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Evaluation of AquaCrop's Ability to Simulate Water Stress Based on 2-Year Case Study of Maize Crop

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Abstract: To apply AquaCrop to the study of agricultural soil moisture in the North China Plain, a water-treatment experiment on summer maize was carried out at the Fengqiu experimental station of the Chinese Academy of Sciences from 2017 to 2018. A water treatment was used to achieve field water capacities of 20 (W1), 40 (W2), and 60 (W3) cm soil layers under irrigation, and a rain-fed treatment (W0) was added. The model parameters were calibrated using the measured data in 2017. Then, they were applied to 2018 to verify the ability of the model to simulate water stress. The results showed that the variation trends for crop yield, canopy coverage, total soil water content, and the curve in the growth cycle simulated via AquaCrop were consistent with the actual observations; the results of a discrete analysis showed that the values of b (regression coefficient), R^2 (determination coefficient), and EF (efficiency) were close to 1, and the values of the RMSE (root mean square error) were close to 0, which proved that the model could simulate dynamic changes in summer maize yield, canopy coverage, and total soil water content well. AquaCrop had good applicability in the North China Plain and could be applied to the study of agricultural water consumption and water-use efficiency in this area. The simulated values obtained can serve as an easily obtainable source of long-term experimental data in areas with frequent non-extreme weather events.

Keywords: AquaCrop; North China Plain; water-stress simulation

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1. Introduction

The North China Plain is one of the main grain-producing areas in China [1]. The typical cropping pattern in this region is a winter wheat–summer corn rotation [2]. Rainfall levels in the North China Plain are low and unevenly distributed [3]; 70–80% of the total rainfall occurs from June to September, leading to a mismatch between crop water demand and rainfall in the wheat-growing season. To obtain high grain yields, local farmers rely on flood irrigation and massive fertilization [4]. To meet the needs of industrial and agricultural water, a large amount of groundwater is mined, leading to a large groundwater funnel area [5]. The consumption of water resources is huge, the utilization efficiency is low, and the groundwater resources are declining rapidly [6]. Determining the best way to improve water-use efficiency to ensure continued high yields is the focus of this study.

Irrigation is used to increase crop yield, and it is an important factor affecting crop growth. It has a great influence on crop yields and the water-use efficiency of farmland. Water-management measures mainly include the adjustment of the irrigation amount, irrigation time, and irrigation method. Zhang [7] showed that a regulated deficit irrigation could not only sustain a high crop yield but also mobilize the inherent coordinated stress ability of crops, greatly reducing the evapotranspiration water consumption, thus reducing

groundwater exploitation. Sun's [8] results show that flood irrigation leads not only to low yields but also limited economic benefits. Zhang [9] studied the water-use efficiency of a wheat–maize system treated via fine irrigation, and the results showed that fine irrigation was not only a simple and feasible method but also significantly contributed to the protection of groundwater resources. Other researchers have studied the effects of different combinations of water and fertilizer on crop yields and the environment.

It is not enough to study the influence of irrigation on soil water-use efficiency via field experiments in terms of either time cycle or cost. These issues are addressed by AquaCrop. The newly developed AquaCrop model [10,11] is a free and practitioner-oriented tool that uses a relatively small number of parameters to determine the yield and biomass. As it maintains a balance between accuracy and robustness, crop-growth simulation models of varying complexity have been developed to predict the effects of soil, water, and nutrients on the grain yields, biomass yields, and water productivity of different crops. This model has previously been tested for applications to maize, cotton, sunflower, and wheat [12–16] crops under different environmental conditions. Many past studies [17–20] have shown that the model can accurately simulate crop biomass and yield, as well as soil water dynamics, under full and water-deficit irrigations and soil fertility stress conditions [21–25]. However, the applicability of the model for optimizing corn growth in a water–nitrogen coupling scheme in the Fengqiu area of the North China Plain remains unknown. Thus, the present study mainly aims to evaluate and validate AquaCrop by simulating summer maize growth in the North China Plain, and it further analyzes the influence of water–nitrogen interaction on summer maize.

2. Materials and Methods

2.1. Site Description

The experiment was located in Pandian Village, Fengqiu County, Xinxiang City, Henan Province. Fengqiu County, located in the northeast of Henan Province, is a typical alluvial plain area in the middle and lower reaches of the Yellow River, located between 34°53′ and 35°14′ N and 114°14′ and 114°45′ E. It is located in the northern warm temperate zone and has a semi-arid monsoon climate, with cold winters characterized by less rain and snow, spring characterized by drought and sand, summer characterized by hot rain, and autumn characterized by cool, short solar terms. The main land type is dry land, the main planting mode is a winter wheat–summer corn rotation, and the main soil type is tidal soil.

