Calibration and validation of the AquaCrop model for the culture lettuce (*Lactuca sativa* L.) under fertilization levels in pluvial condition

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Abstract: The search for decision-making tools is essential in order to control agricultural practices and plan for sustainable agriculture that respects the environment. To this end, FAO has developed an evaluation model called AquaCrop, which covers most technical routes, including fertilization. In this perspective, this study focuses on the AquaCrop model (v6.1) to calibrate it for the simulation of lettuce crop yields (*Lactuca sativa* L), under different fertilization levels for the trial periods (2015-2016) and (2016-2017). Four levels of fertilization were examined under rain conditions, namely T1 (0 kg N ha^{-1}), T2 (60 kg N ha^{-1}), T3 (120 kg N ha^{-1}) and T4 (180 kg N ha^{-1}). The accuracy of the model in calibration was tested using R^2, *nRMSE* and *d*, which were $0.64 \leqslant R^2 \leqslant 0.81$; $18 \leqslant nRMSE \leqslant 46.3$ and $0.78 \leqslant d \leqslant 0.94$ for canopy cover and $0.92 \leqslant R^2 \leqslant 0.98$; $21.6 \leqslant nRMSE \leqslant 34.5$ and $0.91 \leqslant d \leqslant 0.96$ for dry biomass, respectively. The R^2, *nRMSE* and *d* values in 2016-2017 (validation year) were obtained as $0.81 \leqslant R^2 \leqslant 0.98$; $5.9 \leqslant nRMSE \leqslant 25.7$ and $0.93 \leqslant d \leqslant 1$ for canopy cover and $0.94 \leqslant R^2 \leqslant 0.98$; $14.8 \leqslant nRMSE \leqslant 24.7$ and $0.97 \leqslant d \leqslant 0.99$ for dry biomass, respectively. Based on yield and dry biomass, the T3 treatment (120 kg N ha^{-1}) gave a better yield compared to other treatments, which was demonstrated by both experimental results and model simulations. These results show that the AquaCrop model could be recommended as a practical tool to better manage fertilization where its performance is poor.

Keywords: AquaCrop, lettuce, calibration, validation, fertility stress, water productivity

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1 Introduction

Agricultural potential in Algeria is 20% focused in the north of the country, characterized by unfertile soils. These soils are distinguished by a pH above 8 and lack nutrients, low water retention capacity and very low organic matter levels, which contribute to the deterioration of crop yields. Fertilization is hypothesized to correct these deficiencies. Several authors have pointed this out in their work on Algerian soils. In this context, Boukhalfa-Deraoui et al. (2011) showed that the influence of phosphate fertilization on the behavior and yield of common wheat cultivation conducted under irrigation in arid areas increases the grain yield by 49.3% compared to the control. Haffaf et al. (2016), and Saoudi et al. (2016), who conducted trials in the same semi-arid climate, respectively, on durum wheat and barley seed production, obtained maximum yields at similar rates. These yields reach the respective values of 3.38 and 3.32

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T ha^{-1}, i.e. gains of 1.15 and 0.97 T ha^{-1}. In Tunisia and Morocco, which have a similar climate, Marouani et al. (2013) have shown poor nitrogen use efficiency in seasonal potato cultivation. This inefficiency is linked to significant losses due to leaching. Kchaou et al. (2011) compared the nitrogen fertilizer value of sludge with that of urea, using isotope marking with N15, applied to forage sorghum. These authors found that sludge inputs caused significant increases in sorghum nitrogen yields and exports, comparable to those obtained in the presence of urea. They concluded that the actual nitrogen utilization coefficient of sludge nitrogen and urea offers values fluctuating between 25% and 32%. In Algeria, Food and Agriculture Organization [FAO] (2005) reported that the use of fertilizers in agriculture is not well controlled, despite the efforts made by farmers in charge of the cereal and potato intensification program. Market gardening, which represents strategic crops in the country, is undergoing significant development. Their area of 320 100 ha in 2003, or 0.75% of the Utilized Agricultural Area (SAU), increased to 511 018 ha in 2015, or 1.18% of the SAU. Production increased from 49.08 million quintals to 124.69 million quintals, respectively Ministry of Agriculture and Rural Development (MADR, 2015). Despite its importance in the country's economy, this sector suffers from a glaring lack of a database and a scarcity of studies relating to fertilization in general and fertilizer use in particular. According to National Institute of Soil for Irrigation and Draining (INSID, 2009), fertilizers are applied in the absence of technical standards, neglecting the initial content of the soil; and consequently, inputs are often poorly fractionated, resulting in enormous waste, which is a source of soil and water pollution.

