Predicting Winter Wheat Yield in 2030 and 2050 in North China Based on BioMa-Site and BioMa-Spatial

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Abstract [1] **—BioMA(Biophysical Model Application) is an application for analyzing, parameterizing and running modeling solutions. BioMA can be extended by the third parties who can add new modeling solutions to meet their requirements of crop modeling. CropSyst is an advanced model for crop growth simulation in the world. CropSyst model has been embedded in BioMa platform with some improvements, for example, with less default parameters, different model algorithm and more user-friendly interface, and links to other model solutions etc. Agricultural production system is increasingly threatened by climate change, the CropSyst model imbedded in BioMa in 2015 year was used to simulate and predict crop.**

Based on the latest BioMa-site model, and using LAI data, soil, crop phenology, above ground biomass and yield data from 2012 to 2014 which come from 11 counties of winter wheat main producing areas in Hengshui city, Hebei province, North China, this paper firstly calibrated some model's parameters and evaluated the CropSyst model by comparing model estimates to field data, and after that, simulated and predicted the winter wheat biomass and yield in "near-future" around 2030 (2021-2040) and "far-future" around 2050 (2041-2060) based on BioMa spatial, and compared model estimates results under two different future climate scenarios.

The simulated results showed that using CropSyst model to simulate the winter wheat yield of North China is promising. The Pearson's correlation coefficient between observed yield and simulated yield is 0.97, the Modelling Efficiency is 0.94, and the Index of Agreement is 0.98. The winter wheat dry yield is higher in "near-future" around 2030(2021-2040) than "far-future" around 2050(2041-2060) both in climate scenario No.1 and climate No.9 based on 15grids mean data in North China, and dry AGB has the same tendency. Under both climate scenarios, winter wheat yield and above ground biomass are much lower with irrigation situation, which showed that moister is a key factor to winter wheat during the growth.

This study got a set of parameters that proved to be suitable to simulate winter wheat growth process and production in China and predicted future yield based on different climate scenarios and condition which could be a reference for future wheat management and national policy.

Keywords—Biophysical model application; CropSys; yield prediction; modeling efficiency; winter wheat; climate scenarios;North China

I. Introduction

Biophysical Model Application(BioMA), which is designed and developed by European Commission Joint Research Center in 2008, is an application for analyzing, parameterizing and running modeling solutions based on biophysical models against a database which includes spatially explicit units[1-3]. BioMA can be extended by third parties adding new modeling solutions, making use of components already used by the application or using new ones[4]. The component-based structure allows BioMA to implement diverse modeling solutions targeted to specific modeling goals, together with sensitivity analysis and optimizer functions. The first version of BioMA achieved great succeed in forecasting rice yield in European 27 countries[5]. Up to now, BioMA has embed some simulation models, including CropSyst, CropSyst extreme, WoFost, WoFost extreme, WARM and WAWM extreme etc.[6]

CropSyst simulation model is a multiyear, multi-crop, daily time-step cropping system simulation model developed by Stockle et al[7]., serves as an analytical tool to study the effect of climate, soil and management on cropping system productivity and the environment. Compared to EPIC [8], CropSyst adds a more process-oriented approach to the simulation of crop growth, and its interaction with management and the surrounding environment [9]. CropSyst model simulates the soil water budget, soil plant nitrogen budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water and salinity. These processes are affected by weather, soil characteristics, crop characteristics and cropping system management options, including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation, water salinity, tillage operation and residue management [10].

One key feature of CropSyst is the implementation of a generic crop simulator that enables the simulation of both yearly and multi-year crops and crop rotations via a single set of parameters. The CropSyst model has been embedded in BioMa platform with some improvements, for example, with less default parameters, different model algorithm and more user-friendly interface, and links to other model solutions etc. More importantly, since agricultural production systems is increasingly threatened by climate change in association with an

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estimated increase in the frequency of extreme weather events such as droughts, heat waves or heavy precipitation events, CropSyst model imbedded in BioMa were divided into CropSyst standard and CropSyst extreme models in 2015 year, and were used to simulate crops under different scenarios.

