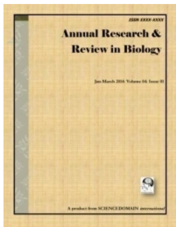

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Application of STICS Model in Assessment of the Effects of Irrigation Practices and Soil Properties on Yield of a Durum Wheat (*Triticum durum* Desf.) Cultivar in the Irrigated Area of Oued Rmel in Tunisia

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Authors' contributions

This work was carried out in collaboration between all authors. Author SBK designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors FR and BD managed the analyses of the study. Authors AM, AB and MM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The progress in computer technology has enabled the development of crop models reproducing the behavior of a crop in a wide range of pedoclimatic conditions and technical itineraries. This work aims to study the impact of total available soil water in the root zone (TAW) on durum wheat yield (*Triticum durum* Desf.) as affected by irrigation regime in Mediterranean climatic conditions of Tunisia. In this work, STICS model was used to simulate effects of farmer's irrigation practices in wheat in the pedoclimatic conditions of the irrigated area of Oued Rmel in Tunisia over a 20-year period. Assessment of irrigation practices in the study area was performed, compared to rainfed system, in terms of yield

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and produced biomass at harvest. The model was calibrated to simulate the growth and development of winter wheat using the field observed crop data collected from three growing seasons in two locations in Tunisia. To carry out the study, three types of soil (S1, S2 and S3) in the Oued rmel irrigation scheme were chosen on the basis of their available soil water in the root zone (TAW). The study showed that the model adequately predicts crop yield and biomass. Simulation results showed that the farmers' irrigation practice results, in higher grain yield and dry matter at harvest as compared to rainfed system. Simulated grain yield was significantly higher in soil with high TAW than in the other soils. Results showed that the highest difference (30%) in simulated grain yield, between the two water regimes, was obtained in soil having high TAW. Depending on the soil type, simulated dry matter at harvest increased from 4% to 12% compared to rainfed system.

Keywords: Durum wheat; yield; irrigation; crop model.

1. INTRODUCTION

In Tunisia, cereal yields are subject to significant fluctuation, given the interannual variability of rainfall, in addition to seasonal moisture deficits that may prevail, even during a wet year (Sakiss et al. [1]) Results obtained in terms of yields of irrigated cereals show that there has been no great improvement in performance. Indeed, it is always of supplementary irrigation where farmers irrigate their crops in case of urgent needs [2]. Conducting irrigated cereals require further development, especially under conditions of droughts that have become increasingly frequent. Obtaining high yields of cereals require, in addition to chemical treatments, irrigation and use of mineral fertilizers [3,4,5]. The irrigation regime may strongly affect crop productivity [6,7]. This may be particularly important as shortage of water is ever one of the main limitations for agricultural development in the arid and semiarid zones. Faced with demographic change, the fragility of the agricultural sector and the scarcity of water resources, it is clear that the challenge is the increase in grain yields, to ensure food security, while ensuring a water security [9]. However, the variability of climate and of soil properties should be taken into account before devising any reliable suggestions in terms of irrigation practice [10,11,12]. Crop growth simulation models can be used as a tool to estimate increase in water productivity with appropriate irrigation management [13]. In the last years, crop growth models have been widely used as an important tool to investigate the responses of crops and varieties in different pedoclimatic conditions [14,15]. Simulation models are a modern research tool of data generation, which complements the field experiments [16]. Simulation modeling of several proposed cropping systems in a few experimental locations can provide more useful, quicker and less costly alternative approach [17,18]. Studies on crop models have addressed a wide range of issues while only few studies on durum wheat modeling are available for Mediterranean climate conditions [19] [20,21,22,23,24,25,26]. As such, the aim of this paper was the application and evaluation of STICS model [27] with the objective of analyzing the effects of farmer's irrigation practices compared to rainfed system on yield components of durum wheat under Mediterranean climatic conditions of Tunisia.

2. MATERIALS AND METHODS

2.1 The Study Area

The analysis has been carried out on the Oued Rmel irrigation scheme (35°55' N-10°25' E) located in Northeastern part of Tunisia (Fig. 1). In the study area, the climate is typically Mediterranean with hot-dry summers and mild-rainy winters. According to long term weather data (1986-2006) summarized in Table 1, maximum monthly temperatures range between 16 and 31ºC and minimum monthly temperature vary from 7 to 21ºC. Mean relative humidity varies from 65% to 74% and monthly rainfall ranges between 4 and 48 mm.