In this perspective, this study assesses the capacity of the AquaCrop model, developed by FAO (Steduto et al. 2009; Hsiao et al. 2009), to simulate water productivity of herbaceous crops at different fertility levels. Compared to other models, AquaCrop uses a relatively small number of parameters, achieving a balance between simplicity, precision and robustness (Steduto et al. 2008). AquaCrop is designed for a wide range of herbaceous crops, including cereal crops, root/tuber crops and leafy vegetable crops. It has been extensively and successfully tested by several researchers around the world under various environmental conditions. For cereal crops, it has been tested for barley in sub-Saharan Africa (Araya et al., 2010a), wheat in Iran (Andarzian et al., 2011) and western Canada (Mkhabela and Bullock, 2012). Also teff in Ethiopia (Araya et al. 2010b), quinoa in Bolivia (Geerts et al. 2009), maize in California (Hsiao et al., 2009) and soybean in the northern plain of China (Paredes et al. 2015). For root/tuber crops, the AquaCrop model was calibrated for potato in Cordoba (De La Casa et al. 2013), and in Jiroft, Kerman region, Iran (Afshar and Neshat, 2013); and tomato in central region of Ghana (Darko et al. 2016). Few studies have been carried out on leaf crops, Wellens et al. (2013), evaluated the performance of the AquaCrop model for cabbage cultivation in irrigated areas in the semi-arid climate of Burkina Faso. They concluded that the model is a very useful tool, allowing field users to assess and optimize irrigation water use and cabbage yield. Also, Pawar et al. (2017) calibrated the AquaCrop model under different irrigation regimes in the Akola region of India. The plant material chosen to parameterize the model is lettuce (*Lactuca sativa* L.), with a short vegetative cycle. Also, this plant is very present in the menus and is therefore a source of wealth for producers.

The main objective of this study is essentially to calibrate the AquaCrop model under different levels of soil fertility stress, based on the reality on the ground in order to simulate the growth and development of lettuce cultivation. And on the other hand, to improve the reliability of the parameters included in the model, so that it can be used as a decision-making tool for market gardening managers and producers.

2 Materials and methods

2.1 Experimentation site

The experiment was carried out at the Mahdi Boualem National Institute of Agronomic Research (INRA) experimental station (Figure 1) located southwest of Algiers in the eastern part of Mitidja, between 36°68'N and 3°1'E, at an average altitude of 18 m.

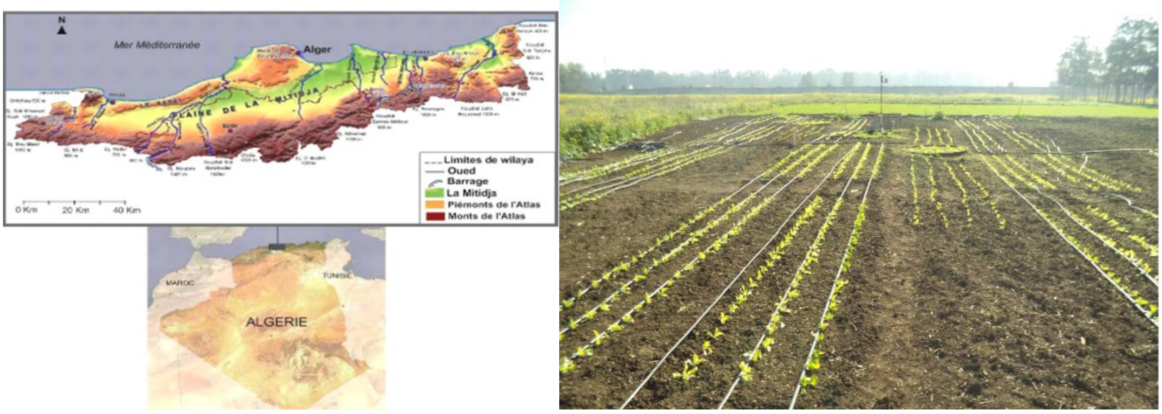

Figure 1 Location of the study area

Reference evapotranspiration was calculated using daily data obtained from an automatic weather station (Allen et al., 1998). These meteorological parameters were minimum and maximum temperature (°C), precipitation (mm), wind speed ($m\ s^{-1}$) at 2 m above the ground, solar radiation ($W\ m^{-1}$) and air relative humidity. With regard to the soil, a soil profile was carried out over a depth of one meter, including three horizons, the results of which are presented in Table 1.

Table 1 Physico-chemical properties of the soil

Parameters		Horizon 1 (0-25 cm)	Horizon 2 (25-55 cm)	Horizon 3 (> 55 cm)
hydraulic conductivity at Saturation (mm day^{-1})		15	15	13
pH		7.87	7.77	7.8
Electrical Conductivity (dS m^{-1})		0.17	0.17	0.17
Bulk density (g cm^{-3})		1.28	1.29	1.29
Saturated Soil SAT (Vol. %)		44.86	43.19	42.5
Field Capacity FC (Vol. %)		33.52	34.50	34.29
Permanent Wilting Point PWP (Vol. %)		22.87	23.26	21.60
Total limestone (%)		0.73	0.48	0.80
Granulometry (%)	Sand	42.81	48.50	51.89
	Clay	48.35	44.67	44.20
	Silt	7.98	7.77	7.80
Soil texture class		Silty clay	Silty clay	Silty clay

