SIMULATING THE EFFECT OF CLIMATE CHANGE ON WINTER WHEAT PRODUCTION AND WATER / NITROGEN USE EFFICIENCY IN IRAQ: CASE STUDY

T. K. Masood[1] **S. S. Shahadha[2]**
Lecturer **Lecturer**
[1:]Dep. Soil and Water Resources -Coll. Agric. Engine. Sci. University of Baghdad
[2:] Dep.Environmental Sci., Coll. Energy and Environmental Sci. Al Karkh University of Sci.
E-mail: tareqmasood@coagri.uobaghdad.edu.iq

ABSTRACT

The objective of this study was to investigate the capability of modifying the irrigation and nitrogen application rates as an adaptation to climate change, especially, increasing air temperature, using the Root Zone Water Quality Model (RZWQM2). Field experiments were conducted in the winter wheat season of 2015-2016 and 2019-2020 at the Rasheed County, south of Baghdad, Iraq. The effect of increasing air temperature on the water use efficiency, nitrogen use efficiency, and grain yield of wheat was assessed under different irrigation deficits and nitrogen application rates. Three levels of water depletion: 30, 50, and 70 of available water and four N application rates (0, 140, 200, and 260 kg N ha^{-1}) were applied for winter wheat. Two temperature scenarios in the RZWQM2 were created for the study purpose. The first scenario was to add 2C^{o} to the normal temperature, and the second scenario was to add 4C^{o} to the normal temperature. Results showed that high irrigation levels presented better results than the low levels under projected temperature scenarios. However, all applied nitrogen rates presented similar results under projected temperature (2C^{o} and 4C^{o} scenarios). Therefore, modifying irrigation requirements is a workable adaption strategy to the increased temperature.

Key words: RZWQM2, water/nitrogen use efficiency, wheat production, climate change

محاكاة تاثير تغير المناخ على انتاج الحنطة الشتوي وكفاءة استعمال المياه في العراق: دراسة حالة

طارق كمال مسعود[1] **سعدي ستار شحاذه[2]**
مدرس **مدرس**
[1]: قسم علوم التربة والموارد المائية/كلية علوم الهندسة الزراعية/جامعة بغداد
[2]: قسم علوم البيئة/كلية علوم الطاقة والبيئة/جامعة الكرخ للعلوم

المستخلص

الهدف من هذه الدراسة هو التحقق من إمكانية تعديل معدلات استعمال الري والنيتروجين كاستراتيجية تكيف مع تغير المناخ، وخاصة درجة حرارة الجو، باستعمال موديل نوعية مياه منطقة الجذر (RZWQM2). أجريت تجارب حقلية في الموسم الشتوي 2015-2016 و2019-2020 في ناحية الرشيد جنوب بغداد-العراق. تم تقييم تأثير زيادة درجة حرارة الجو على كفاءة استعمال المياه، وكفاءة استعمال النيتروجين، لمحصول الحنطة في ظل نقص الري ومعدلات استعمال النيتروجين المختلفة. تم تطبيق ثلاثة مستويات لاستنفاد المياه: 30 ، 50 ، 70 من الماء الجاهز وأربعة معدلات استعمال من النيتروجين (0 ، 140 ، 200 ، 260 كغم هـ$^{-1}$). تم إنشاء نموذجين محاكاة لدرجة الحرارة في RZWQM2 لغرض الدراسة. السيناريو الأول كان إضافة 2 م^{0} إلى درجة الحرارة العادية، والسيناريو الثاني هو إضافة 4 م^{0} إلى درجة الحرارة العادية. أظهرت النتائج أن مستويات الري المرتفعة قدمت أفضل من المستويات المنخفضة في نموذج محاكاة درجات الحرارة المتوقعة. كانت جميع معدلات النيتروجين المضافة متماثلة في ظل درجة الحرارة المفترضة (نماذج محاكاة 2 م^{0} و 4 م^{0}). لذلك، يعد تعديل متطلبات الري استراتيجية عملية في التكيف مع زيادة درجة الحرارة.

