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Monitor key parameters of winter wheat using Crop model

Yue Jibo[1,2], Feng Haikuan[2] and Qi Xiudong[1]

[1] School of Surveying and land Information Engineering, Henan Polytechnic University, Jiaozuo, China
[2] National Engineering Research Center for Information Technology in Agriculture, Beijing, China

E-mail: fenghaikuan123@163.com

Abstract. Estimation of biomass, canopy cover and yield is very important to agricultural decision Precision Farming. During the winter wheat growing season of 2013/2014, field measurements were conducted at Yangling District, Shaanxi Province at the jointing stage, heading stage and filling stage. AquaCrop model and Particle swarm optimization algorithm was used to find the global optimal simulation when the intermediate variable was the biomass. Through the simulation for each of the experimental data, biomass, canopy coverage and soil moisture were verification by ground measurements. Based on 8 sets of data, the simulation accuracy was calculated. The RMSE, nRMSE, MAE and R2 between simulation and measured biomass were 1.06 ton/ha, 11.92%, 0.90 ton/ha and 0.92. The RMSE, nRMSE, MAE and R2 between simulation and measured canopy cover were 8.92%, 9.84%, 7.84% and 0.66, respectively. The simulation results show that the AquaCrop model can help the decision making of winter wheat field in arid areas.

1. Introduction

Winter wheat biomass, crop coverage and soil moisture are frequently used variables in precision agriculture. Those parameters play an important role in monitoring the growth of agriculture, the accurate and continuous parameter estimation can provide guidance for farming production scientifically. Biomass refers to the total amount of organic matter (dry weight) in the unit area of a certain time (including the weight of the food stored in the body), crop coverage refers to the ratio of the vertical projection area to the area of a plant, those parameters can be intuitive to use to monitor the growth of crops. Soil moisture refers to the proportion of water in a certain volume (weight) of soil, it is a parameter to characterize the water in the soil during crop growth, in many crop growing areas, the growth of crops is affected by water stress. In agricultural production, the water use in irrigated agriculture was about 72% of the fresh water resources in the whole world, but drought in arid regions is still a widespread phenomenon for the shortage of water resources [1]. Therefore, monitor the parameters of crops, take the drought in arid and semi-arid regions effectively is very important for agricultural management department.

Crop growth simulation model has become one of the most powerful tool in the agricultural scientific research and management of crop planting, sustainable agriculture and the role of the government decision has been gradually known by people, is also expanding its application field. Because the attention to the developing countries, the United Nations food and agriculture organization (FAO) developed the AquaCrop to help make the irrigation plan, and improve the utilization efficiency of water [2][3]. Many studies were carried out, such as maize, wheat, soybean, Rice [4][5][6].

AquaCrop crop model is widely used in various types of crop growth simulation and irrigation analysis. By calculating the crop transpiration, water productivity was used to calculate the biomass, harvest index in AquaCrop crop model, then complete the simulation of crop growth. The aim of this paper is to explore the performances of AquaCrop model by monitoring key parameters of winter wheat.

2. Methodology

2.1. Study area and Data Collection

The study site is located in Yangling district (34°2′25″ to 34°7′23″ N, 107°5′10″ to 108°9′23″ E) of Shaanxi, China. The campaigns were carried out during the winter wheat growing season of 2014. During the winter wheat growing season of 2013/2014, field measurements were conducted at Yangling District, Shaanxi Province.8 fields were employed to addition in the experiment with Biomass, canopy cover and soil moisture at the jointing stage, heading stage and filling stage. The ground was measured in 8 field, winter wheat LAI, biomass and soil moisture were collect. Canopy cover were calculated using equation 1.

$$CC=1-\exp(-0.65\times LAI) \tag{1}$$

2.2. Aquacrop and model data

Aquacrop model is developed by the Food and Agriculture Organization of the United Nations (FAO, http://www.fao.org/nr/water/aquacrop.html), AquaCrop uses the first Doorenbos and Kassam [7] equation for the biomass calculation. The most important part of AquaCrop model was the crop response to water, using the experience of first Doorenbos and Kassam equation.