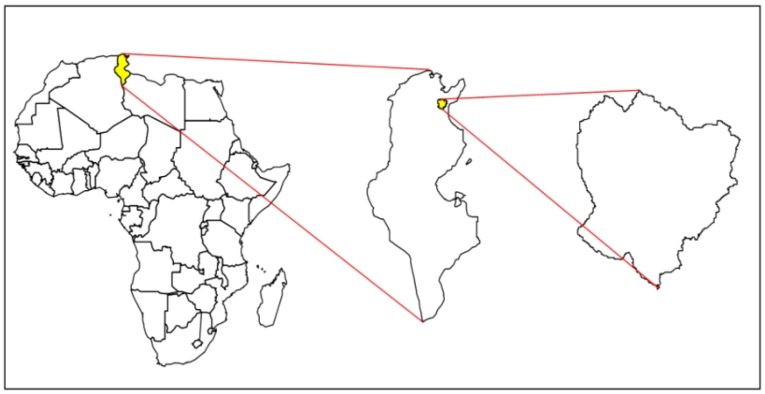

Fig. 1. Location of the study area

Table 1. Long term mean (1986-2006) meteorological data in the study area (source: National Meteorological Institute of Tunisia)

	Average of temperatures		**monthly total of precipitation (mm)**	**Mean relative humidity (%)**	**wind speed ($m.s^{-1}$)**
	T_{max} (°C)	T_{min} (°C)			
January	15.69	7.24	41.43	76.16	1.49
February	16.32	7.04	29.18	72.98	1.72
March	18.28	8.79	28.83	71.52	1.82
April	20.3	10.49	26.37	71.13	1.7
May	23.64	13.92	23.09	69.67	1.78
June	28.49	17.44	11.53	65.25	1.66
July	31.15	20.05	4.86	65.6	1.68
August	32.08	21.25	10.13	67.51	1.61
September	28.84	19.87	42.52	73.21	1.5
October	25.38	16.85	37.09	74.73	1.37
November	20.27	12.01	48.1	73.93	1.49
December	17.03	8.36	40.97	75.32	1.41

The scheme covers an irrigated area of about 4770 ha. The dominant crops are fruit trees and cereals (Fig. 2), mainly durum wheat. The Oued Rmel scheme is supplied by the Oued Rmel dam, located in a dominant position compared to the served area. Its reservoir has a total capacity of 70 Mm^3.

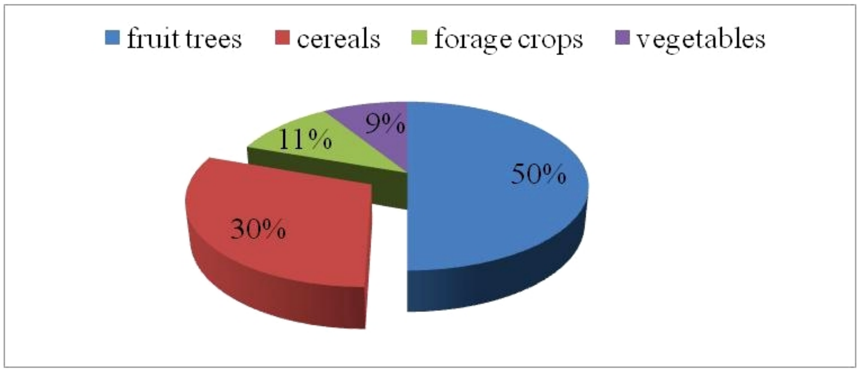

Fig. 2. Proportions of crops in the study area

The overall amount of water withdrawn from the Oued Rmel reservoir for irrigation purpose varies from 3 Mm^3 to 100 Mm^3 since annual distribution of precipitation is very irregular. Water is distributed to farmers by means of large-scale pressurized distribution system, operated by a local Water Users Association. The irrigation delivery service usually starts from mid October and lasts up to the end of May. Frequency and amount of water delivered depends by the dam water level. Most farmers apply traditional irrigation methods. Trickle and sprinkler irrigation are used by respectively 37% and 16% of farmers respectively in the study area. Wheat is generally sown between mid November and mid December, depending on climatic conditions and the start of the rainfall season.

To carry out the study, three types of soil (S1, S2 and S3) in the Oued rmel irrigation scheme were chosen on the basis of their available soil water in the root zone (TAW) and their significant representativeness in the region. Soil characteristics were obtained from the soil map (1:25,000) accompanied by a complete pedological study which provides information for the suitability of soils and their characteristics (texture, structure, soil depth, etc.). the study was elaborated by the Regional Agricultural Development Commissioner of Sousse. According to [28], the three soils show contrasting characteristics in terms of total available soil water in the root zone. Tables 2, 3 and 4 summarize the main characteristics of these soils.

