A simple theory and data based model of wheat yield

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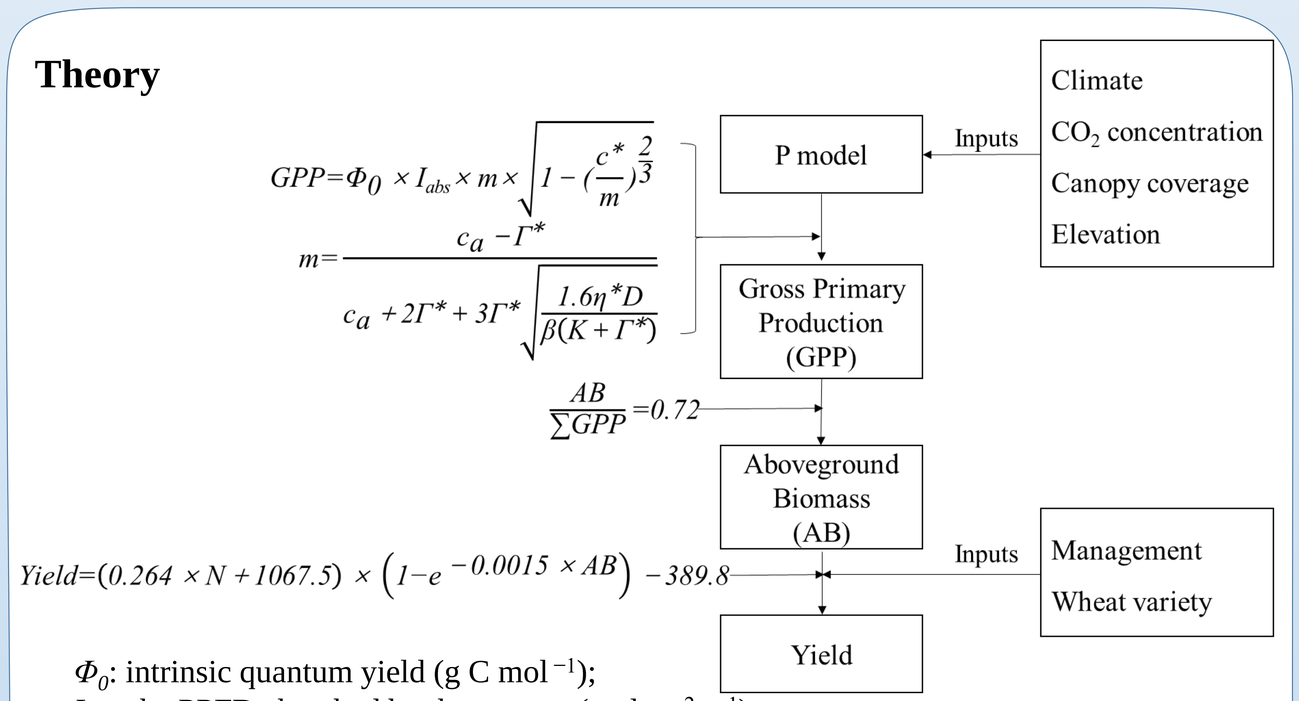
Summary

Climate exerts a major influence on crop development and yield. However, despite extensive modelling efforts, there is still considerable uncertainty about the impacts of climate change for wheat yield. In this study, we extend a first-principles based primary production model (P model, Wang et al., 2017 *Nature Plants*) to predict wheat yield at agricultural research sites of China. This simple theory and data based model (named PC model, Production of Crop) we present, accounts for the influence of climate, CO_2 and management practices on wheat growth and yield using empirical relationships that link time-integrated gross primary production (GPP) to above-ground biomass (AB), and AB to grain yield. We show that the PC model can predict wheat growth and yield at agricultural sites in China. We then use the PC model to project the response of wheat yield to environmental change. It also can catch similar interannual change of wheat yield as LPJml model.

