Evaluation of the FAO Aquacrop Model for Bell Pepper (*Capsicum annuum* L.) Crop Water Productivity under Deficit Irrigation

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Abstract

With the drive to determine solutions for water scarcity during crop production, crop production models, such as AquaCrop, were used to model the crop water productivity of bell pepper. This study was conducted in La Paz, Zamboanga City, Philippines, to simulate and validate the crop water productivity of the Emperor F1 variety of bell pepper cultivated under deficit irrigation. Bell peppers were produced until the onset of flowering, randomly arranged according to three levels of irrigation applied, which are 80%, 70%, and 60% of the full irrigation treatment. Calibration of AquaCrop was conducted following a full irrigation treatment. The model was validated following the variation in the amount of irrigation applied. Plant height, leaf length, fresh and dry-above-ground biomass, and crop water productivity were determined and statistically analyzed. Modeling resulted in excellent goodness of fit for the RMSE test and moderate agreement for the index of agreement. This study showed that deficit irrigation is a viable method in water management for bell pepper production, especially in farm areas where water rationing is limited. Using AquaCrop to simulate crop water productivity is a feasible solution to help farmers determine whether the intended irrigation strategy will best fit bell pepper production.

***Keywords**:* AquaCrop, bell pepper, crop production model, crop water productivity, deficit irrigation

1. Introduction

Crop production relates to the growing of crops for food, feed, and raw materials for consumer goods and industries. Water management is essential as agriculture rates 80% of the total water consumed as compared to water utilized for industries and households (Inocencio and Barker, 2018). During a press interview last March 28, 2023, President Ferdinand "Bongbong" Marcos Jr. said that the Philippines is experiencing a water crisis affecting many sectors, most especially agriculture, for which water management will be a great solution to such a problem (Antonio, 2023). When there is a limited water supply, the response typically will be to develop methods to increase the water supply or operate existing irrigation systems or methods appropriately. Among these responses is to improve water productivity in crop production. It has the notion of producing more while utilizing less water. But because of the complexity of plant systems and behaviors, crop modeling was conceptualized to mimic these systems and allow empirical adjustments to tally what is simulated and observed in the actual field (Brauman *et al*., 2013). The concept of crop water productivity (CWP) results from the drive to prevent water scarcity, but it is also applicable to areas where water scarcity is not experienced. As described by Letseku and Grové (2022), CWP is the fraction of yield formed by the crops to water utilized by the crops. Yield, as part of the equation, is a factor affected by the genetic make-up of the crop, the surrounding environment, and agronomic management factors that may indirectly influence achieving high CWP. The water consumed or applied affects the water use determination, which is influenced by the planting date variations, plant maturity, irrigation, and agronomic methods. Determining these factors is essential in achieving high CWP (Salman *et al*., 2020). However, because of the complexity of plant systems and behaviors, crop modeling was conceptualized to mimic these systems and allow empirical adjustments to tally what is simulated and observed in the actual field (Brauman *et al.,* 2013).