Table 2. Main characteristics of the soil S1

Soil Properties	Depth			
	0 - 20	**20 - 40**	**40 - 70**	**70-120**
Clay (%)	29	41	48	44
Sand (%)	35	23	13	5
Silt (%)	36	36	39	50
Apparent density ($g.cm^{-3}$)	1.5	1.45	1.5	1.4
Water content at field capacity (% in volume)	33	53	57	44
Water content at wilting point (% in volume)	16	36	37	26
TAW in the soil depth explored by the root zone (mm)	181			

Table 3. Main characteristics of the soil S2

Soil Properties	Depth		
	0 - 50	**50 - 80**	**80 - 120**
Clay (%)	15	19	17
Sand (%)	70	71	75
Silt (%)	14	10	8
Apparent density ($g.cm^{-3}$)	1.45	1.5	1.5
Water content at field capacity (% in volume)	17	28	27
Water content at wilting point (% in volume)	7	15	14
TAW in the soil depth explored by the root zone (mm)	129		

Table 4. Main characteristics of the soil S3

Soil Properties	Depth		
	0 - 50	**50 - 70**	**70 - 120**
Clay (%)	16	14	16
Sand (%)	80	70	78
Silt (%)	4	16	6
Apparent density ($g.cm^{-3}$)	1.35	1.4	1.35
Water content at field capacity (% in volume)	10	16	10
Water content at wilting point (% in volume)	4	7	4
TAW in the soil depth explored by the root zone (mm)	72.8		

The TAW describes the available water storage in the soil which may be exploited by the root system. It is defined as the difference between the soil water contents at field capacity and at wilting point, multiplied by the depth of the root system [29]. The water content at field capacity and at wilting point depends on the specific physical properties of the soil, especially its texture. The soil depth which may be explored by the root system is a specific characteristic of each cultivated species [30]. As for durum wheat, [31] proved that the soil depth explored by the root system is not deeper than 1 m.

2.1 Model Description

STICS (Simulateur Multidisciplinaire des Cultures Standards), has been developed since 1996 at INRA (France) in collaboration with other research or professional institutes [32]. The STICS model was developed as an analytical tool to study the effects of climate and cropping systems management on both crop productivity and environment. STICS is presented as a model exhibiting the following qualities: robustness, an easy access to inputs and an uncomplicated future evolution thanks to a modular (easy adaptation to various types of plant) nature and generic [32]. From the characterization of climate, soil, species and crop management, it computes output variables related to yield in terms of quantity and quality, environment in terms of drainage and nitrate leaching, and to soil characteristics evolution under cropping system [33]. STICS is widely used in a lot of agro-environmental contexts [34,35,36]. It was retained in this study as it showed a wider scope, serving at the same time for research and management objectives. In addition, some tests carried out in the South of France showed that the STICS model correctly simulated winter wheat crop behaviour under water shortage conditions [37]. The model is composed of of modules. There are modules that deal with: i) the physiology of the aboveground plant parts, ii) the interactions between the crop management and the soil-crop system, iii) the micro-climate, and iv) the interactions between soil and subsurface plant parts (Fig. 3).

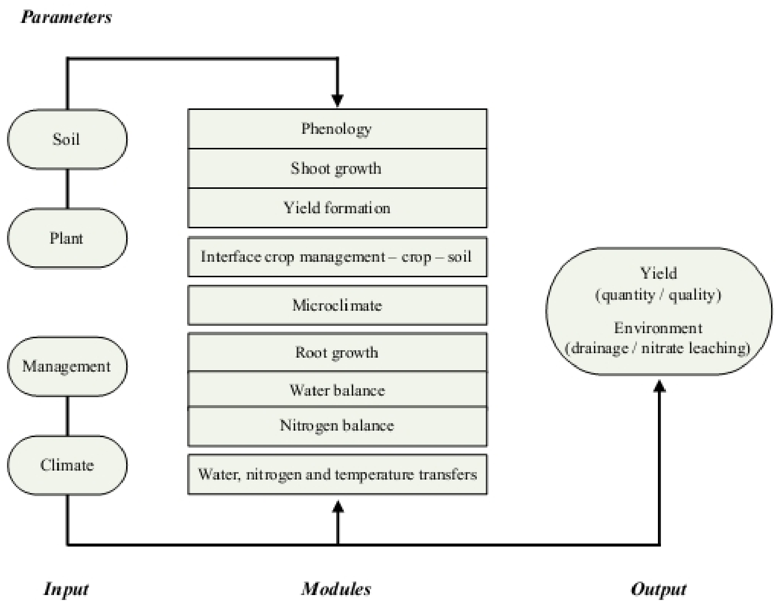

Fig. 3. Overview of the model system and its components [37]

The model requires information about initial and permanent conditions of soil, plant physiology and crop management and is driven by daily climatic data (solar radiation, minimum and maximum temperature, precipitation and reference evapotranspiration) [38]. The STICS model is based on three types of functions:

– A physiological calendar defines the growing stages (development module), using a thermal (degree-day), photothermal, or vernal-photothermal index according to the species;
– The crop growth functions (leaf area setting, light absorption, conversion of absorbed light and partition to grain) depend on climatic variables (temperature and radiation);
– Functions to simulate the effects of water and nitrogen stresses. They require root growth in order to access the water and nitrogen resources [39]
.
The upper and lower limits of the model are the atmosphere and the soil / subsoil interface, respectively [38]. STICS simulates the crop growth from sowing to harvest, focusing on the evolution of the LAI (Leaf Area Index) at a few selected vegetative stages [33]. Crop growth is driven by the plant carbon accumulation [40]: solar radiation intercepted by the foliage and then transformed into aboveground biomass that is directed to the harvested organs during the final phase of the crop cycle. Daily accumulation of aboveground biomass is a function of the intercepted radiation according to a parabolic law involving the maximal radiation use efficiency (RUE) [32].

