Ferdowsi University of Mashhad

Simulation of winter wheat yield and its uncertainty band; A comparison of two crop growth models

Mohammad Javad Khordadi[1], Mehdi Nassiri Mahallati[2], Amin Alizadeh[1]

[1]Department of Water Engineering, College of Agriculture, Ferdowsi University of Mashhad, Iran
[2]Department of Agronomy and Plant Breeding, College of Agriculture, Ferdowsi University of Mashhad, Iran

Contact: khordadi@ag.iut.ac.ir

This presentation participates in OSPP
EGU
Outstanding Student Poster & PICO Contest

European Geosciences Union
General Assembly 2016
Vienna | Austria | 17 – 22 April 2016

Introduction

Decision making and planning in agriculture increasingly makes use of various model-based decision support tools, particularly in relation to changing climate issues. The crop growth simulation models applied are mostly mechanistic, i.e. they attempt to explain not only the relationship between parameters and simulated variables, but also the mechanism of the described processes (Challinor et al., 2009; Porter and Semenov, 2005).

Comparison of different modelling approaches and models can reveal the uncertainties related to crop growth and yield predictions, including also the uncertainty related to model structure, which is the most difficult source of uncertainty to quantify (Chatfield, 1995).

Comparisons can help to identify those parts in models that produce systematic errors and require improvements (see e.g. Porter et al., 1993).

The purpose of this study was 1) to examine responses in crop yield to a set of variants of anticipated changes in climatic conditions using the WOFOST and AquaCrop crop growth simulation models and 2) to present and discuss the different sources of uncertainty involved in the model application.

Material & Methods

The dynamic crop growth simulation model WOFOST (Boogaard et al., 1998) and AquaCrop (Steduto et al., 2009) were applied to examine crop yield responses to a set of plausible scenarios of climate change for a field experiment at Research Station, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran (36° 15′ N, 56° 28′ E, elevation 985 m) up to 2040 (Fig. 1).

