

Soil Water Balance and Water Use Efficiency of Rain-fed Maize under a Cool Temperate Climate as Modeled by the AquaCrop

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Abstract The AquaCrop model has been widely studied and examined for its feasibility and applicability in simulating the crop growth – water relationship under tropical and warm temperate. However, the model is rarely tested under cool temperate climates. As the second largest agricultural area of China, the Sanjiang Plain is characterized with relatively lower accumulative temperature and higher annual precipitation, showing typical features of a sub-humid and cool temperate climate. This study employed the AquaCrop model to compute soil water balance and water use efficiency of rain-fed maize in the Sanjiang Plain using a 5-year monitoring dataset (2011 – 2015). The results demonstrated an acceptable performance of AquaCrop in depicting soil water content, biomass accumulation and grain yield. Soil water balance including soil water content, evapotranspiration and precipitation was described throughout the growing period. The hysteresis of the daily soil water content as responses to daily precipitation was revealed. Water use efficiency for the observed rain-fed maize increased with rising accumulative temperature and decreased with rising atmospheric CO₂ concentration. This study provided a perspective for the extensive application of the AquaCrop model and the precise simulation in water dynamics under sub-humid and cool temperate climates.

1 Introduction

China has been facing increasingly severe water scarcity. With insufficient water resources to meet rising water consumption, over-withdrawal of both surface water and groundwater has occurred in many areas of northern and eastern China. Meanwhile, poor water quality caused by pollution further exacerbates the lack of water availability in water-scarce areas. The water shortages and the poor water quality are interacting with each other and threatening China's food security, economic development, and life quality[1].

As an important commodity grain production base in China, the water resources of Sanjiang Plain region have a key role in the scale of agricultural production. After large-scale development about nearly 50 years, the cultivated land area of Sanjiang Plain has increased from 7.86×10^5 hm² in 1949 to 3.83×10^6 hm² in 2008[2]. In early 1980s, restricted by the development of agricultural technology and economic factors, there was to be beginning a widespread change from dry land to paddy land. In particular, since 1990, the Sanjiang Plain has implemented the comprehensive agricultural development and management measures of "flood control by rice planting". The rice planting area has increased from 2.17×10^5 hm² in 1990 to 1.42×10^6 hm² in 2008[3], and there is still a tendency of continuous expansion. Field management

translated from the typical dry land farming by rain-fed to paddy land farming based on groundwater irrigation, which would inevitably lead to a substantial increase for agricultural water demand. As one of the crops with a large number of water consumption, the large-scale rice planting has increased the demand for water resources in agriculture. Thus the water supply capacity of the region has been facing a huge challenge. In addition, with the expansion of rice planting area, uncontrolled and unplanned over-exploitation of groundwater, groundwater dynamic balance has been destroyed. Furthermore, a large number phenomenon of "hanging pumps" (a pump that is suspended in a wellbore using a wire rope, winch and frame) and groundwater depression occur each year[4]. As for the dry land of crop rotation between soybean and corn without irrigation, the water resources crisis is increasingly becoming more severe. For other aspects (including the local business, industrial production, wetland ecological environment as well as residents) competing with agriculture for water resources, there are more demands for water resources. And the evidence provided by the deteriorating natural vegetation in this region indicates that the available water resources was over-utilized. Therefore, in order to maintain the overall benefit of the local economy and preserve the integrity of the natural environment, the quantification of the crop water consumption and the crop grain yield in this area is an essential step

toward the agricultural development of more efficient systems for reasonable allocation of the limited water resources in Sanjiang Plain of Northeast China[4].

With regard to the effect of water content on crop growth, different researchers have different research methods for different research environments. Yingxin Xie et al has selected the experimental field in the North China Plain and has carried out three groups of experiments (including no irrigation (rain-fed) during the whole growth period, once irrigation only at jointing stage as well as twice respective irrigation at jointing and flowering stages) to analyze the effects of water conditions on water consumption, dry matter accumulation and grain yield of Wheat. Results showed that increasing irrigation times significantly increased mean grain yield of wheat[1]. E.K. Liu et al has conducted a mobile rain shelter experiment using winter wheat cultivar to assess the effects of different levels of water stress on photosynthetic characteristics, dry matter translocation and water use efficiency (WUE) in the Shijiazhuang 8(one drought resistant cultivars) and Yanmai 20(a drought sensitive cultivars)at different growth stages. The establishment of water stress conditions was achieved by setting four degrees of irrigation including 40-45% (severe stress), 55-60% (moderate stress), 65-70% (mild stress) and 75-80% (full irrigation) in three different growth periods of recovering-jointing stage, jointing-flowering stage and grain-filling stage, respectively. The results indicated that mild soil water stress can improve grain yields and WUE. The way of researching the effects of water stress on crop growth by applying different levels of water stress to different crops growth stages has been adopted by more researchers[5].

Yang Gao et al has researched the effect of moisture content on wheat growth and yield in North China Plain by the calculation and analysis of the response of evapotranspiration(ET_a), crop coefficient(K_{cb}) and water use efficiency(WUE) to different irrigation practice in different growth stages of wheat based on the application of the SIMDualKc model. There were differences in the growth of wheat under different irrigation amount. For the appropriate amount of irrigation, it can promote the growth of wheat; However, the higher or lower amount of irrigation does not take advantage of wheat growth. Meanwhile, the water demand of wheat in different growth period has its own characteristics. During the grain filling period of vegetative growth and reproductive growth, there is a higher demand for irrigation amount[4]. Based on STICS 4.0 simulated crop growth as well as soil water and nitrogen balances driven by daily climatic data, Philippe D EBAEKE carried out numerical experiments on winter wheat in order to evaluate drought escape and crop rationing in three climatic environments:Avignon, Meknès (Morocco) and Toulouse. Results indicated that the contribution of soil evaporation to total water use was reduced by rapid canopy closure (fast-growing cultivar and high plant density); meanwhile, water stress during grain filling was more frequent with excessive plant density; furthermore, with irrigation or under wetter conditions, yield sho

uld be improved by maximizing early canopy closure and lengthening the growing season period[6]. At present, in the quantitative study of the effect of water stress on crop growth process and crop yield, a considerable number of researchers has started to use the relevant model, such as the application of WOFOST model in C.A.van Diepen's research[7], the application of Penma-Monteith model in A. Tegos's research[6].