A more detailed description of the model, its structure and inter-linkages is given in [27,37].

2.2 Model Evaluation

Model evaluation is an essential step in the modelling process because it indicates if the implementation of the calculations involved reproduces the conceptual model of the system to be simulated (model reliability) and the level of accuracy of the model in reproducing the actual system (model usefulness) [41]. Model evaluation includes any action in which the goodness of a mathematical model is established (e.g., [42,43]. The topic of model evaluation has long attracted considerable debate amongst members of the scientific community. Much debate has stressed over the meaning of terms such as "testing", "validation", "verification" and "calibration" as part of the process collectively referred to as "evaluation" [44]. Model calibration could be defined as the estimation of some model parameters by fitting the overall model to field data [45]. Parameter estimation for complex process models used in agronomy or the environmental sciences is important, because it is a major determinant of model predictive power, and difficult, because the models and associated data are complex [45].

A database from eight experiments conducted on a durum wheat (*Triticum durum* Desf. Var. Karim.) cultivar was used to evaluate and calibrate the model. As shown in Tables 5 and 6, the data sets for these experiments are characterized by variability of location, soil characteristics and crop management. Since the cultivation practices affect the development, growth and grain yield. The model was evaluated in various conditions,

Table 5. Some management practices carried out during the experiments used for model calibration and validation

Experiment	Location	Sowing date	Seed number.m^{-2}	Harvest date	Irrigation (mm)	Fertilization ($kg.ha^{-1}$)
Calibration						
1	Nabeul	10/12/1991	500	26/06/1992	230	none
2	Nabeul	10/12/1991	500	11/06/1992	none	120
3	Nabeul	10/12/1991	500	24/06/1992	none	none
4	Nabeul	10/12/1991	500	26/06/1992	230	120
Validation						
5	Bizerte	15/11/1998	350	15/05/1999	83	500
6	Tunis	17/11/1998	350	12/05/1999	25	450
7	Tunis	16/11/1995	350	15/05/1996	100	none
8	Tunis	24/11/1995	350	19/05/1996	100	none

Experiments were carried out in Tunis (36°48′N-10°11′E) during 1995-1996 and 1998-1999 growing seasons, Nabeul (36°60'N-10°44'E) during 1991-1992 growing season and Bizerte (37°15' N-9°48' E) during 1998-1999 growing season. The campaigns of measures during the trials have concerned phenological stages, above-ground biomass, final grain yield and soil water content. Experiments from 1 to 4 have been described by [47]. Experiments 5 and 6 have been described in detail by [46]; while experiments 7 and 8 have been described by [48].

Table 6. Mean characteristics of the soils observed at the experimental sites

Experiment	Soil depth (cm)	Clay (%)	Sand (%)	Silt (%)	Apparent density ($g.cm^{-3}$)	Water content at field capacity (% in volume)	Water content at wilting point (% in volume)
Experiments from 1 to 4	100	8	76	16	1.57	32	11
Experiment 5	100	31	35	34	1.47	36	25
Experiment 6	100	41	32	27	1.65	34	22
Experiment 7	120	30	20	50	1.55	33	20
Experiment 8	120	55	5	40	1.56	47	32

The total number of parameters is very large in a crop simulation model such as the STICS model [34]. Thus, in some parameters, the recommended default values by model guidelines were considered. Moreover, as the aim is the adaptation of the STICS model to a local durum wheat cultivar, calibration concerned only parameters values which are assumed to differ between cultivars (genotype parameters). The other parameters are assumed to be the same for all cultivars (crop parameters). In STICS, the parameters which correspond to varietal differences are those defining the crop phenology i.e the time (degree-days) between phonological stages (LEV: emergence, AMF: end of juvenile phase, LAX: maximal leaf area index, DRP: beginning of grain filling, SEN: beginning of net senescence, MAT: physiological maturity) [37]. The calibration method aimed at adjusting the crop varietal parameter of the model until a minimal difference between observed and modelled yield and biomass had been achieved.