Field experiments are among the traditional methods of conducting agronomic research which entails laborious fieldwork, time, and cost. Acquiring data will take time and that data will be site and season specific. With these, using crop simulation models (CSMs) such as the FAO AquaCrop will help create opportunities to explore crop production and field experiments through modeling (Kephe *et al*., 2021). Crop growth is a multipart process that includes the interaction of soil, water, and weather. To ease field experiments, models to simulate crop growth have been utilized. These models are mathematical algorithms and formal representations of quantitative data representing interactions of the plants with the environment and simulating crop growth, development, water utilization, yield performances, and nutrient consumption. With the utilization of weather data and other environmental data essential for plant growth, crop simulation models can simulate seasons, sites, situations, and treatments in a short period (Asseng *et al*., 2014). There are numerous CSMs utilized to simulate the soil-plant-atmosphere system, and these include DSSAT (Decision Support System for Agrotechnology Transfer), CropSyst (Cropping System Simulation Model), and AquaCrop, among others. Unfortunately, some of these models need numerous data to be inputted that are inaccessible to users (Lopez-Urrea *et al*., 2020). According to the Food and Agriculture Organization of the United Nations (2017), AquaCrop is an easy and tough crop growth model. With the issues of crop cultivation and concerns about food security in mind, AquaCrop was developed. AquaCrop represents the relationship and interaction between water and the soil, starting from the absorption of water from the soil, canopy growth, and root development, and production of yield and biomass of the crop (Salman *et al*., 2021). It utilizes reasonably few specific input parameters but is based on challenging scientific bio-physical processes. It consists of a component that determines the water needed for the growth of herbaceous crops and a module that applies the connection of biomass to transpiration. It presents parameters relative to the crop's agronomy on daily, calendar days, or growing degree days (GDD) (Adeboye *et al*., 2020). AquaCrop has been successfully applied in various crops to provide a sound theoretical framework when investigating yield in relationship to environmental stress. Various herbaceous crops were successfully utilized to simulate the growth and yield of crops that were subjected to variations in the water content of the soil. AquaCrop has been used in various related research such as sowing optimization, deficit irrigation, predicting and increasing water use efficiency, evapotranspiration forecasting, yield estimation, biomass assessment, and canopy cover estimation (Ćosić *et al.,* 2017). It also encompasses studies on fertility levels and water management (Steduto *et al*., 2009).

Water management has been a challenge for organic farmers. Moreover, various undertakings to reduce water wastage were also utilized such as interchanging wetting and drying over the area (Benchmark Labs, 2022). Bell pepper is considered a high-value crop and has rendered higher income for producers. But despite this gain, there was a decline in bell pepper production each year, in terms of total yield, with an average decrease of 0.71% due to a decline in soil fertility and water shortage (Poliquit and Briones, 2022). Thus, there is a need to optimize the irrigation system for organic bell pepper production. This study aimed to simulate and validate the crop water productivity of bell pepper (*Capsicum annuum* L.) grown under deficit irrigation using the FAO AquaCrop from transplanting to flowering stage.

2. Methodology

2.1 Study Site

Figure 1. Location of SARAI PCA-ZRC Zamboanga del Sur Station and the study area

The study was conducted in La Paz, Zamboanga City, Philippines (7° 1' North and 121° 59' East) with an elevation of 600 meters above sea level. The climatic condition of Zamboanga City is a Type III Zone category based on the Modified Corona's Climate Classification (DOST-PAGASA, 2024). This means that no distinct maximum rain periods together with rapid dry seasons are experienced, continuing from one to three months, and it is relatively dry from November to April. The weather data gathered for the study includes sunshine duration in hours, minimum and maximum temperature (°C), wind speed ($m.s^{-1}$) at 2 m height, actual vapor pressure (kPa), and rainfall (mm). These data were requested from the SARAI PCA-ZRC Zamboanga del Sur station at San Ramon, Zamboanga City, around 4.30 km from the study area, as shown in Figure 1. Though there is another PAGASA station in Zamboanga City located near the Zamboanga International Airport, this station is around 22 km from the study area of which the weather data that may be gathered from the station may not represent the conditions in the study area. A soil analysis was conducted before land preparation. Results showed that the experimental area's soil texture is clay with 81.65% water holding capacity and is acidic with a pH of 5.0. The farmers in the study area generally practice floriculture and cultivate vegetables when the demand for flowers is low. The specific location of the study area is where the farmers usually plant their vegetables for an alternative source of income.

2.2 Research Design and Sampling Method

The study was arranged following a complete randomized design experiment where the amount of water applied was the factor considered. Three levels of water application were applied from transplanting until the flowering stage only: 80%, 70%, and 60% of the full irrigation requirement. The study has three treatments replicated six times with twenty bell pepper plants in each replicate. A systematic sampling was applied during the on-farm data collection, where each of the eighteen plots was subdivided into five sections. For the study, there was a total population of 360 bell pepper plants. The sample size needed 90 plants since only five plants were chosen per replicate. To get the interval, the total population was divided by the sample size. Therefore, an interval of four was used, meaning every fourth plant was selected for the sample, where the starting point was the first bell pepper plant from the top of the left section of the plot.