Most traditional models of crop water demand analysis are built on the basis of a certain crop or macroscopic analysis, which neglect regional crop allocation and the difference of water demand in different crop growing periods. The AquaCrop model is a crop water productivity simulation model developed by the Food and Agriculture Organization (FAO) of the United Nations[7]. The AquaCrop model[8] is free and practitioner oriented for the users. And there is a certain reference for a wide range of regional research. The aim of AquaCrop is to simulate crop yield response to water, and is applicable for address conditions where water is a principal limiting factor for crop growth and production. The AquaCrop uses a relatively small number of explicit and mostly intuitive parameters and input variables requiring simple methods for their derivation [9]. In the simulation process of AquaCrop, the simulations of crop growth and development are implemented with daily time steps, using temperature, precipitation, evapotranspiration, carbon dioxide concentration, crop growth system, etc. The applicability of AquaCrop to simulate growth and yields for different crops has been widely tested by numerous experts around the world in different environments and all have reported positive results, e.g., barley[10], teff, maize[7], potato[2], wheat[13].

The Advantage of AquaCrop model lies in maintaining a balance between accuracy, robustness, however, it has not been tested in Northern east China where crop yields is often limited by moisture deficit. Whether it can be used to optimize the planting/sowing and irrigation systems scheme in Northern east China remains unknown.

Most of the research has focused on the dry lands, which is capable of being given different levels of irrigation, and has analysed its changes about related parameters in different growth stages, based on relevant model, such as biomass, crop evapotranspiration and canopy development etc. Evidence clearly shows this is possible. Less researches were reported so far about study on the effect of the water condition characteristics in arid area itself on crop growth during the stage of crop growth. And at present, the application of AquaCrop model is less in China, especially for the application of Sanjiang plain research.

Therefore, based on the above content, this paper has three research aspects based on AquaCrop model: (1) Analysis of soil water balance for study area during growing period of 2011-2015; (3) Analysis of crop water use efficiency (WUE) for study during 2011-2015.

2 Materials and methods

2.1 Study site description and crop management

2.1.1 Study site description The Sanjiang Plain, located in the eastern part of Heilongjiang Province, Northeast China, is an alluvial plain formed by the Heilong, Wusuli, and Songhua rivers. The suitable natural condition of low slope grade and boreal climate makes it the largest area of freshwater wetlands in China. There are 52 typical Chinese state-owned farms spread over the Sanjiang Plain, which are managed by the Bureau of State Farms and Land Reclamation (BSFLR). Most of the grain produced by these farms is sold as commodity grain across the nation and abroad.

The study area is Bawujiu Farm, located in the northeast portion of the Sanjiang Plain in Heilongjiang Province provided for our research project, which is located at 47°18'-47°50'N, 133°50'-134°33'E. The Bawujiu Farm has an area of 1356 km². This farm keeps a temperate continental monsoon climate, with a mean annual temperature of 2.94°C, an average frost-free period of 138 day and mean annual precipitation of 600mm. More than 60% of the annual precipitation is concentrated between July and September. The farm was covered with extensive wetland and forest before its establishment in 1956; since then it has been affected by widespread land reclamation[13].

According to the local land use policy, more virgin lands, such as wetland and forest, would be reclaimed as paddy land and dry land. The transformation of the Sanjiang Plain for grain production was achieved at considerable cost to the environment. Construction of immense networks of drainage channels, pump

ing stations, and flood control dikes have destroyed millions of hectares of peat land, further altering the water cycle of entire watersheds and destroying wetland biodiversity[14].

2.1.2 Crop management The adjustment of crop planting structure has been changing for more than 30 years, and agricultural production has rapidly developed. The main changes reflected in three aspects: the accelerated adjustment of planting structure, strengthening of cultivation measures and improvement of production management level. Planting structure adjusted from the traditional ternary planting structure of soybean, wheat, corn to diversification planting structure of rice, soybean, wheat, corn and other economic crops. On the application of cultivation techniques, scientific planting and reasonable rotation system has been effectively implemented, the new technology has gradually been widely used. Furthermore, the agricultural production has achieved modern agricultural production mode of formulation of technical measures, standardization of production management and field operation standardization and on the whole[14]. In 1990s, the land use situation of Sanjiang plain had been changed greatly due to the profound influence of the change of grain production demand. It is the comprehensive of the conversion on dry land and paddy field with time changing that has important guiding significance for regional food security in the Sanjiang plain of Northeast China. Especially in recent years, the transformation from dry land to paddy land as well as from wetland to paddy land has gradually become the main form of agricultural land use status changes, which would inevitably lead to a substantial increase for agricultural water demand[15].