This study is based on a long-term experimental platform of water–nitrogen coupling located at the Fengqiu Agroecological Experimental Station, in the Chinese Academy of Sciences. In this experiment, five nitrogen fertilizer treatments, three water treatments, and one rain-fed treatment were set up, with three repetitions for each treatment. A total of 48 plots, covering an area of 48 m^2 (8 × 6), were randomly arranged, and a small weather station was set up in the experimental site, with the organization of the experimental plots as shown in Figure 1. The basic physical and chemical properties of the soil at the experimental site are shown in Tables 1 and 2.

Table 1. The physico-chemical properties of soil in different layers of the long-term experimental field [26].

Soil Layer	SOM	BD	SW	SC	pH	EC	CEC	FC	O-P	Sand	Silt	Clay
cm	g/kg	g/cm^3	cm^3/cm^3	Mm/h		μS/cm	cmol/kg/	%	g/kg	g/kg	g/kg	g/kg
0–30	10.2	1.51	0.42	22.6	8.28	86	7.88	40.5	5.75	456	407	137
30–80	7.1	1.48	0.48	19.3	8.48	141	14.35	40.4	2.03	84	558	359
80–180	3.2	1.42	0.45	18.1	8.95	75	5.27	37.6	2.92	73	824	103

SOM, soil organic matter; BD, bulk density; SW, saturated soil water content; SC, saturated soil hydro-conductivity; EC, electric conductivity; CEC, cation-exchange capacity; FC, field capacity.

Figure 1. The organization of the experimental plots.

Table 2. The basic parameters of soil moisture in different soil layers were tested for a long time.

Depth (cm)	TAW (mm/m)		Moisture Content (vol%)		Permeability Coefficient
		PWP	FC	SWC	SHC (mm/day)
0–30	325	8	40.5	42	542.4
30–80	176	23	40.6	48	463.2
80–180	226	15	37.6	45	434.4

TAW, total soil available water; PWP, permanent wilting point; FC, field water capacity; SWC, saturated water content; SHC, soil hydraulic conductivity.

2.2. Experimental Design

The cropping system adopted a winter wheat–summer maize rotation, which was popular in the North China Plain. In this study, 230 (F3) kg/ha of nitrogen was applied in consecutive seasons. The nitrogen fertilizer was twice divided into base fertilizer and top fertilizer. Urea (46.3% nitrogen content) was used as the nitrogen fertilizer. Corn base fertilizer made up 60% of the total content, and the remaining 40% was top fertilizer applied during the trumpet period. Ploughing was carried out after the uniform application of the base fertilizer (surface layer of 20 cm); after topdressing, the irrigation treatment was carried out depending on the weather conditions, i.e., if there was no precipitation process or the rainfall was less than 20 mm. If extreme droughts occurred or if the soil moisture could not ensure the emergence of seedlings, proper irrigation was carried out to ensure crop growth and irrigation. Irrigation was carried out if the soil (0–170 cm) water deficit (the difference between the soil field water-holding capacity and the soil water-storage capacity) exceeded 100 mm during the important water-demand period. The water treatment reached a field water-holding capacity of 20 (W1), 40 (W2), and 60 (W3) cm soil layers during irrigation, and the rain treatment (W0) was added, with three repetitions for each option. There were 12 districts in total.

The meteorological data were sourced from the meteorological observation station based at the Fengqiu National Experimental Station of Agroecology, managed by the Chinese Academy of Sciences, which is located near the experimental site. The meteorological indicators included temperature, atmospheric relative humidity, wind speed, wind direction, rainfall, evaporation on the water surface, sunshine duration, etc., which were tested based on the specifications of the Chinese Ecosystem Research Network (CERN).

The crop yield was measured via the single collection and single collection in the plot methods. The storehouse yield was designated as the dried yield (80 °C to constant weight) plus 14% water content. One day before maize maturity and harvest, 5 representative maize plants were randomly selected from each plot and divided into straw, ear, and root for seed testing, air drying, and drying. The crop's grass to seed ratio was calculated, and representative samples of grain, straw, and root were collected for a nutrient content analysis.

We used small evaporation buckets, a TDR detector, a leaf area meter, etc., and special personnel were responsible for collecting soil evaporation data, TDR data (monitoring total soil water content), LAI data (conversion of crop canopy coverage, conversion formula $CC = 1.005[1 - \exp(-0.6LAI)]^{1.2}$), and other data every 7 days. These data were used to monitor the characteristics of the crop growth and soil moisture processes.

