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F – literature search

Impact of climate change on the water requirements of the Bounamoussa perimeter, North-East of Algeria

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Abstract

The objective of this work is to determine the effects of climate change on the water needs of crops in the Bounamoussa perimeter, which is one of the large irrigation systems in the North-East of Algeria in order to predict a diagnosis of its operation. This region covers an area of 16,500 ha and is specialized in vegetable production.

The climatic trend of recent years in the study area is characterized by increasingly severe drought conditions that have compromised agricultural production at this perimeter. In this study, the results of the climatic parameters projected to 2050 and 2080 under the Climate Wizard program were used in the CropWat 8.0 program for estimating the future water requirements of crops, taking into account the three Scenarios (B1, A1B, A2) of greenhouse gases (GHGs). The Decision Support System for Agrotechnology Transfer (DSSAT) 4.5 program has also been used to generate future climatic parameters (temperatures and rains) to be compared with those of the climate wizard. The results obtained in 2050 and 2080 show a trend towards increasing temperatures and a fall in rainfall for all models and that the water requirements will be multiplied by 3 to 5 times the current needs. This situation will cause an imbalance in the operation of perimeter irrigation systems. Among the measures of adaptation to this situation in the first place is the change of the date of planting after calibration of the two models for all the cultures of the perimeter.

Key words: *Algeria, climate change, Climate Wizard program, CropWat model, DSSAT model, water requirements*

INTRODUCTION

Climate change has become a serious threat to food security in areas where agricultural production is highly sensitive to weather conditions. Indeed, changes in precipitation and temperature regimes combined with other environmental constraints such as soil degradation, pests and diseases have contributed to the decline in agricultural production [FRANKEL-REED *et al.* 2009; GIEC 2007].

In the North-East of Algeria, irrigated crops occupy an important place in the agricultural landscape. Yet the climatic trend of recent years has been characterised by increasingly drought conditions. The resulting water restrictions, especially during the summer period where irrigated crops are practiced, raise the problem of water requirements for irrigation. It is in this context that we will address this work. We study the situation of the plain of Bounamoussa located in the North-East of Algeria, through a study of the current and future water needs of irrigated crops. For this purpose, we will carry out specific agronomic calculations according to the crop rotation recommended by the FAO experts within the framework of the national water plan adopted in 2007 [MREE 2007].

In this study, the results of the climate parameters projected to 2050 and 2080 (according to the "average overall" approach of the Web-based program "Climate Wizard") were compared with those of the DSSAT program and used in the CropWat 8.0 program for estimating the future water requirements of crops.

MATERIALS AND METHODS

PRESENTATION OF THE STUDY AREA

The study area is represented by the plain of Bounamoussa (Fig. 1). The total gross area is about 16 500 ha of which 14 800 ha represent the irrigable net area. The perimeter irrigation water comes entirely from the Cheffia dam located upstream of the perimeter at about 20 km on the Bounamoussa River.

According to our survey carried out during the crop year 2013–2014 the irrigation technique most adopted is the sprinkling with 80%, followed by the surface irrigation with 18.50% and the drip system with 1.5%. Not far from the sea, the area undergoes a humid temperate climate where the annual rainfall varies from 600 to 700 mm and the mean temperature is of the order of 18°C. In this 48-year period, from 1972 to 1990, the wind speed varies from 3.1 to 3.5 $m \cdot s^{-1}$. The average relative humidity varies between 71 and 79%. The minimum varies between 43 and 53%, and the maximum between 92 and 96%.

The sunshine duration reached the average minimum in January with 4.4 hours per day, and the maximum in July with 11.4 hours per day. The number of sirocco days is about 14 days per year. It is most frequent in July and August and lasts respectively 2 and 3 days per month [MEDJERAB, HENIA 2005].

CROP WATER REQUIREMENTS

The continuous fictitious flow, following the calculations period of the irrigation water requirements, is adopted during the Bounamoussa perimeter creation studies in the late 1960s, and is based on evapotranspiration, rainfall and the planned 0.7 $dm^3 \cdot s^{-1} \cdot ha^{-1}$ [SARES 1966]. The total requirements according to this study total 10 300 $dm^3 \cdot s^{-1}$ for the irrigation of 16 258 ha. The irrigation water is provided by the Cheffia dam with a stopped flow during the study design of 60 hm^3 per year.

STUDY METHODS

The assessment of potential evapotranspiration is necessary to estimate the irrigation needs [DOORENBOS, PRUITT 1977; FUHRER, JASPER 2010]. It is considered as an indicator of optimal vegetation development and plays a capital role in assessing a region's climatic fitness for agriculture [CALANCA, HOLZKÄMPER 2010]. However, it is not so simple to define with precision the potential evapotranspiration [BRUTSAERT 1982], because it depends not only on the conditions of the atmosphere and the soil, but also on the vegetation's characteristics. For this reason, FAO has introduced in its report No. 56 on irrigation and drainage the concept of evapotranspiration of reference (*ET*o) [ALLEN *et al.* 1998].

We calculated the annual and monthly water requirements for the reference year (1950–2002) and for the projected 2050 and 2080 years of the various agricultural speculations by adopting the following approach.

