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



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Introduction Decision making and planning in agriculture increasingly makes use of variou model-based decision support tools, particularly in relation to changing climar issues. The crop growth simulation models applied are mostly mechanistic, i. 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 product 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 ar AquaCrop crop growth simulation models and 2) to present and discuss the different sources of uncertainty involved in the model application.	For comparison, simulations are also conducted for climate prassuming atmospheric composition consistent with the SRES A2 emissions scenarios published by the IPCC (Special Report on H Scenarios – Nakicenovic et al., 2000), for the time slice 2011–2040. changes in daily long-term means simulated by six General C Models (GCM), GFCM21 (GFDL GAMDT, 2004), HadCM3 (Gord 2000), INCM3 (Galin et al., 2003), IPCM4 (Hourdin et al., 2006), (Roeckner et al., 1996) and NCCCSM (Collins et al., 2004) were at temperature, precipitation and solar radiation. Bootstrap Method Bootstrap Method Bootstrapping is a simple technique to estimate the required va specific statistical pattern. The general structure in confidence-interv in the majority of usual cases is to obtain a function from the parameter having independent distribution from that parameter. Ma the function finding is not easy; for overcoming this problem, the I method could be used. The further information about bootstrap is in Efron and Tibshirani (1993) and DiCiccio and Efron (1996).
Material & Methods	
The dynamic crop growth simulation model WOFOST (Boogaard et al., 1992 and AquaCrop (Steduto et al., 2009) were applied to examine crop yiel responses to a set of plausible scenarios of climate change for a fiel	Using this method, the uncertainty band due to the six AOGCMs an emission scenarios in a 95% confidence interval for estimating cro drawn. These bands show possible changes for the yield in the futu to the past one.
experiment at Research Station, Faculty of Agriculture, Ferdowsi University of Mashbad Iran (36° 15' N 56° 28' E elevation 985 m) up to 2040 (Fig. 1)	of Results
Fig. 1. Logation of the study site	observations at the site and in all years, and none could unequive labelled robust and accurate in terms of yield prediction with only a calibration. The best performance regarding yield estimation WOFOST, for which the RMSE values were lowest (18%) and deter coefficient (0.81) highest. AquaCrop clearly overestimated the yield of the models calibration are shown in Tables 2 and 3. Table 2. Calibrated crop parameters of the AquaCrop
Fig. 1. Location of the study site	Parameter Units or Meaning Value
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 (Triticun aestivum L.) was used as the test crop since this is the most widespread cerea cultivated in Iran.	Base temperature °C 0 Cut-off temperature °C 26 Canopy growth coefficient increase in CC relative to 3.8 (CGC) existing CC per GDD model Canopy decline coefficient decrease in CC relative to CCx 9.81 (CDC) at senescence per GDD TSUM1 Water productivity g (biomass) m-2, function of plant density 94 Maximum canopy cover (CCx) function of plant density 94 Reference harvest index % 45 RGRLAI maximum relative increase in LAI [ha ha-Crop coefficient for transpiration at CC = 100%
Table 1. Physico-chemical properties of soil (0-30 cm) at the experimenta site	Leaf growth threshold p—upper as fraction of TAW, above this 0.22 ha-1 hr-1] leaf growth is inhibited Leaf growth threshold p—lower leaf growth stops completely at 0.55 EFFTB light-use effic. single leaf [kg ha-1 hr-1 j-1] function of daily mean temp
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	this p this p function of daily mean temp. Leaf growth stress coefficient 4.8 KDIFTB extinction coefficient for diffuse visible life curve shape above this stomata begin to 0.63 function of DVS Stomatal conductance above this stomata begin to 0.63 TSUM2 temperature sum from anthesis to matu Stomata stress coefficient curve 2.3 2.3 1 1
pH (1:1:H2O)7.8Available K (meq/100 g)1.5OC (%)0.6Available Ca (meq/100 g)2.6Total N (%)0.2Available Mg (meq/100 g)3.2	snape Senescence stress coefficient above this early canopy 0.68 p—upper senescence begins Senescence stress coefficient 2.3 curve shape