2.3. Model Description

AquaCrop was developed by the FAO based on a water-driven growth engine. AquaCrop includes 4 submodel components: (i) soil module, (ii) crop (development, growth, and yield), (iii) atmosphere (temperature, rainfall, evapotranspiration (ET), and carbon dioxide (CO_2) concentration), and (iv) management (major agronomic practices, such as planting dates, fertilizer application, and irrigation, if any were employed). The data were stored in climate, crop, soil, management, and initial soil water condition files [10]. When simulating crop growth, AquaCrop uses both thermal time and calendar time with daily time steps. The model estimated the yields of crops as a function of their water consumption. The aboveground dry biomass and harvest index (HI) were used to calculate the crop yield. All possible water sources were considered when using AquaCrop, including rainfall, supplementary irrigation, deficit irrigation, full irrigation, capillary action, etc. AquaCrop's field management file contained data regarding soil fertility, crop residue, and surface practices. For each level of N treatment, the corresponding soil fertility was considered and inputted. The advantage of using AquaCrop is that it only requires a small amount of input data, hence the easiness of data collection. A more detailed description of the model is given by Heng et al. [12,21,22].

AquaCrop is a crop–water productivity model developed by the FAO's Land and Water Division to address food security and assess environmental and management-related effects on crop production. AquaCrop was developed based on a revised version of the FAO's "Relationship between Yield and Water" model. It simulates the responses of crop biomass and yield to water supply and identifies the response mechanism of crop water. It expresses crop productivity through the functional relationship between biomass and the harvest index. In the model, the acquisition of biomass is realized by simulating the development of the crop canopy and the growth of crop roots. The development of the canopy responds to changes in the external environment (changes in soil moisture, fertilizer application, etc.), and this response mechanism, in turn, affects the crop yield. AquaCrop divides evapotranspiration (ET) into evaporation (E) and transpiration (Tr), thus avoiding confusing the effects of non-productive and productive water on crop growth. AquaCrop distinguishes the effects of environmental stress on biomass and the harvest index. The responses of crops to water stress were expressed by simulating the formation of the crop canopy, canopy aging, stomatal movement, and changes in the harvest index. The overall effect of water stress on crop growth was detailed, which was more conducive to understanding the mechanism of the crop water response and highlighting the influence of water on crop growth.

2.4. Tuning of Non-Conservative Crop Parameters to the Local Environment and Model Validation

Models were carefully calibrated, parameterized, and validated before they were applied [23,24]. During parameterization and calibration, we changed the model parameters and, potentially, its underlying code to obtain simulated results that matched well with pre-existing experimental data. During validation, the simulated results that were

generated using the model without modifying the parameters or code were compared with independent experimental data.

2.4.1. Calibration Process

The calibration process followed the procedure adopted in an earlier study [18]. Firstly, the parameters that determined the development of canopy cover matched those detailed in the previous study [22], such as plant density, days to emergency, days to senescence, days to full maturity, initial canopy cover, maximum canopy cover, canopy growth coefficient, canopy decline coefficient, and maximum effective rooting depth (Z_X). Secondly, by adjusting each treatment, the biomass was simulated by adjusting Z_X, the initial soil water content, the characteristics of soil horizons, surface runoff, and evaporation-related parameters at the time, keeping the values of the canopy cover parameters fixed. The water-use efficiency was simultaneously adjusted. Finally, the harvest index was adjusted based on the efficient simulation of the biomass. We mainly used this process to assign an initial value to the reference harvest index and water-stress sensitivity to the HI in different periods through a comparison with the measured yield. This process was conducted repeatedly until the simulation value aligned with the measured value.

2.4.2. Calibration Parameters

The time (in days) from sowing to emergence, maximum canopy cover, flowering, onset of senescence, and harvesting were recorded using the Clarke method [27]. The soil water content was measured each week using a TDR. After adjusting the model parameters based on the on-site conditions of the experimental site, we simulated the crop canopy coverage curve of the 2017 corn season experimental site and compared the measured data for 2017 to fine tune and calibrate the model. If the model performed well in terms of applicability, the model parameters were determined at this time, and no parameter adjustment was carried out. After simulating the total soil moisture content and ET value, if the simulation results were ideal, the localization adjustment and calibration of the model in this experiment was completed. If the simulation results showed that at least one of the total soil moisture content and ET values were not applicable, we adjusted the sensitive parameters accordingly and repeated this step to re-verify whether it was still applicable until the model showed good applicability for simulating crop canopy coverage, total soil moisture content, and ET values; then, the model calibration was completed.

2.4.3. Model Evaluation Criterion

Evaluation is an important aspect of model validation. It involves comparing the experimental data measured in the field with the simulation results. In this study, the soil water content above the root depth, CC, grain yield, and ET in the AquaCrop model were calibrated against the experimental data for the 2017 growing season. The resulting model was validated by comparing the model output to the experimental data obtained for the 2018 growing season.

