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CALIBRATION AND VALIDATION OF AQUA CROP FOR FULL AND DEFICIT IRRIGATION OF HOT PEPPER

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ABSTRACT

This paper reports on a study whose objective was to calibrate and test Aqua Crop for hot pepper grown under full and deficit irrigation in a tropical humid coastal savanna zone in south-central Ghana (Cape Coast). The calibrated Aqua Crop model concentrated on its performance to predict crop yield and seasonal crop water requirement (ETc). Four treatments were investigated: T_1 (100% ETc), T_2 (90% ETc), T_3 (80% ETc) and T_4 (70% ETc). Aqua Crop could not simulate accurately the yield of hot pepper for all the treatments with the exception of Treatment T_2 which was simulated with the lowest deviation of 4%. On the other hand, the model was able to simulate the seasonal water requirements to an appreciable degree in both experiments. It must be pointed out that the calibration of Aqua Crop suffered from a lack of data on the progress of crop canopy cover which is a very important parameter used in developing the model.

Keywords: hot pepper, aqua crop, calibration, water requirements, yields.

1. INTRODUCTION

It is estimated that between 16950 and 18600km^3 of water is consumed annually in global food production (Rockstrom *et al*., 2007). Out of this, 35% is green water consumed under rain-fed crop production, 10% blue water consumed under irrigated crop lands and 55% green water consumed by pastures (Ridoutt *et al*., 2009). According to Rockstrom *et al*. (2009), holding the current rates of agricultural water use efficiency constant, an estimated additional amount of 5700km^3 of fresh water will be required annually to meet the estimated food demand in 2050. The threats of climate change exacerbate this imposing challenge and raise concerns over food security and sustainability.

Simulation models that quantify the effects of water on yield at the farm level can be valuable tools in water and irrigation management. Modelling tools that support management decisions with regard to efficient water use in crop production are essential. Aqua Crop is a new decision support tool useful in modelling and devising strategies for efficient management of crop-water productivity at farm level. To make Aqua Crop globally applicable, it must be tested in different locations with different soil conditions, crops, agronomic practices and climatic conditions. Calibration and performance evaluation has been done for cotton by Farahani *et al*. (2009) and Garcia-Vila *et al*. (2009) and for maize by Heng *et al*. (2009) and Hsiao *et al*. (2009).

Given the economic importance of hot pepper in Ghana, it was felt that Aqua Crop could be used to study the crop's response to various levels of water application. Ultimately, this would lead to a better understanding of how to improve on the yield of pepper through the adoption of optimal water management practices. The primary objective of this work was thus to calibrate and test Aqua Crop for hot pepper grown under full and deficit irrigation in a tropical humid coastal savanna zone in south-central Ghana (Cape Coast).

2. MATERIALS AND METHODS

2.1. Study area

The study area was the School of Agriculture Teaching and Research Farm at the University of Cape Coast, located at latitude 5^{o}06' N and longitude -1^{o}15'W at an altitude of 1.1m in the Cape Coast municipality, which lies in the coastal savanna agro-ecological zone of Ghana. The soil is described as sandy loam with characteristics as neutral to slightly acidic in reaction and with a pH of 6.5. According to Owusu-Sekyere *et al*. (2010), the annual temperature is 23.2-33.2ºC with an annual mean of 27.6ºC and a relative humidity of 81.3-84.4%. The study area experiences two rainy seasons namely the major season which starts from May and ends in July, and a minor season that starts around September and ends around mid November to give way to the dry Harmattan season that runs till the end of March in the subsequent year.

In all, two field experiments were carried out (November, 2010 to March, 2011 and January, 2011 to May, 2011) (Table-1). Both experiments were conducted under a rain shelter and involved the growing of hot pepper in buckets filled with sandy loam soil using an irrigation interval of two days with different irrigation treatments. The data from the first experiment were used to calibrate the model whilst the second experiment was used to validate it.

Table-1. Duration and dates for the various growth stages for both experiments.

Growth stage	Duration (Days)	1st Experiment	2nd Experiment
Initial	16	18/11/10 - 4/12/10	26/1/11 - 8/2/11
Development	30	5/12/10 - 5/1/11	9/02/11 - 10/03/11
Mid-Season	50	6/01/11 - 26/02/11	12/03/11-30/04/11
Late Season	22	27/02/11 - 18/03/11	1/05/11 - 22/5/11

2.2. A short description of aqua crop

Steduto *et al*. (2009) have described the conceptual framework, underlying principles, and distinctive components and features of Aqua Crop. The structural details and algorithms of Aqua Crop have also been reported by Raes *et al*. (2009). Aqua Crop is a menu-driven program with a well-developed user interface. Menus (Windows) are the interface between the user and the program. Multiple graphs and schematic displays in the menus help the user to discern the consequences of input changes and to analyze the simulation results. From the main menu, the user has access to a whole set of menus where input data is displayed and can be updated. Input data consist of climate data, crop, management and soil characteristics that define the environment in which the crop will develop. Before one simulates, the simulation period and the initial conditions at the start of the simulation must be entered.

