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A Crop Model for Improvement Water Use Efficiency and Durum Wheat Production in the Siliana Region

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ABSTRACT

In Tunisia, the development of the irrigation within the water scarcity context, remains one of the crucial issues in agricultural activity. The phenomenon of climate change is likely to make the problematic while threatening the country's food security. Thus, high water use efficiency is essential to overcome these constraints and to facilitate sustainable agricultural activity. This work aims to optimize irrigation water use and to increase the production of the durum wheat (DW) through improving irrigation practices. For this, a field survey was carried out with a sample of 43 farms from the Siliana region. In data collection process, current study focused on the DW activity during the agricultural compain of 2015 in terms of the applied doses of water and fertilizer as well as the crop rotation. A crop model, CROPSYST, has been developed. The model used DW activity during three consecutive crop production periods as 2015, 2016 and 2017. Three strategies of varied mix in terms of irrigation water and fertilizer doses were simulated. The results showed the improvement of the yield by 9% that allowed an improvement of the water productivity up to 8,2 kgha^{-1}mm^{-1}.Given these results the Gross Margin may increase by 3% up to 11%.

1. Introduction

In Tunisia, irrigation development remains a strategic activity to increase agricultural production as well as national economy.The irrigated activities use only 8% of the arable land but ensure up to 40% of the national agricultural production value.

Thanks to irrigation, Tunisia has achieved self-sufficiency in fruits and vegetables, even generating surpluses for export. However, within the context of limited water resources (quantity and quality) and climate change, this orientation is increasingly problematic.As a result, Tunisia is currently facing an imminent risk of water scarcity and even if the water volumes allocated to the agricultural sector will tend to decline with an annual growth rate of around 1.3%, this sector will remain the main consumer with an average of 80% of available water resources (Hammami et al.2017). In addition, despite the huge efforts made over the past 40 years to save water, the current situation shows an overconsumption that sometimes exceeds 30% which highlights lack of mastering the technology production mainly the irrigation practices (Bhouri et al.2015; Chemak et al.2010). Thus improving the water productivity of strategic crops, particularly DW is required to better value this scarce resource and to deal with the challenges of food security. In Tunisia, the irrigated DW occupies an average of 48806 ha equal to 36% of the total area of irrigated cereals and provides about 67% of the total production of irrigated cereals (MA.2018). The DW crop is grown in large-scale crops for human consumption only. Indeed, this activity represents, depending on the period, between 40 and 50% of the vegetal food availability (Ben Zekri.2017).

However, yields of the DW are still insufficient, with a–high fluctuating national average of around 36qha^{-1} (1q=100Kg; 1ha=10^{4}m^{2}) compared to a target of 70qha^{1} (Maihol et al.2007). Indeed, Hammami et al.(2016) confirm that it is possible to obtain a yield greater than 70 qha^{-1} for irrigated DW with a good match between the potential of the medium and the high-yielding varieties.

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Rajram and Braun (2008) stated reasons behind the low yields (10qha^{-1} at 60 q ha^{-1}) of the Razak variety (with a production potential of 95 q ha^{-1}) are drought effect and the poor crop management. Other authors (Mouelhi et al.2016; Latiri et al.2010) have also reported the low yields observed due to the variability of pedoclimatic conditions, the inadequacy of sowing date with varietal choice, the monoculture and inappropriate rotation of crops.

Nevertheless, despite the variability of the mentioned factors above, water and nitrogen remain the main limiting factors of DW production in Tunisia (Ben Zekri 2017; Latiri et al. 2010).

Within this context, the maximization of production through a good match between the new irrigation and fertilization practices was the major concern of agricultural economists who seek to design sustainable production systems and meet the growing demand for products for a rapidly growing population. However, the proposal of novice practices of irrigation and nitrogen fertilization is based on a preliminary evaluation phase of these practices. Thus several approaches are available to agronomists to accomplish these evaluation tasks among which the experimental evaluation in the field (Guillaume 2011).