2.2 Experimental protocol

The test is carried out in the field according to the randomized complete block design (RCBD), with four nitrogen levels, namely: T1 (0 kg N ha^{-1}), T2 (60 kg N ha^{-1}), T3 (120 kg N ha^{-1}) and T4 (180 kg N ha^{-1}) arranged in four blocks. Each block has four micro-plots (Figure 2). Each micro-plot has a total area of 18 m^2. Phosphate and potassium fertilizers were incorporated into the soil as bottom manure at a rate of 100 K Kg ha^{-1} and 150 P kg ha^{-1}. The trial was repeated over two consecutive years (2015-2016) and (2016-2017). The quantities of nitrogen used are distributed throughout the crop development cycle, namely: 10% at 15 days after transplanting (DAT), 30% at 40 DAT, 40% at 60 DAT and 20% at 75 DAT. The growing season runs from January to April for both seasons, coinciding with the winter season, during which irrigation is not necessary

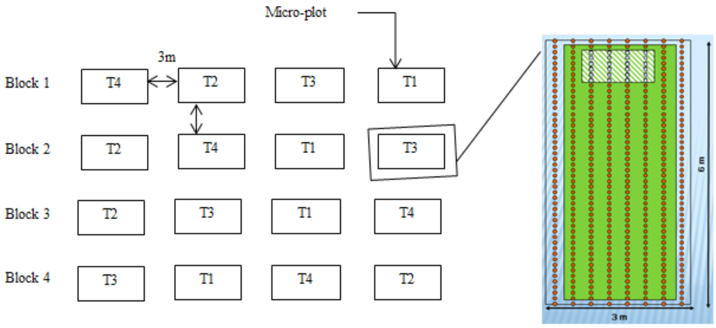

Figure 2 Experimental device

The crop taken into consideration is variety lettuce, têtue de nîmes, belonging to the lettuce to be applesauce class, which is eaten young, before it goes to seed. Lettuce seeds were sown in the honeycomb plates for 19 to 25 days in the nursery. The young lettuce plants were transplanted at the three to four leaf stages onto well ploughed soil in the field.

2.3 Measured parameters

The parameters measured in the field are essentially above-ground biomass (B), which represents a parameter that best verifies the effectiveness of fertilizers in lettuce, where the growth of the above-ground part is a determining factor in agricultural value (Blasco et al. 2011). Every ten days, samples of six plants/micro-plot are taken and brought back to the laboratory where they are dried in the open air for 24 hours and then in the oven for 48 hours at 70°C. Finally, the evolution of the green canopy (CC) coverage is monitored by reference to photos taken vertically at a height of 1.8 m above the crop, by a photometric camera, and analyzed using Arcgis 10.1 software using the ***supervised classification by maximum likelihood method*** (Figure 3). Harvesting is done when the apples are tight and full for each 1m × 1m subplot. Yields are converted into T ha^{-1} to compare them with those simulated by the AquaCrop model.

Figure 3 Analysis of the fraction of the green canopy for the growth stage

2.4 Description and evaluation of the data by AquaCrop

AquaCrop requires five important components to be functional: climate, with its thermal regime, rainfall, evaporative demand (ETP) and carbon dioxide concentration; then crop characteristics, including development, growth and yield formation processes (Table 2); then soil, with its hydraulic characteristics (hydraulic conductivity at saturation, moisture at saturation, field capacity and permanent wilting point); and finally management practices, which are divided into two categories: plot management and irrigation practice management; and finally initial conditions.

Table 2 Input culture parameters to calibrate the AquaCrop model

Description	Units	2015-2017		Source
Conservative crop parameters				
Base temperature	°C	7		Calibrated
Upper temperature	C°	30		Calibrated
Upper threshold for canopy expansion, Pexp,upper	-	0.25		Simulated
Lower threshold for canopy expansion, Pexp,lower	-	0.55		Simulated
Shape factor for the stress coefficient for canopy expansion	-	3		Calibrated
Upper threshold for stomatal closure, Psto,upper	-	0.50		Calibrated
Shape factor for the stress coefficient for stomatal closure	-	3		Calibrated
Water productivity (WP)	g m^{-2}	19		Calibrated
Reference harvest index (HIo)	%	95		Measured
Crop coefficient when canopy is complete	-	0.85		Simulated
Non conservative parameters		2015-16	2016-17	
Number of plants per m^2	Plant m^{-2}	15	15	Measured
CC0	%	2.25	2.10	Simulated
Maximum canopy cover CCx	%	81	77	Measured
canopy size of the transplanted seedling	cm^2 $plant^{-1}$	15	14	Measured
Time from transplantation to	days	7	9	Observed

emergence				
Time from transplantation to senescence	days	80	87	Observed
Time from transplantation to maximum (CCx)	days	50	50	Observed
Time from transplantation to maturity	days	95	99	Observed
Minimum effective rooting depth	m	0.20		Measured
Maximum effective rooting depth	m	0.40		Measured
Transplantation time at maximum depth of rooting	days	55	60	Observed
Date of transplantation		11/01/16	07/01/2017	
Harvest date		14/04/2016	15/04/2017	
Canopy growth coefficient (CGC)	% days^{-1}	14.30	15.30	
Canopy decline coefficient (CDC)	% days^{-1}	8.0	8.0	

2.5 Calibrating crop response to soil fertility

The crop's response to soil fertility stress is described with conservative crop parameters, for this purpose it must be calibrated for each specific case. Calibration of the model to fertility stress requires coverage of the green canopy (CC) and biomass production (B), recorded on the “stressed plot” and the “unstressed plot” (Table 3).soil fertility stress in the AquaCrop model is given as follows:

$$Stress = 100 \times (1 - Brel) \quad (1)$$

Where: *Brel* is the ratio between the total dry above-ground biomass at the end of the growing season in the reference plot (Bref) and the one under stress (Bstress).