AquaCrop's performance was evaluated using a 1:1 regression line with respect to the following measures: the root mean square error ($\mathrm{RMSE} = [\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}]^{0.5}$) and the average relative error ($\mathrm{ARE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{O_i - P_i}{O_i}\right|$), where O_i and P_i refer to the observed and simulated values of the study variable, respectively, and n is the number of observations, provided as a measure (%) of the relative difference between the simulated and the observed results. If the normalized RMSE or ARE were less than 10%, the quality of the simulation was excellent; if they were between 10% and 20%, the quality of the simulation was good; if they were between 20% and 30%, the quality was of the simulation was fair; and if they were above 30%, the quality of the simulation was poor [28]. In addition, an efficiency indicator was used to assess the quality of the modeling ($\mathrm{EF} = 1.0 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2}$), which is a normalized statistic corresponding to the ratio between the residual and observed

variances. The target value for EF is 1.0, while a null or negative value indicates that the average of the observations is as good or better than those predicted using the model [18].

3. Results and Discussion

3.1. Model Parameter Calibration and Verification

Before using the model, the model parameters had to be calibrated and verified based on the measured data of the meteorological, soil, and irrigation systems, the field management measures, and the original soil moisture content of the test target area. In this study, the measured field data generated at the test site in 2017 were used to calibrate the model, and the parameters of the basic model used in this test were obtained (Table 3).

Table 3. Basic model parameters' selection values.

	Model Parameter	Unit	Value
mat	The time from sowing to ripening	GDD	2950
ccs	Soil coverage when emergence rate reaches 90%	cm^2	1.60
mcc	Maximum canopy coverage	%	1.0
eme	Time from sowing to emergence	GDD	168
sen	Time from sowing to the onset of aging	GDD	1596
Flo	Time from sowing to flowering	GDD	1272
Flolen	Length of the flowering period	GDD	340
cgc	Canopy growth coefficient	Fraction/GDD	0.0075
cdc	Canopy aging coefficient	Fraction/GDD	0.0035
root	Time from sowing to reaching maximum root depth	GDD	2000
rtnx	Minimum effective root depth	m	0.21
rtx	Maximum effective root depth	m	1.56
rtexup	Maximum water extraction from top quarter of root zone	m^3/m^3 soil/d	0.0351
rtexlw	Maximum amount of water extracted from bottom quarter of root zone	m^3/m^3 soil/d	0.104
rtshp	Shape factor of root zone expansion	—	18
evladc	Effect of canopy coverage on reducing soil evaporation in late growing season		60
wp	Normalized water productivity	G/m^2	18
hi	Reference harvest index	%	46
puexp	Upper threshold of soil water consumption limiting canopy expansion	Fraction TAW	0.22
plexp	Lower limit of soil water consumption limiting canopy expansion	Fraction TAW	0.540
psto	Upper threshold of soil water consumption limiting stomatal conductance	Fraction TAW	0.540
pstoshp	Water-stress shape factors that limit stomatal conductance		2.95
psen	Upper limit of soil water consumption causing premature canopy failure	Fraction TAW	0.74
psenshp	Water-stress shape factors causing premature canopy aging		3.1
polmn	Limit the minimum temperature of pollination	°C	4
polmx	Limit the maximum temperature for pollination	°C	40
stbio	Minimum degree of growth for biomass production	GDD/d	11
hipsveg	Positive influence coefficient of limiting crop growth on harvest index during yield formation		1
hinsveg	Negative influence coefficient of limiting crop growth on harvest index during yield formation		3
lelecon	Lower threshold of conductivity of saturated soil extract	Ds/m	4.2
uelecon	Upper soil consumption thresholds that limit pollination	Ds/m	26

GDD, growth degree–day; TAW, total soil available water in root zone; HI, harvest index.

3.2. Soil Water Content

In 2018, the simulation results of the total soil water content indicated that AquaCrop effectively replicated the variations in soil water content throughout the growth stages of summer maize. The simulated values closely aligned with the observed values, displaying a consistent trend. All evaluation index values fell within the range of good applicability, affirming that the calibrated model was well-suited to simulating changes in soil total water content during the summer maize season in the tested area. This result is similar to that of the study by Abdalhi et al. [29], though their evaluation results were better under normal and low-irrigation conditions, as well as slightly worse under excessive-irrigation conditions. This outcome may have occurred because the parameter calibration of AquaCrop in this study was based on the treatment of excessive irrigation. However, the evaluation values were all within an acceptable range. This result suggests that the model can be reliably employed for studying the total soil water content in this specific region (Table 4).

Table 4. The measured soil moisture content data for the 2018 maize season verified the evaluation index value of the model.