Nevertheless, Guillaume (2011) showed that applied experimentation techniques reach their limits as soon as we try to estimate the impact of technical change or to evaluate the effects of climate or agricultural practices on production systems.To overcome this obstacle, agronomists took advantage of advances in the field of computer language to develop cropping system models that simulate farms' actions in a simplified form. According to Guillaume (2011), agricultural models make it possible to simultaneously evaluate the effect of interactions between climates, soil type and cultivation techniques on the performance of the system under study.Thus, these models offer the possibility of exploring a wider range of situations in a short timeframe.

This work aims to evaluate the performance of the irrigated DW in the governorate of Siliana and to analyze, with the CROPSYST model, the possibilities of jointly increasing the yields and the efficiency of water use in DW farming systems.

Before identifying and evaluating the alternative levers, it was first necessary to carry out a detailed characterization of agricultural diversity and to evaluate, based on the concept of resources use efficiency, the performance of each agricultural household constituting this diversity.

2. Materials and Methods

2.1. Study area and data collection

This study was conducted in the region of Siliana, which is located in the Northwest of Tunisia (Figure 1). The region is characterized by continental climate with average annual precipitation of about 486 mm.The economy of the region is mainly based on agriculture where the areas arable land reaches 313,000 ha. Agricultural activity consists of cereals wich is carried out by 9269 farms, representing 43% of all grain producers in the country (Khaldi et al.2017). Irrigated cereal crops occupy only 3% of the total area of cereal crops.

On the other hand, this activity contributes with an average of 13% of the total production of cereals reaching more than 30% in the dry year.The most irrigated cereal is DW with an average area of about 3000 ha, representing about 68% of the irrigated cereal area in the region.

The data required for our study was collected by performing survey with a sample of 43 farmers who practiced irrigated cereals during the cropping year 2014/2015

The survey questionnairy was designed with the aim of characterizing the production system practiced, but also with a focus on cropping practices in irrigated cerealso (Sowing, tilling, fertilization, irrigation, treatment, harvest) as well as the achieved yields.Through this database, we will characterize the agronomic and economic performances of this activity.

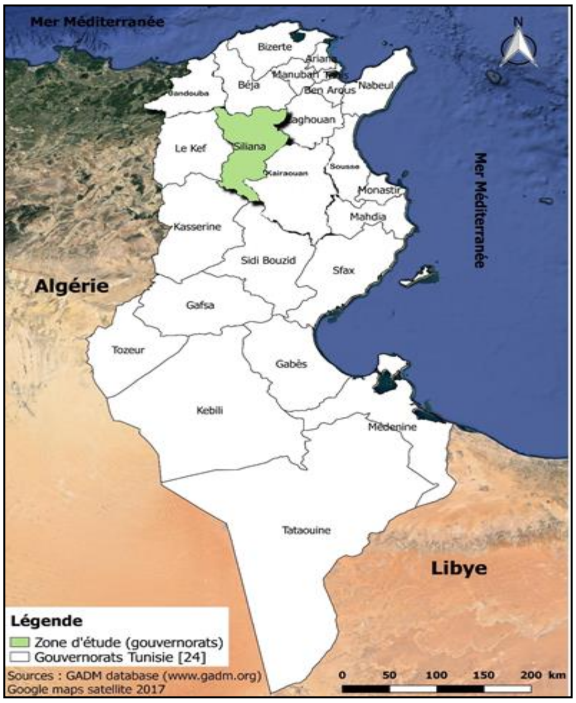

Figure1
Location of study area

Indeed, to evaluate agronomic performance analysis of grain yields and water productivity were assessed.The economic performance is estimated by gross margin.

2.2. CROPSYST for Biophysical modeling

In order to evaluate success of irrigation practices on durum wheat yields, CROPSYST, biophysical simulation model, cropping systems simulation multi-year model was used (Stockle et al.2003).