Soil fertility affects water productivity (WP), canopy growth coefficient (CGC), maximum cover (CCx) and canopy senescence. AquaCrop offers a semi-quantitative option to evaluate the effects of fertility levels on these parameters, and thus on biomass and yield response (Mondal et al. 2015).

Table 3 Input data for calibrating the AquaCrop soil fertility stress model

Treatments	Brel (%)	CCx under level fertility (%)	Canopy declin (-)
2015-16 T1	51	51	0.44
T2	73	55	0.17
T3	1000	61	0
T4	1000	58	0.2
2016-17 T1	33	48	0.33
T2	49	58	0.10
T3	100	73	0
T4	93	69	0.02

The effects of soil fertility stress on the evolution of the green canopy and crop transpiration are included in the model through four parameters: the stress coefficient for (i) canopy expansion (Ksexp, f), (ii) maximum canopy coverage (KsCCx), (iii) canopy cover decline (fCDecline), and (iv) water productivity (KsWP).

The performance evaluation of a model is important to provide a quantitative estimate of the model's ability to reproduce an observed variable, to assess the impact of calibrating the model parameters and to compare the model results with those observed (Krause et al. 2005). Changes in canopy coverage, dry above-ground biomass and yield were taken into account in the evaluation of the AquaCrop model, while using statistical indicators. The statistical criteria used are: the coefficient of determination (R^2) of the linear adjustment, the square root of the normalized mean square error (*nRMSE*) and the Willmott agreement index (*d*).

3 Results and discussions

3.1 Analysis of climate data

Variations in rainfall and ETP are shown in Figure 4. The cumulative rainfall received during the two years of experience 2015-2016 and 2016-2017 between September and August was around 551 and 525 mm respectively. Those corresponding to the experimental seasons (January to April) are in the order of 303.4 and 332.6 mm. The corresponding potential annual evapotranspiration is in the order of 782.6 and 596.3 mm. The ones corresponding to the growing seasons are 196.5 and 137.5 mm respectively. Figure 5 shows the fluctuations in mean monthly temperatures over the same period (2015-2017). They are between 12.70°C and 30.90°C.

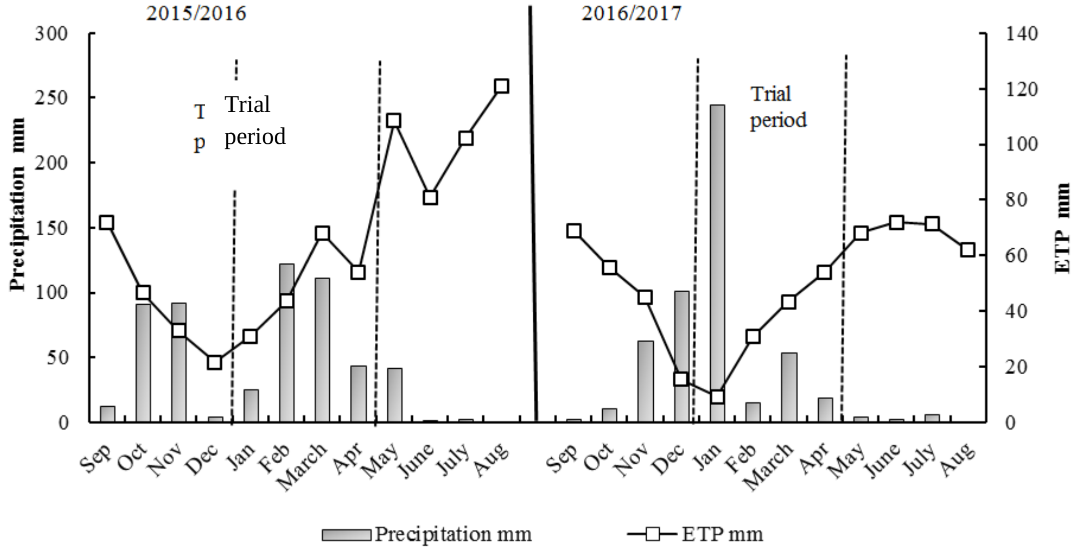

Figure 4 Precipitation, potential evapotranspiration (ETP) on a monthly scale for test years 2015–2016 and 2016–2017