Model evaluation was conducted using root mean square of error (RMSE), model efficiency (ME), coefficient of determination (R^2) and mean Biais (MB) criterions obtained as follows:

$$R^2 = \frac{[\sum_{i=1}^{n} (Y_i - \bar{Y})(X_i - \bar{X})]^2}{[\sum_{i=1}^{n} (Y_i - \bar{Y})^2][\sum_{i=1}^{n} (X_i - \bar{X})^2]} \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Y_i - X_i)^2} \quad (2)$$

$$RRMSE = \frac{RMSE}{\bar{X}} \quad (3)$$

$$ME = 1 - \frac{\sum_{i=1}^{N} (X_i - Y_i)^2}{\sum_{I=1}^{N} (X_i - \bar{X})^2} \quad (4)$$

$$MB = \frac{\sum_{I=1}^{N} X_i - \sum_{I=1}^{N} Y_i}{\sum_{I=1}^{N} Y_i} \quad (5)$$

Where Y_i is the predicted variable, X_i is the observed value, $\bar{Y}$ is the predicted mean, $\bar{X}$ is the measured mean, and n is the number of observation.

R^2 represents the proportion of variation in the sample data that is explained by the regression model. It is only an estimate of the proportion of variation in the population that is explained by the regression model [49]. Practitioners would be advised to avoid selecting a model based solely on the criterion of observing a high R^2 value. This is especially true when many terms are included in a model to fit a relatively small number of observations [49].

The RMSE indicates the error of prediction of the model by giving more weight to high errors. A low value of RMSE means a good prediction ability of the model. Also, ME ranges from negative infinity to positive 1; the closer to 1, the more robust the model. RMSE provides quantitative estimates of the deviation of modelled outcomes from measurements [50]. [51], likewise, indicated RMSE as stable statistics.

The ME [52], interpreted as the proportion of variation explained by the model, has been extensively used in plant and hydrology models (e.g. [53,54]) and can certainly be used in biological and ecological models [50].

MB may be used in conjunction with RMSE to evaluate crop models (Brisson et al. 2002; [36].

Moreover, visual comparison of modelled and measured data, and experience-based judgement on the part of the modeller have been deemed important by researchers for assessing model validity and applicability in decision making [55].

After calibration and validation the model was used to assess the farmer's irrigation in a durum wheat cultivar (Triticum durum Desf. Var. Karim.) compared to rainfed system in the study area. In fact, farmers generally irrigate winter wheat one time at sowing. Usually, the amount of irrigation water applied is equal to 40 mm. Fertilizer (ammonium nitrate 33.5%) is generally applied at a rate of 200 $kg.ha^{-1}$. Simulations were performed year by year during the 1986–2006 period at the three identified soils, under experimental neutrality (same sowing date and fertilisation). Precipitation was obtained from recorded measurements on the test site itself while other climate data were documented using records from the nearby "Oued Souhil" weather station (20 km away).

Collected data in this study were analyzed and examined statistically using analysis of variance (ANOVA) from the Statistical Analysis System (SPSS 17.0 for Windows) (SPSS inc., Chicago, IL, USA). Means were compared by the SNK Test at the 5% level of significance.

3. RESULTS AND DISCUSSIONS

3.1 Model Calibration

Model calibration was conducted by changing the crop parameters and based on the best matching between simulated and measured dry biomass and grain yield. The initial cultivar parameters were chosen based on default values for the durum wheat cultivar named "Acalou" included in the model. The calibrated parameters were determined by testing a range of values as suggested by [39]. The selected values were those which minimized the difference between simulations and measurements. Through repeated simulation runs and output comparison of simulated versus observed yield and biomass, a set of four conservative parameters was obtained which seemed most appropriate and gave satisfactory results of situations simulated (Table 7).

Table 7. Adjusted model parameters

Parameter	Definition	Evaluation range (degree-days)	Initial Value	Value after calibration
Stlevamf	The sum of development units between the day of seedling emergence and the day of maximum acceleration in the growth of LAI	210 - 450	228	218
Stamflax	sum of development units between the day of maximum acceleration in the growth of LAI and the first day of maximum LAI	300 - 474	207	207
Stlevdrp	sum of development units between the day of seedling emergence and the first day of seed filling	600 – 1300	695	650
stdrpmat	sum of development units between the first day of seed filling and the first day of seed filling and physiological maturity	520 - 700	527	572

STICS performed with satisfactory precision in terms of wheat yield and biomass. This is confirmed by the statistics displayed in Tables 8 and 9. It should be noticed that, given the complexity of crop models and the associated data, it is difficult to know what assumptions about model error are reasonable, and it is difficult to test the assumptions that one does make [45]. However values of RRMSE, ME, R^2 and ND indicate that the calibrated model performed with satisfactory precision in terms of wheat yield and biomass. According to [36] and [36], values of MB and ME indicate that the calibration is satisfactory.