Theory



$$GPP = \Phi_0 \times I_{abs} \times m \times \sqrt{1 - \left(\frac{c^*}{m}\right)^{\frac{2}{3}}}$$

$$m = \frac{c_a - \Gamma^*}{c_a + 2\Gamma^* + 3\Gamma^* \sqrt{\frac{1.6\eta^* D}{\beta(K + \Gamma^*)}}}$$

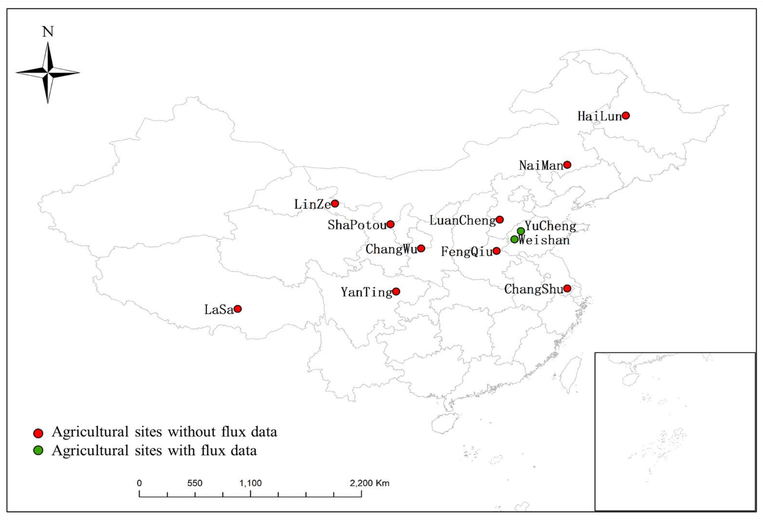
$$Yield = (0.264 \times N + 1067.5) \times \left(1 - e^{-0.0015 \times AB}\right) - 389.8$$

Φ_0: intrinsic quantum yield (g C mol^{-1});
I_{abs}: the PPFD absorbed by the canopy (mol m^{-2} s^{-1});
c_a: ambient CO_2 partial pressure (Pa);
Γ^*: photorespiratory compensation point (Pa);
η^*: the viscosity of water, relative to its value at 25 °C;
D : vapor pressure deficit (kPa);
K : the effective Michaelis-Menten coefficient of Rubisco (Pa);
c^*: the cost factor for electron transport (c^*=0.41);
β: the ratio of cost factors for carboxylation and transpiration (β=146);
N: total application of nitrogen (kg hm^{-2}).