This model was developed for a large number of cultivated species including wheat, maize, sorghum and works with a daily time step. This model has been used and adapted to the Tunisian context in order to analyze the impact of climate and technical management on the productivity of cropping systems (Belhouchette 2004; Jeder 2011). Cropsyst needs five inputs files (Figure 2) that describe location (latitude,weather file, ET model selection Penman-Monteith (Pm) or Priestly-Taylor (PT) on automatic model), Soil file (soil type, pH, fieldcapacity and hydraulic conductivity), Crop file (emergence,thermal time accumulation,phenology and harvest), management file (irrigation, fertilization, planting and harvesting) and simulation control (a combination of different input files such as start and ending days, simulation of soil salinity and crop rotation) for simulation (Umair et al.2017). To run this model, all these modules should be properly defined one after the other. In present study, the daily climatic data on rainfall, temperature,solar radiation,relative humidity and wind speed are provided by the National Institute of Meteorology of Tunis (INM).While the soil analysis data are obtained from CRDA's soil boundaries. The technical itinerary of the wheat crop is obtained via technical and economic data sheets completed in consultation with farms and CTV technicians in the delegations.The phenological characteristics of crop are drawn from research work that has been carried out and adapted to the Tunisian context (Belhouchette 2004; Abbess 2007; Jeder 2011). To calibrate model we first introduced in CROPSYST the current technical itineraries related to DW cultivation whose yields were known and we launched a first simulation.Then, based on data from the bibliography, we adapted the parameters of the model to bring the simulated yields closer to those actually achieved at the level of the farm.

