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SUSTAINABILITY THE WATER PRODUCTIVITY AND SORGHUM YIELD USING AQUACROP MODEL UNDER SURFACE DRIP IRRIGATION SYSTEM IN BAGHDAD GOVERNATE

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ABSTRACT

The experiment was conducted to study the water productivity of the sorghum crop in Al-Jadriya region for the spring season in Al-Jadriya/ University of Baghdad. Experiment treatments included six irrigation levels: Treatment of 100% at 50% depletion of the available water and compensation in terms of accumulate evaporation from the evaporation basin class A to the field capacity, deficit irrigation treatments 80, 70, 60, 50, and 40% from complete irrigation were applied, using the Completely Randomized Block Design with three replicates. The seeds of the crop were planted on 13-3-2022 and harvested on 15-7-2022. Future studies were conducted to extract the expected values for the study year and the years coming to 2050 for the RCP 4.5 and RCP 8.5 scenarios, using the AquaCrop model and the results were;

1. The highest depth of water added was 487 mm at 100% full irrigation treatment, then the values decreased to 413, 377, 340, 303 and 267 mm season^{-1} for 80, 70, 60, 50 and 40% deficit irrigation coefficients, respectively.

2. Deficit irrigation of 80 and 70% of treatments outperformed the highest average water productivity of 1.17 kg m^{-3} for both treatments. There was a slight increase in rainfall rates (2020-2030) and an almost non-existent decrease for the period (2040-2050) of 0.09 and 0.03 mm decrease, respectively, compared to the base period (1985-2005).

3. The model was able to simulate the productivity of grain and water yield of white corn in an excellent way due to the high compatibility between the measured field values and the predicted values, the measured grain yield values were (5.79-1.64) ton ha^{-1}, the simulation values amounted to (5.70-3.66) ton ha^{-1}, while the water productivity was measured between (0.87 - 1.17) kg m^{-3} and the simulation values amounted to (0.96-2.12) kg m-3.

4. The productivity values of the sorghum crop ranged between (6.72) ─ (3.84) ton ha^{-1} and a relative change ranged between [(-5.79) ─ (-12.73) %] at the scenario (RCP 4.5), while at the scenario (RCP 8.5) for the time period (2040-2050), the productivity values ranged between (4.92-2.44) ton ha^{-1}, with a relative change ranging between [(-0.49) ─ (-4.43) %].

Keywords: water productivity, Sorghum, Aqua Crop program, Baghdad governate

***The article is taken from the master's thesis of the first researcher.**

استدامة إنتاجية المياه ومحصول الذرة البيضاء باستخدام نموذج AquaCrop تحت نظام الري بالتنقيط السطحي في محافظة بغداد

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الخلاصة

اجريت التجربة لدراسة انتاجية المياه لمحصول الذرة البيضاء في منطقة الجادرية للموسم الربيعي في الجادرية / جامعة بغداد. تضمنت المعالجات التجريبية ستة مستويات للري: معالجة 100% عند استنفاد 50% من المياه المتاحة والتعويض من حيث التبخر المتراكم من حوض التبخير من الفئة A إلى السعة الحقلية، تم تطبيق معالجات الري بالعجز 80 و70 و60 و50 و40% من الري الكامل، باستخدام تصميم القطاعات العشوائية الكاملة بثلاثة مكررات. زرعت بذور المحصول في 13-3-2022 وحصدت في 15-7-2022. أجريت دراسات مستقبلية لاستخراج القيم المتوقعة لسنة الدراسة والسنوات القادمة حتى عام 2050 لسيناريوهات RCP 4.5 وRCP 8.5، باستخدام نموذج AquaCrop وكانت النتائج:

1. **بلغ أعلى عمق للماء المضاف 487 مم عند معاملة الري الكامل 100% ثم انخفضت قيم عمق الماء المضاف عند معاملات الري الناقص 80 و70 و60 و50 و40% الى 413 و377 و340 و303و267 مم موسم$^{-1}$ للمعاملات وعلى الترتيب.**
2. **تفوقت معاملتي الري الناقص 80 و70% بأعلى متوسط إنتاجية مياه بلغت 1.17 كغم م$^{-3}$ للمعاملتين. وجد زيادة طفيفة في معدلات الهطول المطري (2020-2030) وانخفاض يكاد يكون معدوم للفترة (2040-2050) وبلغت الزيادة 0.09 والانخفاض 0.03 مم على الترتيب مقارنة بالفترة الأساس (1985-2005).**
3. **استطاع النموذج على محاكاة حاصل الحبوب وانتاجية المياه لمحصول الذرة البيضاء بشكل ممتاز نظراً للتوافق العالي بين القيم الحقلية المقاسة والقيم المتنبأ بها، بلغت قيم حاصل الحبوب المقاسة (1.64 - 5.79) طن هكتار$^{-1}$ اما القيم المحاكاة فبلغت (3.66 - 5.70) طن هكتار$^{-1}$، اما انتاجية المياه فقد بلغت قيمها المقاسة بين (0.57 - 1.17) كغم م$^{-3}$ والقيم المحاكاة فقد بلغت (0.96– 2.12) كغم م$^{-3}$.**
4. **تراوحت قيم الإنتاجية لمحصول الذرة البيضاء بين (3.84) — (6.72) طن هكتار$^{-1}$ وتغير نسبي تراوح بين (-5.79) % — (-12.73) %عند السيناريو (4.5 RCP)، اما عند السيناريو (8.5 RCP) للفترة الزمنية (2040-2050) فقد تراوحت قيم الانتاجية بين (2.44- 4.92) كغم م$^{-3}$ وبتغير نسبي تراوح بين (-0.49) % — (-4.43 %).**

الكلمات المفتاحية: إنتاجية المياه، الذرة البيضاء، برنامج AquaCrop، محافظة بغداد.

INTRODUCTION

The suitable soils for Sorghum cultivation are silty loam and clay loam soils with a low salt content, and the date of its cultivation in irrigated areas is during the month of March or July. There are few studies in Iraq on the water consumption of the Sorghum crop grown in different climatic environments and textures from northern to southern Iraq, but they were limited to surface irrigation only and did not study the water consumption under the surface drip irrigation system, which is almost very limited. The values of crop water consumption for Sorghum ranged between 500-800 mm when they applied management systems, irrigation intervals, and different fertilizer treatments **(Imam 2022; Mutlaq *et al*.,2015).** At water scarcity religion as in Iraq the amount and time of irrigation process can have very pronounced effect on crop production and food security, and Desertification control. Increasing water productivity or water use efficiency can be the key to solve most water crices **(Tabib Loghmani *et al*.,2019).**

The AquaCrop model is considered one of the effective and successful means in forecasting agricultural productivity. It serves as a tool for planning and managing both rained and irrigated cultivation. When running the program, it needs a set of inputs, which include climatic data for the study area, crop characteristics, description of the soil profile, its initial moisture, and the conditions in which the crop grow. For the purpose of determining the basic variables of Sorghum, the AquaCrop model was calibrated based on climatic and field data and the approved planting dates in the Baghdad region, in addition to the climatic conditions for the ten years (2012-2022). The aim of study to evaluate the agricultural production of the sorghum crop in Baghdad governate as a result of changing the water and climatic changes in order to Providing scientific rationale for decision-makers to take possible measures and draw more comprehensive future strategies, through calibration and evaluation of the AquaCrop model for sorghum productivity in Baghdad region, and determining the water productivity of the sorghum crop to reached the best productivity using surface drip irrigation system and full, deficit irrigation.

MATERIALS AND METHODS

The study was conducted during the spring of 2022, at the University of Baghdad / Jadriya (station F, located at latitude 16' 28' 33°N, longitude '25' 23' 44°E, the soil was morphologically described and classified into sub-main groups according to the subject of Torrifluvent **(Black, 1965).**

I took models representative of the soil a depth of 0.00-0.30 m, and 0.30-0.60 m, the soil was clay loam texture (sand=352, 343 silt=272,261 clay=376, 396 g kg^{-1}) for the two depths, as for the chemical qualities, they were: (EC=4.8-5.2 dS m^{-1}, pH=7.18-7.16, O.M=7.1-6.3 g kg^{-1} soil, $CaCO_3$=274.1-252 g kg^{-1} soil according to **(Soil survey, 2021).**

Experiment treatments and statistical design

1. Full Irrigation 100% treatment (control treatment) when 50% of the available water is depleted and compensated in terms of the cumulative evaporation from the evaporation basin class A, from which the incomplete irrigation parameters are calculated.