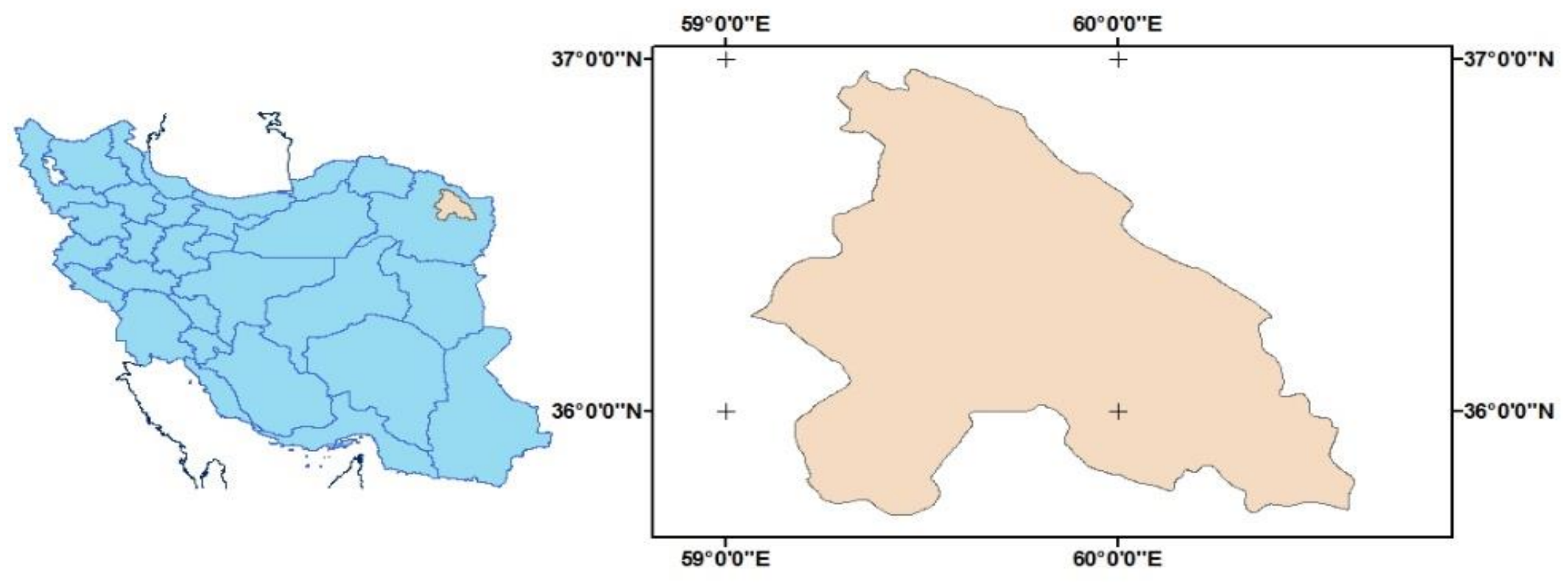

Fig. 1. Location of the study site

The average annual rainfall is 278.6 mm and the long-term average air temperature is 12.4 °C for the area. A composed soil sample was taken in before cultivation in depth of 0-30 cm at experimental site. Physical and chemical properties of the soil were determined in the Soil and Plant Analysis Laboratory (Table 1). We calibrated and then validated the two models based on 7-year observed crop data from the research farm. Winter wheat (Triticum aestivum L.) was used as the test crop since this is the most widespread cereal cultivated in Iran.

Table 1. Physico-chemical properties of soil (0-30 cm) at the experimental site

Parameter	Value	Parameter	Value
Clay (%)	60.7	NO_3-N (ppm)	8.5
Silt (%)	25.4	Available P (ppm)	6.7
Sand (%)	13.9	Available Na (meq/100 g)	0.3
pH (1:1:H_2O)	7.8	Available K (meq/100 g)	1.5
OC (%)	0.6	Available Ca (meq/100 g)	2.6
Total N (%)	0.2	Available Mg (meq/100 g)	3.2

For comparison, simulations are also conducted for climate projections assuming atmospheric composition consistent with the SRES A2 and B1 emissions scenarios published by the IPCC (Special Report on Emissions Scenarios – Nakicenovic et al., 2000), for the time slice 2011–2040. In these, changes in daily long-term means simulated by six General Circulation Models (GCM), GFCM21 (GFDL GAMDT, 2004), HadCM3 (Gordon et al., 2000), INCM3 (Galin et al., 2003), IPCM4 (Hourdin et al., 2006), MPEH5 (Roeckner et al., 1996) and NCCCSM (Collins et al., 2004) were applied for temperature, precipitation and solar radiation.

Bootstrap Method

Bootstrapping is a simple technique to estimate the required values in a specific statistical pattern. The general structure in confidence-interval finding in the majority of usual cases is to obtain a function from the required parameter having independent distribution from that parameter. Many times, the function finding is not easy; for overcoming this problem, the bootstrap method could be used. The further information about bootstrap is available in Efron and Tibshirani (1993) and DiCiccio and Efron (1996).

Using this method, the uncertainty band due to the six AOGCMs and the two emission scenarios in a 95% confidence interval for estimating crop yield is drawn. These bands show possible changes for the yield in the future period to the past one.

Results

Our results showed that none of the models perfectly reproduced recorded observations at the site and in all years, and none could unequivocally be labelled robust and accurate in terms of yield prediction with only minimum calibration. The best performance regarding yield estimation was for WOFOST, for which the RMSE values were lowest (18%) and determination coefficient (0.81) highest. AquaCrop clearly overestimated the yields. Results of the models calibration are shown in Tables 2 and 3.

Table 2. Calibrated crop parameters of the AquaCrop model

Parameter	Units or Meaning	Value
Base temperature	°C	0
Cut-off temperature	°C	26
Canopy growth coefficient (CGC)	increase in CC relative to existing CC per GDD	3.8
Canopy decline coefficient (CDC) at senescence	decrease in CC relative to CCx per GDD	9.81
Water productivity	g (biomass) m–2, function of atmospheric CO2	19
Maximum canopy cover (CCx)	function of plant density	94
Reference harvest index	%	45
Crop coefficient for transpiration at CC = 100%	full canopy transpiration relative to ETo	1.004
Leaf growth threshold p—upper	as fraction of TAW, above this leaf growth is inhibited	0.22
Leaf growth threshold p—lower	leaf growth stops completely at this p	0.55
Leaf growth stress coefficient curve shape		4.8
Stomatal conductance threshold p—upper	above this stomata begin to close	0.63
Stomata stress coefficient curve shape		2.3
Senescence stress coefficient p—upper	above this early canopy senescence begins	0.68
Senescence stress coefficient curve shape		2.3