الكلمات المفتاحية: نمذجة ادارة المياه والمحصول، كفاءة استخدام المياه، كفاءة استخدام النيتروجين، انتاجية الحنطة، التغير المناخي

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INTRODUCTION

Agricultural systems are very sensitive to climate change since meteorological variables are directly affect the fundamental processes involved in crop growth and production (28 ,34). The impacts of climate variability on crop growth and development have been addressed in a wide variety of researches (1,17,36,37). However, crop sensitivity to climate change and crop ability to adapt to new climate conditions vary regionally (16,31). In more than 50% of studies, the most negative impact on crop yields, with regards to climate change, is related to temperature increase (17). Crop yield experiences improvements in some regions, while in other regions it experiences reductions (17,18). This variation relates to many factors, such as precipitation and CO_2. Increasing temperature increases crop transpiration and soil water evaporation, as well as, it leads to an increase in soil water deficits (27). Therefore, a negative impact on crop growth and yield will be noticed unless it is mitigated by a corresponding increase in precipitation and CO_2 (10,19). There have been very few studies in the way of climate change in Iraq due to the continuous wars and political instability in Iraq since the 1980s which leads to less funding and support dedicated to agricultural and environmental researches (11,15). Wheat (*Triticum aestivu*m L.) is the most widely grown cereal crop across the world due to the food source and economic (38). Wheat considers as the first strategic crop in Iraq (29). However, its productivity is much lower than the main global productivity due to insufficient scientific cultivation and field management methods in most of the Iraqi fields (3). Wheat production is facing diverse and complex impacts of global warming, precipitation, and increase in atmospheric CO_2 concentration across the world (17,20,38). Therefore, wheat production becomes a key concern in the future, as it could be increased in some regions while it could be decreased in other regions (18,31). Since the wheat crop is very sensitive to global warming, its production is facing challenges from many factors such as global warming and water shortages (7,13,35). Agricultural system models can be used as a complementary tool to field management practices for conducting exploratory tests for certain crop management practices that may offer benefits for the adaptation to future climate changes (6,8,13). The agricultural system model, RZWQM2 is a comprehensive agricultural model simulating the chemical, physical, and biological processes occurring in the field (9,12). It also simulates the effects of agricultural management practices on water dynamics, crop developments, and crop productions (24,34). Also, it uses for simulating climate change and its influences on the crop, as well as testing the adaptation strategies to climate changes (5,12,14,21). For this study, the RZWQM2 model was used to simulate the effects of climate change on winter wheat production and water use efficiency. The objectives of this study were 1: to predict the impacts of increasing temperature on wheat yield and water/nitrogen use efficiency in Iraq. 2: to explore the impacts of irrigation and nitrogen applications management on wheat production as adaptation strategies to climate change in Iraq.

MATERIALS AND METHODS:

Experimental design

The experiments were conducted at the Rasheed County, south of Baghdad, Iraq; on 33°04’ 28” latitude north and the 44°29’41” longitude. Field study took place in a 0.5 ha. The soil is classified as sedimentary soil with a silt loam texture (Typic Torrifluevents; Entisols) (30). A soil profile was opened to determine the soil properties (Table 1).

Table 1. Soil physical, hydraulic and chemical properties for the experimental field soil.

Soil Property	Value
Sand (gm kg^{-1})	290
Silt (gm kg^{-1})	500
Clay (gm kg^{-1})	210
Soil texture	Silt Loam
Bulk density (Mg m^{-3})	1.33
Field capacity (cm^3 cm^{-3})	0.39
Permanent wilting point (cm^3 cm^{-3})	0.12
Available water (cm^3 cm^{-3})	0.27
$EC_{1:1}$ (dS m^{-1})	3.1
Soil pH	7.4

The first experiment of winter wheat was planted in November 2015, and harvested in May 2016, and it was repeated in December 2019 – 2020 with a randomized complete block design with three replicates for. Three levels of irrigations and four nitrogen application rates were applied for winter wheat. The irrigation treatments were three levels of irrigation water depletion: 30 (I1), 50 (I2), and 70 (I3) of available water. Table 2 shows the irrigation water amount for each level at different dates. The N fertilizer was applied as granular urea (46 % N). The N fertilizer rates were 0 (N1), 140 (N2), 200 (N3), and 260 (N4) kg N ha^{-1} . The N fertilizer rates were split across two applications. The first application occurred in January and the second application in March.

Table 2. Irrigation water amounts for each level at different dates.

Irrigation Date	I30	I50	I70
05/12/2019	42	42	42
25/12/2019	38	38	38
02/02/2020	41		
22/2/2020	38		
06/03/2020	40	40	
13/3/2020	25		40
22/3/2020	52	104	
02/04/2020	51		
10/04/2020	48	96	122
17/4/2020	42		
23/4/2020	55	110	
25/4/2020			120
Sum	472	430	362

Meteorological data

Meteorological datasets were obtained from the Ministry of Water Resources Station, Baghdad, Iraq and were used as model input data for the study period. The used dataset includes maximum and minimum temperatures, wind speed, solar radiation, relative humidity, and rainfall.