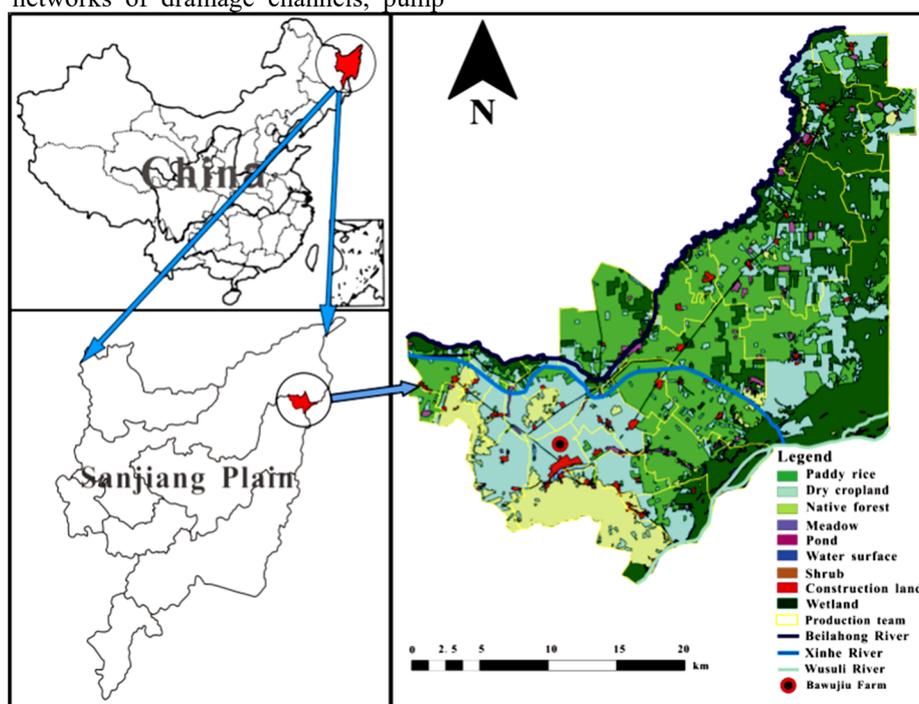


Fig. 1 The location diagram and land use of Bawujiu Farm of Heilongjiang Province in northeastern China.

2.2 AquaCrop model description

AquaCrop is a water-driven, canopy level, engineering type model[9]. It pays particular emphasis to simulating yield response to water under both irrigated and rain-fed conditions. The calculation steps and procedures of Aqua Crop have been described by[9]. AquaCrop model roughly simulates the four stages of crop growth (namely, the emergence stage; vegetative stage; flowering stage; the yield formation and ripening stage). The model mainly simulated the soil water condition in the root zone using a water balance approach. The soil water condition together with the canopy cover information was then used to partition the ET to actual crop transpiration and soil evaporation (according to the standard of FAO). The canopy cover development was modeled using first order kinetics, albeit with facilities for accommodating stress (water, temperature, etc.) induced retardations. Then the biomass production was estimated from the actual crop transpiration using a normalized form of the water productivity (WP) parameter. The normalization of WP for climate in AquaCrop is based on the atmospheric evaporative demand as defined by ET_o and the CO_2 concentration of the atmosphere. The goal is to make the WP value in the model specific for each crop applicable to diverse location and seasons, including future climate scenarios.[16].

$$WP = \left[\frac{B}{\sum \left(\frac{Tr}{ET_o} \right)} \right]_{[CO_2]} \quad (1)$$

Aqua Crop has four sub-model components: (i) the soil (water balance); (ii) the crop (development, growth and yield); (iii) the atmosphere (temperature, rainfall, evapotranspiration (ET) and carbon dioxide (CO_2) concentration); and (iv) the management (major agronomic practices such as planting dates, fertiliser application and irrigation if any). Aqua Crop calculates a daily water balance that includes all the incoming and outgoing water fluxes (infiltration, runoff, deep percolation, evaporation and transpiration) and changes in soil water content. The advantage with Aqua Crop is that it requires only a minimum of input data, which are readily available or can easily be collected. Aqua Crop has default values for several crop parameters that it uses for simulating different crops including wheat, however, some of these parameters are not universal and thus have to be adjusted for local conditions, cultivars and management practice[17]. For a more detailed description of the AquaCrop model see[7][9][18].

2.3. Model parameters and data of inputs and outputs

The model inputs included meteorological conditions, initial values of the model parameters, soil characteristics and management practices like irrigation schedules and water conservation measures such as mulchi-

ng. Apart from the Harvest Index (HI) and the water productivity (WP), Aqua Crop has several parameters for which conservative estimates were available in the User Manual for most commonly cultivated crops; those may generally be used without any further calibration[19]. Crop input parameters used in the Aqua Crop model were either obtained or calculated from [20]. Crop-specific but non-location-specific parameters for major agricultural crops including maize have been determined and validated in varying locations by the FAO and are provided as default values in the model. These parameters are referred to as “conservative” because they do not change with geographic location, management practices and time, and they were determined with data from favourable and non-limiting conditions but remain applicable for stress conditions via their modulation by stress response functions[21]. The other parameters are cultivar specific or less conservative and are affected by the climate, field management or conditions in the soil profile and thus have to be provided by the user (user-specific). However, if not available, Aqua Crop can estimate them (e.g., seeding date, plant density, etc.). In this study, these parameters were determined from values for the five year at this study area presented in Table 1. The simulation outputs included the evolution of soil water depletion in the root zone, the development of the green canopy cover, and the daily transpiration; the soil water balance in a given period; the accumulation of biomass and the final yield.

2.4. Model calibration and validation

Models should be carefully calibrated and validated before being used in practice [22]. During the process of calibration, it is necessary to change the model's parameters in order to obtain simulated results that match well with preexisting experimental data. In contrast, during the process of validation, simulated results generated using the model without any modification of the parameters are compared to independent experimental data[23].

2.4.1. The process of calibration In this study, based on the purpose of calibration, the simulated yield was compared with the observed yield. The yield was simulated by adjusting the initial soil water content, characteristics of soil horizons and evaporation related parameters at the time keeping the harvest index (HI) parameters a fixed value. Then the harvest index was adjusted basing on the good simulation of yield. During the process, it is mainly to assign initial value for reference HI, the water stress sensitivity to HI with different growth stages by comparing with the measured yield. Finally, there is a comparison between the observed data and simulated data in soil moisture content, by comparison of values of RR MSE and EF with the evaluation criterion for further description. The above process was repeated many times until the simulation value in line with measured value.