2.3 Research Site Preparation and Agronomic Practices

Before simulating using the FAO AquaCrop, the researcher first identified the farm and farmer cooperator practicing organic agriculture. Cultural and management practices relevant to organic agriculture were discussed and established with the farmers and the Zamboanga City Office of the City Agriculturist Organic Agriculture Program focal person. A land area of 200 square meters was prepared, and the tilled area was divided into eighteen plots as the model validation site, 1.0 meters in width with two rows per plot spaced at 60.0 cm per hill (Department of Agriculture RFO No. 2, 2017). Two plots were also prepared separately for calibration. The Emperor F1 bell pepper variety was used in the study. This bell pepper variety is high-yielding and propagates well in locations with mid-elevation (Republica, 2020). One sack (25 kg) of dried and decomposed chicken manure was applied per plot before placement of plastic mulch. For the fertilizer application, Effective Microorganism Activated Solution (EMAS) organic fertilizer was used on the third and fourth week after transplanting equally across all treatments in the morning. Spraying of Parker Neem Tonic Organic insecticide was sprayed once a week starting on the second week after transplanting. The seedlings were transplanted after four weeks, with bell pepper seedlings having at least four to five true leaves. Each hill was planted with one seedling. Transplanting was done in the afternoon to prevent transplant shock, and plants were watered instantly to allow the roots to have soil contact.

2.4 Water Application and Monitoring of Soil Moisture

During irrigation, plants were watered manually, and water was measured using a graduated cylinder to measure the volume of water properly. The Maximum Allowable Depletion (MAD), which is 25% of the field capacity for bell peppers (Maughan *et al*., 2015), was the basis for the irrigation depth. The depth of irrigation water during application at the vegetative to flowering stage was computed using Equation 1 (Andales *et al*., 2011). Equation 2 was then used to determine the volume of water applied per treatment.

$$DMAD\ (mm) = \frac{MAD}{100}\ x\ AWC\ x\ Drz \quad (1)$$

$$Volume\ of\ water\ (L) = DMAD\ x\ [\Pi\ (radius\ of\ CC)^2]\ x\ [\frac{1000}{(1000)^3}] \quad (2)$$

where DMAD is the water depth in millimeters, the volume of water is in liters, CC is the canopy cover of the bell pepper in millimeters, MAD is the management-allowed depletion in percent, AWC is the available water capacity of the root zone in inches of water per inch of soil (0.12 for clay soil [Andales *et al*., 2011]), and Drz is the root zone depth in millimeters (457.2 mm for vegetables at the vegetative stage [Andales *et al.*, 2011]). For this study, a radius of 190.5 mm canopy cover (Cho *et al.*, 2010) was used to compute CC. The DMAD for full irrigation during application at the vegetative stage is 14 mm. For the different treatments at 80%, 70% and 60% of the full irrigation requirement, 11 mm, 10 mm, and 8 mm depth of water was applied, respectively. Table 1 presents the summary of values used to solve for DMAD and the volume of water applied per treatment.

Table 1. Summary of values used to compute the depth and volume of water applied per treatment

Treatment	Depth of Water Applied					Volume of Water Applied	
	MAD (%)	AWC (in.in^{-1})	Drz (mm)	Water Reduced (%)	D_{MAD} (mm)	CC (mm)	Volume (L)
Full irrigation	25.0	0.12	457.20	0.0	14.0	190.5	1.60
80%	25.0	0.12	457.20	20.0	11.0	190.5	1.25
70%	25.0	0.12	457.20	30.0	10.0	190.5	1.15
60%	25.0	0.12	457.20	40.0	8.0	190.5	0.90

Using a digital soil moisture meter, soil moisture was measured before transplanting and two days after water application from each section. The average soil moisture for each plot was also computed. Soil moisture was measured two days after irrigation application to determine how much water was held in the pore spaces after excess water had drained off. The digital soil moisture meter was inserted vertically with 2/3 of the depth (127 mm) of the probe and halfway between the plant and the edge of the hole of the mulch.