Table 8. Statistical indices for evaluating the performance of STICS model in predicting dry biomass after calibration

Observed (t ha^{-1})	Simulated (t ha^{-1})
3	2.12
4.7	4.32
7	5.39
10	7.92
12	7.93
15.2	14.9
12.5	11.49
11.3	9.44
6.3	7.62
RMSE	1.84
RRMSE (%)	20
|MB|	0.13
ME	0.76
R^2	0.86

Table 9. Statistical indices for evaluating the performance of STICS model in predicting grain yield after calibration

Observed (t ha^{-1})	Simulated (t ha^{-1})
7.6	6.22
4.9	6.32
6	5.19
2.8	4.19
RMSE	1.28
RRMSE (%)	24
|MB|	0.02
ME	0.47
R^2	0.52

3.2 Model Validation

3.2.1 Grain yield and dry biomass

Generally, there was a close agreement between the measured and simulated dry biomass. These qualitative findings are confirmed by the statistics (Fig. 4). The coefficient of determination is larger than 0.9, ME is 0.9 and RMSE is 0.66 t ha^{-1} representing 20% of the average observed value of dry biomass. Furthermore, the simulation is considered good as the normalized RMSE is greater than 10% and less than 20% [56].

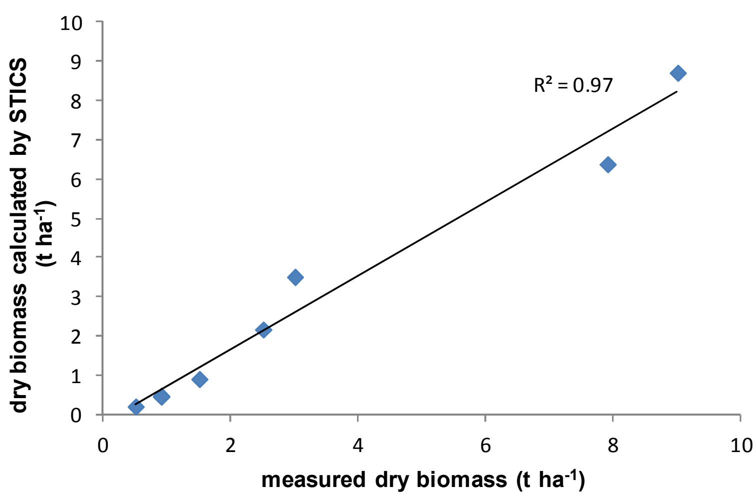

Fig. 4. Comparison of simulated and measured dry matter using validation data set

Fig. 5 shows the comparison of the simulated and observed grain yield. RMSE was 0.65 t.ha^{-1} which represented 11% of the average observed measured yield and MB was 0.08. According to [56] and [37], these values indicate a reasonable agreement between measured and simulated yield

3.2.2 Soil water content

Fig. 6 shows the comparison of the simulated and observed soil water content (SWC). We notice that the performance of STICS is satisfactory as the coefficient of determination is greater than 0.5. Comparative analyses of the observed and simulated SWC had a ME of 0.7, and MB of 0.02. This highlights a comparatively good fit between the observed and the simulated results, as [36] and [37] consider that simulation is acceptable if ME is greater than 0.5 and MB is lower than 0.1. The good agreement between measured and simulated is also reflected in the RMSE value which represents 26 % of the average SWC observed value [56]. These results show the ability of STICS to simulate SWC under various irrigation regimes.

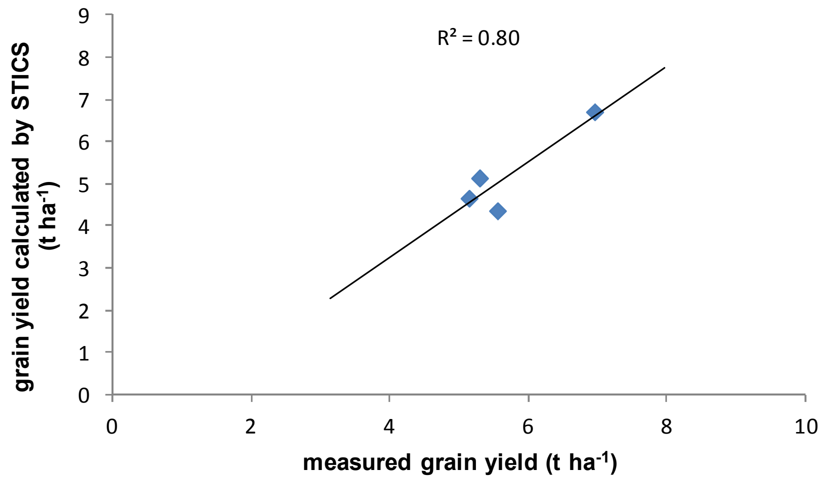

Fig. 5. Comparison of simulated and measured grain yield using validation data set