$$\frac{Y_x-Y_a}{Y_x}=K_y\frac{ET_x-ET_a}{ET_x} \tag{2}$$

In equation 2, Yx is the maximum output of winter wheat, ETx is the maximum evapotranspiration, Ya is the actual output of winter wheat, ETa is the actual evapotranspiration and Ky is the output of winter wheat experience response factor between evapotranspiration and yield. The core growth mechanism of AquaCrop model are as follows:

$$B = WP \times \Sigma Tr \tag{3}$$

$$Y = B \times HI \tag{4}$$

Equation 3 describes how the AquaCrop model simulated of crops growth, Equation 4 gives the method of biomass convert to the output. Where, WP is the water productivity, the unit is kg/m^3, it means how many crop output can be obtained by a certain amount of water consumption. Different varieties of crops have different water productivity. The Tr is crop transpiration, B means the biomass of crop. HI is Harvest index, HI is the response factor between biomass and output of the crops.

Before the simulation, sensitivity analysis was performed, the following model sensitive crop parameters were select [8][9]. Canopy decline coefficient, Canopy growth coefficient, Maximum canopy cover, From sowing to maximum rooting depth, Number of plants per hectare, From sowing to emergence, Water productivity, Soil water depletion factor for canopy senescence and Shape factor for water stress coefficient for stomatal control. Soil investigation has been performed, there are four types of soil in the study area, they are Silty clay loam, Silty loam, Silty clay loam, Silty loam.

2.3. Particle Swarm optimization

Particle swarm optimization (PSO) was originally proposed by Kennedy and Eberhart [10], by simulating the flock foraging behaviour and developed a kind of random search algorithm based on group collaboration. It is a kind of Swarm intelligence (Swarm intelligence, SI). Particle swarm optimization iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO initialized to a group of random particles (random solutions), and then find the optimal solution, through iteration in each iterative, particles by tracking two extreme solutions to update themselves. In particle swarm optimization initial value, Max value, Min value, V Max, V Min of optimize parameters were needed for optimization. The initial value was set as the starting value, the Max value and Min value were the max and min parameters value, V Max, V Min were the maximum and minimum values of each change.

2.4. Optimization method

When optimization was proceeding, 9 crop parameters and 4 soil parameters were adjusted and optimized using Particle swarm optimization. The initial value, Max value, Min value, V Max, V Min of optimize parameters were list in table 1.

Table 1. Optimize parameters.

Crop Parameters	initial value	Max value	Min value	vMax	vMin
Canopy decline coefficient	0.05	0.03	0.07	0.001	-0.001
Canopy growth coefficient	0.05	0.02	0.07	0.001	-0.001
Maximum canopy cover	0.75	0.82	0.99	0.01	-0.01
From sowing to maximum rooting depth	1500	1200	1800	15	-15
Number of plants per hectare	4250000	2000000	5500000	125	-125
From sowing to emergence	170	120	250	4	-4
Soil water depletion factor for canopy senescence	0.65	0.55	0.75	0.01	-0.01
Shape factor for water stress coefficient for stomatal control	2.5	1.5	3.5	0.1	-0.1
WP	15	13	18	0.2	-0.2
Soil Parameters					
Silty clay loam	0.10	0.05	0.15	0.01	-0.01
Silty clay	0.30	0.20	0.40	0.02	-0.02
Silty clay loam	0.10	0.05	0.15	0.01	-0.01
Silty loam	0.30	0.20	0.40	0.02	-0.02

In the AquaCrop model, soil parameters and crop parameters which were sensitive were selected to assist model simulation optimization. Particle swarm optimization algorithm was used to adjust the above parameters, using 30 particle populations, the 80 iteration to find the global optimal simulation with intermediate variable was the biomass. Through the simulation for each of the experimental data, biomass, canopy coverage and soil moisture were verification by ground measurements. Finally, the final biomass and yield were simulated and predicted.