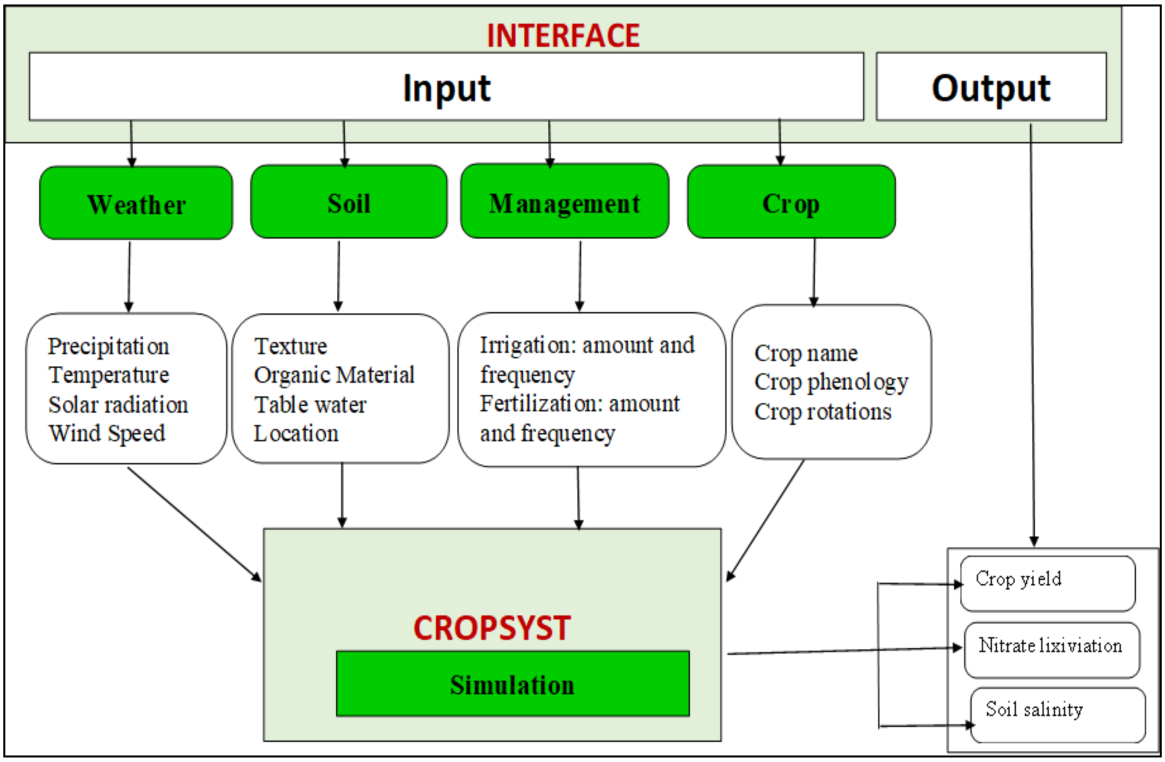

Figure2
Presentation of CROPSYST Model

Once calibrated, the model is validated for different soil, climate and crop conditions. The validation is based on the only available criteria, mainly the yields of DW irrigated in the 2014/2015 crop season identified by our survey. Indeed, it consists in comparing simulated yields with those currently obtained for a series of farms, depending on the type of soil, irrigation practices and climate, assuming that these farms apply the same technical itinerary (fertilization rate, sowing dates and harvest date) than the typical farm for each system. Similarly, considering the importance of the representativity of the simulations to properly evaluate the robustness of CROPSYST, we adopted the method of survey by stratum in setting our survey rate at 15%. Thus, the final sample chosen to validate our model is 5 farms belonging to very heterogeneous zones from the point of view of nature of the climate and the type of soil.

3. Results and discussion

Before identifying and evaluating the alternative levers it is necessary to carry out a detailed characterization of the crop system and the technical management of the DW and to evaluate, based on the concept of water productivity, the performance of this activity.

3.1. Management of the durum wheat

The results showed that the total agricultural surveyed land reached 460 ha. The analysis of the land use during the cropping year 2014/2015 showed that the cropping system involves, cereal crops (82%), horticulture (15%), fruit trees (2%) and fodder crops (1%). The the cultivated area of irrigated DW reached 195 ha which represents 58% of the total cereal area.

In terms of technical management of the crop, results showed that sowing seeds is carried out during the period from mid-November to mid-December at varying dose from 180 kg ha^{-1} to 200kgha^{-1}.

The fertilization program applied depends on the vegetative stage of the plant. Indeed DAP (Diammonium phosphate) is often provided with an average dose of 170 kgha^{-1} before sowing.While nitrogen is supplied as an ammo nitrate at varying doses from 150 kgha^{-1} to 350 kgha^{-1} and in one to three intakes (Table1).

Then in order to irrigate the DW, the results showed that farmers had used the available water at the level of 650 m^3 ha^{-1}. However, the average of applied water volume varies from one farm to another depending on the availability of water resource (Table1).The results showed also, that irrigation is practiced without taking into account either the theoretical need of the plant or the monthly distribution.

Table 1
Average quantity of inputs using during 2014-2015

variables	unit	Average
Seeds	Kgha^{-1}	200
DAP	Kgha^{-1}	170
Nitrogen	Kgha^{-1}	350
Applied water volume	m^{3}ha^{-1}	650

3.2. Agronomic and economic performance of durum wheat

The results showed that achieved yield of the DW reached an average of 36 q ha^{-1}. The average ranges within 11qha^{-1} and 60 q ha^{-1} and it remains under the potential expected level that should reach 70 qha^{-1} (Figure3).

This low yield of DW may be explained by the water supplies, which were always below the crop water requirement (Figure4).The results showed also that the variation in yield depends on the quantity of nitrogen. Indeed an analysis of figure 5 showed that, yield can increase by increasing nitrogen fertilization until reaching a maximum value from wich it tends to decrease with increasing nitrogen fertilization (Bhouri et al.2015). In fact given our results and by taking into account the quantity of the rainfalls, the water productivity reached only 7.8 kgha^{-1}mm^{-1} which is the half of the potential level that should be reached following agronomical studies (Chemak et al.2018; Lasram et al.2015; Wim and Pasqueleto.2014). This result allowed farmer to earn 1836 TNDha^{-1} (Tunisian Dinar; 1TND=0.32 Euros) as Gross Margin