Model simulations

RZWQM2 was used to simulate wheat production as a function of current and projected climate changes. The correspondent model parameters were obtained from a calibration experiment of irrigated winter wheat carried out during the growing season of 2015 - 2016 at the Rasheed County, south of Baghdad, Iraq. While the model evaluation and projected climate change was during the wheat growing season of 2019 -2020 at the same location. To test the management strategy and identify the possibility of adaptation, treatments of irrigation and nitrogen applications were evaluated regards to the projected climate change (9,14,25,34).

Three model scenarios were built with regards to temperature changes, to study the effect of increasing maximum air temperature on wheat yield and water/nitrogen use efficiency (Figure 1). In the first scenario (NT), the normal maximum temperature was used without any change. In the second scenario (T2), 2^{o}C were added to the normal maximum temperature. In the third scenario (T4), 4^{o}C was added to the normal maximum temperature. The model was operated individually for each scenario; the model was initiated three months a head of planting for each scenario to equilibrate the initial conditions based on the measured meteorological data (35,34).

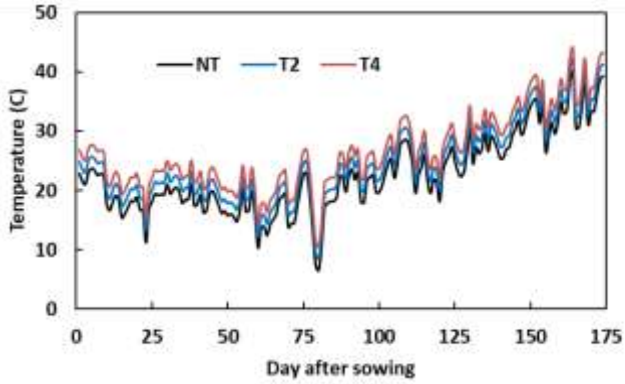

Figure 1. Daily normal air temperature (NT), increased temperature by 2^{o}C (T2), and 4^{o}C (T4) during the growing season of 2019 - 2020.

Statistical analysis

The model performance was evaluated by using the Root Mean Squared Error (RMSE). It reflects the mean difference between simulated and measured results. The acceptable value of RMSE varies with the observed characteristic, crop type, method of measurements, and management practice (22). Therefore, there is no specific range that could characterize an appropriate value of RMSE. Ahuja and Ma (2) suggest Normalized Root Mean Square Errors (NRMSE); it indicates the goodness of the model performance. NRMSE = 0 means a perfect agreement between simulated and measured results (23,32,34). (%E) is the percentage error between simulated and measured results. The reduction between simulated values of yield, WUE, and NUE under normal temperature and projected temperature was calculated as well.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\text{Pi} - \text{Oi})^2} \ldots\ldots\ldots\ldots\ldots.1$$

$$\text{NRMSE} = \frac{\text{RMSE}}{\text{O}_{\text{avg}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

$$\%\text{E} = \left(\frac{\text{P}_{\text{avg}} - \text{O}_{\text{avg}}}{\text{O}_{\text{avg}}}\right) \times 100 \ldots\ldots\ldots\ldots\ldots 3$$

$$\text{Reduction} = \frac{\text{Pih} - \text{Pil}}{\text{Pih}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where Oi and Pi are the measured and simulated values, respectively. Oavg and Pavg are the arithmetic mean of measured and simulated values, respectively. Pih is the simulated value under normal temperature, and Pil is the simulated values under projected temperature T2 and T4 scenarios.

RESULTS AND DISCUSSIONS:

RZWQM model can help optimize the impacts of varied climatic conditions on crop evapotranspiration, grain yield, water use efficiency, and nitrogen use efficiency, as well as test the adaptation strategies to climate change. During the calibration season of 2015 – 2016, the model was tested against data from an experimental field of nitrogen treatment of 200 kg/ha and irrigation depletion of 30 % of available water. The RZWQM2 presented a satisfying capability for simulating soil water content, evapotranspiration, grain yield, crop biomass, and WUE (Table 3).

Table 3. The RMSE values during the calibration season of 2015 – 2016.