- **Climate data**. The data used for the projected *ET*o calculation, minimum and maximum temperature and precipitation, were extracted from Climate Wizard, which is a web-based climate assistant used in the United States and recommended by the OECD in 2009. It uses 16 climate models accord-

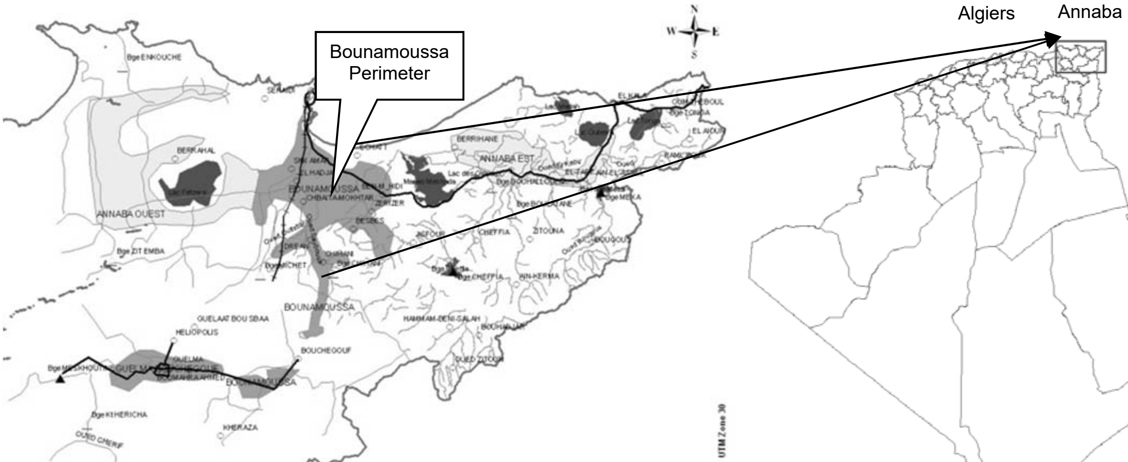

Fig. 1. Study area – Bounamoussa Perimeter, Algeria; source: own elaboration

Table 1. Crop coefficients applied in the study area

Crop	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Citrus	0.75	0.75	0.70	0.70	0.70	0.65	0.65	0.65	0.65	0.7	0.70	0.70
Stone/pome – fruits	0.40	0.40	0.55	0.70	0.75	0.80	0.80	0.70	0.70	0.65	0.55	0.40
Winter cereals	0.80	1.04	1.04	0.96	0.68	0	0	0	0	0.30	0.50	0.60
Summer cereals	0	0	0.30	0.70	0.50	0.80	0.55	0	0	0	0	0
Industrial crops	0	0	0.40	0.60	0.80	0.90	0.90	0.80	0.60	0	0	0
Winter fodder	1.00	1.00	1.00	1.00	0	0	0	0	0	0	0.50	0.80
Summer fodder	0	0	0.50	0.75	0.75	0.75	0.40	0	0	0	0	0
Winter vegetable crops	0	0	0.50	0.80	0.90	1.00	1.00	0.80	0	0	0	0
Summer vegetable crops	0	0	0	0	0	0	0	0.40	0.70	1.00	0.95	0.70
Late winter vegetable crops	1.00	1.00	0	0	0	0	0	0	0	0.50	0.65	0.95

Source: own elaboration.

ing to the three emission scenarios B1 (low emission), A1B (medium emission) and A2 (high emission) developed by IPCC [2000]. The simulations were made for the two periods of mid-century (2050) and end-of-century (2080). According to GIRVETZ *et al.* [2009], the results of the "Climate Wizard" analyses are consistent with those reported by the Intergovernmental Panel on Climate Change, but at the same time they provide examples of how the Climate Assistant can be used to explore the regional scale. In addition, the Climate Assistant is not a static product, but rather a data analysis framework to be used for climate change impact studies on agricultural production.

- **Crop water requirements***:* The FAO software, CropWat 8.0 was used for the calculation of reference evapotranspiration by application of the Penman–Monteith formula modified by FAO. The crop water requirements at the maximum evapotranspiration are based on the following formula:

$$B = K_c \cdot ET_0 - P_{\mathrm{ef}} \quad (1)$$

Where: B = water requirement (mm); Kc = crop coefficient; ETo = evapotranspiration of reference (mm); P_{ef} = effective rain determined from the USDA method (mm).

In the absence of crop coefficients used for the different crops that are truly representative for the study area, we were inspired by the work carried out within the framework of the national water plan adopted in 2007, enabling the same projection of land use by crops (Tab. 1).

Crop simulation models. CropWat. The CropWat 8.0 was used in order to have more complete outputs. CropWat is a free computer program developed by the FAO Land and Water Development Division in the early 1990s to assist agricultural water specialists in irrigation management [TURRAL *et al.* 2011]. This decision-making tool allows estimation of reference evapotranspiration, crop water requirements and irrigation needs of crops. It can also be used to design irrigation systems and assess the effectiveness of irrigation practices. Several studies [MUHAMMAD 2009; SMITH 1992; SMITH *et al.* 2002; STANCALIE *et al.* 2010] have used CropWat in various applications related to irrigation and water consumption of crops. The Centre for the Economy of the Environment and Policy in Africa (CEEPA) reported in 2006 a series of studies on the analysis of the impacts of climate change on several crops in several countries of Africa, for example Senegal, Mali, Niger, Egypt, and others using climate data generated with CropWat.

The Decision Support System for Agrotechnology Transfer (DSSAT) model. The DSSAT model is well known for its wide use [SOLTANI, HOOGENBOOM 2003]. It is a model of crop simulation (for more than 20 different crops). It is a set of programs integrated into a single software to facilitate the application of crop simulation models in research and decision-making [HOOGENBOOM *et al.* 2003; TSUJI *et al.* 1994]. The model simulates the daily growth stages of crops (wheat, tomatoes, potatoes, maize and other crops) such as phenological development from seeding to harvesting, photosynthesis, the biomass, root development, stem, leaves and grains, and water in soil and movement of nutrients.