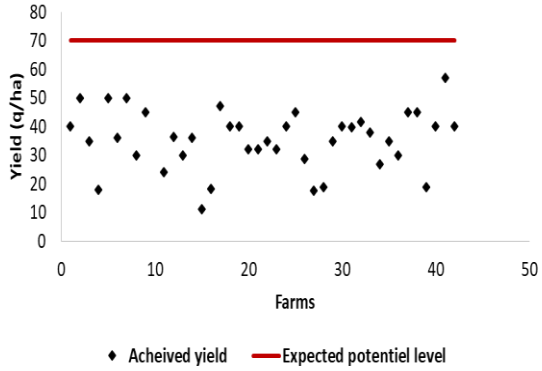

Figure 3
Acheived yield for he cropping year 2014-2015

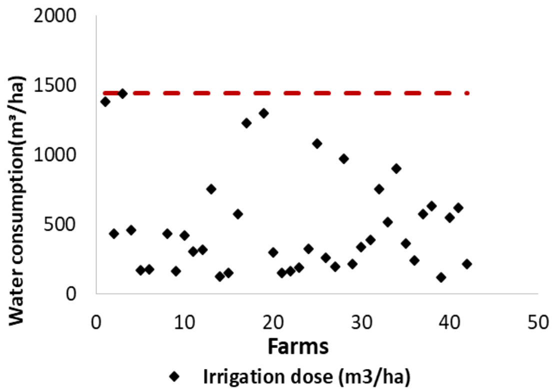

Figure 4
Variability of Applied water volume during the cropping year 2014-2015

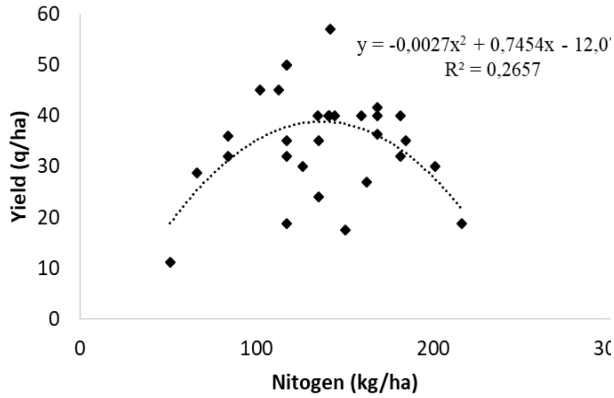

Figure 5
Variability in yield depending on the amount of nitogen during the cropping year 2014-2015

3.2. CROPSYST results

Results of the calibration confirm that CROPSYST simulates the yields quite correctly. Thus, the comparison of the simulated yields (34 q ha^{-1}) with those actually observed (36 q ha^{-1}) shows a slight difference of 5%.

Once calibrated the model was then tested on a sample of 5 farms (15% of the total sample) based on the yields of the 2014-2015 crop year. The results of validation showed a difference of only 9% in terms of simulated yield compared to that achieved (Table 2). Referring to the results of EL Ansari (2018), we can conclude that our model is well validated and could be used to simulate expected strategies.

Table 2
Comparison between the simulated and observed yields

	Achieved yield (qha^{-1})	Simulated yield (qha^{-1})	Difference (%)
Farm 1	40	33	-17
Farm 2	32	32	0
Farm 3	27	28	+3
Farm 4	40	35	-12
Farm 5	39	36	-8
Average	35.6	32.8	-9

Under the analysis of the farmers' practices in terms of the amount of Nitogen and the applied water volume, we propose three strategies, of varied mix in terms of irrigation water and fertilizer doses in order to improve the wheat production and the water productivity. Indeed, these strategies aim to generate simulations with CROPSYST by the combination of three doses of irrigation (0%, + 15%, +25%) and three doses of fertilization (0%, + 10%, +15%) taking into account theoretical needs for growing DW (Mellouli et al.2007; Bhouri et al.2015) during the cropping years 2015, 2016, 2017.The obtained results showed that the average yields of DW increase by applying various combinations of water supply and nitrogen fertilization (Table 3). Indeed, the analysis of the first strategy showed that the average of yield increases by 3% with an increase of nitrogen dose of 10%. However even we increase by increasing nitrogen dose of 15% we obtained the same simulated yield (Figure 6).While for the second strategy, results showed that the average yield will be increased by 6% from 34 q ha^{-1} to 36 qha^{-1}by increasing the irrigation dose of 15% and by applying the same amount of nitrogen initially used (S21). Whereas increasing the Nitrogen quantity by 10% and 15% (S22 and S23) might increase the average yield by 7%. For the third strategy,the results presented in Figure 6 showed an improvement of average yield by 8% in for an increase in irrigation dose of 25% (S31) while it is 9% for a both increase in irrigation dose of 25% and the Nitrogen of 10% and 15% (S32, S33).