When running a simulation, the user can track changes in the soil water content and the corresponding changes in the crop development, soil evaporation, transpiration, evapotranspiration rate, biomass production and yield.

Simulation results are stored in output files and the data can be retrieved in spread sheet format for further processing and analysis. Program settings allow the user to alter default settings and also reset to their default values again.

2.3. Creating input files

2.3.1. Climate file

Creating a climate file consists of selecting or creating a Temperature file, ETo file, Rain file and CO_2 file. When creating these files, the user has to specify the type of data (daily, 10-daily or monthly data), the time range and the data. Existing climatic data can also be pasted in an ETo, Rain or Temperature file as long as the structure of the file is respected.

Temperature and rainfall data covering the period of the experiments were obtained from thermometers and a rain gauge situated at the farm where the experiments were conducted. A US Class A evaporation pan was used to estimate the daily reference evapotranspiration (ETo) over the growth season by using the equation:

ETo = Kp × Epan, Where

Kp = Pan co-efficient
Epan = Pan evaporation (mm/d)

As the experiments were conducted under a rain shelter, the Rain file contained only zero values even though there were rainfall events over the seasons.

The default CO_2 file supplied with Aqua Crop was used.

2.3.2. Crop file

When creating a crop file, the user selects the type of crop (Fruit/Grain producing crops, Leafy vegetable crop, Roots and tubers of Forage crops) and specifies a few parameters. With the help of this information Aqua Crop generates the complete set of required crop parameters. The parameters are displayed and the values can be adjusted in the Crop characteristics menu.

Four growth stages were considered namely: the initial stage (excluding seedlings at the nursery), the development stage (period of rapid growth of the crop, also known as vegetative stage), the mid-season stage (flowering and fruiting stage), and the late season stage (full maturity and ripening of fruits) were considered for the two experiments conducted.

2.3.3. Irrigation schedule

When creating an irrigation schedule the user specifies the time and the application depth of the irrigation events. In both experiments, a two-day interval irrigation schedule was adopted, and the volume of water to be applied on each two-day interval was derived from the computed loss in weight of each bucket with plant over the last two-days. The equivalent in volume basis was found and applied to the plants according to the various treatments. Irrigation days for both experiments amounted to 59 days out of the 118 days of the growing period. Irrigation files were created for each of the treatments in the two experiments.

2.3.4. Soil file

When creating a soil file, the user has to specify only a few characteristics (soil type, depth of soil etc). With the aid of this information, Aqua Crop generates the complete set of soil parameters. The parameters and values can be adjusted in the Soil Profile Characteristics menu. The texture of the soil was sandy loam.

2.4. Aqua crop model parameterization

Some crop parameters were assumed to be conservative (i.e., their values do not change) while the user-specific parameters were estimated from the first experiment (Tables 2 and 3).

Table-2. Conservative parameters of aqua crop used in simulation.

Description	Units/Meaning	Value
Base temperature	^0C	10
Upper temperature	^0C	30
Soil H_2O depletion factor, canopy expansion	Upper threshold (p-exp)	0.25
Soil H_2O depletion factor, canopy expansion	Lower threshold (p-exp)	0.55
Coefficient of positive impact on HI	Vegetative growth	10
Coefficient of negative impact on HI	Stomatal closure	8
Allowable maximum increase of specified HI	%	15
H_20 productivity normalized for ETo and CO_2	gram/m^2 (WP*)	17
H_20 productivity normalized for ETo and CO_2 during yield formation	gram/m^2 (WP*)	100

Table-3. User-Specific parameters used in simulation.

Parameter	Unit	Measured or calibrated
Soil surface covered by an individual seedling at (90%) recover	(cm^2/plant)	5
Number of plants per hectare	Ha^{-1}	80000
Time from transplanting to recover	Days	7
Maximum canopy cover, CCx	%	55
Time from transplanting to start senescence	Days	90
Time from transplanting to maturity, i.e. length of crop cycle	Days	118
Time from transplanting to flowering	Days	87
Length of flowering stage	Days	11
Maximum effective rooting depth	(m)	0.80
Time from sowing to maximum rooting depth	Days	70
Reference Harvest Index (HIO)	%	50
Water productivity (WP*)	g/m^2	17
Soil texture		Sandy loam

3. RESULTS AND DISCUSSIONS

The calibrated Aqua Crop model concentrated on its performance to predict crop yield and seasonal crop water requirement (ETc). As a summary of the outcome of the simulations, the simulated fruit yield and the seasonal ETc of the different irrigation treatments were compared with the measured values for the first and second experiments in Tables 4 and 5.