Winter wheat is the dominant cropping System in Chinese Huang-Huai-Hai Plain (namely 3H Plain). The sown area of winter wheat in this region accounts for over 65% of the total sown area of winter wheat in China [11]. Crop growth modelling is a major tool for analyzing the impacts of climate change on agricultural production，so it is important to predict the winter wheat yield under future different climate scenarios based on crop models. Based on the latest BioMa site model(CropSyst standard model imbedded in BioMa in 2015), and using field data come from 11 counties of winter wheat main producing areas in Hengshui city, Hebei province, this paper firstly calibrated some model's parameters and evaluated the CropSyst model by comparing model estimates to field data, and then simulated the winter wheat biomass and yield in "near-future" around 2030 (2021-2040) and "far-future" around 2050 (2041-2060), and compared model estimates results under future two different climate scenarios based on BioMa–spatial model.

II. Materials and Methods

A. Study area

The 3H Plain is the main producing region of winter wheat in China. The study area is Hengshui city, which located within the 3H Plain, and includes 11 counties. Geographical location ranges from 37° 03′ N to 38° 23′ N and from 115° 10′ E -116° 34′ E with a total area of 8815 km^2.(Figure 1). Hengshui city is a plain terrain with a mean elevation of 12 to 30m. The study area has a temperate semi-humid monsoon climate, the mean temperature is 13℃. Mean precipitation is about 500-600mm, and mean evaporation is about 1300-1800mm. The accumulated active temperature ≥ 0 ℃ 4200-5500 ℃. Frost-free period is about 170-220d. The cumulative amount of year radiation is about 5.0×10^6 -5.2×106kJ/m^2. The soil types in Hengshui city is semi-hydromorphic soil, tidal soil, which include sandy, loam and clay soil, which is suitable for the growth of a variety of crops. The main crops are winter wheat and summer maize with rotation in one year [12-13].

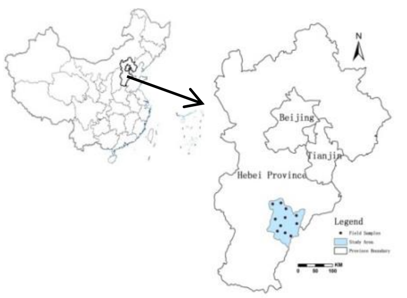

Fig. 1 Location of the study area and the field samples

B. Data preparation

Weather data: daily weather data on maximum, minimum and average temperature, relative humidity, average atmospheric pressure, solar radiation, sunshine hours, wind speed and precipitation during the crop growth period from 2000-2014 from Meteorological stations near the study area were collected from China Meteorological Administration and then processed and analyzed by Institute for Environment and Sustainability, European Commission Joint Research Centre. Input data consist of daily temperature and precipitation from three dynamically downscaled and bias-corrected regional climate simulations of the IPCC A1B emission scenario created within the ENSEMBLES project. Solar radiation is estimated from temperature based on an auto-calibration procedure. Wind speed and relative air humidity are collected from historical series. From these variables, reference evapotranspiration and vapor pressure deficit are estimated ensuring consistency within daily records. The weather generator ClimGen is then used to create 30 synthetic years of all variables to characterize the time horizons 2030 (2021-2040) and 2050 (2041-2060) for the North China study areas based on both RCM-GCM (Regional-Global Climate Models) outputs and historical series, see details in reference[14].

Crop, soil and management data: there are 11 observational samples with detailed experimental data. These 11 field sites are taocheng, jizhou, zaoqiang, wuyi, shenzhou, wuqiang, raoyang, pingan, gucheng, jingxian and fucheng. Detailed experimental data include location, elevation, cultivation method, crop phenology(planting day, emergence day, flowering day and harvest day), LAI and above ground biomass or yield in each phenology, irrigation information, soil type, some soil parameters etc.