2.5. Optimal relationship

Each run of AquaCrop model will simulate the crop growth, biomass, canopy coverage and soil moisture. Then, the relationship between measured value and simulated value could calculated by equation 4. Assisted by particle swarm optimization algorithm, simulation of the growth process is recorded when the Minimum f was obtained.

$$\mathrm{f} = \sqrt{\frac{\sum_{1}^{n}(Bsim_i - Bm_i)^2}{n}} \tag{4}$$

In equation 4, $Bsim_i$ is the estimated values, Bm_i is the observed values, n means the sampling number (this paper for 3 times). In fact, each spot had simulated 2400 times, gBest is the parameters when f gets minimum value in 2400 times simulation. The gBest was accepted as the winter wheat growth simulation.

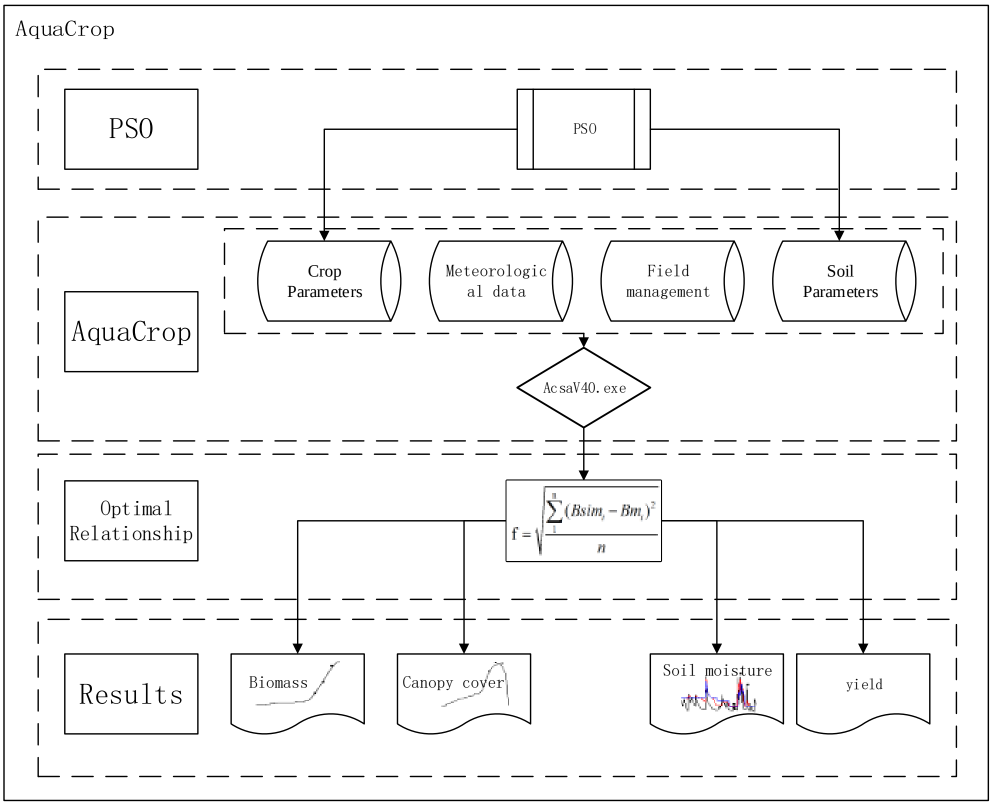

Figure 1. The flow chart.

3. Results

3.1. Biomass

In simulation experiments, the role of biomass data was intermediate variable, therefore, simulation accuracy can be show from observed biomass and AquaCrop model estimated biomass directly. In figure 2, the curve means the estimated biomass from planting to harvest, observed values means the ground measurement biomass.