Table 3. Calibrated crop parameters of the WOFOST model

Parameter	Description	Value
TSUM1	temperature sum from sowing to emergence [cel d-1]	1200
SLATB	specific leaf area as a function of DVS [-; ha kg-1]	0.0025
RGRLAI	maximum relative increase in LAI [ha ha-1 d-1]	0.02
AMAXTB	maximum leaf CO2 assimilation as function of DVS [kg ha-1 hr-1]	37
EFFTB	light-use effic. single leaf [kg ha-1 hr-1 j-1 m2 s] as function of daily mean temp.	0.45
KDIFTB	extinction coefficient for diffuse visible light [-] as function of DVS	0.6
TSUM2	temperature sum from anthesis to maturity [cel d-1]	950

The results showed that average potential yield of wheat ranged from 3.43 to 8.42 and 2.76 to 6.49 ton/ha, in AquaCrop and WOFOST models, respectively.

The uncertainty band for WOFOST indicates the future yield is less than the observed one whereas not any trend is existed and there is a continuous oscillation throughout the estimation (Fig. 2).

The band related to AquaCrop is completely different since yield values are more than observed mean almost from 2023 till the end of period. There is an increasing trend whereas to the end of period value of 8.42 ton/ha is estimated (Fig. 3).

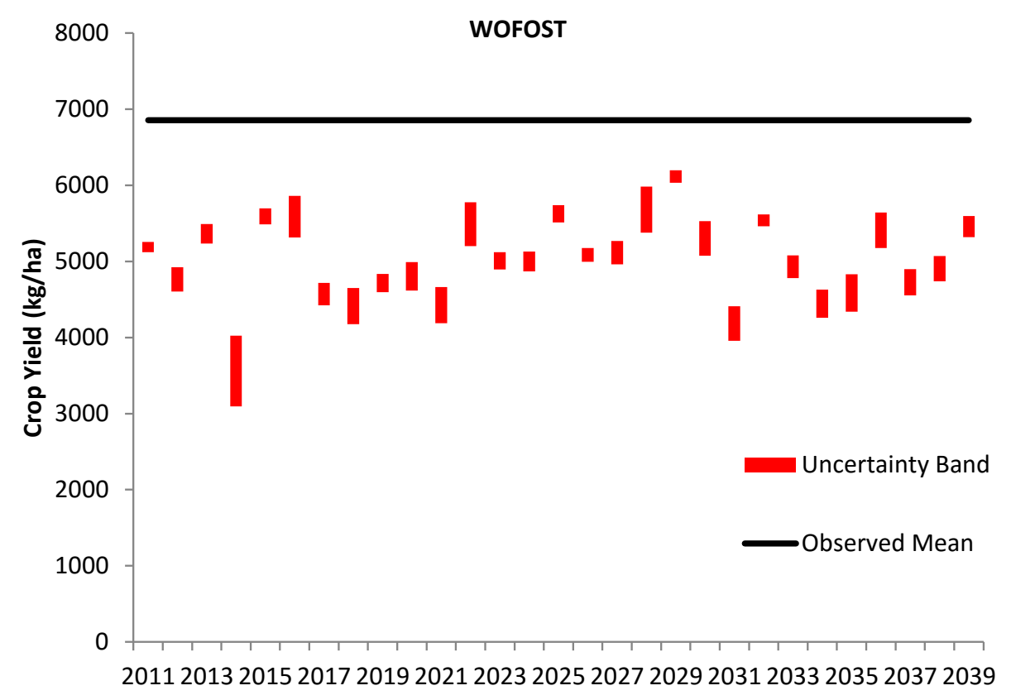

Fig. 2. Uncertainty band of crop yield estimation in WOFOST

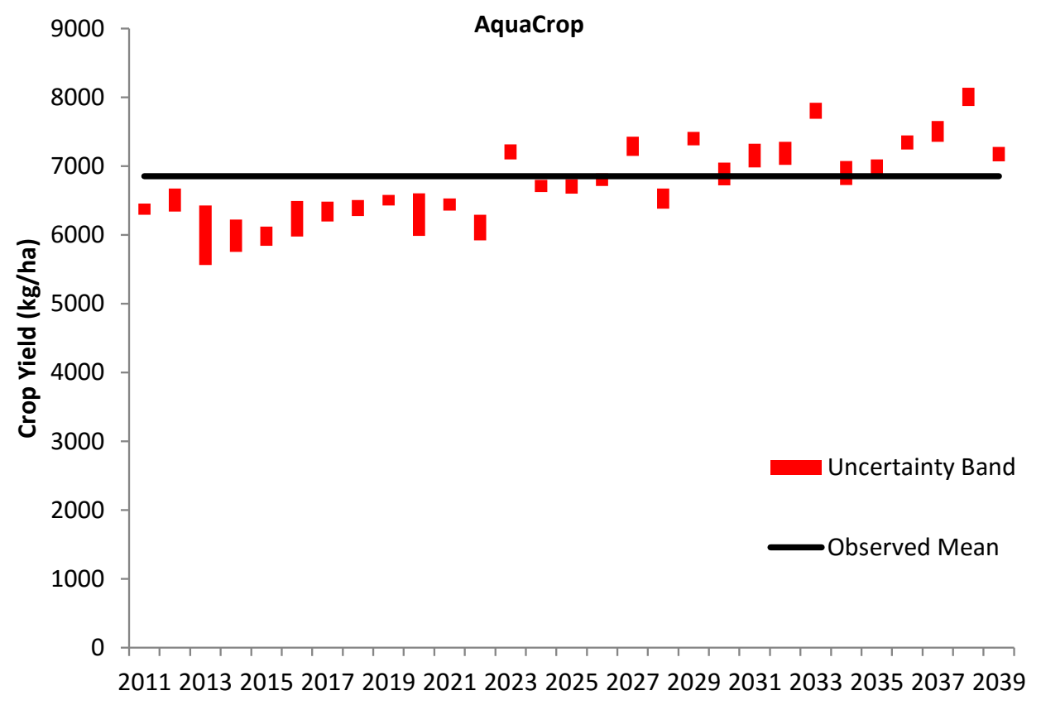

Fig. 3. Uncertainty band of crop yield estimation in AquaCrop

Conclusions