Treatments	b	R^2	RMSE (%)	ARE (%)	EF
F3W3	0.88	0.89	11.0	10.8	0.90
F3W2	0.81	0.88	13.1	12.1	0.86
F3W1	0.82	0.87	11.6	13.8	0.88
F3W0	0.86	0.86	13.6	11.4	0.82

For the experimental results shown in Figure 2, we observe that AquaCrop performs well in simulating the total soil moisture content change process module during crop growth, and the trend of the simulated change curve is in line with that of the measured results. This result is similar to that of the studies by Wang [30], Augusto [31], and Amiri [32]. However, the overall measured results are generally slightly lower than the simulation results, of which there are two possible causes. One possibility is that the calibration and validation process of the model is based on crop coverage (CC), and there is a slight lack of consideration for the parameters affecting the total soil moisture content. However, the sensitivity of the model is relatively high, resulting in some quite significant differences. Another possibility is that the soil stratification of the model only considered the approximate soil properties of the three main levels, while the actual soil structure in the model may not have been not detailed enough, resulting in certain differences in the water movement process and the actual process. The soil type in the target experimental area is mainly sandy yellow tidal soil, and the water movement speed is relatively fast, resulting in the measured data values being slightly lower than those of the simulated data. This speculation will be further validated and improved in a future study.

In addition, in the case of water replenishment, the simulated values are relatively closer to those of the measured data. This result shows that AquaCrop has high sensitivity for simulating the process of water movement in soil. If our suppositions about the possible reasons for the two above-mentioned differences are correct, we can more accurately determine whether the belief that the measured values are relatively close to the simulated values under water replenishment conditions is true, because there is a certain gap between the actual soil structure and the simulated soil structure, generating relatively accurate simulation results in a very short period of time, yet gradually producing differences over time. The measured total soil moisture content under the three pre-sowing irrigation conditions were higher than the simulated values, while the measured values under rain-fed conditions were lower than the simulated values, validating the above claims to some extent.