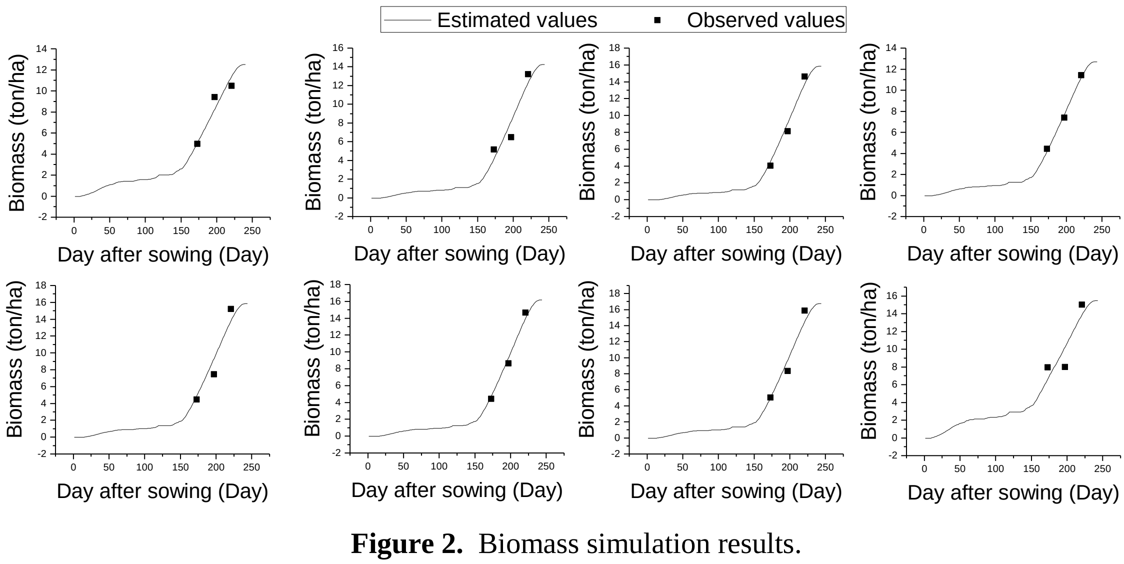

Figure 2. Biomass simulation results.

In figure 2, the estimated biomass was simulated by Aquacrop in whole growth period, figure 2(a), 2(b), 2(c), 2(d), 2(e), 2(f), 2(g), 2(h) were the observed values and the results of simulation each sampling field. The observed values and the estimated are very close. The model was obtaining a precision results by using PSO algorithm. The RMSE, nRMSE, MAE and R2 between simulation and measured biomass were 1.06 ton/ha, 11.92%, 0.90 ton/ha and 0.92.

3.2. Canopy cover

In Figure 2, canopy cover and soil moisture were saved. Figure 2(a), 2(b), 2(c), 2(d), 2(e), 2(f), 2(g), 2(h) were the canopy cover of simulation each sampling field. The RMSE, nRMSE, MAE and R2 between simulation and measured canopy cover were 8.92%, 9.84%, 7.84% and 0.66, respectively.