Characteristic	RMSE
Soil water content	**0.1 cm^3/cm^3**
Evapotranspiration	**1.2 mm/day**
Grain yield	**0.3 t/ha**
Crop biomass	**0.4 t/ha**
WUE	**0.3 kg/m^3**

The RMSE was 0.1 cm^3/cm^3, 1.2 mm/day, 0.3 t/ha, 0.4 t/ha, and 0.3 kg/m^3 for soil water content, evapotranspiration, grain yield, crop biomass, and WUE, respectively. These results are within the simulation range of (9,12,34). This means that RZWQM2 is an appropriate model for the field and climate conditions in Iraq. During the validation season 2019 – 2020 and under the normal temperature scenario, the grain yield was simulated with RMSE values of 0.29, 1.16, and 2.08 t/ha for the irrigation levels of I30, I50, and I70, respectively (Figure 2 - a). Both simulated and measured yield decreased with the increasing deficit irrigation. Grain yield was slightly overestimated for the I30 treatment, while it underestimated the I50 and I70 treatments. Similar to simulated grain yield results presented by Fang et al.(12), the model showed very well simulation capability for the irrigation treatment of I30, while its simulation capability was decreased with increasing the irrigation shortage. The NRMSE values of I30, I50, and I70 irrigation levels were 0.06, 0.26, and 0.55, respectively. These results were comparable with the study finding of (4,12,26,33).

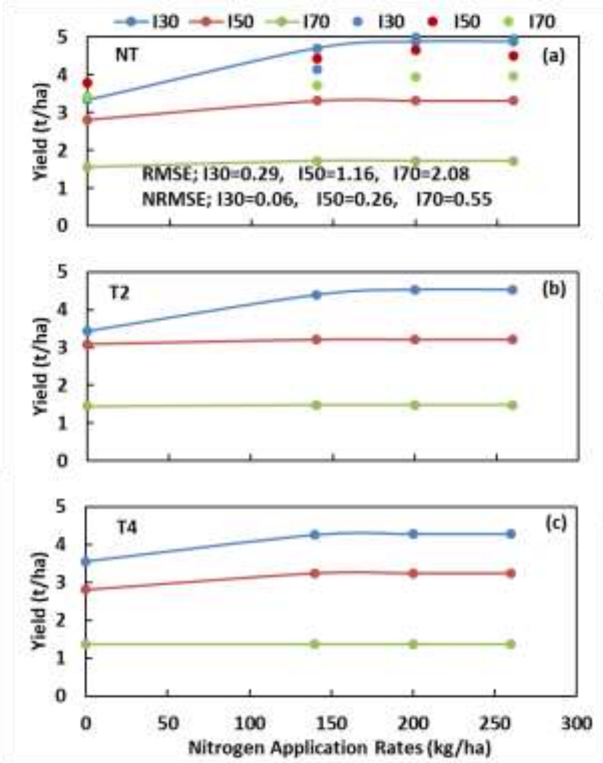

Figure 2. Measured and simulated grain yield for three irrigation levels and four nitrogen rates under (a) Normal temperature (NT), (b) Increased temperature by 2 C^o (T2), and Increased temperature by 4 C^o (T4).

Figure 3 shows the mean measured and simulated consumed water amounts for each irrigation level for the wheat-growing season. The total measured consumed water amounts were 472, 430, and 362 mm for I30, I50, and I70, respectively. RZWQM2 underestimated the consumed water with an error of -12, -20, and -32 mm for I30, I50, and I70, respectively. Simulation error was increased with increasing the irrigation deficit. These results are in agreement with the findings of Ma et al.(24).

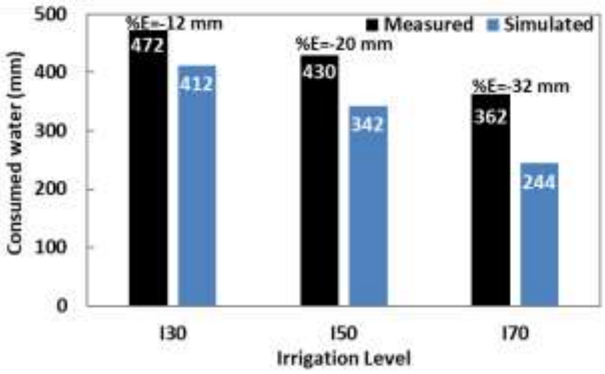

Figure 3. Measured and simulated total consumed water amounts for each irrigation level.