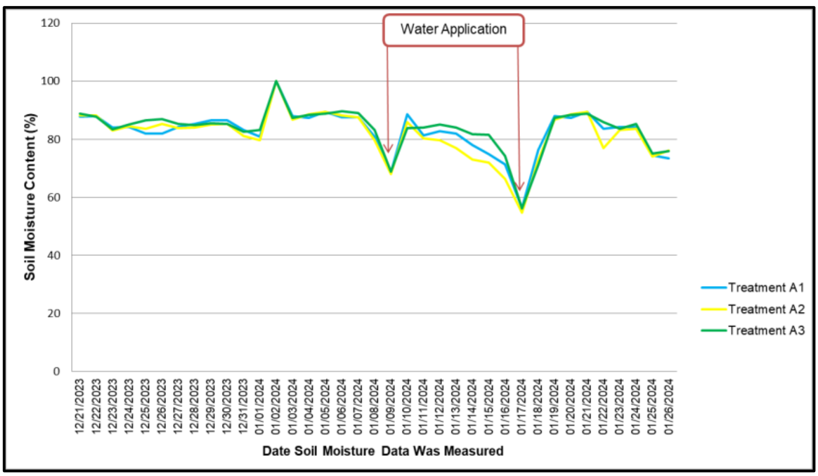

Figure 2. Graphical presentation of the measured soil moisture content from December 21, 2023, to January 26, 2024

From transplanting to the onset of flowering, the total depth of irrigation water applied plus rainfall was 51.90 mm, 49.90 mm, and 45.90 mm for water used at 80%, 70% and 60% of the full irrigation, respectively. Figure 2 presents the graphical presentation of the soil moisture content gathered from December 21, 2023, to January 26, 2024. Two irrigation events occurred in the validation area, where at this time, the soil moisture had already depleted by 25% from the last irrigation event. The reference soil moisture was measured after 2 days if a rainfall event occurred.

2.5 Crop Data Collection and Water Productivity

One bell pepper plant was randomly selected per section to measure the plant height, leaf length, and fresh and dry aboveground biomass. The growth of the bell pepper was observed from its emergence until the harvesting of the fruits. Since the bell peppers were transplanted and the study is limited only to transplanting until the flowering stage, the crop parameters necessary as inputs in AquaCrop included the date of transplanting, number of days to maximum canopy cover, flowering and maturity, plant spacing, and planting density. The plant height was measured from the stem base above the soil to the tip of the apical bud. In measuring the leaf length for each plant, three leaves were selected: one from the bottom, middle, and top. The leaf length was measured using a ruler from the tip to the stem level, and the average leaf length was computed for each selected plant. Information on the crop's total fresh and dry weight during the flowering stage was gathered to calculate the above-ground plant biomass. Five identified crops per plot were uprooted, and the fresh weight of the crop, not including the roots, was measured on a weighing scale. The fresh weights of the plant were recorded separately. The fresh plants were oven-dried for 48 hours at 60ºC until a constant weight was reached. The dried bell pepper's weight was measured after oven drying. To determine the Crop Water Productivity (CWP) of the study based on crop data gathered, dry above-ground biomass and total irrigation water input from transplanting to flowering were determined. Equation 3 was used to compute the crop water productivity.

$$Crop\ Water\ Productivity\ \left(\frac{kg}{m^3}\right) = \frac{dry\ above\ ground\ biomass\ (kg)}{total\ water\ used\ (m^3)} \qquad (3)$$

2.6 Model Calibration and Validation

In calibrating the AquaCrop model, the reference field with forty bell pepper plants entailed non-limiting conditions relative to water applications. The parameters calibrated were based on the data collected during the actual experiment in the reference field. Parameters calibrated were the calendar days from day one after transplanting, canopy development, flowering, maturity, planting density, and maximum rooting depth. Calibration was done until a good fit of the actual and simulated values was attained. The AquaCrop model was validated using the data observed and recorded from different water application treatments, specifically for 80%, 70%, and 60% of the full irrigation requirement, and was compared to the simulated data in AquaCrop.