2. FI 80% of the full irrigation treatment.
3. FI 70% of the full irrigation treatment.
4. FI 60% of the full irrigation treatment.
5. FI 50% of the full irrigation treatment.
6. FI 40% of the full irrigation treatment.

With three replicates, the Randomized Complete Block Design (RCBD) was used. The experiment was conducted on a land area of 1000 m^2, its dimensions are 25 m^2 × 40 m^2, and the land was plowed with a perpendicular plow, and the smoothing operations were conducted using the rotary hoes. The area per experimental unit was (5 m× 6 m = 30 m2), and the distance between the experimental units was 1.5 m2. The sectors were divided into six experimental units representing irrigation levels. This is to calculate the amount of water that needs to be added to the field from the water requirement equation. In order to schedule watering, depending on the evaporation data from the pan, we follow

$ET_0 = Kp \times Epan$ ... ... (1)

Where:

ET_0 = reference evapotranspiration .

Kp = evapotranspiration coefficient of 0.85 **(FAO, 1984).**

Epan = daily evapotranspiration from pan.

$ET_C = ET_0 \times K_C$ ... ...(2)

Where:

ET_C = evapotranspiration of the crop.

ET_0 = reference evapotranspiration.

Kc= crop coefficient (0.7, 0.7, 1.07, and 0.55). according to growth stages, seedling growth stage, vegetative growth, the stage of flowering and grain maturity respectively **(FAO, 1986).** The crop evapotranspiration was modified for the drip irrigation method by reduction coefficient according to the following equation, and calculate the quantities of irrigation water according to the equations (3,4,5): **(Keller &Karmeli,1974)**

$ET_C = ET_0 \times K_C \times Kr$... ... (3)

$IWT = \frac{NDI}{Ea}$ … … (4): (**Hajim & Yassin, 1992**)

Where:

NDI= Net depth irrigation.

Ea = Irrigation efficiency.

$Qt=Ad$ … … (5): (**Israelsen & Hansen 1962**)

Where:

Q = discharge.

t = irrigation time.

A = Area of the experimental unit.

d = depth of water added.

Statistical Analysis

In this study, the AquaCrop 6.0 model obtained from the official web location. was used to estimate the water consumption of sorghum and to estimate the yield under deficit irrigation using the drip irrigation system irrigation method to evaluate AquaCrop performance, the following equations were used: (RMSE), (R^2) and (d) **(Cameron & Windmeijer, 1995).**

Climate Modeling

The results of climate change were adopted on a daily basis, for future climate models for the expected change in average annual rainfall and maximum and minimum temperatures during the two periods:
- The near future (2020-2030).
-The distant future (204-2050).
- The reference period (1985-2005) compared to the base period.

In order to assess the impact of climate change on sorghum productivity, the AquaCrop model of the three climate models was used, and then the three results were averaged for an estimate (mean productivity or water consumption). For both the RCP4.5 medium emission scenario and the RCP8.5 high emission scenario. The main source of these data is biased-corrected data from the RCM adapted from the experience of RICCARD's Harmonized Regional Climate Model CORDEX **(ESCWA, 2017).**

RESULTS AND DISCUSSION

Water requirement for sorghum crop

Table (1) shows the water requirement of sorghum crop. The highest water requirement was when the full irrigation treatment was 487.25 mm season^{-1} and it was supplied in 32 applications of irrigation, this is normal because the water depth reached to the field capacity limit, then the quantity was reduced at the levels of deficit irrigation 80, 70, 60, 50, and 40% of the full irrigation by 15.06, 22.59, 30.11, 37.64, and 45.17% until it became 413.87, 377.19, 340.50, 303.81 and 267.12 mm for season^{-1} treatments, respectively.