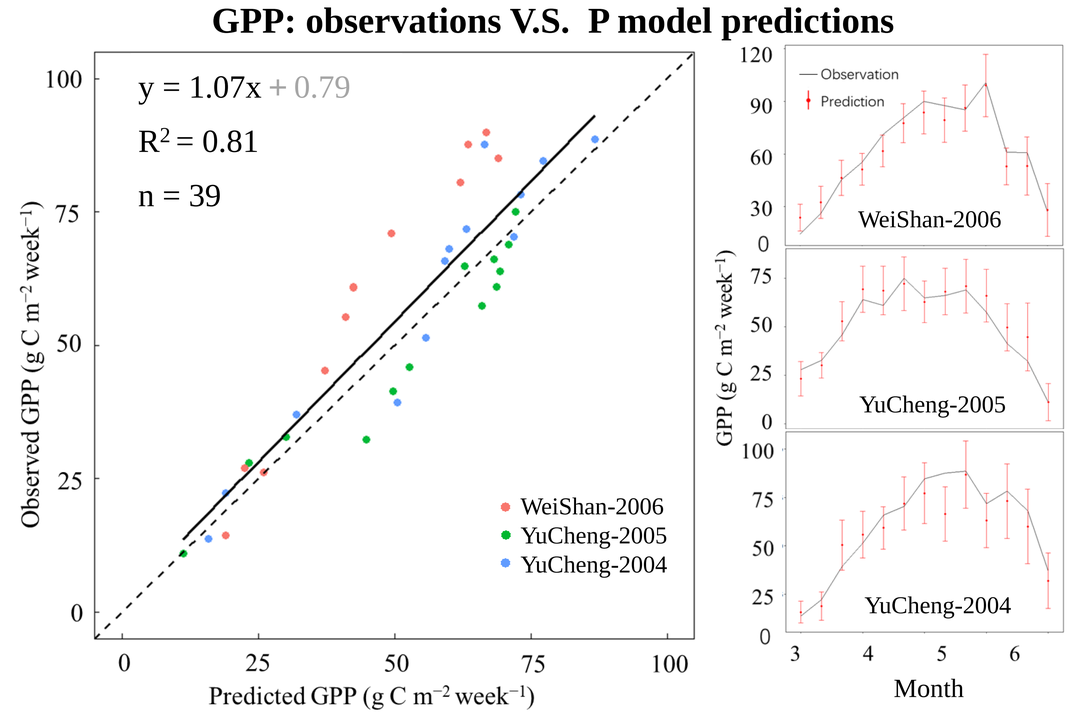
Data

Sites	Data span	PPFD (mol m^{-2} day^{-1})	T (°C)	RH (%)	CO_2 (ppm)	LAI	AB (g m^{-2})	Yield (g m^{-2})	Fertilization Irrigation	Wheat variety	Flux data (g C m^{-2} day^{-1})
WeiShan	2006	#	#	#	#	#					#
YuCheng	2004-2015	√#	√#	√#	√#	√#	√*	√	√	√	#*
ChangShu	2004-2015	√	√	√	√	√	√	√	√	√	
ChangWu	2004-2015	√	√	√	√	√	√	√	√	√	
FengQiu	2004-2015	√	√	√	√	√	√	√	√	√	
LuanCheng	2004-2015	√	√	√	√	√	√	√	√	√	
YanTing	2004-2015	√	√	√	√	√	√	√	√	√	
HaiLun	2005-2006										
LaSa	2004-2015										
LinZe	2006										
NaiMan	2006										
ShaPotou	2006										

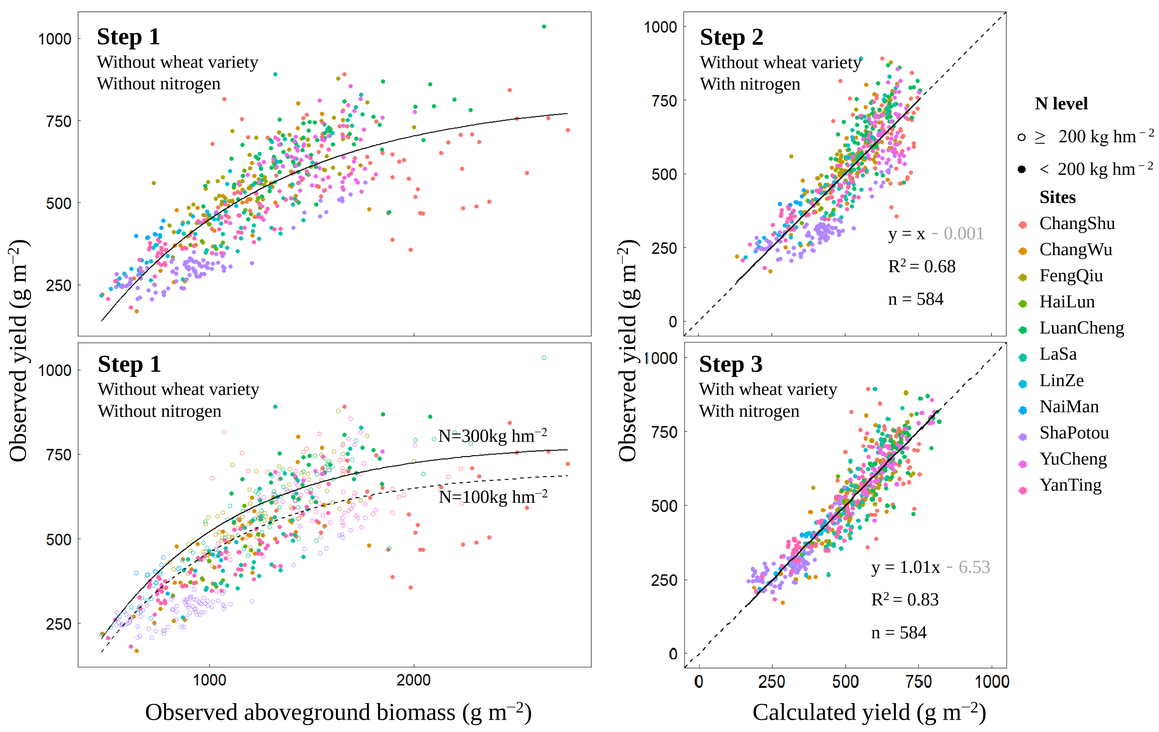
√: data used to test PC model;
#: data used to test P model;
*: data used to derive the ratio of AB to GPP;
: data used to derive allocation relationship from AB to yield