C. Method

1) Present BioMa-site model

Temperature is one of the most important driving variables for crop growth and development. Average canopy temperature was used for simulating thermal limitation to photosynthesis and leaf aging. For crop development, the thermal time accumulated between a base temperature and a cut-off temperature was computed. The accumulated thermal time can be optionally corrected with a factor accounting for photoperiod. Base and cut-off temperatures can be set to different values for the periods sowing - emergence and emergence - physiological maturity. Development stages are standardized by converting growing degree-days (GDDs) into a numerical code (DVS) from 0.00 to 2.00 (respectively, emergence and physiological maturity, with DVS = 1.00 corresponding to flowering), useful for synchronizing the simulation of different processes. There variables are obtained as follows (formula 1, 2), respectively, for the period's emergence-flowering and flowering-physiological maturity:

$$DVS = \frac{(GDD\,cum - GDD\,em)}{GDD\,flo} \tag{1}$$

$$DVS = \frac{1 + (GDD\,cum - GDD\,em - GDD\,flo)}{GDD\,mat} \tag{2}$$

Where, GDDcum (℃/day) are the cumulated GDDs, GDDem (℃/day) are the GDDs required to reach emergence, GDDflo (℃/day) are the GDDs required to reach flowering, and GDDmat (℃/day) are the GDDs required to reach physiological maturity [15-17].

Steps of using CropSyst model embedded in BioMa-site platform to simulate the yield of winter wheat in North China are as follows: Firstly: processed all data into standard format required by models. Secondly: selected simulation environment, input/edited all the parameters: weather data, location definition, soil profiles, soil initial conditions, agromanament, location, start simulation time; end simulation time, etc. Thirdly: configured model components, including weather, soil water etc. selected output configuration, including weather, soil water, soil data, simulation configuration, CropSyst potential and agromanagement etc. Fourthly: ran BioMa site tools, and compared the simulated data with real field results (here including planting date, emergency date, flowering data and maturity date, LAI, biomass and yield), if the precision is not very good, using the manual calibration to calibrate some parameters(example management data, radiation use efficiency, base/optimum/maximum temperature for growth, leaf duration harvest index, etc.),and repeated the process until the differences between simulates and ground data were the least. Fifthly: used the parameters adjusted before to simulate the yield of all field sites, and evaluate the results[6,18].

2) Future BioMa-spatial model

Based on the parameters used in BioMa-site and using different climate scenarios provided by Institute for Environment and Sustainability, European Commission Joint Research Centre(climate scenariosNo.1 and scenarioNo.9, irrigated and on irrigated respectively), we predicted winter wheat yield and above ground biomass in "near-future" around 2030(2021-2040) and "far-future" around 2050(2041-2060) based on 15grids data in North China. These variables are obtained as grand mean over the 15 grid cells. The fundamental statistics for each requested variable is the cell mean, i.e. the mean of the estimates calculated over the 20 years of each time period. The cell mean is associated to a dispersion metric, to account for inter-annual variability. Irrigation is scheduled by setting a rule to perform automatic irrigation when soil moisture content is below 60%. And a maximum irrigation time is scheduled 2 times before winter stage and a maximum irrigation time is scheduled 4 times between reviving and harvest, irrigation volume is set 100 per time.

$$\overline{X} = \frac{\sum \overline{\mathrm{Xi}}}{N\mathrm{cells}} \tag{3}$$

Where $\overline{Xi}$ the cell mean, Ncells is the number of grid cells participated in calculation.

III. RESULTS

1)Calibrated Parameters and Performance of CropSyst

Table 1 are the comparison of default and calibrated parameters based on the field measured data and the optimal parameters of system simulation. Some parameters which are not listed used the defaults or values in reference [19-20].