The simulated WUE showed similar trends with calculated WUE across all nitrogen treatments. However, WUE was slightly overestimated for the I50 and I70 because of the underestimated ET. It was simulated with RMSE values of 0.51, 0.31, and 0.13 for I30, I50, and I70, respectively, and with NRMSE values of 0.18, and 0.08, and 0.33 for I30, I50, and I70, respectively (Figure 4 - a). Similar simulation results were obtained for WUE by (12,37). Similar to grain yield simulation, the model underestimated the NUE, especially, for the I50 and I70. NUE was simulated with RMSE values of 2.54, 1.35, and 1.53 and NRMSE values of 0.39, 0.34, 0.60 for the I30, I50, and I70, respectively (Figure 5 - a). Grain yield was decreased when the air temperature increased by 2 and 4 C during the scenario of projected air temperature. Under the impact of the T2 scenario, the average reduction of the grain yield was 0.04, 0.00, and 0.12 t/ha for the I30, I50, and I70 treatments, respectively (Table 4). Moreover, the reduction of the grain yield was increased under the effect of the T4 scenario. Crop yield is affected by the increasing temperature. However, the impact of increasing temperature was manipulated by the irrigation treatments while all nitrogen treatments showed a similar effect. This means that the negative effect of increasing air temperature can be controlled by irrigation levels, while it can not be controlled by the applied nitrogen rates.

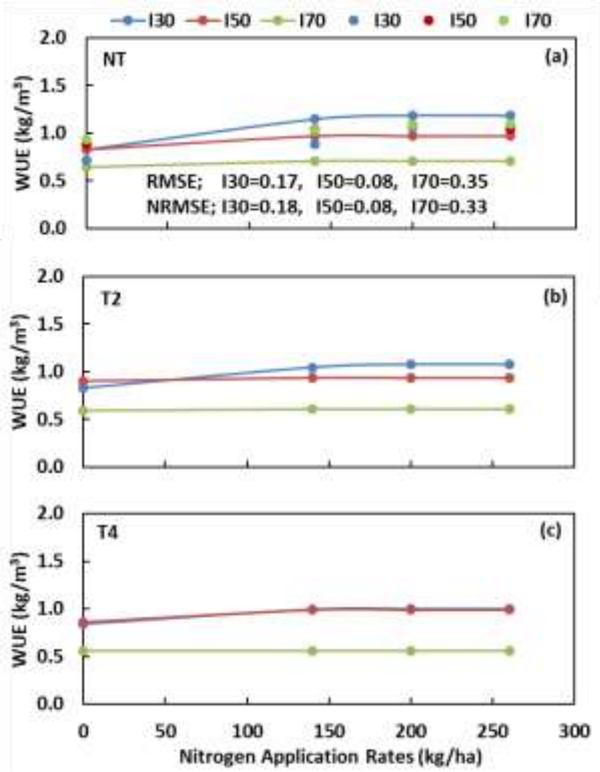

Figure 4. Measured and simulated water use efficiency for three irrigation levels and four nitrogen rates under (a) Normal temperature (NT), (b) Increased temperature by 2 C^{o} (T2), and Increased temperature by 4 C^{o} (T4).

On the inversion of the crop yield, the evapotranspiration amounts were increased with increasing air temperature for the I30 level with an average of 0.02 and 0.04 mm under the impact of T2 and T4 scenarios, respectively. I50 and I70 presented a 0.00 mm reduction under the impact of the T2 scenario (Table 4). The WUE is also affected by increasing the air temperature. Under the influence of the T2 scenario, the I70 irrigation level presented the highest reduction of 0.12 kg/m3, but the lowest reduction was obtained under the irrigation level of I50 with 0.00 kg/m3.

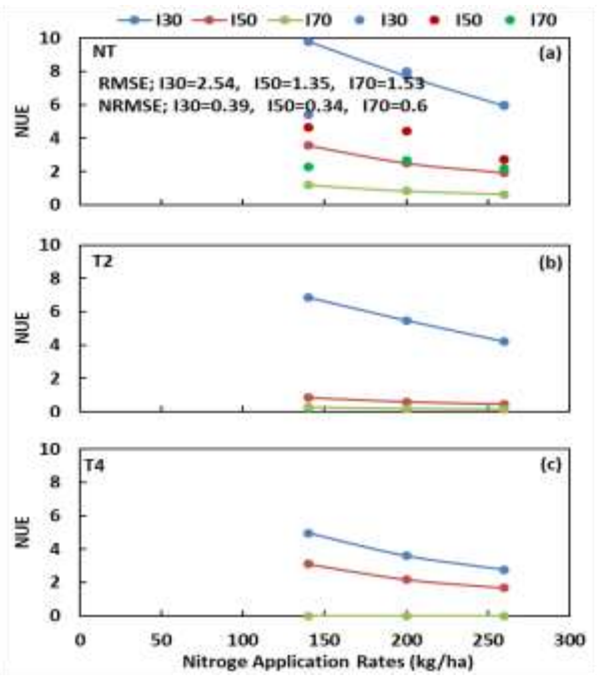

Figure 5. Measured and simulated nitrogen use efficiency for three irrigation levels and four nitrogen rates under (a) Normal temperature (NT), (b) Increased temperature by 2 C° (T2), and Increased temperature by 4 C° (T4).

