0.80	0.81	0.82	0.81	0.83	0.83	0.86	0.85	0.85
k	PAR extinction coefficient	0.65	0.62	0.62	0.65	0.65	0.65	0.58	0.55	0.52	0.52
MaxRadUseEff	Maximum radiation use efficiency (g MJ^{-1})	3.2	3.2	3.1	3.4	3.4	3.4	3.3	3.1	3.1	3.1
LAINitrogenRatio	Maximum LAI/N ratio in vegetative top (m^2 g^{-1} N)	0.60	0.58	0.58	0.61	0.61	0.61	0.60	0.57	0.58	0.58
LAIDMRatio	Maximum LAI/DM ratio in vegetative top (m^2 m^{-2} g^{-1} DM)	0.010	0.009	0.009	0.010	0.010	0.011	0.011	0.012	0.012	0.012
StoreForFilling	Fraction of DM present at initiation of grain filling that is translocated to grain	0.30	0.23	0.18	0.22	0.22	0.24	0.20	0.21	0.18	0.20
FillFactor	Fraction of net production after anthesis that goes into grain	0.48	0.46	0.44	0.52	0.54	0.51	0.43	0.38	0.36	0.36

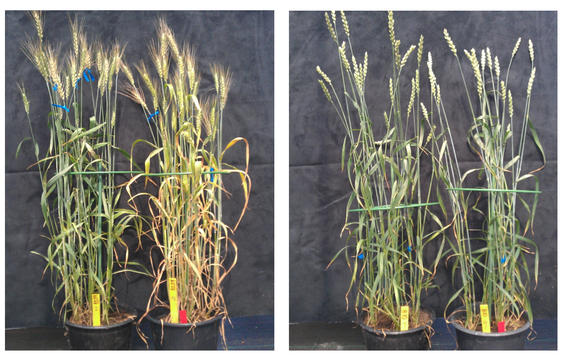
Sirius	Description	Standard	810	1110	Taifun	Tercie	Vinjett	1216	882	844	633
TTSOWEM	Thermal time sowing to emergence (°Cd)	150	129	129	129	129	129	129	129	129	129
TTANBGF	Thermal time anthesis to beginning of grain fill (°Cd)	190	190	190	190	190	190	190	190	190	190
TTBGEG	Thermal time beginning grain fill to end grain fill (°Cd)	550	520	538	550	565	570	570	610	630	635
TTEGFMAT	Thermal time end grain fill to harvest maturity (°Cd)	200	200	200	200	200	200	200	200	200	200
AreaMax	Potential maximum leaf size (m^2)	0.0065	0.0057	0.0055	0.0063	0.0061	0.0062	0.0047	0.0065	0.0070	0.0070
PHYLL	Phyllochron (°Cd)	90	75	75	80	80	80	85	100	105	105
EXTINC	PAR extinction coefficient	0.60	0.62	0.62	0.65	0.65	0.65	0.58	0.55	0.52	0.52



Simulated changes in grain yield at higher temperatures for a range spring wheat cultivars with two crop models.



Change in grain yield from post-anthesis heat stress in a pot experiment related to effects on green leaf area.



"1039" variety "810" variety

Wheat varieties after heat treatment in growth chamber: control – left, heat - right

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