- It should be considered that we start at a fairly high yield level recorded at researcher-managed sites and only reached by the best farmers. Furthermore, there is evidence of yield increases slowing down in the region. This is either caused by closing gap between potential and actual yields, or, by more stringent environmental regulations, which in the future, will certainly set tighter limits to attainable yields.
- On the other hand, like climate models, crop simulation models are far from perfect. Therefore, it will be imperative to carry out comprehensive crop model comparisons both at site- and regional scales to take uncertainties in impact studies stemming from crop modelling uncertainties into account (Rotter et al., 2011).
- Finally, mean predictions from the two models were in good agreement with measured data which supports the use of multi-model estimates rather than reliance on just one model.

References

Boogaard, H.L., van Diepen, C.A., Rotter, R.P., Cabrera, J.M., van Laar, H.H., 1998. User's Guide for the WOFOST 7.1 Crop Growth Simulation Model and WOFOST Control Center, Techn. Doc. 52. Alterra, WUR, Wageningen, p. 144.

Efron, B., and Tibshirani, R. J., 1993. An introduction to the bootstrap, Chapman & Hall/CRC, New York.

Ewert, F., Rounsevell, M.D.A., Reginster, I., Metzger, M.J., Leemans, R., 2005. I. Estimating changes in crop productivity. Agric. Ecosyst. Environ. 107, 101–116.

Porter, J.R., Semenov, M.A., 2005. Crop responses to climatic variation. Philos. Trans. R. Soc. B 360 (1463), 2021–2038.

Rotter, R.P., Carter, T.R., Olesen, J.E., Porter, J.R., 2011. Crop-climate models need an overhaul. Nat. Clim. Change 1, 175–177.