2.4.2. The process of validation In model validation progress, evaluation is an important part that involves a comparison between field measurement data and simulated data. Soil water content over the root depth and grain yield in Aqua crop were calibrated using the measured data sets in 2011 whereas they were validated by other four years (experimental data of 2012, 2013, 2014 and 2015 cropping seasons).

Some of parameter were assumed to be conservative according to Aqua Crop manual appendix [18]. The parameters changed little with the sowing date, field management, and the experiment location. When using the data of the 2011 growth season to calibrate the model, the main parameters were first assigned with the default values, and then were modified until the simulated data were more consistent to the observed data. The values of these parameters are located in proposed ranges by FAO. Table 1 lists the values assigned to specific parameters in order to simulate the responses of dry land crop.

2.5. Assessment of Aqua Crop performance

To assess the performance of Aqua Crop during calibration and validation, the relative root mean square error (RRMSE), the Nash–Sutcliffe modeling efficiency were computed as in Eqs. (2) and (3) respectively:

$$RRMSE = \frac{\sqrt{\frac{1}{N} \sum_{i=1}^N (s_i - o_i)^2}}{O_{ave}} \quad (2)$$

$$EF = 1 - \frac{\sum_{i=1}^N (s_i - o_i)^2}{\sum_{i=1}^N (o_i - o_a)^2} \quad (3)$$

where N is the number of the evaluated points, S_i is the simulated value and O_i is the observation value, and O_{ave} is the average of the observation values, respectively.

The relative error (RE) in the simulated final yield was also evaluated using:

$$RE(\%) = 100 \frac{|Y_o - Y_s|}{Y_o} \quad (4)$$

where RE is the relative error (%), Y_o and Y_s are the observed and simulated final yields (t/ha), respectively.

The relative root mean square error (RRMSE) is used to evaluate the relative error of the model, and the smaller the value, the better the simulation. The quality of the simulation is considered to be excellent if the RRMSE is less than 0.10, good if it is between 0.10 and 0.20, fair if it is between 0.20 and 0.30, and poor if it is above 0.30[25]. The efficiency of the model (EF) is used to describe the overall predictive ability of the model, which indicates the robustness of the model. The value of EF ranges from 0 to 1 with higher values indicating a better agreement. The simulated results is considered to be excellent if the RRMSE is higher than 0.95 excellent, good if it is between 0.80 and 0.95, fair if it is between 0.60 and 0.80, and poor if it is above 0.65.

The relative error (RE) of the simulated yield reflects the accuracy of the simulation, whose value ranges from 0-100%, considered to be good if it is less than 5%, fair if it is between 5% and 10%, and poor if it is above 10%. The lower the value of RE, the higher the accuracy of the simulation[26].

Table 1 Selected input and calibrated parameters used in the study.

Types	Abbreviation	Description	Values (for this study)	Activity
1.1 Threshold air temperature	T-base	Base temperature(°C)	10.0	Measured
	T-upper	Upper temperature(°C)	30.0	
1.2 Development of green canopy cover	CC ₀	Soil surface covered by an individual seedling at 90% emergence (cm ²)	5	Default
		Number of plants per hectare	5340000	Default
		Time from sowing to emergence(growing degree day)	69	Measured
	CGC	Canopy growth coefficient (%/day)	0.116	Calibrated
1. Crop Phenology	CCx	Maximum canopy cover (%)	85%	Calibrated
	CDC	Canopy decline coefficient (%/day)	0.0197	Calibrated
1.3 Flowering		GDD(Length of the flowering stage)	106	Calibrated
1.4 Development of root zone	Zn	Minimum effective rooting zone (m)	0.45	Measured
	Zx	Maximum effective rooting zone (m)	1.0	Measured
		Shape factor describing root zone expansion	13	Measured
		Average expansion rate of the effective root zone (cm/day) _s	1.058	Calibrated
2. Crop transpiration	Kc(Tr)	Crop coefficient when canopy is complete but prior to senescence	1.20	Calibrated

		Effect of canopy cover in reducing soil evaporation in late season stage		65	Calibrated
3. Biomass production and yield formation	3.1 Crop water production	WP*	Water productivity normalised for ET0 and CO2 (g m ⁻²) during yield formation(as percent WP* before yield formation)	26.866	Default
	3.2 Harvest Index	HI0	Reference harvest index (%)	47	Calibrated
4. Stresses			Soil water depletion threshold for failure of pollination (upper threshold)	0.85	Default
	4.1 Soil water stresses		Soil water depletion threshold for stomatal control (upper threshold)	0.55	Default
			Shape factor for water stress coefficient for canopy expansion	3.5	Default
	4.2 Air temperature stress		Min air temperature below and above which pollination starts to fail (°C)	8.0	Measured
			Max air temperature below and above which pollination starts to fail (°C)	30	Measured
			Minimum growing degrees required for full biomass production(°C-day)	10.0	Calibrated

2.6 Crop water use efficiency (WUE)

The increase of crop water use efficiency (WUE) is an indirect response to the increase of crop yield. In recent years, with the profound study of water stresses, many researchers had developed various definition of WUE. The most popular WUE are the following two types.