Table (1): water requirement (mm) according to growth stages and irrigation levels.

irrigation levels	seasonal water requirement (mm)	seedling growth stage	vegetative growth stage	flowering stage	grain maturity stage	Total
%100	The duration of the growth stage	22	41	42	20	125
	Number of irrigations	4	9	14	5	32
	Seasonal water requirement (mm)	114.77	50.83	235.25	86.40	**487.25**
	Daily water requirement (mm)	5.21	1.24	5.60	4.33	
	Average water requirement per irrigation(mm)	28.69	5.65	16.80	17.30	
%80	The duration of the growth stage	22	41	42	20	125
	Number of irrigations	4	9	14	5	32
	Seasonal water requirement (mm)	114.77	41.78	188.20	69.12	**413.87**
	Daily water requirement (mm)	5.21	1.02	4.48	3.46	
	Average water requirement per irrigation(mm)	28.69	4.64	13.44	13.83	
%70	The duration of the growth stage	22	41	42	20	125
	Number of irrigations	4	9	14	5	32
	Seasonal water requirement (mm)	114.77	37.26	164.67	60.48	**377.18**
	Daily water requirement (mm)	5.21	0.91	3.92	3.03	
	Average water requirement per irrigation(mm)	28.69	4.14	11.76	12.10	
%60	The duration of the growth stage	22	41	42	20	125
	Number of irrigations	4	9	14	5	32
	Seasonal water requirement (mm)	114.77	32.73	141.15	51.84	**340.50**
	Daily water requirement (mm)	5.21	0.80	3.36	2.60	
	Average water requirement per irrigation(mm)	28.69	3.64	10.08	10.37	
%50	The duration of the growth stage	22	41	42	20	125
	Number of irrigations	4	9	14	5	32
	Seasonal water requirement (mm)	114.77	28.89	117.62	43.20	**303.81**
	Daily water requirement (mm)	5.21	0.70	2.80	2.16	
	Average water requirement per irrigation(mm)	28.69	3.21	8.40	8.64	
%40	The duration of the growth stage	22	41	42	20	125
	Number of irrigations	4	9	14	5	32
	Seasonal water requirement (mm)	114.77	24.21	94.10	34.56	**267.12**
	Daily water requirement (mm)	5.21	0.69	2.24	1.73	
	Average water requirement per irrigation(mm)	28.69	2.69	6.72	6.91	

Grain Yield

In Figure (1), which shows the average grain yield for Sorghum bicolor crop, it is noted that the full irrigation treatment (100%) was significantly excelled by giving the highest average grain yield of 5.79 Ton ha^{-1}, with significant increases of 140.03, 252.74, and 286. 39% for the incomplete irrigation treatments 60, 50, and 40%, which gave the lowest average yield of 3.44, 1.9 and 1.64 Ton ha^{-1}, and that the two treatments of 80 and 70% incomplete irrigation gave grain yields of 5.32 and 4.82 tons' ha^{-1}, and thus they did not differ significantly from complete irrigation treatment. (**Ati *et al.*, 2017**)

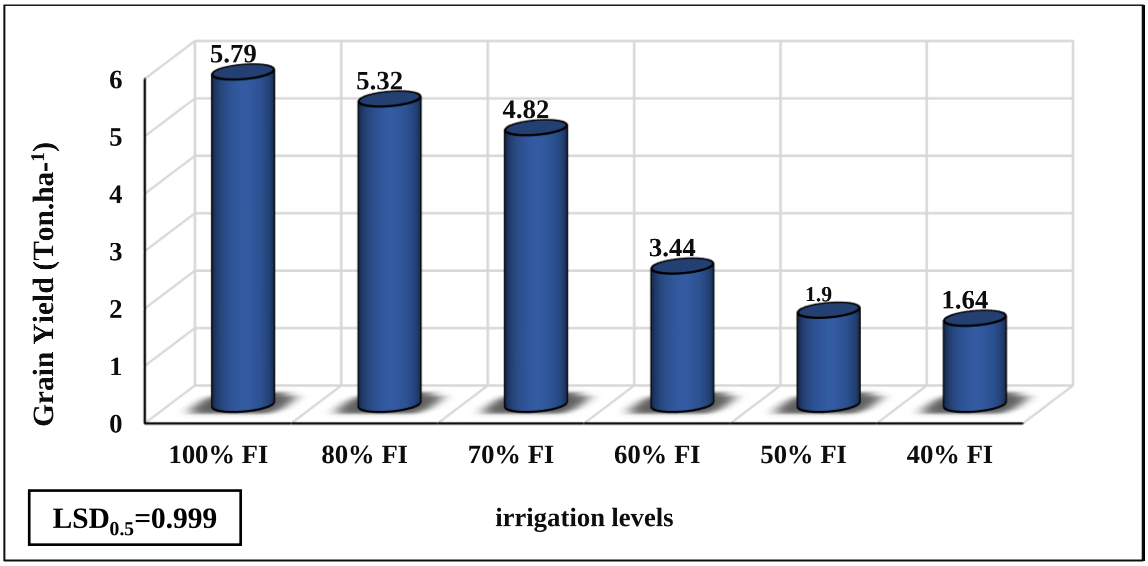

Figure (1): Effect of deficit irrigation on sorghum Grain Yield.