In the light of these results, we found out that there is a significant interaction between wheat yield, applied water volume and fertilization. Thus the best yield of DW (37.5 qha^{-1}) was obtained by applying an irrigation dose of 1440 mm (+ 25% compared to the dose initially applied) and a fertilization dose of 127.6 KgNha^{-1} (+ 10%) and 133.4 kgNha^{-1} (+ 15%). Analysis of simulations showed also a both increase in water productivity and the gross margin of irrigated DW. Thus, results presented in Table 3 showed an improvement of the water productivity up to 8.2 kgha^{-1}mm^{-1}. In terms of Gross margins, the results showed a high increase, ranged between 2 and 3% for the first strategy, 6 and 8% for the second strategy and 9 and 11% for the third strategy (Table 3). An analysis of figure 7 showed that it is possible to obtain an overall gross margin of about 1850 TNDha^{-1} (+ 11%) with a simultaneous increase in the irrigation dose of 25% and nitrogen fertilization 10%.

Table 3
Results of differents simulations in term of yield, water productivity and Gross margin

Strategy		Definition	Yield (qha^{-1})	Water productivity (Kgha^{-1}mm^{-1})	Gross Margin (TNDha^{-1})
Baseline	S00	E0= 115 mm; N0 =116 kg N ha^{-1}	34	7.8	1650.6
	S11	E1=E0; N1= N0+10%*N0	35	8	1701.9
Strategy 1	S12	E1=E0; N1= N0+15%*N0	35	8	1695
	S21	E1=E0+15%*E0; N1= N0	36	8	1772.9
Strategy 2	S22	E1=E0+ 15%*E0 ; N1= N0+10%*N0	36.4	8.1	1784.6
	S23	E1=E0+ 15%*E0 ; N1= N0+15%*N0	36.4	8.1	1778.3
	S31	E1=E0+25%*E0; N1= N0	37	8	1829.8
Strategy 3	S32	E1=E0+ 25%*E0 ; N1= N0+10%*N0	37.5	8.2	1850
	S33	E1=E0+ 25%*E0 ; N1= N0+15%*N0	37.5	8.2	1841.8

Figure6
Simulation of durum wheat yields

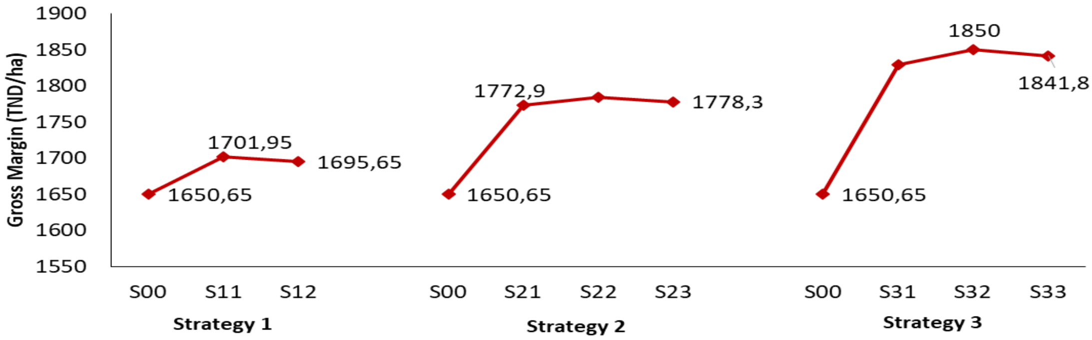

Figure7
Simulation of durum wheat Gross margin

4. Conclusion

The results of this work showed that modeling irrigation and nitrogen fertilization practices by the CROPSYST model are satisfactory. Thus the results from this model have approved that the best match between irrigation water volume and nitrogen fertilization is an essential alternative not only to increase durum yield and water productivity of irrigated DW but also to improve the economic performance of the activity.However, these strategies could be tested and validated by experimental protocols at the farms' level in order to be dissminated and adopted by wider farmers.

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