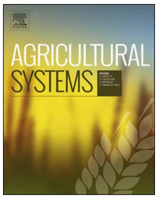
Agricultural Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy



Classifying multi-model wheat yield impact response surfaces showing sensitivity to temperature and precipitation change

Stefan Fronzek[a,*], Nina Pirttioja[a], Timothy R. Carter[a], Marco Bindi[b], Holger Hoffmann[c], Taru Palosuo[d], Margarita Ruiz-Ramos[e], Fulu Tao[d], Miroslav Trnka[f,g], Marco Acutis[h], Senthold Asseng[i], Piotr Baranowski[j], Bruno Basso[k], Per Bodin[l], Samuel Buis[m], Davide Cammarano[n], Paola Deligios[o], Marie-France Destain[p], Benjamin Dumont[p], Frank Ewert[c,q], Roberto Ferrise[b], Louis François[p], Thomas Gaiser[c], Petr Hlavinka[f,g], Ingrid Jacquemin[p], Kurt Christian Kersebaum[q], Chris Kollas[q,u], Jaromir Krzyszczak[j], Ignacio J. Lorite[r], Julien Minet[p], M. Ines Minguez[e], Manuel Montesino[s], Marco Moriondo[t], Christoph Müller[u], Claas Nendel[q], Isik Öztürk[v], Alessia Perego[h], Alfredo Rodríguez[e], Alex C. Ruane[w], Françoise Ruget[m], Mattia Sanna[h], Mikhail A. Semenov[x], Cezary Slawinski[j], Pierre Stratonovitch[x], Iwan Supit[y], Katharina Waha[u,z], Enli Wang[aa], Lianhai Wu[ab], Zhigan Zhao[aa,ac], Reimund P. Rötter[ad,ae]

[a] Finnish Environment Institute (SYKE), 00251 Helsinki, Finland
[b] University of Florence, 50144 Florence, Italy
[c] INRES, University of Bonn, 53115 Bonn, Germany
[d] Natural Resources Institute Finland (Luke), 00790 Helsinki, Finland
[e] CEIGRAM-AgSystems, Universidad Politecnica de Madrid, 28040 Madrid, Spain
[f] Institute of Agrosystems and Bioclimatology, Mendel University in Brno, Brno 613 00, Czech Republic
[g] Global Change Research Centre AS CR, v.v.i., 603 00 Brno, Czech Republic
[h] University of Milan, 20133 Milan, Italy
[i] University of Florida, Gainesville, FL 32611, USA
[j] Institute of Agrophysics, Polish Academy of Sciences, 20-290 Lublin, Poland
[k] Michigan State University, East Lansing, MI 48824, USA
[l] Lund University, 223 62 Lund, Sweden
[m] INRA, UMR 1114 EMMAH, F-84914 Avignon, France
[n] James Hutton Institute, Invergowrie, Dundee, DD2 5DA, Scotland
[o] University of Sassari, 07100 Sassari, Italy
[p] Université de Liège, 4000 Liège, Belgium
[q] Leibniz Centre for Agricultural Landscape Research (ZALF), 15374 Müncheberg, Germany
[r] IFAPA Junta de Andalucia, 14004 Córdoba, Spain
[s] University of Copenhagen, 2630 Taastrup, Denmark
[t] CNR-IBIMET, 50145 Florence, Italy
[u] Potsdam Institute for Climate Impact Research, 14473 Potsdam, Germany
[v] Aarhus University, 8830 Tjele, Denmark
[w] NASA Goddard Institute for Space Studies, New York, NY 10025, USA
[x] Rothamsted Research, Harpenden, Herts, AL5 2JQ, UK
[y] Wageningen University, 6700AA Wageningen, The Netherlands
[z] CSIRO Agriculture Flagship, 4067 St Lucia, Australia
[aa] CSIRO Agriculture Flagship, 2601 Canberra, Australia
[ab] Rothamsted Research, North Wyke, Okehampton, EX20 2SB, UK
[ac] China Agricultural University, 100094 Beijing, China
[ad] University of Göttingen, Tropical Plant Production and Agricultural Systems Modelling (TROPAGS), Grisebachstraße 6, 37077 Göttingen, Germany
[ae] University of Göttingen, Centre for Biodiversity and Sustainable Land Use (CBL), Büsgenweg 1, 37077 Göttingen, Germany

ARTICLE INFO

Keywords:
Classification

ABSTRACT

Crop growth simulation models can differ greatly in their treatment of key processes and hence in their response to environmental conditions. Here, we used an ensemble of 26 process-based wheat models applied at sites

---

[*] Corresponding author.
E-mail address: stefan.fronzek@ymparisto.fi (S. Fronzek).

http://dx.doi.org/10.1016/j.agsy.2017.08.004
Received 28 October 2016; Received in revised form 30 June 2017; Accepted 18 August 2017

Please cite this article as: Fronzek, S., Agricultural Systems (2017), http://dx.doi.org/10.1016/j.agsy.2017.08.004

Climate change
Crop model
Ensemble
Sensitivity analysis
Wheat

across a European transect to compare their sensitivity to changes in temperature (−2 to +9°C) and precipitation (−50 to +50%). Model results were analysed by plotting them as impact response surfaces (IRSs), classifying the IRS patterns of individual model simulations, describing these classes and analysing factors that may explain the major differences in model responses.