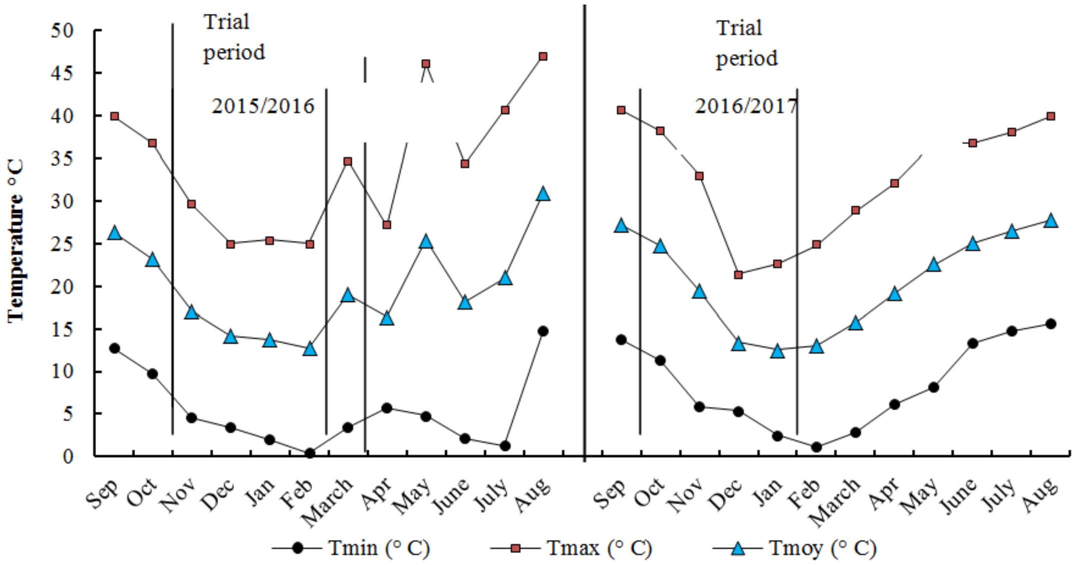

Figure 5 Monthly variations in maximum, minimum and average temperatures for the 2015/2016 and 2016/2017 test years

3.2 Effect of fertilization on water productivity

Table 4 shows the effect of different fertility levels on the reduction of maximum Canopy Cover (CCx), Canopy Growth Coefficient (CGC) and Water Productivity (WP).

It is noted that from T1 Treatment (0 kg N ha-1) to T3 Treatment (120 kg N ha-1), the reduction of these parameters (CCx, CGC and WP) is significantly reduced. For the T3 treatment where fertility stresses is at 0% no longer affects canopy coverage and biomass production, for this reason the reduction in WP is 0%. So says that the T4 treatment (180 kg N ha-1), negatively influences the expansion of canopy and biomass, and for this reason the reduction of WP for the two experimental seasons is 2% and 10%, respectively.

Table 4 The effect of soil fertility stress on water productivity and canopy cover development

Treatments		Reduction of CCx %	Reduction of CGC %	Average decline of cover	Reduction of WP %
2015-2016	T1	46	28	0.4	48
	T2	30	18	0.17	30
	T3	0	0	0	0
	T4	2	2	0.2	2
2016-2017	T1	46	28	0.33	40
	T2	35	21	0.10	26
	T3	0	0	0	0
	T4	6	6	0.02	10

3.3 Model calibration result

Experimental results of yield, canopy cover and dry above-ground biomass under different fertilization levels are presented in Table 5 for the calibration season (2015-2016) and validation season (2016-2017); the AquaCrop model (v6.1) was calibrated for the 2015-2016 season, using the entire crop data for T3 treatment (120 kg N ha^{-1}). The lowest observed dry above-ground biomass yields are in the order of 4.021 T ha^{-1} and 4.125 T ha^{-1} under T1 treatment (0 kg N ha^{-1}) in 2015-2016, and the highest are in the order of 9.199 T ha^{-1} and 9.785 T ha^{-1} under T4 treatment (180 kg N ha^{-1}) in 2016-2017, respectively.

Table 5 Results of biomass calibration and validation, yield and coverage of the maximum canopy under different fertilization levels in 2015-2016 and 2016-2017

Treatments		Biomass (T ha^{-1})		Dry yield (T ha^{-1})			CCx (%)		
		Obs	Sim	Obs	Sim	SD(±%)	Obs	Sim	SD(±%)
2015-2016	T1	4.125	4.785	4.021	4.546	(6.70)	51	44.80	(1.68)
	T2	5.872	6.806	5.234	5.785	(11.68)	55	54.10	(5.76)
	T3	7.969	9.320	7.834	8.854	(8.27)	61	63.9	(2.67)
	T4	7.788	9.100	7.626	8.645	(8.40)	58	63.7	(3.55)
2016-2017	T1	5.252	5.733	4.253	4.873	(1.29)	48	47.30	(3.38)
	T2	6.452	7.124	5.371	6.768	(5.05)	58	57.30	(0.86)
	T3	9.775	10.709	9.045	10.173	(5.72)	73	77.9	(2.72)
	T4	9.785	10.699	9.199	10.164	(8.31)	69	76.00	(2.25)

Table 6 Indicators of the quality of the adjustment in the estimation of canopy cover and biomass for model calibration in 2015-2016 and validation in 2016-2017