The input data required by the DSSAT program includes meteorological data, soil properties, plant characteristics, and crop management (technical itinerary). The output file contains a list of input conditions, crop yields, soil characteristics summary, cultivar coefficients, soil condition at major stages of crop development, temporal distribution of Crops and soil moisture content and future climate data generated by WEATHERMAN (DSSAT integrated program).

DESCRIPTION OF THE CLIMATE TOOL

Climate Wizard is a web-based Climate Assistant, created in partnership with The Nature Conservancy, the University of Washington, and the University of Southern Mississippi. It is a mapping tool that uses advanced climate models and statistical analyses to study both current and future climate conditions from any place on Earth [GIRVETZ *et al.* 2009]. Future climate projections are based on the general circulation model.

The results of the models are produced for three different scenarios of greenhouse gas emissions for two future periods; average (2050) and end of century (2080). Projections were made using the period 1950–2002 as a baseline (Tab. 2). *ETo* is calculated by CropWat 8.0 software using the results obtained from

Table 2. Monthly climate data used as a reference for reference evapotranspiration (*ETo*) estimation and future water needs of the study area (average 1950–2002)

Climatic parameter	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Temperature T_{min}, °C	6.70	7.05	8.37	9.87	13.09	16.58	19.38	20.35	19.07	15.23	11.29	8.53
Temperature T_{max}, °C	14.87	15.62	18.05	20.06	23.44	27.36	30.63	31.15	28.60	24.72	19.89	16.58
Rain, mm	79.07	93.89	65.37	61.98	41.82	18.44	9.23	12.90	40.42	66.89	76.36	82.92
Effective rain, mm	69.1	79.8	58.5	55.8	39.0	17.9	9.1	12.6	37.8	59.7	67.0	71.9
*ET*o, mm	1.25	1.59	2.31	3.05	3.78	4.49	4.96	4.65	3.62	2.62	1.70	1.26

Source: ONM [2010].

the Climate Wizard model. For each month of the year, the average change of monthly temperature was extracted for our study area for the average of the century (2050) and the end of the century (2080). In other words, for the year 2050 and 2080, the average predicted average change in temperature for a given month was obtained by calculating the mean of the predicted temperature changes for the 16 models for Scenario B1. The same procedure was repeated on the basis of Scenario A1B and A2. The scenarios used in the Climate Wizard program are B1, A1B and A2, corresponding to a low, moderate and high (worst) case of greenhouse gases emissions [IPCC 2000].

The results obtained from the model, namely projected temperature and precipitation, were used to generate future data for the half and the end of the century (2050 and 2080). These generated results were then used to replace those existing in the observed data set. At the end of the overall process, data (projected minimum and maximum temperatures and precipitation) that have been generated corresponding to 2050 and 2080 are obtained. These data were used in the CropWat 8.0 crop model to simulate future water requirements Irrigation for crops in the study area.

RESULTS AND DISCUSSIONS

The results obtained from Climate Wizard (Tab. 3, 4) provide information on changes in temperature and precipitation during the middle and end of the century (2050 and 2080) according to the three climatic scenarios and according to the climate simulation models provided by Climate Wizard. It is noted that variations are very important for both temperatures and precipitation compared with the year of reference. Concerning the temperatures, we note a very important evolution, which varies between 1°C and 6°C for the three scenarios for the middle and the end of the century. There is also a very significant reduction in precipitation, which ranges from 1.5 mm to 31.93 mm. These results are similar to those reported by the 2002 UNDP / GEF study entitled “Vulnerability of the Maghreb Region to Algeria, Morocco, and Tunisia” [UNDP/GEF 2002].

These results are already mentioned in the Algerian national communication of 2001 on climate change. A trend towards increasing temperatures and decreasing rainfall in the year 2020 is expected (Tab. 5).

By adopting the DSSAT4.5 model, projected monthly variations (2050 and 2080) of climatic parameters without climate change during the vegetative cycle of the potato crop and compared to the base year, there is a slight increase in 2050 minimum and maximum temperatures varying from 0.07 to 2.35°C. For the year 2080, there is a decrease in the minimum temperatures from 0.73 to 1.85°C while the maximum fluctuates between a decrease of 0.65 and an increase of 1.75.

Concerning precipitation, there is a decrease in the minimum of 5.14 mm for the year 2050. In the year 2080 there is a decrease of rain of 17.68 mm, while for the maximum rains they undergo an increase going from 19.21 (2050) to 182.51 mm (2080) (Tab. 6). It is also noted that the minimum temperatures are reported in January and February, while the maximums are reported in July and August. The highest precipitation is reported in February and the lowest in July and August.

The results obtained from the DSSAT 4.5 software concern the growing period of the potato for a stable rate of CO_2 emission of 385 mg·dm^{-3}. These results show that the model provides virtually the same projections as the 16 above-mentioned models for temperature, but overestimates precipitation.

Concerning the assessment of crop water requirements in 2050 and 2080 according to the rotation recommended by FAO experts when drawing up the National Water Plan (2007), the three climatic scenarios (B1-A1B- A2) and the five climate models most used around the world (Tab. 7), we note:

- a variation of the results between the models;
- irrespective of the model adopted and the year of projection and the scenario considered, the water requirements exceed 22 000 m^3·ha^{-1}, which represent between 3 and 4 times the requirements calculated during the study design;
- winter vegetables dominate crop water requirements followed by industrial crops and then citrus fruits in both 2050 and 2080, regardless of the scenarios of climate change adopted.