A higher reduction was obtained when the air temperature increased through the T4 scenario. The irrigation level of I50 did not show any reduction for all N treatments, while the highest reduction was obtained from the I70 with 0.19 kg/m3 (Table 4). The NUE was influenced by increasing temperature. The highest reduction was obtained from the irrigation level of I70 with 0.76 and 1.00 for T2 and T4, respectively. However, I30 presented the lowest reduction of 0.29 under the effect of the T2 scenario, and I50 showed the lowest reduction of 0.13 under the impact of the T4 scenario (Table 4). The applied irrigation levels showed an obvious effect for controlling the impact of increasing air temperature on grain yield, WUE, and NUE under. However, applied nitrogen rates did not show any adaptation capability for increasing temperature scenarios.

Table 4. The reduction values of yield, WUE, and NUE for the irrigation and nitrogen treatments under T2 and T4 scenarios.

		T2				T4		
		I30	I50	I70		I30	I50	I70
Yield (t/ha)	N0	-0.03	-0.10	0.07	N0	-0.07	0.00	0.12
	N140	0.07	0.03	0.14	N140	0.10	0.02	0.21
	N200	0.07	0.03	0.14	N200	0.12	0.02	0.21
	N260	0.07	0.03	0.14	N260	0.12	0.02	0.21
	mean	0.04	0.00	0.12	mean	0.07	0.01	0.19
		T2				T4		
		I30	I50	I70		I30	I50	I70
ET (mm)	N0	-0.02	-0.01	0.00	N0	-0.05	0.04	0.00
	N140	-0.02	0.00	0.00	N140	-0.04	0.04	0.00
	N200	-0.02	0.00	0.00	N200	-0.04	0.04	0.00
	N260	-0.02	0.00	0.00	N260	-0.04	0.04	0.00
	mean	-0.02	0.00	0.00	mean	-0.04	0.04	0.00
		T2				T4		
		I30	I50	I70		I30	I50	I70
WUE (kg/m^3)	N0	0.00	-0.09	0.08	N0	-0.02	-0.04	0.13
	N140	0.09	0.03	0.14	N140	0.13	-0.02	0.21
	N200	0.09	0.03	0.14	N200	0.15	-0.02	0.21
	N260	0.09	0.03	0.14	N260	0.15	-0.02	0.21
	mean	0.07	0.00	0.12	mean	0.12	-0.03	0.19
		T2				T4		
		I30	I50	I70		I30	I50	I70
NUE	N0				N0			
	N140	0.30	0.76	0.76	N140	0.49	0.13	1.00
	N200	0.29	0.76	0.76	N200	0.53	0.13	1.00
	N260	0.29	0.76	0.76	N260	0.53	0.13	1.00
	mean	0.29	0.76	0.76	mean	0.52	0.13	1.00

CONCLUSIONS:

Field experiments were conducted at the center of Iraq for testing and evaluating the RZWQM2 model for the Iraqi conditions, as well as for testing the adaptation strategies to the expected future climate change. RZWQM model was a helpful tool for optimizing the impacts of increasing temperature on grain yield, consumed water, water use efficiency, and nitrogen use efficiency, as well as testing the adaptation strategies of irrigation and nitrogen rates. Manipulating irrigation levels is a workable strategy for adapting to the impact of increasing temperature. High irrigation levels presented better results than the low levels under increased temperature scenarios. Manipulating nitrogen rates could not show any adaptation capability to the increasing temperature. Despite this study, similar testing across diverse crops, soils, and climate would be an important need in the future to facilitate building further confidence in the use of modified irrigation requirements as an adaptation strategy to climate change.

REFERENCES

1-Ahmad, S., G. Abbas, Z. Fatima, R. Khan, M. Anjum, M. Ahmed, M. Khan, C. Porter and G. Hoogenboom. 2017. Quantification of the impacts of climate warming and crop management on canola phenology in punjab, pakistan. Journal of Agronomy and Crop Science 203: 442-452.