Indicators		CC (%)				Biomass (T ha^{-1})			
		T1	T2	T3	T4	T1	T2	T3	T4
2015-2016	R^2	0.81	0.71	0.66	0.64	0.92	0.98	0.94	0.94
	nRMSE	18.00	35.5	41.4	46.3	34.5	21.6	25.6	25
	EF	0.79	0.03	-0.13	-0.06	0.55	0.85	0.82	0.82
	d	0.94	0.81	0.78	0.80	0.91	0.96	0.96	0.96
2016-2017	R^2	0.81	0.98	0.94	0.98	0.94	0.98	0.98	0.98
	nRMSE	15.8	5.9	23.8	25.7	24.7	16.40	14.8	12.50
	EF	0.87	0.98	0.68	0.63	0.87	0.94	0.96	0.97
	d	0.99	1	0.94	0.93	0.97	0.98	0.99	0.99

Figure 6 shows the comparison between canopy coverage (CC) and dry above-ground biomass (B) simulated and observed for the calibration period (2015-2016). This Figure shows that there is a close correspondence between the observed and simulated CC and B. The AquaCrop model is able to simulate these parameters. Overall, the agreement between the CC and B simulated and observed is satisfactory with $0.64 \leqslant R^2 \leqslant 0.81$, $18 \leqslant nRMSE \leqslant 46.3$ and $0.78 \leqslant d \leqslant 0.94$; $0.92 \leqslant R^2 \leqslant 0.94$, $21.6 \leqslant nRMSE \leqslant 34.5$, $0.91 < d > 0.96$. It is also important to note that the AquaCrop model correctly simulates the CC from seeding to the maximum growth phase at which the CCx is reached. This observation has been reported in several studies, such as Andarzian et al. (2011), Wang et al. (2013) and Toumi et al. (2016). From Figure 7, it is clear that both parameters (CC) and B were overestimated by the AquaCrop model. Pawar et al. (2017) showed that the AquaCrop model overestimated the vegetative cover of cabbage under different irrigation regimes. Nikolaus (2013) also noted a slight (10%) but systematic overestimation of the amount of rice biomass conducted under different levels of irrigation and fertilization.

3.4 Model validation results

In this study, the model performance was validated with a simulation of dry yield, dry biomass and vegetation cover. The validation was performed with data for the different fertilization levels (0, 60, 120 and 180 kg N ha^{-1}) during the growing season (2016-2017); the comparison of simulated and observed dry above-ground biomass and canopy coverage is illustrated in Figure 7 and Table 6. The observed dry above-ground biomass varies from 5.252 to 9.787 T ha^{-1}, while the observed yield fluctuates between 4.253 and 9.199 T ha^{-1} for treatments between T1 (0 kg N ha^{-1}) and T4 (180 kg N ha^{-1}).

The indicative fit quality parameters for the model validation season for CC and B are $0.81 \leqslant R^2 \leqslant 0.98$ and $0.94 \leqslant R^2 \leqslant 0.98$ respectively; $5.9 < nRMSE > 25.7$ and $12.5 \leqslant nRMSE \leqslant 24.7$; $0.63 \leqslant EF \leqslant 0.87$ and

$0.87 \leqslant EF \leqslant 0.97$; $0.97 \leqslant d \leqslant 0.99$ and $0.93 \leqslant d \leqslant 1$. The AquaCrop model showed robust performance during validation. Similar to the calibration results, the estimates of canopy and dry above-ground biomass coverage were somewhat, but systematically higher than the observed values; this results in differences of 8.39% to 8.54% and 1.47% to 6.29% respectively between the different fertilization levels.

3.5 Yield

The observed and simulated lettuce yields are illustrated in Figure 8. The yields observed for T1, T2, T3 and T4 treatments are respectively 4.021; 5.234; 7.834 and 7.626 T ha^{-1}, while those simulated are in the order of 4.546; 5.785; 8.854 and 8.645 T ha^{-1} for the calibration period (2015-2016), with a correlation coefficient R^2 = 0.99. On the other hand, the observed and simulated yields under the four treatments for the validation period (2016-2017) are of the order of 4.253; 5.371; 9.045 and 9.199 T ha^{-1}; 4.873; 6.768; 10.173 and 10.164 T ha^{-1}, respectively, with a correlation coefficient R^2 = 0.98. It is found that the treatment T3 gave a better performance compared to other treatments. This observation is corroborated with that of Amirouche et al. (2019). This statistical indicator indicates that the values simulated by the AquaCrop model are in good agreement with those observed. Araya et al. (2010a) reported values of $R^2 > 0.80$ when simulating above-ground biomass and barley grain yield using AquaCrop.