According to the results of calculation of the water needs of the crops it is noted that whatever the model of climate change adopted, there is an increase of these needs nevertheless a difference between one model and another is to be noted.

During the study of the Bounamoussa perimeter, water requirements were estimated at 60 hm^3 per year

Table 3. Variation of the climate parameters projects 2050 according to different scenarios and according to the models of climate change

Model	Temperature				Rain, mm		Reference evapotranspiration *ETo*, mm	
	$T_{\min}$, °C		$T_{\max}$, °C					
	min	max	min	max	min	max	min	max
B1 scenario								
BCCR–BCM2.0	7.70(1)	21.47(8)	15.87(1)	32.27(8)	9.87(7)	89.34(11)	1.30(1)	5.17(7)
CGCM3.1(T47)	7.19(2)	23.62(8)	16.36(1)	34.42(8)	4.89(7)	90.13(2)	1.33(1)	5.35(7)
CRNM–CM3	8.11(1)	22.17(8)	16.28(1)	32.97(8)	9.23(7)	100.46(2)	1.31(1)	5.21(7)
CSIRO–Mk3.0	7.54(1)	21.79(9)	15.71(1)	32.57(8)	9.41(7)	91.07(2)	1.28(1)	5.08(7)
GFDL–CM2.0	7.84(1)	22.36(8)	16.01(1)	33.16(8)	13.10(7)	83.02(1)	1.30(1)	5.17(7)
GFDL–CM2.1	8.20(1)	21.84(8)	16.37(1)	32.64(8)	7.01(7)	89.19(2)	1.31(1)	5.21(7)
GISS–ER	8.20(1)	22.19(8)	16.37(1)	32.99(8)	6.36(7)	83.99(11)	1.31(1)	5.20(7)
INM–CM3.0	7.59(1)	23.56(8)	15.76(1)	34.36(8)	8.03(7)	93.92(11)	1.29(1)	5.22(7)
IPSL–CM4	8.50(1)	23.55(8)	16.67(1)	34.35(8)	5.53(7)	88.28(2)	1.34(1)	5.31(7)
MIROC3.2	8.70(2)	23.38(8)	17.27(2)	34.18(8)	8.03(7)	89.34(11)	1.37(12)	5.30(7)
ECHO–G	7.70(1)	22.35(8)	15.87(1)	33.15(8)	7.22(8)	92.01(2)	1.30(1)	5.17(7)
ECHAM5/MPI–OM	8.34(1)	22.50(8)	16.51(1)	33.30(8)	10.91(8)	97.64(2)	1.33(1)	5.21(7)
MRI–CFCM2.3.2	8.20(1)	21.55(8)	16.37(1)	32.35(8)	7.01(7)	88.25(2)	1.32(1)	5.10(7)
CCSM3	7.91(1)	23.03(8)	16.08(1)	33.83(8)	12.38(8)	82.46(11)	1.31(1)	5.34(7)
PCM	7.94(1)	22.13(8)	16.11(1)	32.93(8)	9.13(7)	97.64(2)	1.31(1)	5.10(7)
UKMO–HadCM3	7.80(1)	22.90(8)	15.97(1)	33.70(8)	6.06(8)	92.01(2)	1.30(1)	5.25(7)
A1B scenario								
BCCR–BCM2.0	8.36(1)	21.88(8)	16.53(1)	32.97(7)	6.00(7)	70.23(10)	1.32(12)	5.26(7)
CGCM3.1(T47)	8.73(1)	24.47(8)	16.90(1)	35.27(8)	5.26(7)	86.38(2)	1.35(1)	5.40(7)
CRNM–CM3	8.78(1)	23.16(8)	16.95(1)	33.96(8)	6.33(7)	77.93(2)	1.35(1)	5.36(7)
CSIRO–Mk3.0	7.72(1)	22.71(8)	15.89(1)	33.51(8)	8.77(7)	97.64(2)	1.29(1)	5.13(7)