2-Ahuja, L., Ma, L., 2002. Parameterization of agricultural system models: Current approaches and future needs. Agricultural system models in field research and technology transfer. Lewis Publishers, Boca Raton, FL.

3-Ali, H.Z., M.S. Hameed, A.A. Abdulrahman and H.M. Saood. 2020. First report on fusarium brachygibbosum isolate fir 16_its isolated from iraqi wheat plant. Journal of Ecological Engineering 21.

4-Anapalli, S.S., D.K. Fisher, K.N. Reddy, W.T. Pettigrew, R. Sui and L.R. Ahuja. 2016. Vulnerabilities and adapting irrigated and rainfed cotton to climate change in the Lower Mississippi Delta Region. Climate 4: 55.

5-Anex, R., L. Gu and M. Helmers. 2018. A metric for evaluating the ability of the rzwqm model to project the impact of climate change.

6-Aslam, M.A., M. Ahmed, C.O. Stöckle, S.S. Higgins and R. Hayat. 2017. Can growing degree days and photoperiod predict spring wheat phenology?. Frontiers in Environmental Science 5: (57)1-10.

7-Asseng, S., I. Foster, and N.C. Turner. 2011. The impact of temperature variability on wheat yields. Glob. Change Biol.17(2): 997–1012.

8-Bergez, J.-E., N. Colbach, O. Crespo, F. Garcia, M.-H. Jeuffroy, E. Justes, C. Loyce, N. Munier-Jolain and W. Sadok. 2010. Designing crop management systems by simulation. European Journal of Agronomy 32: 3-9.

9-Cameira, M., R. Fernando, L. Ahuja and L. Ma. 2007. Using RZWQM to Simulate the fate of nitrogen in field soil–crop environment in the mediterranean region. Agricultural Water Management 90: 121-136.

10-Daba, K., T. D. Warkentin, R. Bueckert, C.D. Todd and B. Tar'an. 2016. Determination of photoperiod- sensitive phase in chickpea (*Cicer arietinum* L.). Front. Plant Sci. 11:478.

11-Daham, A., D. Han, W. Matt Jolly, M. Rico-Ramirez and A. Marsh. 2019. Predicting vegetation phenology in response to climate change using bioclimatic indices in iraq. Journal of Water and Climate Change 10: 835-851.

12-Fang, Q.X., L. Ma, D.C. Nielsen, T.J. Trout and L.R. Ahuja. 2014. Quantifying corn yield and water use efficiency under growth stage–based deficit irrigation conditions. Practical applications of agricultural system models to optimize the use of limited water 5: 1-24.

13-Hernandez-Ochoa, I.M., D.N.L. Pequeno, M. Reynolds, M.A. Babar, K. Sonder, A.M. Milan, G. Hoogenboom, R. Robertson, S. Gerber and D.L. Rowland. 2019. Adapting irrigated and rainfed wheat to climate change in semi-arid environments: management, breeding options and land use change. European Journal of Agronomy 109: 125915.

14-Islam, A., L.R. Ahuja, L.A. Garcia, L. Ma, A.S. Saseendran and T.J. Trout. 2012. Modeling the impacts of climate change on irrigated corn production in the central great plains. Agricultural Water Management 110: 94-108.

15-Jaradat, A. 2003. Agriculture in Iraq: resources, potentials, constraints, research needs and priorities. Journal of food, Agriculture and Environment. 1(2) pp:160

16-Kahiluoto, H., J. Kaseva, J. Balek, J.E. Olesen, M. Ruiz-Ramos, A. Gobin, K.C. Kersebaum, J. Takáč, F. Ruget and R. Ferrise. 2019. Decline in climate resilience of european wheat. Proceedings of the National Academy of Sciences 116: 123-128.

17-Karimi, T., C. Stöckle, S. Higgins and R. Nelson. 2018. Climate Change and Dryland Wheat Systems in the Us Pacific Northwest. Agricultural Systems 159: 144-156.

18-Kristensen, K., K. Schelde and J.E. Olesen. 2011. Winter wheat yield response to climate variability in denmark. The Journal of Agricultural Science 149(1): 33-47.

19-Leisner, C.P. 2020. Climate change impacts on food security-focus on perennial cropping systems and nutritional value. Plant Science 293: 110412.