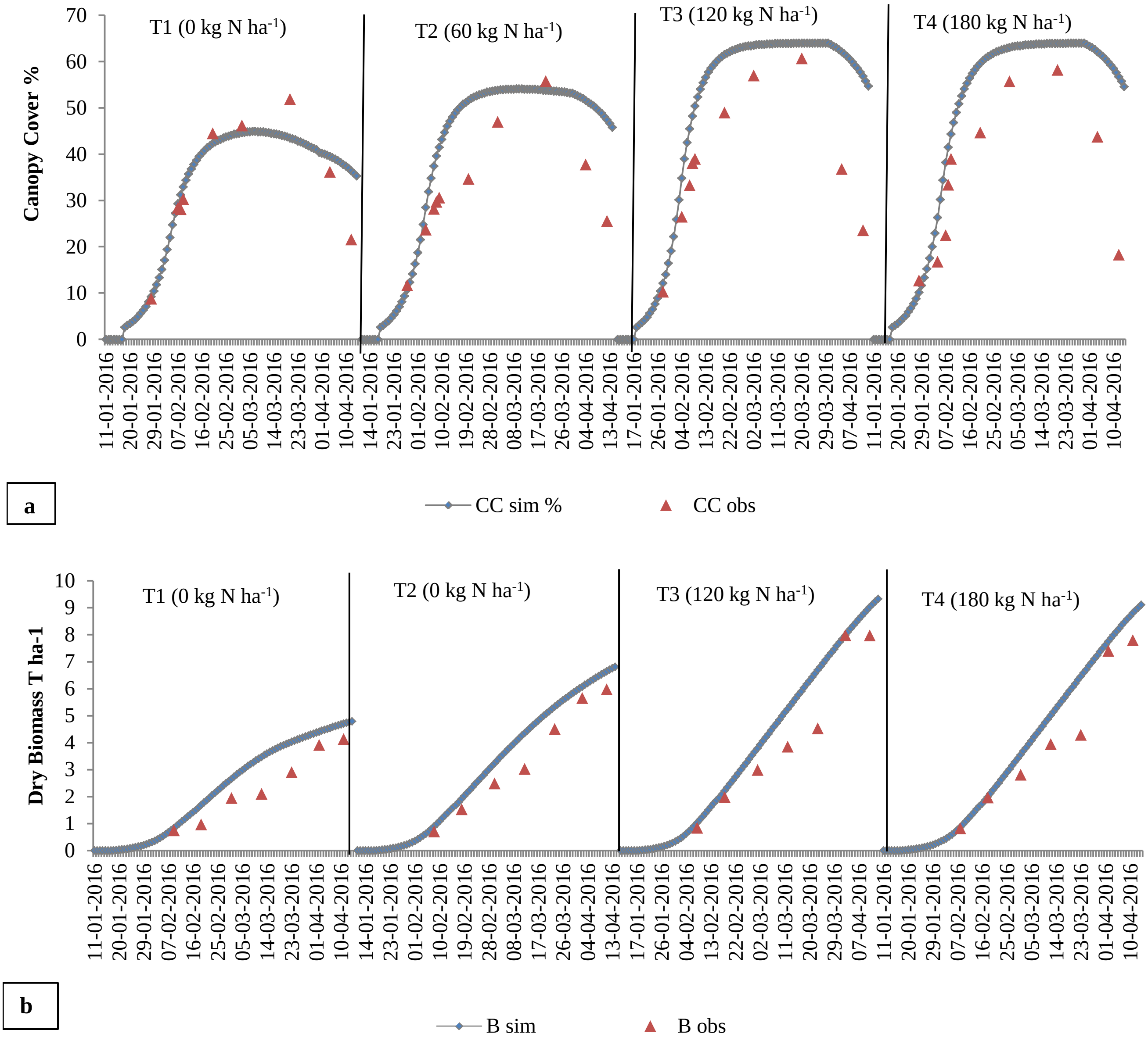

Figure 6 Coverage of canopy (a) and dry biomass (b) simulated and measured for the calibration period (2015-2016) under different fertilization levels (T1, T2, T3 and T4)