GFDL–CM2.0	8.55(1)	24.10(8)	16.72(1)	34.90(8)	7.11(7)	70.25(11)	1.33(1)	5.28(7)
GFDL–CM2.1	8.34(1)	24.33(8)	16.51(1)	35.16(8)	5.44(7)	76.70(1)	1.32(1)	5.37(7)
GISS–ER	8.05(1)	22.70(8)	16.22(1)	33.50(8)	6.36(7)	79.60(12)	1.31(1)	5.23(7)
INM–CM3.0	7.94(1)	24.00(8)	16.11(1)	34.80(8)	4.98(7)	80.74(2)	1.30(1)	5.32(7)
IPSL–CM4	8.81(1)	23.68(8)	16.98(1)	34.48(8)	5.17(7)	96.70(2)	1.35(1)	5.44(7)
MIROC3.2	9.41(1)	24.10(8)	17.52(2)	34.90(8)	9.51(7)	82.92(12)	1.38(1)	5.37(7)
ECHO–G	8.22(1)	22.90(8)	16.39(1)	33.75(8)	6.92(7)	116.42(2)	1.33(1)	5.26(7)
ECHAM5/MPI–OM	8.59(1)	23.83(8)	16.76(1)	34.63(8)	6.27(7)	75.45(12)	1.34(1)	5.36(7)
MRI–CFCM2.3.2	8.51(1)	21.82(8)	16.68(1)	32.62(8)	8.12(7)	81.70(11)	1.34(1)	5.21(7)
CCSM3	8.97(1)	24.06(8)	17.14(1)	34.86(8)	9.23(7)	77.88(11)	1.35(1)	5.38(7)
PCM	8.40(1)	22.22(8)	16.57(1)	33.02(8)	8.12(7)	93.70(12)	1.32(1)	5.20(7)
UKMO–HadCM3	7.83(1)	23.81(8)	16.70(1)	34.61(8)	5.81(7)	89.19(2)	1.37(12)	5.32(7)
A2 scenario								
BCCR–BCM2.0	8.01(1)	21.58(8)	16.18(1)	32.66(7)	10.24(7)	80.93(10)	1.31(1)	5.23(7)
CGCM3.1(T47)	8.89(1)	24.28(8)	17.06(1)	35.08(8)	5.07(7)	68.53(2)	1.35(1)	5.45(7)
CRNM–CM3	8.47(1)	22.95(8)	16.64(1)	33.75(8)	7.29(7)	75.11(2)	1.33(1)	5.32(7)
CSIRO–Mk3.0	7.88(1)	22.56(8)	16.05(1)	33.36(8)	11.53(7)	88.25(2)	1.30(1)	5.16(7)
GFDL–CM2.0	8.66(1)	22.94(8)	16.83(1)	33.74(8)	7.84(7)	77.88(11)	1.34(1)	5.28(7)
GFDL–CM2.1	8.31(1)	23.42(8)	16.48(1)	34.22(8)	4.79(7)	75.11(2)	1.31(1)	5.36(7)
GISS–ER	8.76(1)	22.91(8)	16.93(1)	33.71(8)	6.46(7)	85.52(11)	1.31(12)	5.28(7)
INM–CM3.0	8.36(2)	24.20(8)	16.76(1)	35.00(8)	5.90(7)	93.89(2)	1.32(12)	5.35(7)
IPSL–CM4	9.25(2)	23.62(8)	17.45(1)	34.42(8)	4.79(7)	97.64(2)	1.37(12)	5.41(7)
MIROC3.2	9.27(1)	23.90(8)	17.44(1)	34.70(8)	8.67(7)	87.81(11)	1.37(12)	5.33(7)
ECHO–G	7.77(1)	22.70(8)	15.94(1)	33.50(8)	7.38(7)	91.07(2)	1.31(1)	5.27(7)
ECHAM5/MPI–OM	8.54(2)	23.19(8)	17.06(1)	33.99(8)	8.76(7)	90.13(2)	1.36(1)	5.29(7)
MRI–CFCM2.3.2	8.63(1)	21.93(8)	16.80(1)	32.73(8)	11.26(7)	94.82(2)	1.34(1)	5.12(7)
CCSM3	8.67(1)	24.23(8)	16.84(1)	35.03(8)	7.29(7)	93.69(12)	1.33(1)	5.38(7)
PCM	7.83(1)	22.24(8)	16.00(1)	33.04(8)	8.30(7)	87.06(12)	1.30(1)	5.18(7)
UKMO–HadCM3	8.30(1)	23.84(8)	16.47(1)	34.64(8)	6.83(7)	90.93(1)	1.32(1)	5.34(7)