The conventional equation of $WUE_{Y/ET}$ is used to estimate the crop water use efficiency, as follow:

$$WUE_{Y/ET} = \frac{Y}{ET} \quad (5)$$

where Y is the crop yield (kg/hm²) and ET is the crop evapotranspiration (mm), or the crop water consumption (mm). The $WUE_{Y/ET}$ of dry matter levels focused on evaluating the crop water use status for ultimately producing grain yield. In addition, in this paper, we used former researchers' $WUE_{B/Tr}$ that was calculated as the ratio between biomass (kg/hm²) and transpiration (mm), Equation is as follows:

$$WUE_{B/Tr} = \frac{B}{Tr} \quad (6)$$

where B is the crop biomass (kg/hm²) and Tr is the crop transpiration (mm). The $WUE_{B/ET}$ of biocoenosis level aimed at analysing of the water use status of crops during the whole growth period.

3 Results and discussion

3.1. Model calibration and validation

3.1.1. Model calibration As shown in Fig.2, Aqua Crop was calibrated by comparison of the averaged soil moisture in 0-100 cm depth between the simulated and measured data for dry land. In general, the simulated total soil water content values follow closely

the trend of the observed values although there are cases where the errors are much higher than the standard deviation [25] of the observed values. The simulated values were basically in accordance with the observations, with the simulated moisture content responding to water input through precipitation, followed by a gradual decrease due to the continuous evapotranspiration. At the end of the crop growth period, the simulation results showed a downward bias relative to the observation, such as 2015. The reason may be that the model overestimates the root uptake and transpiration at the latter growth stages due to the inclusion of the non-transpiring dry leaves. But in 2013 there was an upward bias relative to the observation; the most appropriate reason is due to the combination of a sudden precipitation event and a significant decline of the absorption of water and the evapotranspiration of crops in the later stage of growth.

In terms of soil moisture assessment, the RRMSE value ranged from 0.131 to 0.189 during 2011-2015 (except 2012), indicating a good simulation accuracy. In B.Andarzian's research, the calculated RRMSE of wheat soil moisture content were 0.035 for full irrigation and 0.04 for water deficit irrigation, respectively, indicating an excellent quality of the simulation[12]. The model efficiency was all above 0.696 and some were near 0.805, indicating a fair simulation accuracy. In Dirk Raes's research of soil water balance, the statistical analysis resulted in an EF of 0.21 for Mornag and an EF of 0.83 for the Kou Valley[26]. The calibration results of yield for dry land crop (Table 2) showed the relative errors (RE) of yield for dry land crop were average 2.14% and ranged from 0.175 to 5.26%, except for the value of RE (5.26%) slightly higher than 5% in 2011, which indicated a good quality of the simulation. In Jiang Li's study, RE of yield for seed maize in 2013 were nearly 8.72%, which were less than the RE fair standard, indicating a moderate ability to simulate crop yield changes[16]. Therefore Aqua Crop model had a moderate ability to depict the fluctuation of soil moisture and crop yield in this region.

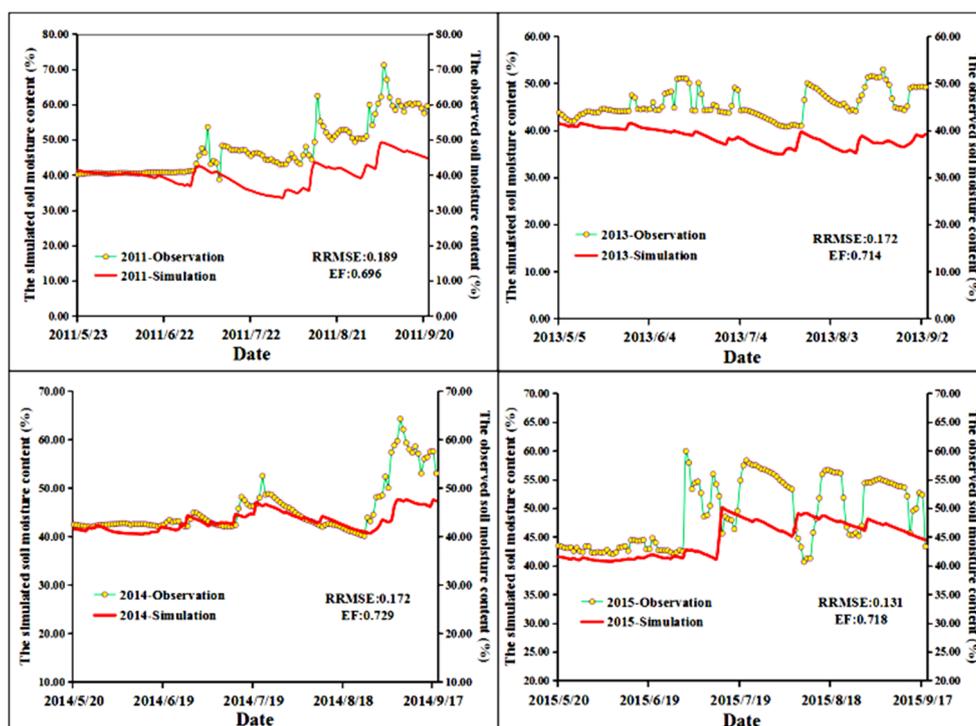


Fig.2 Comparison of the averaged soil moisture in 0-100 cm between the simulated and measured data for dry land during 2011,2013,2014,2015

3.1.2. Model validation The model for soil moisture content of dry land was validated with experiment data in 2012 using calibrated parameters in Table 1, and the results were shown in Fig.3. For the validation of soil moisture content in different depths 0 - 15 cm, 15 - 30 cm, 30 - 60 cm, 60 - 90 cm of Dry land in 2012, EF were all above 0.64 and some were nearly 0.87, meanwhile RRMSE ranged from 0.18 to 0.27. Although the verification values are lower than the calibration values, the values of RRMSE are all in accordance with fair criteria and the values of EF are all above poor fair. Refer to the results of B. Andarzian's research, this validated value is an acceptable result [12]. The Validation results of yield for dry land crop (Table 2) showed the RE of yield for dry land maize in 2012 were 3.05%, less than the RE good standard. Knowing the results from Jiang Li and Ting Zhu's study, this is a reasonable result [16]. The above results indicate a moderate performance of this model and capable to be used for p

redicting the water consumption and yield of dry land crop in the study area, shown in Fig 3, Table 2.