Table 1 Some default and calibrated crop parameters of CropSyst model for China winter wheat

Parameter	Unit	Description	Default	Calibrated
Tsumeme	°C-days	Thermal time to emergence	100	70
Tsumflo	°C-days	Thermal time to flowering	500	800
Tsumfil	°C-days	Thermal time to begin yield formation	700	1000
Tsummat	°C-days	Thermal time to maturity	1200	1500
Tbasedev	°C	Base temperature for development	-1	0
Tcutoffdev	°C	Cutoff temperature for development	40	33
LAIini	m^2 M^{-2}	Initial leaf area index	0.01	0.13
PARfactor		photosynthetically active radiation factor	0.5	0.47
ET CropCoeff		ET crop Coefficient at full canopy	1.2	1.18
TransCoebio		Transpiration Biomass Coeffieient	5	5.5
TbaseG	°C	Base temperature for growth	-1	0
ToptG	°C	Optimum temperature for growth	19	20
RUEmax	g MJ^{-1}	Maximum radiation use efficiency	2.5	2.9
k	unitless	Extinction coefficient for solar radiation	0.48	0.5
LAImax	m^2 M^{-2}	Initial leaf area index	0.01	0.13
Harvest Index	0.4	Harvest Index	0.40	0.45

Table 2 Some default and calibrated soil parameters of CropSyst model for China winter wheat[21]

Parameter	Unit	Default	Calibrated
Volumetric Water Content At Saturation	m^3 m^{-3}	0.5	0.43,0.44,0.46
Volumetric Wilting Point	m^3 m^{-3}	0.17	0.1,0.11,0.14
Volumetric Field Capacity	m^3 m^{-3}	0.3	0.27,0.32,0.0.4
Saturated Hydraulic Conductivity	mm h^{-1}	30	18.1,19.3,22.6
Sand	%	10	75,70,65

Silt	%	10	20,20,25
Clay	%	0	5,10,10
Bulk Density Max	t m^{-3}	1.3	1.49,1.51,1.41
Organic Carbon	%	0	0.2,0.75,1.5

The performance and behavior of crop models is commonly made through the comparison of simulated and observed variables. Pearson's correlation coefficient between estimates and measurements, Modeling Efficiency and Index of Agreement were used to assess CropSyst model performance in simulating winter wheat.

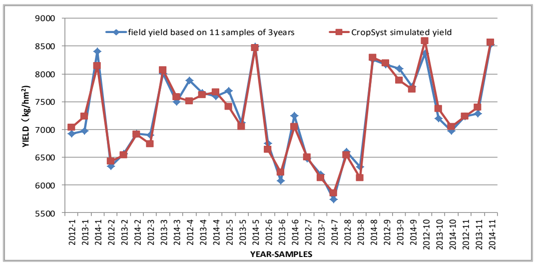

Fig. 2 Field Measured yield vs simulated yield using CropSyst Mode for winter wheat

Fig. 2 showed the results analyzed by integrated metrics model analyzer software[22]. It showed that using CropSyst model to simulate the winter wheat yield of North China is promising. The Pearson's correlation coefficient between observed yield and simulated yield is 0.97, the Modelling Efficiency is 0.94, and the Index of Agreement is 0.98.

2) prediction of future winter wheat yield and AGB

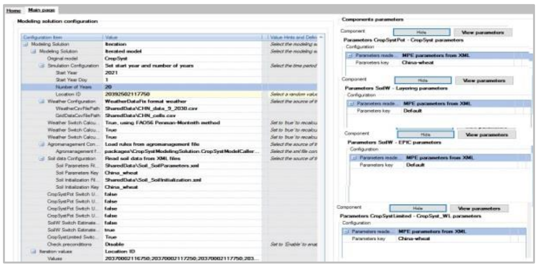

Fig.3 Some modeling solution configuration and parameters of BioMa-spatial in predicting 2030 winter wheat yield over 15 grids.

Figures 4-7 are predicted winter wheat yields and above ground biomass under climate scenario No.1 and No.9 on three time horizons (2000, 2030, and 2050) in North China considering irrigation and no irrigation condition.