Explanation: (1)–(12) = consecutive months in the year.
Source: own study.

Table 4. Variation of projected climate parameters 2080 according to different scenarios and according to models of climate change

Model	Temperature				Rain, mm		Reference evapotranspiration *ETo*, mm	
	T_{min}, °C		T_{max}, °C					
	min	max	min	max	min	max	min	max
B1 scenario								
BCCR–BCM2.0	8.31(1)	21.92(8)	16.48(1)	32.83(7)	8.03(7)	79.41(11)	1.31(12)	5.25(7)
CGCM3.1(T47)	8.56(1)	24.21(8)	16.73(1)	35.01(8)	5.07(7)	73.23(2)	1.34(1)	5.34(6)
CRNM–CM3	8.51(1)	22.70(8)	16.68(1)	33.50(8)	9.41(7)	88.25(2)	1.32(1)	5.30(7)
CSIRO–Mk3.0	7.99(1)	22.73(8)	16.16(1)	33.53(8)	8.95(7)	93.89(2)	1.31(1)	5.11(7)
GFDL–CM2.0	8.51(1)	23.18(8)	16.68(1)	33.98(8)	7.66(7)	92.01(2)	1.34(1)	5.26(7)
GFDL–CM2.1	8.58(1)	23.16(8)	16.75(1)	33.96(8)	9.04(7)	90.13(2)	1.34(1)	5.24(7)
GISS–ER	8.53(1)	22.52(8)	16.70(1)	33.32(8)	7.47(7)	92.95(2)	1.33(1)	5.20(7)
INM–CM3.0	7.71(1)	23.83(8)	15.88(1)	34.63(8)	8.12(7)	73.23(2)	1.29(1)	5.34(7)
IPSL–CM4	9.23(1)	23.61(8)	17.40(1)	34.57(7)	4.43(7)	95.76(2)	1.37(1)	5.46(7)
MIROC3.2	9.37(2)	24.98(8)	17.76(1)	35.29(8)	8.12(7)	84.50(2)	1.38(12)	5.50(8)
ECHO–G	8.39(1)	23.17(8)	16.56(1)	33.97(8)	6.83(7)	91.07(2)	1.33(1)	5.29(7)
ECHAM5/MPI–OM	8.93(2)	24.01(8)	17.36(1)	34.81(8)	6.46(7)	85.44(2)	1.38(1)	5.39(7)
MRI–CFCM2.3.2	8.57(1)	22.38(8)	16.74(1)	33.18(8)	10.33(7)	94.88(2)	1.34(1)	5.17(7)
CCSM3	8.01(1)	22.76(8)	16.18(1)	33.56(8)	8.58(7)	10.43(2)	1.30(1)	5.26(7)
PCM	8.54(1)	22.38(8)	16.71(1)	33.18(8)	9.13(7)	100.46(2)	1.34(1)	5.16(7)
UKMO–HadCM3	8.86(1)	24.00(8)	17.03(1)	34.80(8)	4.89(7)	102.34(2)	1.34(12)	5.30(7)
A1B scenario								
BCCR–BCM2.0	8.88(2)	23.00(8)	17.12(1)	33.88(7)	7.57(7)	78.93(10)	1.35(12)	5.38(7)
CGCM3.1(T47)	9.43(1)	25.71(8)	17.60(1)	36.51(8)	4.43(7)	66.66(2)	1.37(1)	5.56(7)
CRNM–CM3	9.23(1)	24.08(8)	17.40(1)	34.88(8)	6.27(7)	97.64(2)	1.37(1)	5.50(7)
CSIRO–Mk3.0	8.27(1)	23.08(8)	16.44(1)	33.88(8)	10.52(7)	81.44(1)	1.32(1)	5.19(7)
GFDL–CM2.0	9.63(1)	25.14(8)	17.80(1)	35.94(8)	5.54(7)	75.59(11)	1.37(12)	5.49(7)
GFDL–CM2.1	8.70(1)	25.99(8)	16.87(1)	36.79(8)	4.15(7)	71.95(1)	1.34(1)	5.50(7)
GISS–ER	9.21(1)	24.11(8)	17.38(1)	34.91(8)	5.15(7)	81.26(12)	1.37(1)	5.37(7)
INM–CM3.0	8.49(1)	24.99(8)	16.66(1)	35.79(8)	5.35(7)	87.81(11)	1.33(1)	5.44(7)
IPSL–CM4	10.15(2)	25.22(8)	18.30(1)	36.02(8)	4.52(7)	107.03(2)	1.21(1)	5.31(7)
MIROC3.2	10.18(2)	25.52(8)	18.52(1)	36.32(8)	8.40(7)	74.63(12)	1.42(12)	5.56(7)
ECHO–G	9.20(1)	24.37(8)	17.37(1)	35.17(8)	5.17(7)	89.19(2)	1.37(1)	5.45(7)
ECHAM5/MPI–OM	10.36(1)	25.79(8)	18.53(1)	36.59(8)	5.91(7)	79.41(11)	1.43(1)	5.56(7)
MRI–CFCM2.3.2	9.53(1)	22.78(8)	17.70(1)	33.58(8)	6.83(7)	79.80(2)	1.38(1)	5.24(7)
CCSM3	9.39(1)	24.48(8)	17.56(1)	35.28(8)	8.58(7)	72.14(12)	1.37(1)	5.42(7)
PCM	8.73(1)	23.16(8)	16.90(1)	33.96(8)	7.56(7)	98.67(12)	1.33(1)	5.29(7)
UKMO–HadCM3	9.68(1)	25.41(8)	17.85(1)	36.21(8)	4.15(7)	76.36(11)	1.40(1)	5.49(7)
A2 scenario								
BCCR–BCM2.0	9.02(1)	23.40(8)	17.19(1)	34.20(8)	7.29(7)	94.31(10)	1.35(1)	5.38(7)
CGCM3.1(T47)	10.01(1)	27.13(8)	18.18(1)	37.93(8)	2.76(7)	61.96(2)	1.40(1)	5.77(7)
CRNM–CM3	9.81(1)	24.87(8)	17.98(1)	35.67(8)	7.10(7)	86.37(2)	1.40(1)	5.60(7)
CSIRO–Mk3.0	9.08(1)	24.45(8)	17.25(1)	35.25(8)	8.76(7)	79.86(1)	1.36(1)	5.40(7)
GFDL–CM2.0	9.78(1)	26.42(8)	17.95(1)	37.22(8)	2.86(7)	63.37(11)	1.40(1)	5.55(7)
GFDL–CM2.1	9.07(1)	25.80(8)	17.24(1)	36.55(8)	3.32(7)	68.53(2)	1.35(1)	5.66(7)
GISS–ER	9.67(1)	24.31(8)	17.84(1)	35.11(8)	5.44(7)	80.94(11)	1.38(12)	5.43(7)
INM–CM3.0	9.16(1)	26.01(8)	17.33(1)	36.81(8)	6.09(7)	76.05(2)	1.36(1)	5.56(7)
IPSL–CM4	10.57(2)	25.38(8)	18.92(1)	36.23(8)	3.87(7)	96.70(2)	1.44(1)	5.61(7)
MIROC3.2	10.09(2)	26.13(8)	18.66(1)	36.93(8)	5.44(7)	89.19(2)	1.44(1)	5.62(1)
ECHO–G	9.23(1)	24.70(8)	17.40(1)	35.50(8)	6.46(7)	93.89(2)	1.37(1)	5.50(7)
ECHAM5/MPI–OM	10.14(2)	25.82(8)	18.52(1)	36.62(8)	7.01(7)	69.48(11)	1.42(12)	5.62(7)
MRI–CFCM2.3.2	9.46(2)	23.14(8)	17.78(1)	33.94(8)	9.69(7)	89.19(2)	1.39(1)	5.27(7)
CCSM3	9.83(1)	26.64(8)	18.00(1)	37.44(8)	8.76(7)	79.86(1)	1.41(1)	5.77(7)
PCM	9.03(1)	23.39(8)	17.23(1)	34.19(8)	6.09(7)	85.52(11)	1.35(1)	5.34(7)
UKMO–HadCM3	9.64(1)	26.41(8)	17.81(1)	37.21(8)	3.35(7)	76.28(12)	1.38(1)	5.62(7)

Explanation: (1)–(12) = consecutive months in the year.
Source: own study.