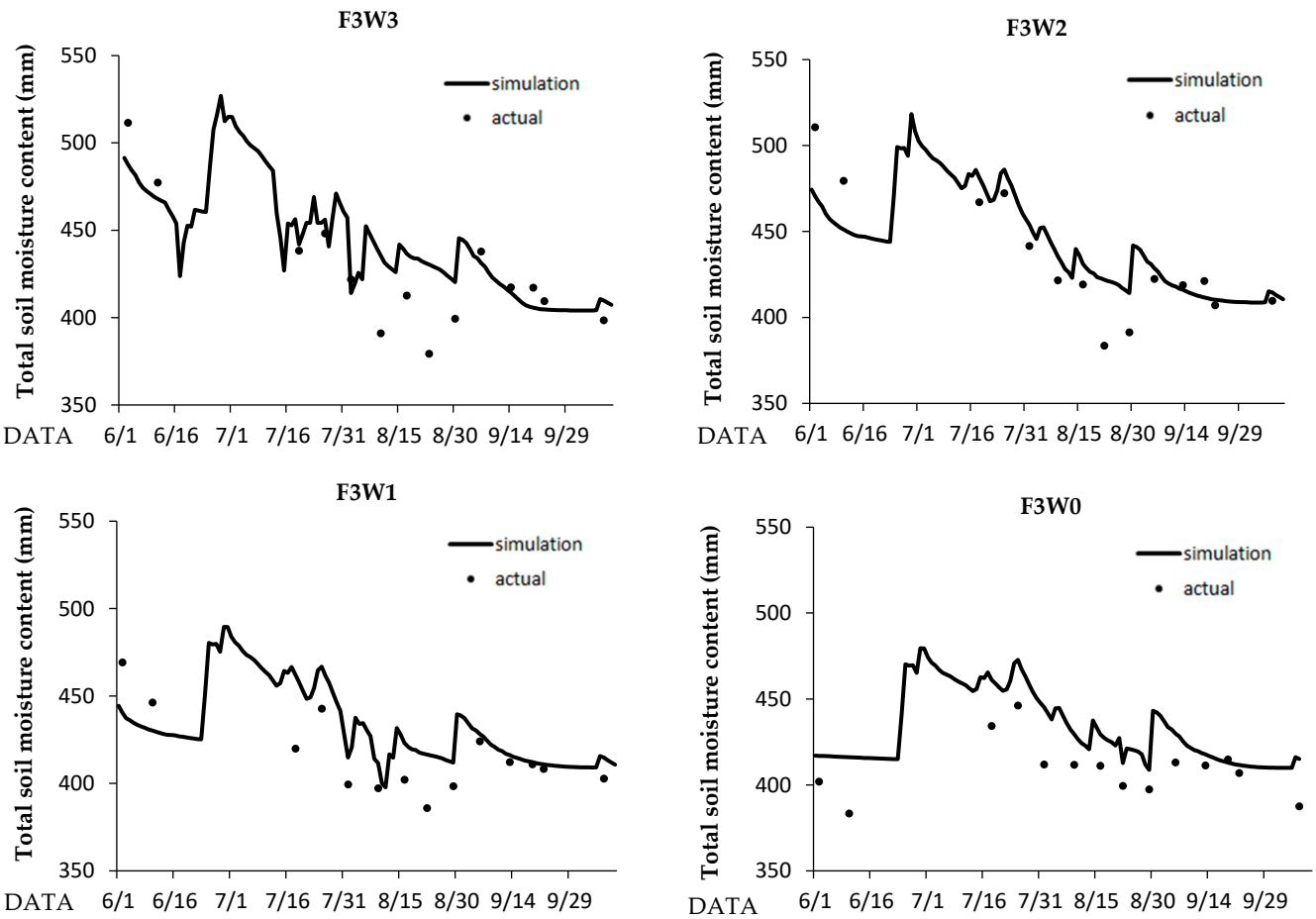

Figure 2. A validation model comparing the measured data of total soil water content for the 2018 corn season.

3.3. Canopy Cover Development

The simulation results of crop canopy coverage in 2018 showed that, when simulating the change trend of crop coverage in the whole summer maize-growing process, the simulated change trend was basically consistent with the measured change trend, and the evaluation index values were all in the range of good applicability, proving that the model had good applicability in the summer maize-planting process in the North China Plain. This result is also similar to the research findings of Abdalhi [29], Jin [33], and Kim [34], as the model is unable to make a comprehensive response to the impact of extreme weather, but it is generally in line with crop growth conditions, and the difference in evaluation index values are within an acceptable range, meaning that they do not affect the use of the model (Table 5).

Table 5. The measured canopy coverage data for the 2018 maize season verified the evaluation index values of the model.

Treatments	b	R^2	RMSE (%)	ARE (%)	EF
F3W3	0.93	0.92	10.2	11.1	0.89
F3W2	0.88	0.87	13.2	13.1	0.87
F3W1	0.87	0.84	11.5	11.6	0.82
F3W0	0.90	0.86	15.2	15.7	0.86

From the experimental results (Figure 3), we can see that AquaCrop has a good simulation effect for simulating crop coverage (CC). The calibration and validation of this manuscript are based on crop coverage, meaning that in this part of the results, the

relative fit between the simulated and measured values is relatively high. When calibrating the model, the F3W3 treatment was used as the benchmark, meaning that the validation result had the highest fit when using this treatment. For other treatments, although the fit was less good than that of the F3W3 treatment, it was within an acceptable range. After verification, the correctness of this result was also proven. Therefore, model calibration can provide guidance for agricultural production in the experimental area by applying the model to practical tasks. For the F3W0 treatment, due to the rain-fed conditions, the results were more affected by climatic conditions, resulting in the lowest fit of the four treatments. The main reason for the significant difference was that the model was unable to simulate extreme weather, while the target area was conducted in a field environment during this experiment, which could not prevent interference from natural events such as strong winds. Moreover, extreme weather cannot be expressed through models, as it leads to significant differences. However, in the actual production process, the probability of extreme weather occurrence is relatively low, and although extreme weather occurred during this experiment, the simulation results are within an acceptable range. Therefore, although AquaCrop cannot temporarily negate the impact of extreme weather, this weather does not affect the simulation's accuracy. It should be noted that in areas where extreme weather events frequently occur, it is not recommended to use AquaCrop for data acquisition.