Fig 4 shows the relationship between observed and simulated maize yield for study area during 2011-2015. The Observed and simulated maize yield correlated well giving a R of 0.9993 ($P = 0.01982 < 0.05$), a slope of 1.0679 and a d of -0.8124 indicating that the model had a good fitting result between observed and simulated maize yield. Araya et al. (2010a) reported R^2 values > 0.80 when simulating barley above-ground biomass and grain yield using AquaCrop (Araya et al., 2010b). Similarly, Stricevic et al., 2011 reported R^2 values > 0.84 when simulating yield of maize, sunflower and sugar beet under both rain-fed and irrigated conditions using AquaCrop [28]. While Karunaratne et al. (2011) reported a R^2 value of 0.72 and a slope of 0.83 when simulating Bambara groundnut yield using AquaCrop [29]. Those results from the above researcher's analysis illustrate that the calibration result of AquaCrop model is good.

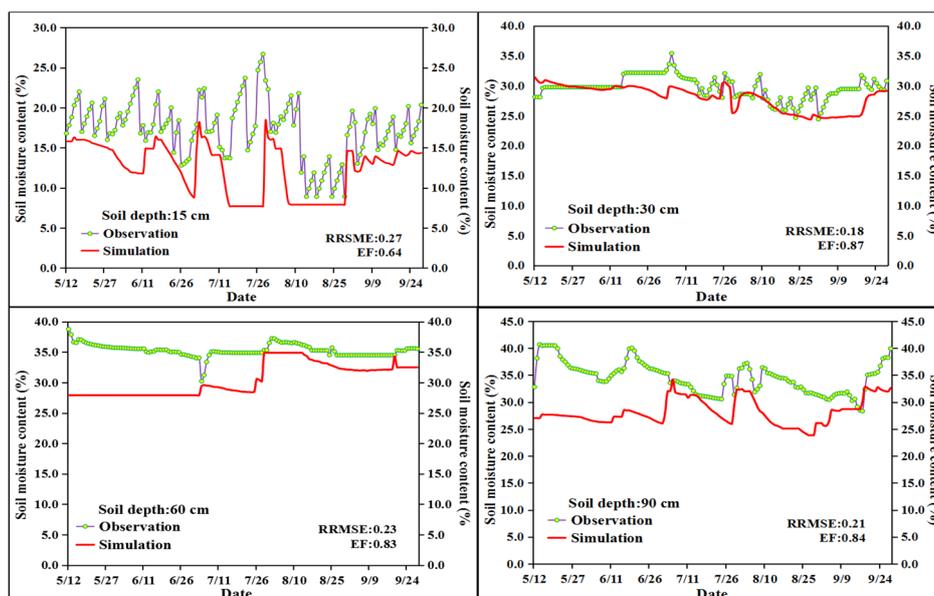


Fig.3 Comparison of the averaged soil moisture in different soil depth of 0-15cm, 15-30cm, 30-60cm, 60-90cm between the simulated and measured data for dry land in 2012.

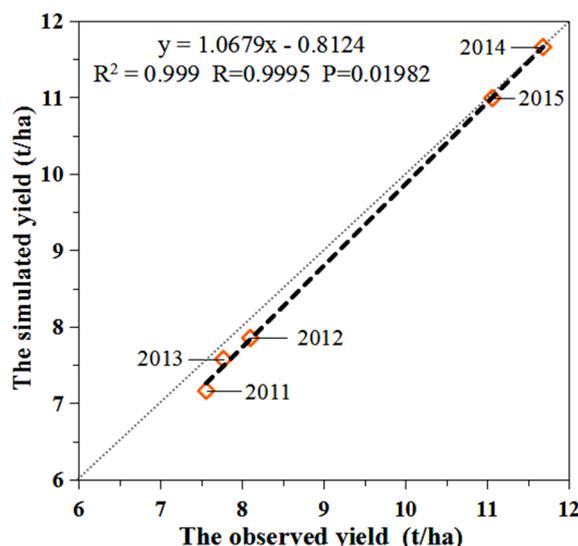


Fig. 4 Relationship between the observed and simulated maize yield (kg/hm²) for study area during 2011-2015.

Table 2 Calibration and Validation of the observed and simulated soil moisture content and yield.

Calibration					Verification (2012)				
Year	2011	2013	2014	2015	Depth	0-15cm	15-30cm	30-60cm	60-90cm
RRMSE	0.189	0.172	0.172	0.131	RRMSE	0.27	0.18	0.23	0.21
EF	0.696	0.714	0.729	0.718	EF	0.64	0.87	0.83	0.84
Observed Yield(kg/hm ²)	7.56	7.77	11.68	11.06	Observed Yield(kg/hm ²)	8.10			
Simulated Yield(kg/hm ²)	7.27	7.58	11.66	10.99	Simulated Yield(kg/hm ²)	7.85			
RE (%)	5.26	2.50	0.17	0.62	RE (%)	3.05			

3.2 Soil water balance

With the simulation results by Aqua Crop, we analyzed the soil water balance of the dry land maize in the study area. Fig 5 showed the evolution of the accumulation of evapotranspiration (ET) and water content in total soil profile (WCT) as simulated by Aqua

Crop, as well as the events of precipitation for dry land maize in different stages of 2011-2015.

As shown in Figure 5, the precipitation distribution was uneven in different growing seasons during 2011-2015; especially in 2011 and 2015, the uneven distribution of precipitation is more remarkable; but most of the precipitation was still concentrated in the critical stage of crop growth, which was in favor

of crop normal growing. And the great mass of precipitation was still concentrated in the whole summer, in accordance with P patterns of temperate monsoon climate region.