Table 5. Projected changes in temperature and rainfall 2020 in northern Algeria according to the results of the First National Communication

Model	Autumn		Winter		Spring		Summer	
	T, °C	rain, mm	*T*, °C	rain, mm	*T*, °C	rain, mm	*T*, °C	rain, mm
UKHI	+0.8 to 1.1	–6 to 8%	+0.65 to 0.8	– 10%	+0.85 to 0.95	–5 to 9%	+0.85 to 1.05	–8 to 13%
ECHAM3TR	+0.8 to 1.3	0	+0.9 to 1	–5%	+0.95 to 1.1	–7 to 10%	+0.95 to 1.45	–5%

Explanation: *T* = temperature.
Source: own elaboration based on MATE [2001].

Table 6. Projected monthly variations (2050 and 2080) of climatic parameters without climate change estimated from the DSSAT 4.5 model during the vegetative cycle of the potato crop

Climatic parameter		2050	2080
		$CO_2 = 385\ mg \cdot dm^{-3}$	
Temperature, T_{min}, °C	min	7.45	4.85
	max	17.24	15.85
Temperature, T_{max}, °C	min	14.94	14.22
	max	29.71	29.11
Rain, mm	min	13.30	0.76
	max	113.10	276.40
Reference evapotranspiration *ETo*, mm	min	1.33	1.50
	max	2.53	3.97

Source: own study.

for an irrigable area of 14 800 ha. By adopting the results of these two models (UKMO-HadCM3 and ECHAM5), there is an increase of more than 25 000 m^3 per ha, which represents 3 to 5 times the actual needs compared to the needs estimated in the initial study, varying from 5000 to 8000 m^3 per ha. Knowing that these needs are necessary to determine the continuous fictitious flow rate we can say that our network put in place will not manage to convey the projected flow. As a result, all the hydraulic infrastructures, namely pumping stations, pipes and other structures, will be undersized, which affects the proper functioning of the perimeter. This is valid for the entire study area.

Table 7. Annual evaluation of future water needs (2050 and 2080) in mm according to the assembly recommended by the 1999–2005 NPP from CropWat 8.0 and three greenhouse gases scenarios (B1-A1B-A2) and five models of climate simulations

Crop	Scenario														
	A2					A1B					B1				
	model														
	CSIRO-Mk3.0	GFDL-CM2.0	ECHAM5/MPI-OM	MRI-CGCM 2.3.2	UKMO-HadCM3	CSIRO-Mk3.0	GFDL-CM2.0	ECHAM5/MPI-OM	MRI-CGCM 2.3.2	UKMO-HadCM3	CSIRO-Mk3.0	GFDL-CM2.0	ECHAM5/MPI-OM	MRI-CGCM 2.3.2	UKMO-HadCM3
2050															
Citrus	358.18	365.69	386.75	358.54	414.44	368.61	407.99	440.40	464.64	429.96	399.97	404.80	392.67	380.39	402.08
Stone/ pome – fruits	411.09	424.99	447.13	420.15	466.41	427.73	463.89	495.73	123.98	480.36	455.27	456.89	456.26	440.17	464.01
Winter cereals	111.42	122.80	120.35	105.78	125.59	109.14	135.53	137.24	234.89	134.32	137.10	141.17	124.28	110.76	115.20
Summer cereals	199.30	212.36	226.97	213.30	232.20	207.52	229.30	245.38	484.06	229.41	225.51	234.99	227.67	221.57	228.43
Industrial crops	430.25	444.27	475.90	449.96	492.56	446.01	486.74	513.94	66.27	494.22	471.96	487.32	487.31	468.88	468.37
Winter fodder	69.60	75.74	61.07	57.01	80.80	67.13	78.60	82.16	239.08	91.75	87.56	91.87	68.38	59.43	67.56
Summer fodder	203.51	216.40	230.84	217.77	235.61	211.59	233.19	249.47	503.27	234.42	230.26	238.88	231.72	225.92	232.10
Winter vegetable crops	460.83	475.67	496.88	475.88	509.90	477.53	505.76	527.31	144.50	512.82	492.77	509.47	503.12	486.59	508.66
Summer vegetable crops	127.08	126.91	134.23	119.12	147.65	133.84	146.17	161.62	0	158.11	134.42	133.86	139.14	133.56	146.73
Late winter vegetable crops	0	0	0	0	0	0	0	0	0	0	0.39	0	0	0	0
Total	2371.26	2464.83	2580.12	2417.51	2705.16	2449.10	2687.17	2853.25	2260.69	2765.37	2635.21	2699.25	2630.55	2527.27	2633.14
2080															
Citrus	354.85	375.23	447.01	371.26	428.43	392.58	467.93	478.20	405.02	463.02	423.61	481.24	503.38	407.97	493.46
Stone/ pome – fruits	414.54	432.96	507.23	435.89	483.65	441.27	522.41	536.09	466.16	525.18	477.94	533.65	556.67	466.77	547.48
Winter cereals	100.93	125.32	145.81	114.99	136.21	129.33	155.89	151.22	122.20	137.45	145.15	165.46	168.85	131.84	163.64
Summer cereals	198.87	227.65	260.48	223.65	244.00	207.08	253.83	265.33	236.15	260.42	241.88	263.29	276.99	240.69	273.67
Industrial crops	439.07	461.02	529.16	465.97	514.93	453.36	531.84	547.26	490.07	542.12	494.75	545.13	569.56	491.42	560.61
Winter fodder	58.54	79.68	81.73	61.25	84.53	90.81	94.31	84.03	66.48	81.98	84.68	107.86	99.64	73.53	100.56
Summer fodder	203.36	231.48	264.78	228.02	248.14	211.41	258.22	269.20	241.04	264.43	246.37	269.16	281.04	245.27	277.62
Winter vegetable crops	464.12	494.21	544.81	493.27	525.94	474.63	541.05	562.32	510.19	553.63	521.00	560.95	575.46	512.37	575.58
Summer vegetable crops	129.06	118.00	157.75	119.89	151.28	145.71	177.48	177.37	143.12	173.12	147.88	171.55	184.30	138.97	181.63
Late winter vegetable crops	0	0	0	0	0	3.79	8.59	8.81	0	1.82	1.63	1.19	3.22	0	6.29
Total	2363.34	2545.55	2938.76	2514.19	2817.11	2549.97	3011.55	3079.83	2680.43	3003.17	2784.89	3099.48	3219.11	2708.83	3180.54