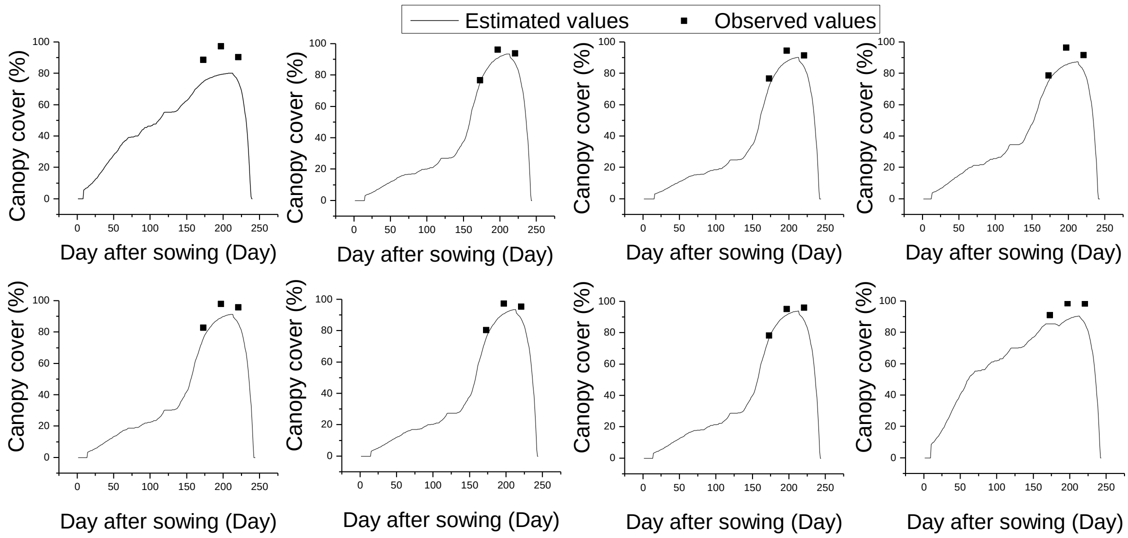

Figure 3. Canopy cover simulation results.

3.3. Soil moisture

AquaCrop model can simulate and gain the soil moisture in 0-0.05cm, 0.05-0.15 cm, 0.15-0.25 cm, 0.25-0.35 cm, 0.35-0.45 cm, 0.45-0.55 cm, 0.55-0.67 cm, 0.67-0.82 cm, 0.82-0.97 cm, 0.97-1.13 cm, 0.13-1.27 cm and 1.27-1.45 cm. When the ground measurements, only the 0-20 cm of soil moisture were obtained. In Figure 4, soil moisture simulated by AquaCrop in 0-0.05cm, 0.05-0.15cm and 0.15-0.25cm were used to contrast measurements.

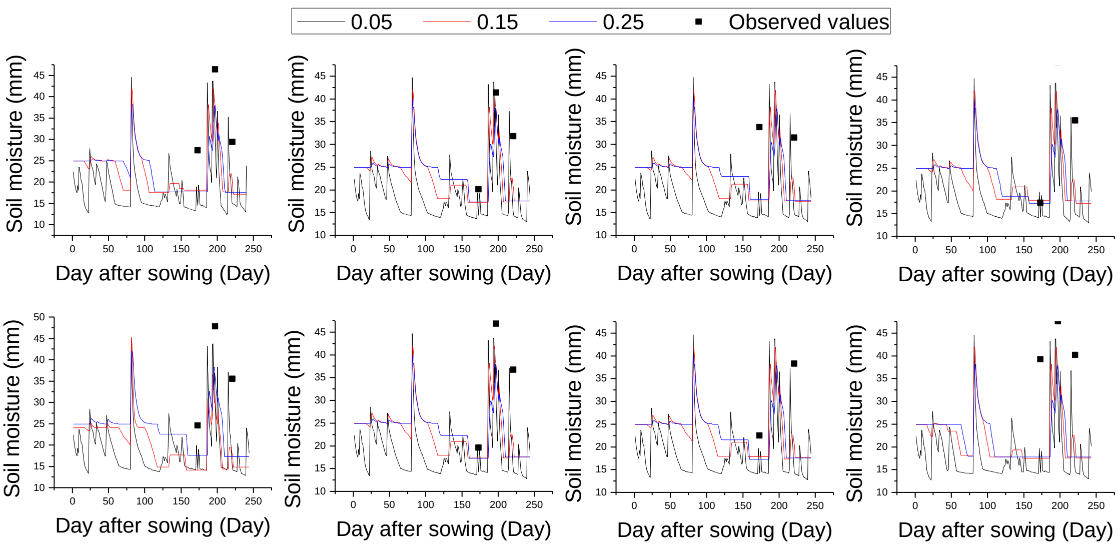

Figure 4. Soil moisture simulation results.

4. Discussion

In this paper, using the AquaCrop model and ground survey data, crop parameters and environmental conditions were estimated, such as biomass, canopy cover and soil moisture which have an important influence on crop yield, and the growth state of the crops was analysed, these calculations can be done on the computer. The growth of winter wheat was simulated, and the data of the three items of the growth cycle, canopy cover and soil moisture were obtained. Result shows that the potential of AquaCrop in farmland management.

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Acknowledgments

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