In 2011-2013, the variation of ET during crop growing stages was not stable, but from stage 2 to stage 4, there was shown a pattern: the variation trend of ET first gradually increased at stage 2, and reached the peak at stage 3, finally started to reduce until to the lowest value at stage 4, which was consistent with the discipline of crop biomass growing and crop yield produced, meanwhile could reflect the law of crop growing and changing at some extent. The reason for the lowest ET during the stage 4 was due to the fallen leaves which became yellow and was paved on the surface and thus reduce the ET. In addition, due to the instability of P, ET in 2014 and 2015 also showed an anomalous variation trend, especially in the stage 3 of 2015, ET was at the lowest value instead. Previous studies for maize have found that 30.49% of ET occurred during the vegetative stage 2, remaining more than half (51.80%) during flowering Stage 3, the lowest (8.0%) amount during the yield formation and ripening stage (Stage 4), and the rest (9.71%) of ET occurred during Stage 1 (Hanafi et al., 2010). There was a similarity between the two researches. The reason might be that the occurrence of meteorological conditions at low temperatures besides accumulated low precipitation, which w

as caused by the combined effects of temperate continental climate and temperature monsoon climate in the Siberia region north for the study area (the Sanjian plain of Northeast China) [30]. Moreover, it could be found that the maximum value of ET was closely followed by that of P or showed a slight hysteresis. The reason might be that the infiltration of natural precipitation into the soil and the absorption and utilization of crops were a cumulative process over time [32].

As shown in Figure 5, the overall trend of WCT gently increased from stage 1 to stage 4, and relatively reached the maximum at the stage 4, whose pattern also conforms to the pattern of the large water requirement during the early and middle stage of crop growth as well as the low water requirement during the later and last stage [33]. The variation of WCT was stable on the whole, however WCT always timely responds to the peak of P and the valleys of ET. Previous research found that the presence of fluctuations in ET tended to increase the variance of soil moisture dynamics to some extent, while the stable variation trend of ET always relatively reduced the water losses of WCT [34]. In fact, the effect of ET and precipitation on the whole variation trend of WCT was not remarkable, which indicated that the original water content of soil in the study area was relatively high and could generally meet the basic demand of crop growth [35].

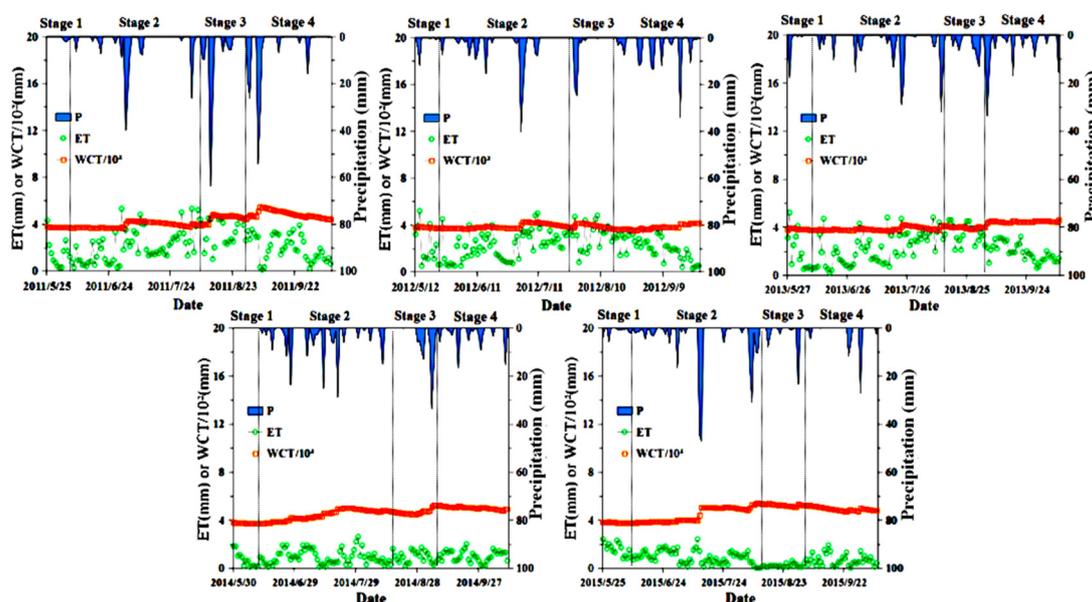


Fig.5 Comparative analysis of accumulation of evapotranspiration (ET), precipitation and water content in total soil profile (WCT) in different growth stages of 2011-2015

3.3 Crop water use efficiency (WUE)

In general, there are many factors influencing the change of WUE, such as meteorological factors, soil factors and crop factors. The purpose of this section is just to study the most important factors of water content in effective root zone (W_r) during the four growth stage, precipitation (P) during the four growth

period and temperature (T) during the four growth stage influencing crop water use efficiency for yield ($WUE_{Y/T}$) and crop water use efficiency at coexistence level ($WUE_{B/ET}$) during the four stage.

For the above three factors, there were two different data types: the mean and the sum. Thus, we had carried out the multivariable linear regression analysis between the standardized $WUE_{Y/T}$, the standardized $WUE_{B/ET}$ and the six kinds of standardized data

($Wr_{SD.Avg}$: standardized average Wr , $Wr_{SD.Cum}$: standardized cumulative Wr , $P_{SD.Cum}$: standardized cumulative precipitation, $P_{SD.Avg}$: standardized average precipitation, $T_{SD.Cum}$: standardized cumulative temperature, $T_{SD.Avg}$: standardized average temperature) in different growth stage. The results were shown in table 5. In addition, as shown in Fig 6, duo to beginning with Biomass production in stage 2, there was a data deficiency in stage 1. Similarly, duo to beginning with yield formation in stage 3, there was a data deficiency in stage 1 and stage 2.