Source: own study.

CONCLUSIONS

This study examined the possible implications of climate change for crop water requirements in an agricultural region in north-eastern Algeria. This region of Algeria is known to be a sub humid region with irregular and low rainfall during periods of irrigation especially vegetable crops. The three scenarios adopted by the IPCC were applied for the years 2050 and 2080. The results were obtained through three programs, namely CropWat 8.0, DSSAT4.5 and Climate Wizard. Using the projected climatic data provided by Climate Wizard as inputs in crop models, the impacts of climate change on irrigation water requirements were analysed.

Water requirements were calculated for all crops grown in this area based on crop rotation recommended by experts in the national water plan. The main crops are wheat, vegetable crops and citrus fruits. This study showed that water needs will increase from 3 to 5 times the current needs. The increase in these needs will be mainly due to the increase in temperature and the decrease in rainfall. This situation will cause a fall in the yields of all agricultural production. One of the methods of adaptation to these changes is the modification of the crop calendar by the modification of the semi-date for field crops. The increase in temperature could be better controlled by the introduction of greenhouse culture and drip irrigation.

This research attempts to explain some of the effects of climate change on the water needs of crops in the North-East of Algeria. Due to the optimistic estimates of irrigation water requirements obtained with CropWat and its ease of use, we believe that this software may be more appropriate to assist farmers in managing irrigation.

The main recommendation for future studies based on current results is to conduct field experiments to calibrate the two CropWat and DSSAT models for all crops. The extension of the meteorological data observation network would add more precision for future work. The development of better climate prediction models at the regional (or even national) level would reduce the uncertainties associated with estimating future climate data.

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Wpływ zmian klimatu na zapotrzebowanie na wodę w okolicach Bounamoussa, północnowschodnia Algieria

STRESZCZENIE

Przedmiotem prezentowanych w niniejszej pracy badań było określenie skutków zmian klimatu na potrzeby wodne upraw w obrębie systemu nawodnieniowego rzeki Bounamoussa, który jest jednym z największych w północnowschodniej Algierii. Miało to na celu sporządzenie diagnozy jego działania w przyszłości. Region zajmuje powierzchnię 16 500 ha i specjalizuje się w produkcji roślinnej.

Zmiany klimatu na badanym obszarze cechuje silna susza o zwiększającym się w ostatnich latach natężeniu, zagrażająca produkcji rolniczej. W badaniach zastosowano parametry klimatyczne prognozowane do roku 2050 i 2080 w ramach programu Climate Wizard do modelu CropWat 8.0 szacującego przyszłe zapotrzebowanie upraw na wodę z uwzględnieniem trzech scenariuszy (B1, A1B i A2) emisji gazów cieplarnianych. Wykorzystano także model wspierania decyzji w transferze agrotechnologii (DSSAT 4.5) do generowania parametrów przyszłego klimatu (temperatury i opady) w celu porównania ich z danymi uzyskanymi z Climate Wizard. Na podstawie wyników uzyskanych ze wszystkich modeli dla lat 2050 i 2080 stwierdzono trendy rosnące temperatury i malejące opadów. Zgodnie z tymi wynikami zapotrzebowanie na wodę ma wzrosnąć 3–5 razy w stosunku do aktualnych potrzeb. Taka sytuacja doprowadzi do zaburzenia równowagi w systemie irygacyjnym. Wśród sposobów przystosowania się do takiej sytuacji jednym z ważniejszych jest zmiana daty siewu, co można osiągnąć po skalibrowaniu obu modeli w dostosowaniu do wszystkich rodzajów upraw w regionie.

Słowa kluczowe: *Algieria, model CropWat, model DSSAT, program Climate Wizard, zapotrzebowanie na wodę, zmiany klimatu*