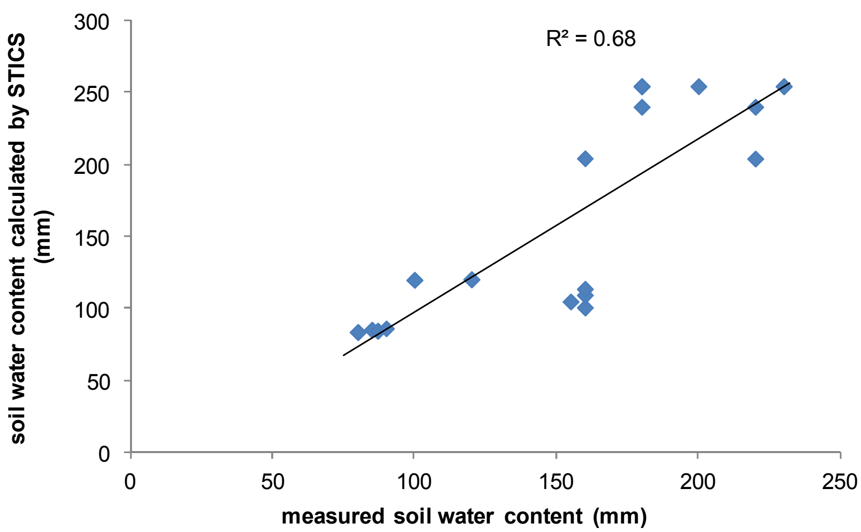

Fig. 6. Comparison of simulated and measured soil water content

These results prove the ability of STICS to study the effect of location, soil type and irrigation management on crop production under rainfed and irrigated agriculture. The aptitude of the STICS model in predicting yield and biomass, in a Mediterranean environment, is therefore acceptable.

3.3 Model Application

3.3.1 Aerial dry matter at harvest

From Fig. 7, it is notable that lowest values of dry matter at harvest were recorded in the soil with a low TAW. Highest aerial dry matter at harvest was obtained in farms where irrigation practices are adopted. This is in agreement with the results reported by [57] and [58] who indicated that biological yield was increased as increasing irrigation volume. Moreover, highest difference in aerial dry biomass, resulting from farmers irrigation practices compared to rainfed system, was obtained in soil with highest TAW. Indeed, in S3, aerial dry matter increased by 4% on average, moving from rainfed system to farmer's irrigation practice. While in S1 having highest TAW, the dry matter values increased by 12% on average moving from rainfed system to farmer's irrigation practice.

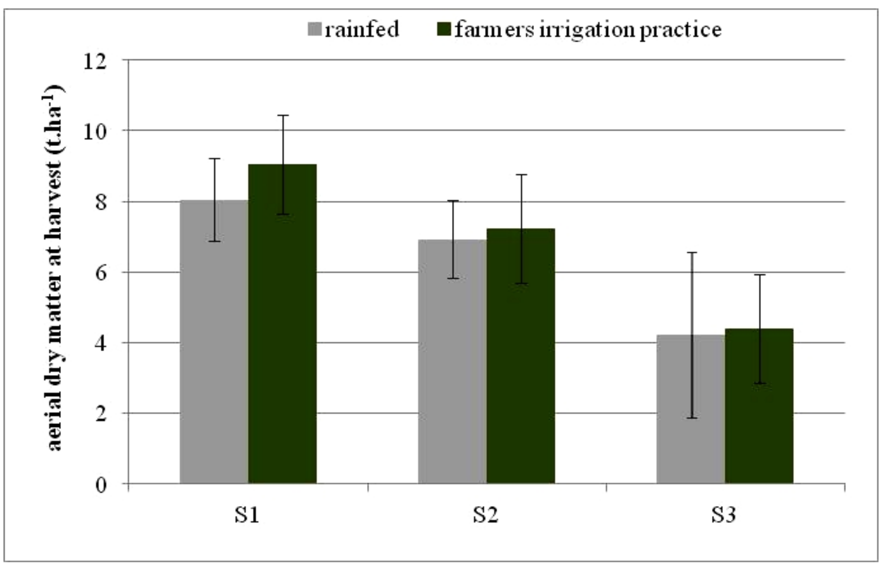

Fig. 7. Average and standard deviations values of aerial dry matter at harvest, simulated by the STICS model, in the three soils with a different total available water (S1= 181mm, S2 = 129 mm; S3= 73 mm) as a function of water management

Moreover, soil TAW significantly affected aerial dry matter production in farmers practices. Highest values were obtained in soil having high TAW with 9.04 $t.ha^{-1}$ and the lowest one was found in soil with lowest TAW with 4.39 $t.ha^{-1}$. In this case, the soil with high TAW produced 25 and 100% higher dry matter compared to respectively to S2 and S3.