20-Li, Y., R. Hou and F. Tao. 2020. Interactive Effects of different warming levels and tillage managements on winter wheat growth, physiological processes, grain yield and quality in the north china plain. Agriculture, Ecosystems & Environment 295: 106923.

21-Liu, H., Y. Liu, L. Zhang, Z. Zhang and Z. Gao. 2019. Quantifying extreme climatic conditions for maize production using RZWQM in siping, northeast china. International Journal of Agricultural and Biological Engineering 12: 111-122.

22-Ma, L. and H. Selim. 1996. Physical nonequilibrium modeling approaches to solute transport in soils. Advances in Agronomy. Elsevier. p. 95-150.

23-Ma, L., L.R. Ahuja, S.A. Saseendran, R.W. Malone, T.R. Green, B.T. Nolan, P.N.S. Bartling, G.N. Flerchinger, K.J. Boote, and G. Hoogenboom. 2011. A protocol for parameterization and calibration of RZWQM2 in Field Research. In: Ahuja, L.R., Ma, L. (Eds.), Methods of introducing system models into agricultural research. SSSA Book Series, Madison, WI. 1–64.

24-Ma, L., L. Ahuja, B. Nolan, R. Malone, T. Trout and Z. Qi. 2012. Root zone water quality model (Rzwqm2): Model Use, calibration, and validation. Transactions of the ASABE 55: 1425-1446.

25-Ma, L., T. Trout, L.R. Ahuja, W.C. Bausch, S.A. Saseendran, R.W. Malone, and D.C. Nielsen. 2012. Calibrating RZWQM2 model for maize responses to deficit irrigation. Agricultural Water Management. 103:140-149

26-Masood, T. K. 2015. Irrigation methods and anti-transpiration as related to wheat and water productivity. The Iraqi J. Agric. Sci, 46(6), 1016-1022.

27-Masood, T. K. 2017. Effect of irrigation methods on water content distribution, water - and corn productivity. Iraqi Journal Of Agricultural Sciences, 48(1):178-184

28-Meza, F.J. and D. Silva. 2009. Dynamic adaptation of maize and wheat production to climate change. Climatic Change 94: 143-156.

29-Minati, M.H. and M.K. Mohammed-Ameen. 2019. novel report on six fusarium species associated with head blight and crown rot of wheat in Basra province, Iraq. Bulletin of the National Research Centre 43: 139.

30-Muhaimeed, A.S., A.J. Saloom, K.A. Saliem, K.A. Alani and W.M. Muklef. 2014. Classification and distribution of Iraqi soils. Int J Agric Innov Res, 2(6).997-1002.

31-Olesen, J.E., M. Trnka, K.-C. Kersebaum, A.O. Skjelvåg, B. Seguin, P. Peltonen-Sainio, F. Rossi, J. Kozyra and F. Micale. 2011. Impacts and adaptation of european crop production systems to climate change. European Journal of Agronomy 34: 96-112.

32-Saseendran, S., L. Ahuja, L. Ma, D. Nielsen, T. Trout, A. Andales, J. Chávez, and J. Ham. 2014. Enhancing the water stress factors for simulation of corn in RZWQM2. Agron. J. 106, 81–94.

33-Saseendran, S.A., T.J. Trout, L.R. Ahuja, L. Ma, G.S. McMaster, D.C. Nielsen, A.A. Andales, J.L. Chavez, and J. Ham. 2015. Quantifying crop water stress factors from soil water measurements in a limited irrigation experiment. Agric. Syst. , 137, 191–205.

34-Shahadha, S.S., O. Wendroth, J. Zhu and J. Walton. 2019. Can measured soil hydraulic properties simulate field water dynamics and crop production?. Agricultural Water Management 223: 105661.

35-Tao, F., and Z. Zhang. 2013. Climate change, wheat productivity and water use in the North China Plain: a new super-ensemble-based probabilistic projection. Agric. For. Meteorol. 170, 146–165.

36-Xiao, D., H. Bai and D.L. Liu. 2018. Impact of future climate change on wheat production: a simulated case for china's wheat system. Sustainability 10: 1277.

37-Zhang, X., W. Qin, S. Chen, L. Shao and H. Sun. 2017. Responses of yield and WUE of winter wheat to water stress during the past three decades—a case study in the north china plain. Agricultural Water Management 179: 47-54.

38-Zheng, Z., G. Hoogenboom, H. Cai and Z. Wang. 2020. Winter wheat production on the guanzhong plain of northwest china under projected future climate with simclim. Agricultural Water Management. 239: 106233.