Water Use Efficiency (kg m^{-3})

The Figure (2) shows the Water use efficiency values of the sorghum grain crop, which means achieving a higher yield with less water for each irrigation treatment. It was found that the deficit irrigation treatments %80 and %70 excelled by giving the highest value of Water use efficiency amounted to both of them 1.17 kg m^{-3}, and that they did not differ significantly when compared to the full irrigation treatment which gave 1.07 kg m^{-3}, despite their difference in the value of water requirement. On the contrary, deficit irrigation treatments 60,50 and %40 gave the lowest values for the average water use efficiency of 0.93,0.58 and 0.57 kg m^{-3}, respectively, if they saved water at the expense of lower yield. This means the management of water scarcity leads to best result (**Jabbar *et al*.,2020: Khamees *et al*., 2023).**

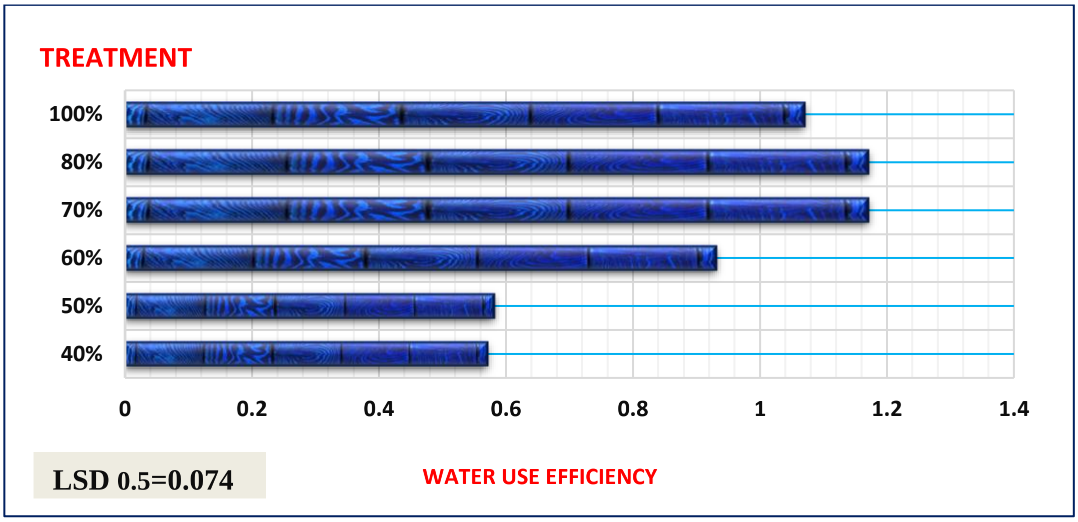

Figure (2): Water Use Efficiency of the sorghum crop under different treatments.

Projected future changes in climate until the end of 2050;

Table 2 shows the impact of the expected climate changes for each of the annual and seasonal precipitation and the minimum and maximum temperatures for the two periods (2020-2030) and (2040-2050) in the near future and the medium future, respectively, compared to the base period (1985-2005) according to the three EC climate models. -Earth, CNRM-CM5, GFDL-ESM2M under climate change scenario RCP4.5 (medium emissions scenario) for sorghum crop under drip irrigation system. Table (2) shows that there is an increase in the amount of annual rainfall during the two periods (2020-2030) and decrease (2040-2050) amounting to 0.09 and -0.03 mm, respectively, compared to the base period (1985-2005) as an average for the three models used. For the climate change scenario RCP4.5 Table (2) also shows that there was an increase in each of the maximum and minimum temperatures, which amounted to 0.88 and 0.89 °C for the maximum and minimum temperatures, respectively, during the period (2020-2030) compared to the base period, with a clear decrease also in temperatures during the period (2040 -2050) compared to the base period of 1.45 and 1.50°C for the maximum and minimum temperatures, respectively (as average values of climate models) **(Al-Lami *et al*.,2023).**