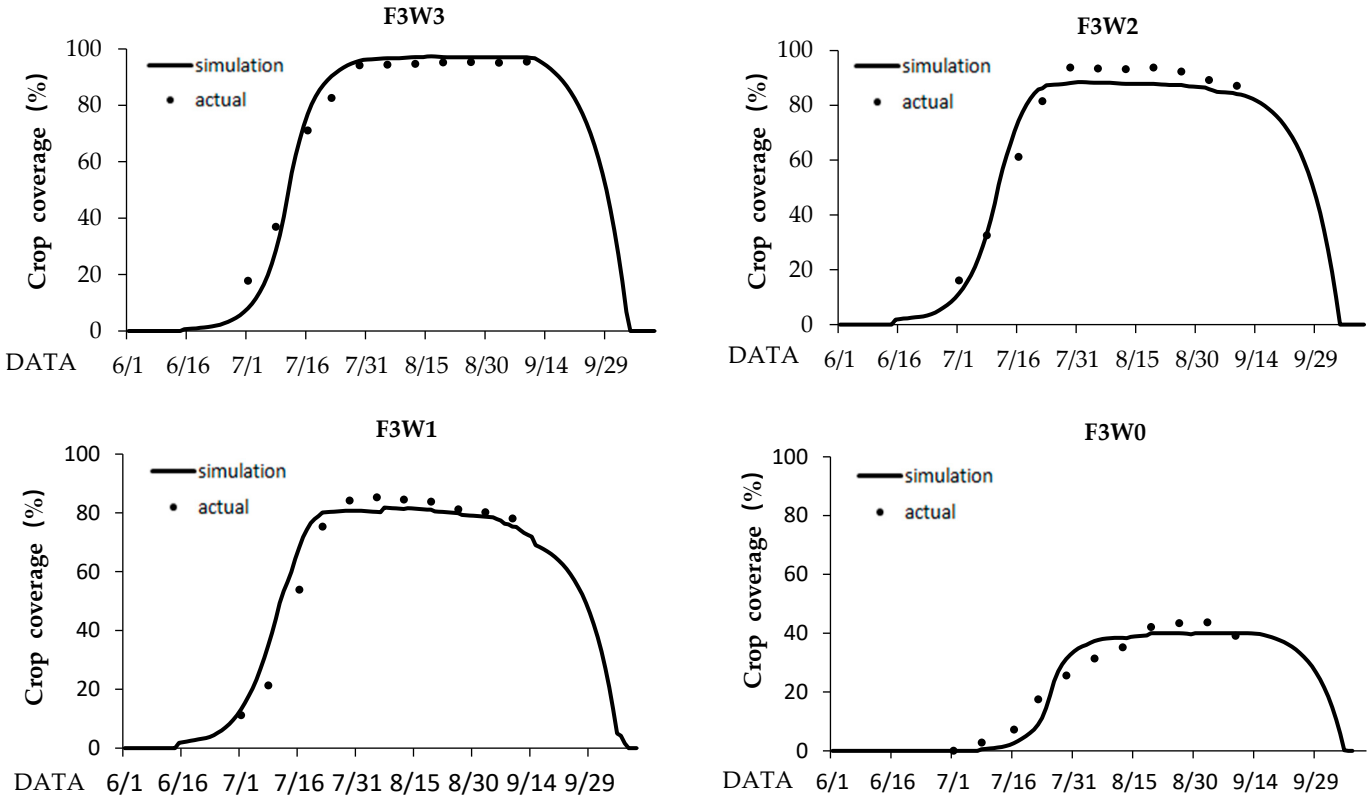

Figure 3. A validation model comparing the measured data of crop canopy coverage for the 2018 maize season.

3.4. Grain Yield and ET

The 2018 output simulation results (Figure 4) show that the simulated value of the final total dried yield of summer maize basically conforms to the measured value, while the value of the total dried yield of summer maize under each water treatment conforms to the actual situation in the field. The difference in the total dried yield when using the rain-fed treatment is obvious. The summer climate in the test area in 2018 was an extreme outlier, with little rainfall and frequent strong winds being recorded, while the plants in the rain-fed treatment were prone to collapse; the model cannot take this factor into account. Therefore,

the predicted value is much higher than the measured data. The results of Shirazi et al. [35] showed that AquaCrop has a deviation of no more than 11% when simulating summer maize yield and biomass, similar to the results of this study. This result is also similar to the research findings of Thamer [36] and Ran [37].

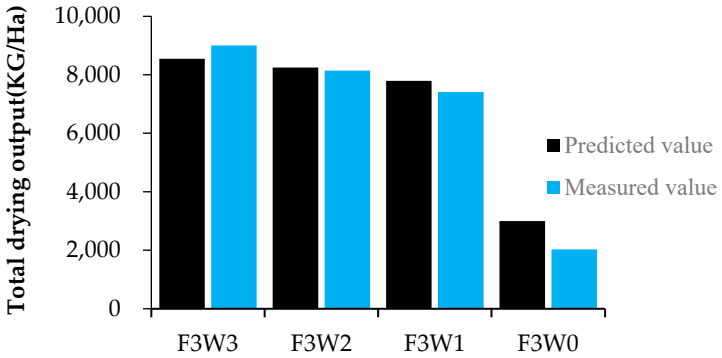

Figure 4. A validation model comparing the measured data of the corn crop yield in 2018.

The evapotranspiration treated in the test area in 2018 was simulated via the adjusted model. Compared with the measured data, we found that the value predicted by AquaCrop is basically consistent with the measured value when simulating field evapotranspiration, showing good applicability, and proving that the model can be applied to simulate and calculate field evapotranspiration. On this basis, relevant studies of water-use efficiency in the target test area were carried out. The experimental results are shown in Figures 5 and 6.