As shown in Table 5, the results of analysis was satisfactory with obtaining two regression equations. In Table 5, it could be seen that the P -value of them were both 0.03, less than 0.05, which indicated that the regression analysis was statistically significant. And the multiple determination coefficient (R^2) were 0.698 and 0.893, which meant explaining 69.8% and 89.3% of independent variables in the total dependent variable, thus there were a explanatory of moderate and superior level for dependent variables in regression equation. In addition, it could be found that both of the standardized partial regression coefficients had a high significance that the value of them were less than 0.05 or 0.01.

Firstly, it could be found that both of $WUE_{B/ET}$ and $WUE_{Y/T}$ had a positive correlation with Wr_{Avg} , however the contribution rates of Wr_{Avg} to $WUE_{B/ET}$ and $WUE_{Y/T}$ were different owing to the standardized partial regression coefficients of 1.06 and 0.9, respectively. It was thus obvious that Wr was critical to the increase of $WUE_{B/ET}$ and $WUE_{Y/T}$. As previous studies had found, although mild water shortage at jointing stage and male stage was beneficial to stimulate physiological mechanism development and slightly improve water use efficiency, moderate water abundance was still the key factor to improve crop water use efficiency throughout the whole growth stage[41].

On the contrary, they had a negative correlation with P_{Cum} , and the contribution rates of P_{Cum} to them were also different due to the standardized partial regression coefficients of -0.46 and -0.88, respectively. Apparently, P_{Cum} restrained the increase of $WUE_{B/ET}$ and $WUE_{Y/T}$. The previous studies on maize and sorghum had found that WUE would decrease with the increases of cumulative precipitation in Western Kenya. The reason might be that seen from the above

studied part, the temporal distribution of precipitation was not uneven with moderate rain and heavy rain in the study area, which significantly increased soil water content in total profile during a long time, thus the normal growth of crop root was inhibited, ultimately almost resulting in crop growth stagnated at a certain period of time[42].

In addition, the correlation between $WUE_{B/ET}$ and T_{Avg} as well as $WUE_{Y/T}$ and T_{Cum} were positive, and the standardized partial regression coefficients were 0.95 and 1.05 which indicated have different contribution rates. Although both T_{Avg} and T_{Cum} had a positive impact on $WUE_{B/ET}$ and $WUE_{Y/T}$, respectively, there was a difference that the emphasis of the independent variables affecting dependent variables was different. The possible reason were as follow: (1) in the stage 1, at high temperature condition, the water absorption amount, water absorption rate and obviously increased[43] and the duration of seeds germination was substantially shortened, which accelerated the growth of crops. Since biomass and yield were not produced at this stage, the impact of temperature on WUE could not be seen at this stage. (2) In the stage 2, only biomass began to be produced. The temperature mainly affected the growth of roots, stems, leaves. If the temperature moderately went up, the duration of stage would be shortened, which to some extent, accelerated the growth of crops and reduce the total transpiration [44]. Therefore, as seen in equation 6, if the growth of cumulative biomass was normal, the $WUE_{B/ET}$ was increased relative to the decrease of Tr . (3) At the stage 3 and 4 (late summer or autumn), because precipitation and temperature significantly decreased, and the crop growth stage gradually got into flowering period as well as ripen stage (grain stage), meanwhile the requirement of crop growth for moisture content gradually decreased, and the temperature became the key factors for grain yield formation. During the period, the biomass growth was about to go into contabescence, whose reasons were complex and diverse, yet the reduction of temperature still occupied a considerable contribution rate. While the increase of cumulative yield and the decrease of ET led to the increase of $WUE_{Y/T}$, what's more, $WUE_{Y/T}$ gradually increased with the decrease of ET resulting from the temperature reduction.

Table 5 The Regression analysis result between soil water content in effective root zone (Wr), precipitation (P), temperature (T) and crop water use efficiency for yield ($WUE_{Y/ET}$), crop water use efficiency for yield ($WUE_{B/Tr}$) at coenosis level during four growth stage

Fitted Stage	Linear Regression Equation	R^2	Sig.
Stage 2, Stage 3 and Stage 4	$WUE_{SD.B/Tr} = 1.06 Wr_{SD.Avg}^* - 0.46 P_{SD.Cum}^{**} + 0.95 T_{SD.Avg}^{**}$	0.698	0.003**
Stage 3 and Stage 4	$WUE_{SD.Y/ET} = 0.90 Wr_{SD.Avg}^{**} - 0.88 P_{SD.Cum}^* + 1.05 T_{SD.Cum}^{**}$	0.893	0.003**

4 Conclusion

In the current study, the AquaCrop model version 5.0 was used to simulate maize yield and soil water content under no irrigation condition of the Sanjiang Plain, Northeast China. The AquaCrop model was calibrated by soil water content and was validated by soil water content in different depths. In addition, the agreement between modelled and observed maize yield was satisfactory with the proper value of R^2 and RE. Results showed that both maize yield and soil water content could be simulated with relative accuracy using AquaCrop.

For no irrigated dry land, precipitation was the key factor influencing soil water supplement. Although the factors about influencing ET were various and complicated and the ET response to the variation of P shown a certain hysteresis, the maximum value of ET varied with that of P. The precipitation greatly varied, but as long as the change of ET was stable, the soil water balance would not be broken.

In the absence of precipitation events, biomass and grain yield increased with the increase soil moisture content. However, when precipitation occurred, especially with the increase of precipitation intensity, the growth rate of biomass gradually decreased, while the growth rate of grain yield shown the trend of first the ascending and then the descending, which had a profound significance for irrigation arrangements.

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