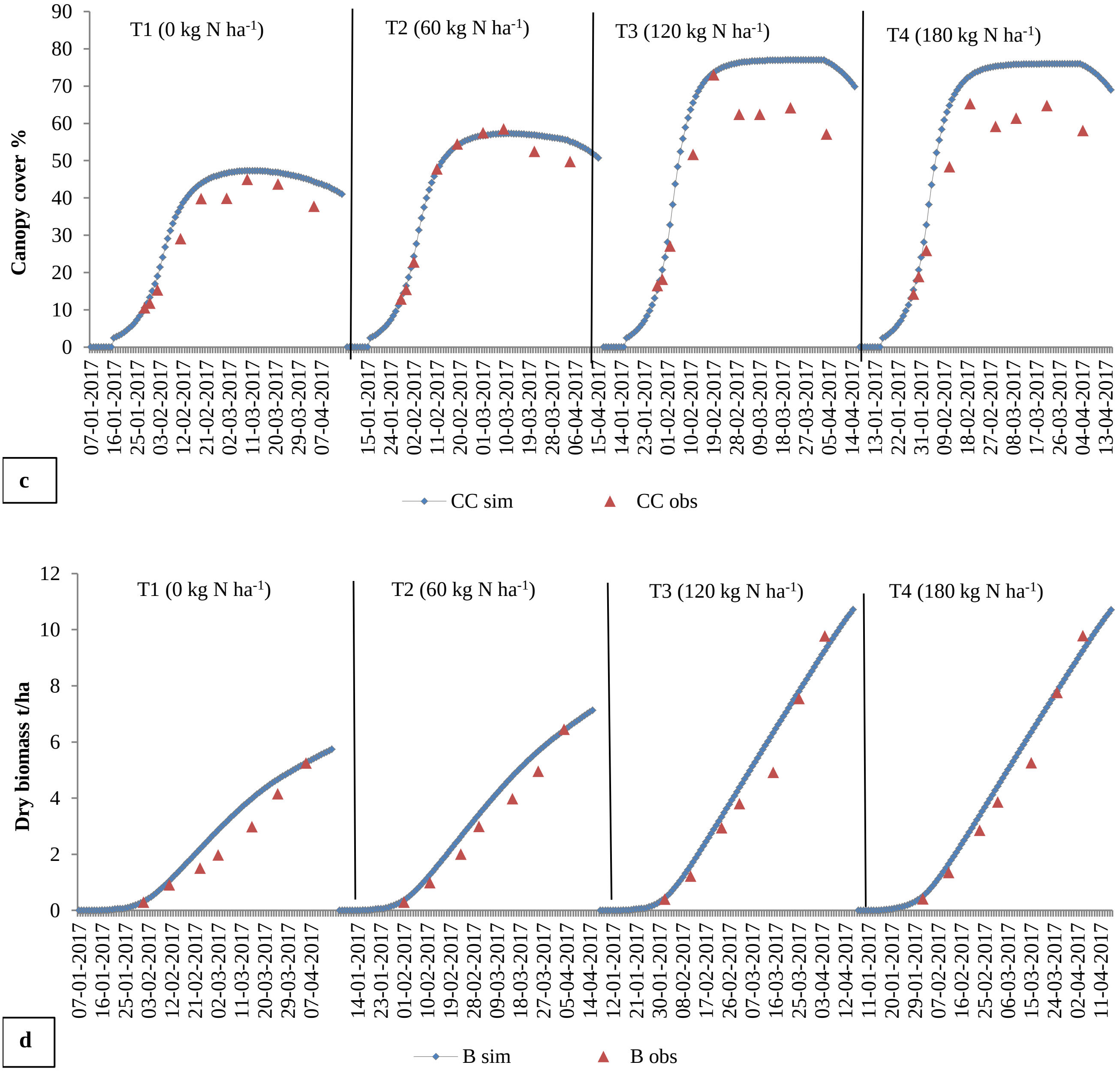

Figure 7 Coverage of canopy (c) and dry biomass (d) simulated and measured for the validation period (2016-17) under different fertilization levels (T1, T2, T3 and T4)

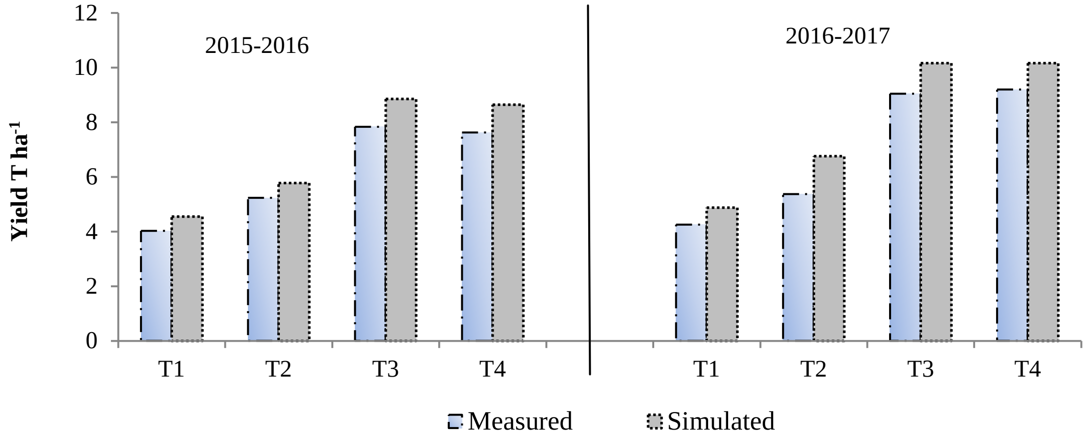

Figure 8 Simulated and observed yields of lettuce under different levels of fertilization

4 Conclusion

In this study AquaCrop model (v 6.1) was calibrated and validated for growing lettuce under different fertilization treatments in the sub-humid zone (South West of Algiers). The results of the model evaluation of simulation, seasonal canopy cover, yield and final harvested biomass showed sufficient accuracy of both simulated and observed model values. Configuration of the AquaCrop model to estimate the effect of fertility constraints on lettuce yield at different levels of fertilization was studied and tended to overestimate canopy cover for T3 (120 kg N ha^{-1}) and T4 (180 kg N ha^{-1}) treatments, but with reasonable statistical indices (*nRMSE*: 14.80 for T3 and 12.50 for T4). AquaCrop confirmed that this is a very useful tool that can be used to optimize N rates to be applied to crops, to play on plot management to maximize yields.

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