	Int	roduction				For comparison	, simulations are	also o	conduc	ted for	clin
on making and pl	anning in ag	griculture increasin	gly makes use of v	various		emissions scenar	pheric compositio	n cons	sistent	with the	SR
based decision su	apport tools	, particularly in rel	ation to changing o	climate		Scenarios – Naki	icenovic et al., 200)0), for	the tin	ne slice 2	011
The crop growth	simulation	models applied an	e mostly mechanis	stic, i.e.		changes in daily	y long-term mean	ns sim	ulated	by six (Ger
red variables bu	n not only	the relationship mechanism of	between parameter	rs and		Models (GCM),	GFCM21 (GFDL	GAMI	T, 20	04), HadC	2M. 1
nor et al., 2009; P	orter and Se	emenov, 2005).	the described pro			(Roeckner et al.	Galin et al., 2005 1996) and NCCC), IPCN CSM (C	014 (He	ourdin et et al. 200	al., 4)
arison of differen	nt modellin	g approaches and	l models can reve	eal the		temperature, pre	cipitation and solar	r radiati	ion.	<i>ct</i> an, 200	•)
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ses to a set of	plausible Station Eag	scenarios of clin	nate change for a	a field		to the past one.					
ad, Iran (36° 15' I	N, 56° 28' E	L, elevation 985 m)	up to 2040 (Fig. 1)).]	Resul	ts		
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	37°0'0''N	59°0'0"E 60°0	'0"E 			observations at	the site and in al	l years,	, and i	none coul	d ı
Card a		2				calibration. The	best performan	nce reg	garding	g vield e	stir
E Star	2 mg	5				WOFOST, for w	which the RMSE va	alues w	ere lov	vest (18%)) ar
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	Fig. 1. Loca	ation of the study	site			model	the Aquaciop)			
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cultivation in de	epth of 0-3	30 cm at experim	ental site. Physica	and		Canopy growth coefficient (CGC)	increase in CC relative to existing CC per GDD	3.8	mode	el	1
al properties of t	the soil were	e determined in the	e Soil and Plant Ar	nalysis		Canopy decline coefficient (CDC) at senescence	decrease in CC relative to CCx per GDD	9.81	Parameter TSUM1	temperature cum (Des from s
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m L.) was used as	s the test cr	op since this is the	most widespread	cereal		Maximum canopy cover (CCx)	function of plant density	94 45	SLAID	specific leaf area a	s d i un
ed in Iran.						Crop coefficient for	% full canopy transpiration	45 1.004		maximum relative	increa
4 101 1 1	• 1	• • • • • • • • • • • • • • • • • • • •	\			transpiration at CC = 100% Leaf growth threshold p—upper	relative to ETo as fraction of TAW, above this	0.22	AIVIAATD	ha-1 hr-1]	: assim
I. Physico-chemi	ical propert	tes of soll (0-30 c	m) at the experim	nental		Leaf growth threshold p—lower	leaf growth is inhibited leaf growth stops completely at	0.55	EFFTB	light-use effic. sing function of daily m	le leaf
Parameter	Value	Parameter	Value			Leaf growth stress coefficient	this p	4.8	KDIFTB	extinction coefficie	ent for
Clay (%)	60.7	NO₃ – N (ppm)	8.5			curve shape Stomatal conductance	above this stomata begin to	0.63		function of DVS	
Silt (%) Sand (%)	25.4 12.0	Available P (ppm) Available Na (mog/100)	b./ ٦) 0.2			threshold p—upper Stomata stress coefficient curve	close	2.3	TSUM2	temperature sum f	irom a
pH (1:1:H ₂ O)	7.8	Available K (meg/100 g)	5, 0.5 1.5			shape Senescence stress coefficient	above this early capeny	0.69			
OC (%)	0.6	Available Ca (meq/100 g	g) 2.6			p-upper	senescence begins	0.00			
Total <mark>N (</mark> %)	0.2	Available Mg (meq/100	g) <u>3.2</u>			Senescence stress coefficient curve shape		2.3	_		
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mate projections RES A2 and B1 rt on Emissions 1-2040. In these, neral Circulation [3 (Gordon et al., 2006), MPEH5 were applied for

uired values in a e-interval finding om the required eter. Many times, m, the bootstrap tstrap is available

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oduced recorded unequivocally be th only minimum mation was for nd determination he yields. Results

alibrated crop the WOFOST

	Value
ence [cel d-1]	1200
ha kg-1]	0.0025
1 d-1]	0.02
on of DVS [kg	37
1 m2 s] as	0.45
ght [-] as	0.6
rity [cel <mark>d-1]</mark>	<mark>9</mark> 50

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

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.

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