Table (2): The expected climate changes in precipitation temperatures for the two periods (2020-2030) and (2040-2050) compared to the base period (1985-2005) for the scenario RCP4.5

Parameter	2020-2030	2040-2050
CNRM-CM5, EC-Earth, GFDL-ESM2M		
Rain (mm), Annual	+0.09	-0.03
Maximum temperature (◦C)	+0.88	-1.45
Minimum temperature (◦C)	+0.89	-1.50

Table (3) shows the relationship between expected climate changes and its impact on annual and seasonal precipitation and minimum and maximum temperatures for the periods (2020-2030) and (2040-2050) in the near and medium future, respectively, when compared with the base period (1985-2005) according to the three climate models of the European Commission. –Earth, CNRM-CM5, GFDL-ESM2M under climate change scenario RCP4.5 (medium emission scenario) for sorghum crop under drip irrigation system. Table (3) shows a decrease in the annual rainfall during the two periods (2020-2030) and an increase (2040-2050) of 0.07 and 4.48 mm respectively compared to the base period (1985-2005) as an average for the three models used. As for the climate change scenario RCP4.5, as Table (3) shows, there is an increase in both the maximum and minimum temperatures, which amounted to 1.13 and 1.07 degrees Celsius for the maximum and minimum temperatures respectively during the period (2020-2030) compared to the maximum and minimum temperatures.

Table (3): The expected climate changes in precipitation temperatures for the two periods (2020-2030) and (2040-2050) compared to the base period (1985-2005) for the scenario RCP4.5

Parameter	2020-2030	2040-2050
CNRM-CM5, EC-Earth, GFDL-ESM2M		
Rain (mm), Annual	+0.09	-0.03
Maximum temperature (◦C)	+0.88	-1.45
Minimum temperature (◦C)	+0.89	-1.50

Statistical criteria

Table 4 shows the productivity and water productivity calibration of the sorghum crop for comparison between the measured and expected productivity. The standard gave a very good agreement with most of the approved standards, where the correlation coefficient R^2 between the data reached a very good agreement of 0.96 and 0.94. The Root Mean Square Error (RMSE) gave a very good agreement of 0.47 and 0.15. The value of the Woltman coefficient for comparison between the measured productivity and the expected productivity recorded a very good agreement, amounting to 0.97 and 0.94 for sorghum yield and water productivity, respectively. **(Cameron & Windmeijer, 1996).**

Table (4): Comparison of water use efficiency and measured and predicted sorghum yield when using a drip irrigation system Surface using statistical criteria.

Water use efficiency ($kg\ m^{-3}$)		**Sorghum yield ($Ton\ ha^{-1}$)**		**Treatment**
Simulation	Measured	Simulation	Measured	
1.92	1.07	5.05	5.79	**%100**
2.05	1.17	5.43	5.32	**%80**
2.12	1.17	5.70	4.82	**%70**
1.66	0.93	4.77	3.44	**%60**
1.10	0.58	3.67	1.90	**%50**
0.96	0.57	3.66	1.64	**%40**
0.15		0.47		**RMSE**
0.94		0.96		**R^2**
0.94		0.97		**D**

It was found that the best treatment for estimating the value of Water use efficiency and grain yield for the white corn crop was when treating incomplete irrigation (70% of the full irrigation), as the use of surface drip irrigation resulted in values for the estimated calibration as a result of providing irrigation water at the effective root depth of the plant, and the preparation of fertilizers With irrigation water, help prepare and provide nutrients near the root system and give the best values for both grain yield and Water use efficiency.

The values of the statistical coefficients that were applied showed the accuracy of the program and its ability to simulate the data, where the RMSE is an indicator of the amount of difference between the measured and expected values and its limits are between (∞-0), and the simulation is good if it is close to infinity. As for Waltman's index (D), it indicates the range of acceptability between the measured values to the expected values and its limits (0-1), and the closer it is to one, the better the simulation.

CONCLUSION

In view of the diminishing water resources, the application of the deficient irrigation levels and the surface drip irrigation technique has positive effects and appropriate solutions to increase the economic return and reduce the cost. Also, the impact of climate change in combination with deficient irrigation strategies can be assessed using crop models as they are simulated tools.

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