No default values in the AquaCrop files relevant to bell pepper result in a need in AquaCrop calibration according to the crop production parameters measured at the reference calibration plots. During the calibration of the AquaCrop software, there were three iterations made until the evapotranspiration water productivity resulted in a good fit for RMSE and d-index, where RMSE must have a low value and d-index must be nearer or equal to 1. The crop parameters used in the third iteration of calibration and simulation of the bell pepper growth and water productivity grown specifically in La Paz, Zamboanga City, Philippines, using the Emperor F1 variety of bell pepper, as well as the method of determining these values, are presented in Table 2. The base temperature (10°C) and upper temperature (30°C) values were given in the AquaCrop software based on the inputted climatic data. Initial canopy cover (0.25%), canopy cover per seedling (15 $cm^2.plant^{-1}$), and plant density (16,667 plants per hectare) were estimated in AquaCrop based on the inputted row and plant spacing of 0.6 m by 1.0 m. The reference harvest index is 50% for all cultivars. The maximum canopy cover is 40% very thinly covered. The observed values for biomass were taken 40 calendar days from day 1 after transplanting.

Table 2. Parameters utilized for AquaCrop model calibration for bell pepper during the third trial of calibration

Crop Parameter	Value	Method of Determination
Base temperature (°C)	10°C	A
Upper temperature (°C)	30°C	A
Initial canopy cover (%)	0.25	E
Canopy cover (CC) per seedling ($cm^2.plant^{-1}$)	15	E
Number of plants per hectare	16 667	E
Number of plants per m^2	1.7	E
Maximum canopy cover (CC) in fraction soil cover (%)	40	E
Maximum effective rooting depth (m)	1.00	L
Water productivity normalized for ET_0 and CO^2 (WP*) (g/m^2)	17	A
Reference harvest index (%)	50	L
Calendar days from day 1 after transplanting to recovered transplant	7	M
Calendar days from day 1 after transplanting to maximum canopy cover	45	M
Calendar days from day 1 after transplanting to maturity	90	M
Calendar days from day 1 after transplanting to flowering	35	M

Note: A = AquaCrop generated, E = estimation, L = literature, M = Measured

2.7 Statistical Analysis

The accumulated agronomic data of the treatments were recorded and statistically analyzed using Shapiro-Wilk test for normality and Analysis of Variance (ANOVA) using SPSS (IBM SPSS Statistics Premium Campus Edition 22.0, Program Number: 5725-A54). ANOVA was used to determine if the means are significantly different, and a post-hoc test using Least Significant Difference (LSD) was used to determine the deviation of treatments with significant differences. The model's performance was evaluated using the Root Mean Square Error (RMSE) and Index of Agreement. The RMSE, which is expressed in percent, was used to compare the results of the simulation and the experimental data. It indicated whether the field data and the model match and determined the closeness between the two data sets. The results of the RMSE are rated excellent if the RMSE is less than 10%. It will be rated good if it is greater than 10% but less than 20%. RMSE will be fair if greater than 20% but less than 30% and rated poor if greater than 30%. For the Index of Agreement, the value of the index of agreement of 1 means that it is a perfect match. Zero will mean that there is no agreement of any kind. If the value is nearer to 1, the variables compared are more in agreement. The RMSE and d are computed using Equations 4 and 5, respectively.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (s_i - o_i)^2}{n}} \tag{4}$$

$$d = 1 - \frac{\sum_{i=1}^{n} (o_i - s_i)^2}{\sum_{i=1}^{n} \left((o_i - \underline{o}) + (s_i - \underline{o})\right)^2} \tag{5}$$

where s_i is the predicted data, o_i is the observed data, $\underline{o}$ is the mean value of o_i, and n is the number of observations.

3. Results and Discussion

Based on statistical analysis, variations in the amount of water supplied to the bell peppers did not affect plant height and leaf length at the flowering stage, as shown in Table 3. The different irrigation treatments significantly affected fresh above-ground biomass and did not affect dry above-ground biomass. The treatment with 60% full irrigation water applied has the highest value of crop water productivity. However, the statistical results presented no significant differences among treatments at the flowering stage.