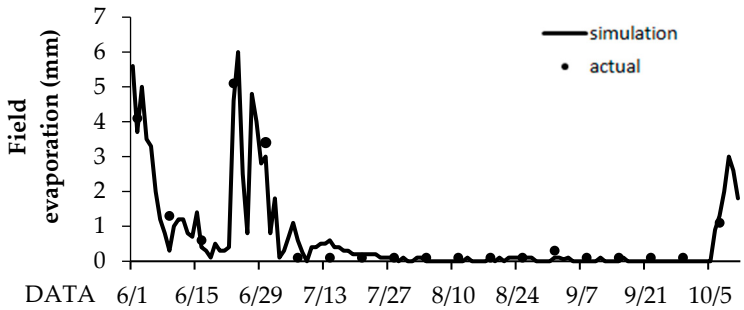

Figure 5. A validation model of field evaporation measured data for the 2018 corn season.

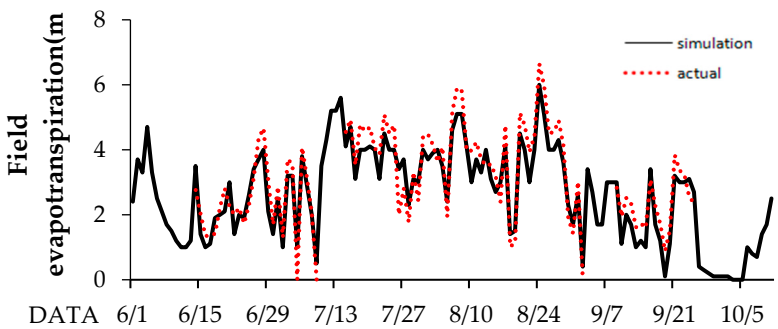

Figure 6. A validation model of field evapotranspiration measured data for the 2018 corn season.

AquaCrop has a high fit between the field yield and the measured values (Figure 4), and the significant difference occurs for the rain-fed treatment (F3W0). This was caused by the extreme weather that occurred during the experiment, i.e., several days of strong winds. For the rain-fed treatment, crop growth was poor, and lodging was very severe during windy weather, resulting in significant differences in the yield results. However, the strong winds cannot be reflected in the model, which means that the model assumes

that the crops experienced normal growth conditions, meaning that the actual yield is significantly lower than the simulated yield. However, the other three irrigation treatments obtained relatively sufficient nutrient input during the crop growth process, and the crops have strong wind resistance, meaning that the impact was relatively low and there was no significant difference; however, in the experimental results, the yield was affected to some extent, with the measured values being lower than the simulated values, with a trend of increasing yield differences as the irrigation amount decreases. As the extreme climatic conditions in the North China Plain were accidental events, which do not affect the feasibility of using AquaCrop in the target area, the simulation effect of the model under different water-stress conditions in the test area was good, and it can be used as a source of simulation data for agricultural production research in the region. In Figures 4 and 5, AquaCrop has a very high fit between the measured and simulated values when simulating field evapotranspiration, and it shows no significant overall difference. Among all the evaluation objectives in this article, it is the only one not affected by extreme climate. The main reason for this is that the extreme climate in this experiment was mainly caused by continuous strong wind, which leads to crop plant lodging. Although crop growth, development, and yield were affected to some extent, the crops remained in a covered state, so the impact on soil evaporation was not significant. The relatively small impact on evapotranspiration within the experimental area shows a high degree of fit. From this, it can be concluded that AquaCrop obtains relatively accurate data when simulating field evapotranspiration. If it is used as a source of experimental data for studying field evapotranspiration, it is relatively accurate, providing a reliable source of data acquisition for subsequent research.

4. Conclusions

AquaCrop can be used to model the effects of different water treatments on summer maize yields in the North China Plain. The model accurately simulates the soil water content in the root zone, as well as changes in grain yields and aboveground biomass.

After calibrating the model parameters with the measured data in 2017, through the evaluation, analysis, and comparison between the measured field data for 2018 and the simulation results of AquaCrop, we concluded that AquaCrop had a good simulation effect on the summer maize yield, canopy development, soil total water content, and the ET change process in the hilly area of the North China Plain under four different water-treatment conditions. The simulated value was basically consistent with the measured value, and the change trend was also basically consistent. The evaluation index values B, R^2, and EF were all around 0.9. The values of the RMSE and ARE were between 10% and 20%, indicating that the model has an excellent simulation ability for water stress and can be applied for studying crop yield and water-use efficiency. Although it does not fully consider the impacts of extreme weather and environmental factors such as pests and diseases, AquaCrop can be applied for studying the crop growth and soil moisture processes in the Henan Fengqiu region of the North China Plain under hydrodynamic conditions, and the data generated via the simulation can serve as a basis for future research in this region.

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