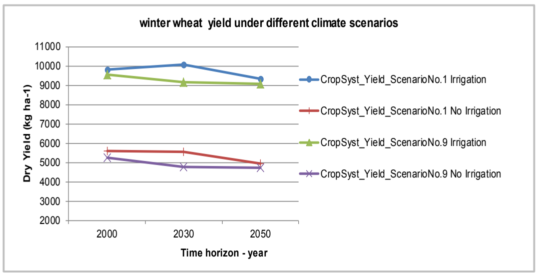

Fig.4 Winter wheat yield prediction over 15 cells of North China under different climate scenarios on three time horizons

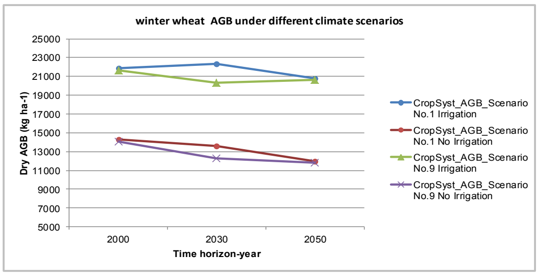

Fig.5 Winter wheat above ground biomass prediction over 15 cells of North China under different climate scenarios on three time horizons

The predicted results showed that the winter wheat dry yield is higher in "near-future" around 2030(2021-2040) than "far-future" around 2050(2041-2060) both in climate scenario No.1 and climate No.9 based on 15grids data in North China, and dry AGB has the same tendency. Under both climate scenarios, winter wheat yield and above ground biomass are much lower with on irrigation.

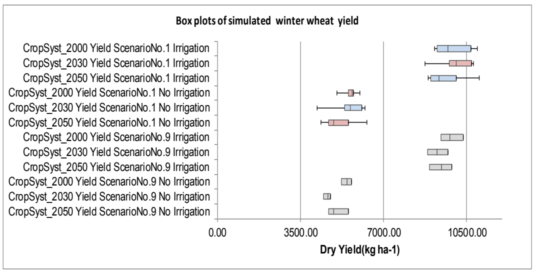

Fig.6 Box plots of simulated winter-wheat yields over 15 cells of North China under different climate scenarios on three time horizons

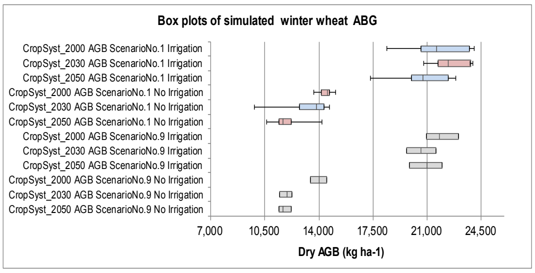

Fig.7 Box plots of simulated winter wheat above ground biomass over 15 cells of North China under different climate scenarios on three time horizons

The box plots showed the changing range of predated yield and above ground biomass over 15 cells of North China under different climate scenarios with irrigation or no irrigation situation. It showed that the yield and above ground biomass with irrigation situation varies with bigger range than no irrigation situation under both climate scenarios, and the yield and above ground biomass has bigger changing range under climate scenariosNo.1 than climate scenariosNo.9

IV. DISCUSSION

The initial parameters of Cropsyst model embedded in the EU BioMa-site platform are mainly suitable for European area. Therefore, an important task of crop model application in China is to localize the model parameters. Based on the measured data of 11 counties, a series of parameters were calibrated and verified for the use of the model in the small area of North China. The winter wheat yield in Hengshui area from 2012 to 2014 was simulated with localized model parameters. The results showed that CropSyst with localized parameters could well simulate the winter wheat yield in this region.

The systematic optimization of irrigation quantity and irrigation times has a great influence on the results, which indicates that water is an important factor in the growth and development of winter wheat, because of the lack of some measured irrigation quantity and irrigation times data. The applicability of some crop parameters to the study area needs more years and more measured sample data.

BioMa platform reduces the number of initialization parameters of many crop models when embedded them and increases the dependence of simulation results on some parameters. Some soil parameters and crop parameters in the study area are derived from the reference documents, the spatial representation of the sampling sites to the whole region is limited since the 11 sample points are selected from 11 counties, and only 15 grids mean value were used to repent the regional yield in predicting future yield based on BioMa spatial.

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