3.3.2 Grain yield

Farmers irrigation practice resulted in higher grain yield as compared to rainfed system (Fig 8) in the three soils. This result corroborates the findings of several studies [59,58] which indicated that grain yield were increased as irrigation amount increased. Higher grain yield obtained in farmers irrigation practices could be attributed to higher grain weight with increasing irrigation [60,61]. The highest values of grain yield were obtained in soil having high TAW, Moreover, the highest difference in grain yield between the two water regime was obtained in soil having high TAW. In S3, the grain yield value increased only by 10% on average, moving from rainfed system to farmer's irrigation practice.

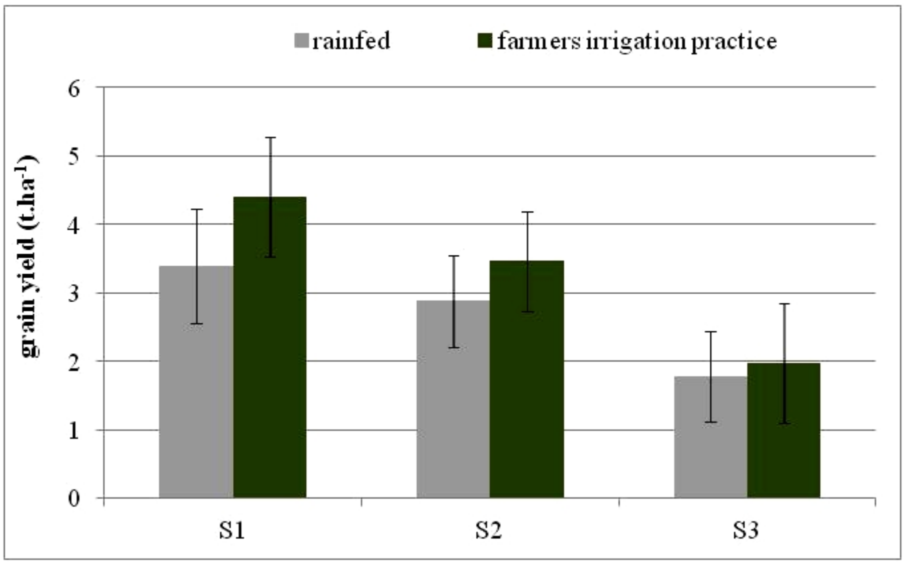

Fig. 8. Average and standard deviations values of yield, simulated by the STICS model, in the three soils as a function of water management

In farmers irrigation practices, highest grain yield, averaging respectively 4.4 t ha^{-1} was obtained in S1, while S3 had the lowest yield value. In S3, the reduction in grain yield may be a consequence of a crop water stress occurring during the reproductive stage of wheat, much more frequent in soil having low total available water. It seems that soil with high TAW creates more suitable conditions in the root zone area for plant production.

The reduction in yield values, in soil which has a low TAW, may be a consequence of a higher water deficit during grain filling period. In order to verify this hypothesis, the values of stomatal water stress indice (SWFAC) calculated by the STICS model as the ratio between actual transpiration and maximum transpiration were summarized in Table 10 It should be noticed that values of SWFAC range between 1 (no stress) and 0 (intensified water stress).

Table 10. Average values of the stress index (SWFAC), simulated by the STICS model in the three soils as a function of farmers irrigation practice

	Soils		
	S1	**S2**	**S3**
Vegetative stage	1.00 a	1.00 a	0.99 a
Reproductive stage	0.74	0.72	0.68

SWFAC shows close values in the three soils during the vegetative stage. Contrarily, this index is significantly weaker in S3 during the reproductive stage compared to that observed in S2 and S1. In the latter, the water stress index is always higher than that observed in S2, though the differences observed are not statistically significant. Consequently, the decrease in grain yield in the soil which has a low TAW, may be related to water stress during the reproductive stage.

4. CONCLUSION

In this study STICS model was used to simulate effects of farmer's irrigation practices on wheat yield in the pedoclimatic conditions of the irrigated area of Oued Rmel in Tunisia over a 20 years period. The results of STICS evaluation indicated that this model performed with satisfactory precision in terms of wheat yield and biomass. It was determined that total available water in the root zone may significantly modulate the response of wheat yield to the water regime. According to the research results, it was found that irrigation at sowing had a positive effect on grain yield and aerial dry matter. Moreover, highest difference in grain yield was obtained in soil with highest TAW. In this soil, grain yield increased by 30% on average, moving from rainfed system to farmer's irrigation practice. Moreover, in farmers irrigation practices, soil TAW significantly affected aerial dry matter and grain yield. Highest values were obtained in S1 having high TAW. In S1, grain yield and aerial dry matter at harvest were respectively 4.4 and 9.04 and t.ha-1. Further studies should be conducted, taking into account the effects of various water regimes, in terms of crop water use efficiency, in soils having different properties.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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