Table-4. Comparison between simulated and measured values of yield and seasonal ETc of hot pepper for various treatments (Experiment 1 - Calibration).

Treatment	**Yield** (t/ha)			**Seasonal ETc** (mm)		
	Measured	Simulated	Deviation (%)	Measured	Simulated	Deviation (%)
T_1	2.44	3.17	29.8	319.5	355.0	11
T_2	1.99	0.83	58.3	280.7	310.7	10.7
T_3	1.69	0.83	50.9	251.9	310.7	23.3
T_4	1.27	0.28	77.9	228.1	262.0	14.9

Table-5. Comparison between simulated and measured values of yield and seasonal ETc of hot pepper for various treatments (Experiment 2 - Validation).

Treatment	**Yield** (t/ha)			**Seasonal ETc** (mm)		
	Measured	**Simulated**	**Deviation** (%)	**Measured**	**Simulated**	**Deviation** (%)
T_1	1.63	1.94	19.0	452.0	443.0	-2.0
T_2	0.96	0.92	4.2	336.9	384.3	14.1
T_3	0.62	0.21	66.1	282.0	315.6	11.9
T_4	0.24	0.00	100.0	238.0	267.7	12.5

Table-4 indicates a rather poor prediction of the yield for the deficit irrigation treatments (T_2-T_4) with deviations of the simulated from the measured yield ranging from about 51% to 80%. However, the deviations for the full irrigation treatment was relatively lower (30%). Considering the calibrated results for the seasonal crop water requirement, the deviations ranged from 11% to 23%, indicating that Aqua Crop was able to simulate the seasonal water requirements relatively accurately.

Considering the validation experiment (Table-5), it can be seen that T_2 was quite accurately simulated by Aqua Crop as the deviation recorded was only 4%. The deviation for T_1 was relatively better than T_3 and T_4. As in the calibration experiment, the seasonal water requirement was quite accurately simulated with the deviations ranging from 2% to 14%.

4. CONCLUSIONS

From the two simulations, it can be concluded that generally, Aqua Crop could not simulate accurately the yield of hot pepper for most of the treatments with the exception of Treatment T_2 which was simulated with the lowest deviation of 4%. On the other hand, the model was able to simulate the seasonal water requirements to an appreciable degree in both experiments.

It must be pointed out that the calibration of Aqua Crop suffered from a lack of data on the progress of crop canopy cover which is a very important parameter used in developing the model.

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REFERENCES

Farahani HJ., Gabriella I. and Oweis TY. 2009. Parameterization and evaluation of the Aqua Crop model for full and deficit irrigated cotton. Agronomy Journal. 101: 469-476.

Garcia-Vila M., Fereres E., Mateos L., Orgaz F. and Steduto P. 2009. Deficit irrigation optimization of cotton with AquaCrop. Agronomy Journal. 101: 477-487.

Heng LK., Hsiao T., Evett S., Howell T. and Steduto P. 2009. Validating the FAO Aqua Crop model for irrigated and water deficit field maize. Agronomy Journal. 101: 488-498.

Hsiao TC., Heng L., Steduto P., Rojas-Lara B., Dirk R. and Fereres E. 2009. Aqua Crop - The FAO crop model to simulate yield response to water: III. Parameterization and Testing for maize. Agronomy Journal. 101(3): 448-459.

Raes D., Steduto P. Hsiao TC. and Fereres E. 2009. Aqua Crop - The FAO Crop Model to simulate yield response to water. II. Main algorithms and software description. Agronomy Journal. 101(3): 438-447.

Ridoutt BG., Juliano P., Sanguansri P. and Sellahewa J. 2009. Consumptive water use associated with food waste: case study of fresh mango in Australia. Hydrol. Earth Syst. Sci. Discuss. 6: 5085-5114.

Rockstrom J., Falkenmark M., Karlberg L., Hoff H., Rost S. and Gerten D. 2009. Future water availability for global food production: the potential of green water to build resilience to global change. Water Resources Research 44, doi:10.1029/2007WR006767.

Rockstrom J., Lannerstad M. and Falkenmark M. 2007. Assessing the water challenge of a new green revolution in developing countries, P. Natl. Acad. Sci. USA. 104(15): 6253-6260.

Steduto P., Hsiao TC., Raes D. and Fereres E. 2009. Aqua Crop - The FAO Crop Model to simulate Yield Response to water: I. Concepts and Underlying Principles. Agronomy Journal. 101(3): 426-437.