The model ensemble was used to simulate yields of winter and spring wheat at four sites in Finland, Germany and Spain. Results were plotted as IRSs that show changes in yields relative to the baseline with respect to temperature and precipitation. IRSs of 30-year means and selected extreme years were classified using two approaches describing their pattern.

The expert diagnostic approach (EDA) combines two aspects of IRS patterns: location of the maximum yield (nine classes) and strength of the yield response with respect to climate (four classes), resulting in a total of 36 combined classes defined using criteria pre-specified by experts. The statistical diagnostic approach (SDA) groups IRSs by comparing their pattern and magnitude, without attempting to interpret these features. It applies a hierarchical clustering method, grouping response patterns using a distance metric that combines the spatial correlation and Euclidian distance between IRS pairs. The two approaches were used to investigate whether different patterns of yield response could be related to different properties of the crop models, specifically their genealogy, calibration and process description.

Although no single model property across a large model ensemble was found to explain the integrated yield response to temperature and precipitation perturbations, the application of the EDA and SDA approaches revealed their capability to distinguish: (i) stronger yield responses to precipitation for winter wheat than spring wheat; (ii) differing strengths of response to climate changes for years with anomalous weather conditions compared to period-average conditions; (iii) the influence of site conditions on yield patterns; (iv) similarities in IRS patterns among models with related genealogy; (v) similarities in IRS patterns for models with simpler process descriptions of root growth and water uptake compared to those with more complex descriptions; and (vi) a closer correspondence of IRS patterns in models using partitioning schemes to represent yield formation than in those using a harvest index.

Such results can inform future crop modelling studies that seek to exploit the diversity of multi-model ensembles, by distinguishing ensemble members that span a wide range of responses as well as those that display implausible behaviour or strong mutual similarities.

1. Introduction

A wide range of dynamic crop growth simulation models have been developed over the past few decades, many of which are being applied to study impacts of climate change (Asseng et al., 2014; Challinor et al., 2014; Ewert et al., 2015; Jones et al., 2017a, 2017b; White et al., 2011). These models can differ greatly in their treatment of key processes and hence in their response to environmental conditions (Asseng et al., 2013; Palosuo et al., 2011; Rötter et al., 2012). Therefore, it is of interest to examine model behaviour under changed climate in order to characterise the types of responses estimated, contrast the responses of different models and consider the reasons for these differences.

Fundamental structural differences in the way models simulate processes such as development, assimilation, partitioning and water and nutrient uptake can be traced back to the purposes for which models were originally developed, their region of origin and the scale of their application (Challinor et al., 2009; van Ittersum et al., 2003). Given the many factors determining crop response, it is not surprising that processes are accorded variable emphasis across different models. For instance, a model developed to examine field-level processes of yield formation under well-watered conditions might focus on growth processes and the partitioning of dry matter, relying on only a simple parameterization of soil water availability. Conversely, regional yield estimates under water-limited conditions might demand a detailed representation of soil water and nutrient uptake, while adopting a simple approach to estimating yield components. Moreover, most models have not been developed independently and may share common antecedents and genealogy, which may provide clues to their comparative behaviour. Models that have evolved from a predecessor can hence exhibit many similar characteristics while including new processes or alternative descriptions of existing processes (Bouman et al., 1996; Rosenzweig et al., 2014).

However, model structure alone cannot explain all of the reported differences between model behaviour under a changing climate. Model calibration – the procedure of adjusting parameter values to obtain a good fit between model outputs and observations (Acutis and Confalonieri, 2006; Kersebaum et al., 2015) – may also play a significant role. Unless fixed calibration techniques have been pre-specified, most model inter-comparison exercises typically rely on “modellers' choice” for the techniques that are applied to the available observations. The techniques themselves can vary from trial and error methods through to optimization and Bayesian techniques (cf. Acutis and Confalonieri, 2006; Angulo et al., 2013), and must necessarily be tailored to the parameters of a given model. Even then, there may be differences in the number of parameters treated and in how the calibration data are interpreted and the techniques deployed (Confalonieri et al., 2016; Palosuo et al., 2011).

Here, a multi-model ensemble approach has been adopted to explore patterns of simulated yield response under climate change. We use an ensemble of wheat models at sites across a European transect (in Finland, Germany and Spain – Pirttioja et al., 2015) and compare their sensitivity to changes in climate by plotting simulated yield as impact response surfaces (IRS; Fronzek et al., 2010). An IRS is plotted from the results of a sensitivity analysis of an impact model with respect to changes in two key climatic variables, e.g. changes in annual mean surface temperature and annual precipitation. The observed baseline climate is adjusted with systematic increments over a range of values. Impacts are computed for each combination of changes in the two climate variables and plotted as contours on a two-dimensional IRS. Examples of IRS applications using crop models include estimates of yield response for maize (Ruane et al., 2013) and barley (Kim et al., 2013), of nitrogen leaching from wheat cultivation (Børgesen and Olesen, 2011) and of adaptation options in wheat cultivation (Ruiz-Ramos et al., 2017). The approach has also been applied in other sectors including hydrology (Holmberg et al., 2014; Prudhomme et al., 2013a; Weiß and Alcamo, 2011) and biodiversity (Fronzek et al., 2011).

IRSs of yield changes were presented in Pirttioja et al. (2015) as multi-model ensemble medians and inter-quartile ranges, focusing on long-term averages. This paper extends that work by classifying the responses of individual models and attempting to interpret differences in response between groups of models by contrasting their structure and representation of selected key processes as well as their behaviour in selected anomalous years.

For the same four sites described in this paper, Pirttioja et al. (2015)