Table 3. Agronomic parameters as affected by the amount of water applied

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Parameter	Treatments **100%**	**80%**	**70%**	**60%**	Grand Mean	SD	CV (%)	F-value	P-value
Plant height (mm)	397.50	382.50	305.99	366.50	363.13	70.09	19.30	1.86	.18
Leaf length (mm)	91.80	94.60	82.60	92.40	90.35	10.92	12.09	1.22	.33
Fresh Above-ground biomass (ton/ha)	0.48[a]	0.36[b]	0.20[c]	0.37[b]	0.35	0.17	48.57	3.51	.04**
Dry Above-ground biomass (ton/ha)	0.08	0.08	0.05	0.08	0.07	0.03	46.29	1.47	.26
Crop water productivity	0.0024	0.0033	0.0020	0.0043	0.0030	0.0015	50.00	3.06	.06

*** shows significant difference at P≤0.05*

3.1 Effect of Irrigation Treatment to Plant Height and Leaf Length

In a similar study by Díaz-Pérez and Hook (2017), where bell peppers were subjected to varying irrigation regimes, plant growth parameters for bell peppers were unaffected by lower irrigation regimes compared to 100% full irrigation. This result indicates that irrigation at lower regimes is adequate to maximize bell pepper vegetative growth. Even at 60% of the full irrigation treatment, irrigating the bell peppers will still result in a comparable plant height and leaf length with bell peppers watered with higher irrigation treatment. This also agrees with the discussion of Abdelkhalik *et al.* (2019) that applying deficit irrigation during the vegetative growth stage of sweet pepper will still allow the plant to recover its growth parameters comparable to those of plants with full irrigation treatments. Also, in a similar study of Díaz-Pérez and Hook (2017), decreased irrigation rates are adequate to increase vegetative growth of bell peppers. They are comparable to bell peppers applied with higher irrigation rates.

3.2 Effect of Irrigation Treatment on Above-ground Biomass

The above-ground biomass pertains to plant parts from the base of the stem to the tip of the foliage, which is an essential factor in monitoring the growth of the crop and its response to management practices applied (Rasti *et al*., 2022). In the study, there is a significant difference among the treatments in terms of fresh above-ground biomass but no significant difference in dry above-ground biomass. In a similar study by Yayra *et al*. (2015) on the effect of different irrigation regimes on onion (*Allium cepa*), different irrigation regimes have no significant effect on the total biomass and dry bulb biomass of onions. Another study by Candido *et al.* (2009) on bell peppers presented no variations in the dry weight of bell peppers in water stress conditions. The result of the study also shows that the bell peppers can still develop fresh and dry above-ground biomass at 60% of full irrigation, comparable to bell peppers watered with 80% of full irrigation.

3.3 Effect of Irrigation Treatment on Crop Water Productivity

The statistical results showed that there is no significant difference between the treatments in terms of crop water productivity. However, as the amount of water applied decreases to 60%, the crop water productivity of the bell pepper reaches a high-water productivity of 0.0039 kg.cu-1.m-1 compared to the treatment with 80% water applied, where crop water productivity is 0.0029 kg.cu-1.m-1. This result aligns with the study conducted by Bello *et al*. (2025), where the crop water productivity of bell pepper increased as the irrigation applied decreased. This also corresponds with the findings of Padron *et al*. (2015), where water productivity increases as the irrigation level decreases.

3.4 Calibration of the AquaCrop Model

The AquaCrop software was calibrated using the values during the third trial of calibration for dry above-ground biomass and evapotranspiration water productivity as affected by the different amounts of water applied. Table 4 shows the percent deviation between the actual and calibrated values for dry-above-ground biomass and evapotranspiration water productivity during the 3^{rd} iteration of calibration. Based on Table 4, the negative sign of the percent deviation indicates that the actual value is lower than the calibrated value by the AquaCrop software. This high deviation implies that the data is skewed and inconsistent with the expected value. The results showed that the actual values for dry above-ground biomass and evapotranspiration water productivity were overestimated by the AquaCrop model. This deviation also corresponds to the study of Ćosić *et al*. (2017) on sweet pepper, where the deviation between the actual and simulated values in the AquaCrop model may have been influenced by weather and soil conditions.