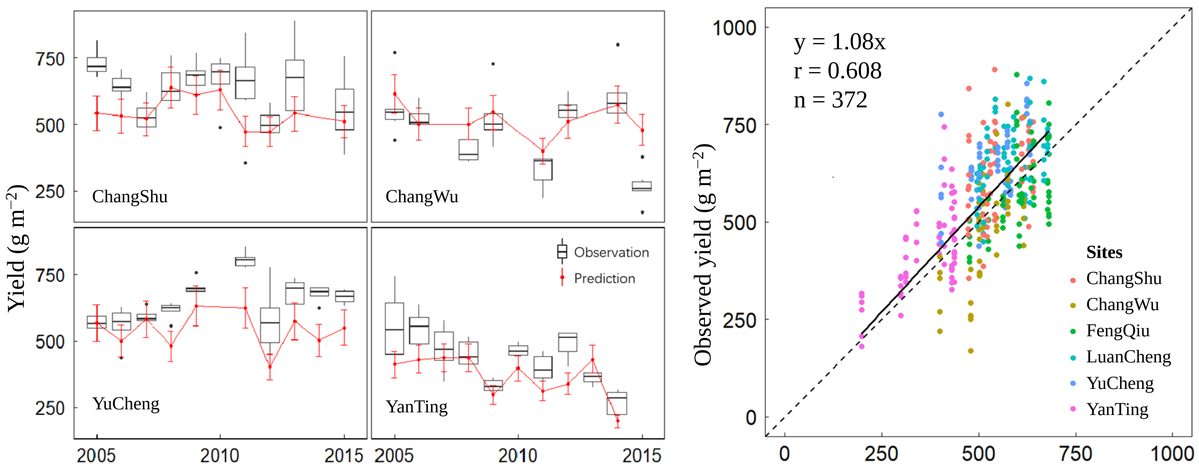
GPP: observations V.S. P model predictions



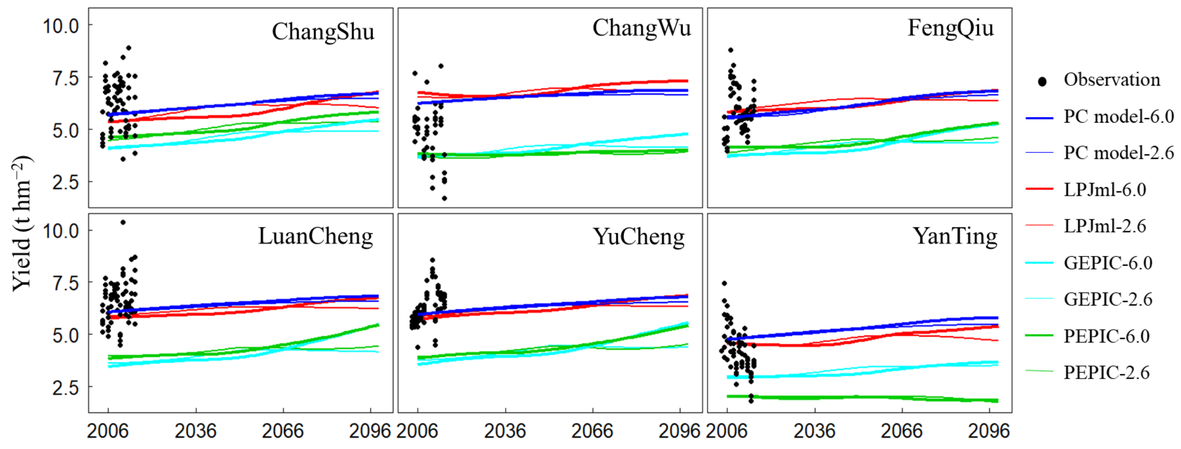
Allocation relationship derived by considering different factors



Wheat yield: observations V.S. PC model predictions



Model Intercomparison in the future scenarios



Conclusions

(1) The simple PC model can successfully capture the observed interannual variability of wheat yields at all agriculture sites.
(2) The simple PC model produces similar results as the complex LPJml model in the future scenarios
(3) The PC model yields insights into how wheat yields respond to environmental variations. A constant harvest index can not be assumed; instead the relationship between yield and AB follows a saturation curve, with both nitrogen addition and crop variety influencing the relationship.