Table 4. Actual and calibrated values of dry above-ground biomass and evapotranspiration water productivity during AquaCrop (7.1) calibration

Parameter	Water applied	Actual	Calibrated	Standard Deviation	Deviation (%)
Dry above-ground	100%	0.05	0.08	0.02	-35.1
biomass ($ton.ha^{-1}$)		0.08	0.10	0.01	-20.0
		0.09	0.12	0.02	-26.8
Evapotranspiration	100%	0.03	0.09	0.04	-64.1
water productivity		0.04	0.12	0.05	-61.7
($kg.m^{-3}$)		0.05	0.16	0.07	-65.9

The results of the calibration of the AquaCrop model are presented in Table 5 and Figure 3. The observed and simulated data for evapotranspiration water productivity during the third trial resulted in an excellent goodness of fit with an RMSE of 8.2 %. The index of agreement in terms of evapotranspiration water productivity resulted in moderate agreement between the calibrated and observed values. These values show that there is a good match between the actual and calibrated values in the AquaCrop model.

Table 5. AquaCrop model performance for evapotranspiration water productivity during calibration

Calibration Trial	Treatment	Efficiency Criteria	
		RMSE (%)	d
1	100%	17.1	0.102
2	100%	17.1	0.102
3	100%	8.2	0.13

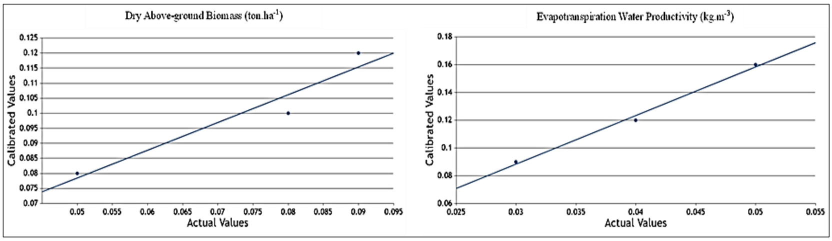

Figure 3. Actual and calibrated dry above-ground biomass and evapotranspiration water productivity during calibration of the AquaCrop (7.1) model

3.5 Simulation and Validation of the Water Productivity of the Bell Peppers

The actual values for evapotranspiration water productivity, as presented in Table 6, ranged between 0.02 kg.m-3 and 0.07 kg.m-3. Table 6 also presents the percent deviation between the actual and simulated values for evapotranspiration water productivity.

Table 6. Actual and simulated values of evapotranspiration water productivity during AquaCrop model (7.1) validation

Water applied	Actual ($kg.m^{-3}$)	Simulated ($kg.m^{-3}$)	Standard Deviation	Deviation (%)
	0.02	0.09	0.05	-77.3
80%	0.07	0.12	0.04	-41.6
	0.04	0.16	0.08	-73.0
	0.02	0.09	0.05	-79.7
70%	0.04	0.12	0.06	-68.9
	0.02	0.16	0.10	-86.2
	0.03	0.09	0.05	-70.1
60%	0.06	0.12	0.04	-47.6
	0.04	0.16	0.08	-74.0

The negative deviation between the actual and simulated values of the evapotranspiration water productivity indicates that the actual value is lower than the simulated value by AquaCrop. This deviation may be caused by the set of values used in the calibration, such as soil characteristics and weather parameters. In a similar study by Greaves and Wang (2016), it was noted that a reduction in model performance with a high percentage of deviation relative to evapotranspiration water productivity can be related to the calibration of the model using one set of soil characteristics only, which may not be representative of the entire planting area. The weather parameters used in the calibration have also affected the percent deviation between the actual and simulated values relative to dry above-ground biomass and evapotranspiration water productivity. During the calibration, data inputted specifically the rainfall data was based on the nearest AgroMeteorological station, the SARAI PCA-ZRC Zamboanga del Sur, Philippines station. This station is 4.30 km away and at a lower elevation than the experimental area. Rainfall data from the SARAI PCA-ZRC AgroMeteorological station may not be a total representation of the actual rainfall at the experimental site. This is relevant to the report of Stričević *et al*. (2023), where soil moisture as predicted by the model was higher than observed in the experimental area. It is stressed that even if the AquaCrop can simulate plant response to water, the model cannot identify local rainfall duration or heavy dew incidence, affecting the amount of soil water. Results of the validation of the model using Root Mean Square Deviation (RMSE) and Index of Agreement (d) are presented in Table 7.

Table 7. Validation of the evapotranspiration water productivity of the AquaCrop model

Parameter	Treatment	Efficiency Criteria	
		RMSE (%)	d
Evapotranspiration Water Productivity	80%	8.4	0.11
	70%	10.2	0.01
	60%	8.4	0.07

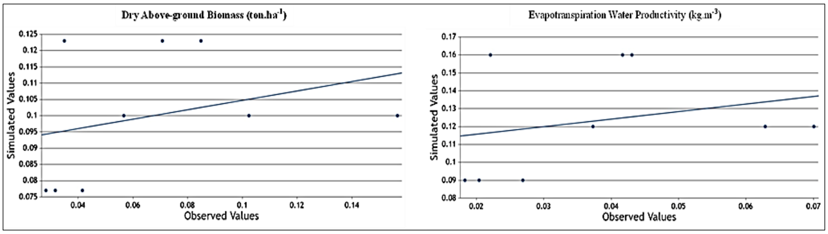

Figure 4. Observed and simulated dry above-ground biomass and evapotranspiration water productivity during the AquaCrop (7.1) model validation

As shown in Figure 4, the observed and simulated data during validation for the evapotranspiration water productivity resulted in an excellent goodness of fit. The index of agreement resulted in moderate agreement between the modeled and observed values during validation. These results imply that the AquaCrop model can generate more precise predictions. These results also emphasized that parameters relative to soil and stresses must be considered as this may post an increase in deviation between the actual and simulated values.

4. Conclusions and Recommendation

The conduct of this study showed the effect of deficit irrigation on the water productivity of bell pepper. The plant height and leaf length measured at flowering stage of the bell peppers showed that the treatment with 80% of full irrigation water applied has the highest mean but statistical results showed that there is no significant result among treatments. Variation in the amount of water supplied to the bell peppers did not affect plant height and leaf length at flowering stage. In terms of fresh above-ground biomass, the treatment where water applied was 60% of full irrigation has the highest value. Relative to the dry above-ground biomass, the treatment with 80% of full irrigation water applied resulted the highest value. Statistically, there is a significant difference among treatments in terms of fresh above-ground biomass while there is no significant difference in terms of dry above-ground biomass. The different irrigation treatments significantly affected fresh above-ground biomass and have not affected the dry above-ground biomass. Relative to the crop water productivity of the bell pepper, the treatment with 60% of full irrigation water applied has the highest value of crop water productivity. The statistical results presented no significant differences among treatments at flowering stage. But the results of the analysis showed that even with a decrease in the amount of water application, the bell pepper still resulted to high water productivity at flowering stage. Modeling the water productivity of the bell pepper using AquaCrop expressed an excellent goodness of fit for RMSE and moderate agreement for d-index results between observed and simulated values in terms of evapotranspiration water productivity. This study showed that deficit irrigation is a viable method in water management for bell pepper production, most especially in farm areas where water ration is limited. The use of AquaCrop in modeling crop water productivity showed that crop production model can aid in decision-making relevant to water management.

With the outcome of this study, it is recommended that precise data for weather, soil, and moisture parameters be determined, as this may affect the model's simulation. Crop stresses relative to water, fertilization, and salinity must also be considered to better determine the model's goodness of fit and observed data in the experimental site. Further iterations of the simulation are also recommended to calibrate the AquaCrop model better. AquaCrop modeling results can help conserve water and improve irrigation applications. In addition, it is suggested that bell pepper farmers utilize the application of deficit irrigation in drip irrigation systems to promote more water-saving management practices. It is also recommended that bell pepper farmers combine the application of deficit irrigation with mulching to conserve more water.

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