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PREDICTION OF TOMATO YIELD AND WATER PRODUCTIVITY UNDER DEFICIT IRRIGATION SCENARIOS USING AQUACROP MODEL IN AFAKA, KADUNA, NIGERIA

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Abstract: Improving water productivity through deficit irrigation has become a major goal for sustainable agriculture amidst global decline in water availability. The study evaluated the yield, crop water use and water productivities of field-grown drip-irrigated tomato in response to regulated deficit irrigation, and subsequent simulation under different deficit and irrigation method scenarios, using AquaCrop model, in Afaka, Nigeria. The field experiment, laid in randomized complete block design, comprised three deficit irrigation levels (80, 60 and 40% of reference evapotranspiration, ETo) imposed at the vegetative, flowering and maturity growth stages, with 100% ETo at the three crop growth stages as the control. The highest fresh fruit yield (19.0 t/ha) was obtained irrigating with 100% ETo value at all growth stages but the highest water productivity of fresh fruit (4.94 kg/m^3) was obtained irrigating with 60% ETo at maturity stage, then full irrigation at vegetative and flowering stages. On fruit dry yield basis, the highest simulated crop water productivity (0.46 kg/m^3) for the deficit scenarios was obtained irrigating with 80% ETo at all the three growth stages, having the highest fruit dry yield (1.67 t/ha) and the lowest seasonal water applied (447 mm). Under the scenarios of irrigation methods (drip, basin and furrow), the fruit dry yield was similar in each treatment, but water productivity was highest (0.53 kg/m^3) under drip irrigation system.

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Irrigating with 80% ETo at all the entire crop growth cycle of UC 82B tomato is recommended for the highest crop water productivity.

Key words: *Prediction, tomato yield, water productivity, deficit irrigation, scenarios, AquaCrop, Nigeria*

INTRODUCTION

Global freshwater is becoming increasingly scarce, due to improper management, indiscriminate use and a changing climate. Water requirements for agriculture is expected to increase by fifty percent to meet increasing food demands of a growing population all over the world [1]. For a better water resources utilization at the crop farm level, it is essential to apply an irrigation scheduling criterion such that the crop is watered at the right time and in the right volume. Hence, on condition of limited water supply, a so called ‘regulated water deficit’ can be conveniently applied [2]. Deficit irrigation aims at supplying lower irrigation volumes compared to the estimates required by the crop during the whole crop cycle but in coincidence with some particular stages that are the most sensitive to water stress [3]. Deficit irrigation is thus, a management strategy aimed at avoiding irrigation when it has a scarce influence on yield, in this way maximizing the productive result with smaller water amounts [4]. In deficit irrigation, the crop is subjected to a certain level of moisture stress either during a particular growth stage or throughout the entire crop growth stages, without significant reductions in yields [5], with the expectation that the yield reduction induced by the controlled moisture stress will not be significant in comparison with the benefits derived by diverting the saved water to irrigate additional cropped area [3], [6].

The challenge for researchers today is to develop viable irrigation scheduling methodologies, that are simple to implement, easy to understand from the farmer and project management standpoints, and profitable. Studies on deficit irrigation scheduling of tomato within the Northern Guinea Savanna of Nigeria are rarely available, and research outcomes on deficit irrigation are generally few for the sub-Saharan Africa [7]. Studies on the impacts of methods of administering growth-stage deficit irrigation on yield and soil water balance of a maize crop in Samaru, Nigeria, has been reported [8]. Also, investigators have studied the effects of deficit irrigation and mulch on yield and water use efficiency of watermelon in Samaru, Nigeria [9], while research on the effect of irrigation regimes on growth and yield of tomato under high water-table conditions in Kadawa, Nigeria was also reported [10]. Yet, knowledge gaps still remain with respect to the regulated deficit irrigation effects on the yield, and water productivity of tomato in Kaduna, Nigeria.

The approach of conducting field experiments has been described as being expensive, time consuming, subject to uncontrolled environmental conditions and difficult for long term analyses [11]. To overcome this problem crop simulation models have been developed as easier options, which can simulate field results [12]. The models help researchers to describe the dynamics of a crop in relation to its environment, understand the interactions of the various components and extend results beyond experimental sites and years [13].

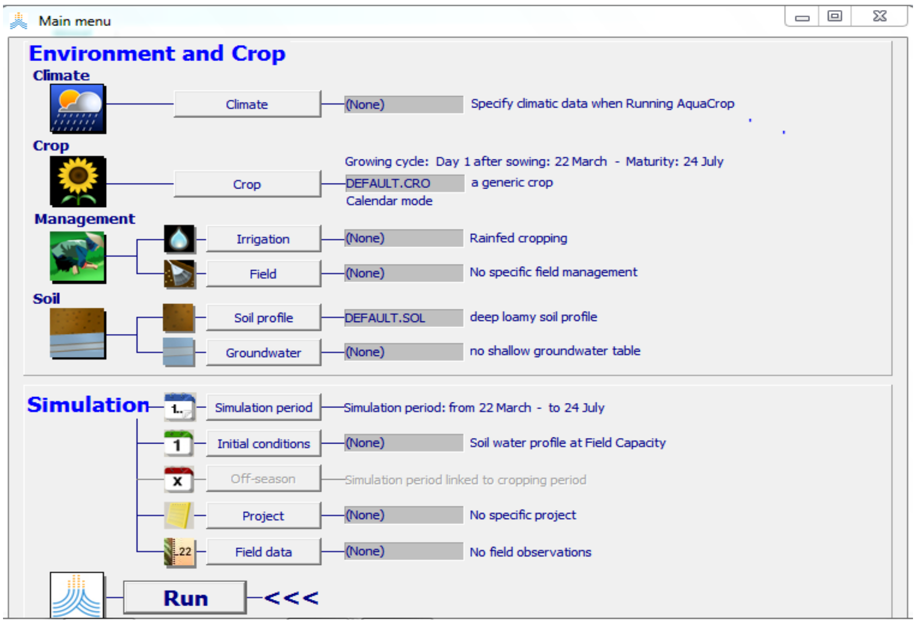
Advances in software technology has enabled development of models (software) which can be used for simulating crop production. This is an excellent strategy for conducting tests and experiments, availing data already collected, wrapping few people, low cost, speed, creation and guessing of ideal scenarios to assist in decision making for public and private sectors [14], [15]. Hence, modeling becomes a valuable tool to study and develop promising deficit irrigation strategies as it allows a combination of different factors affecting yield under different scenarios [16].

The objective of this study, therefore, is to evaluate the effects of various deficit irrigation scheduling scenarios on the yield and water productivity of tomato using the AquaCrop model.

MATERIALS AND METHODS

Description of the AquaCrop Model

The AquaCrop model (Figure 1.), developed by the Food and Agriculture Organization of the United Nations (FAO) is a dynamic menu-driven crop model with a well-developed user interface for simulating the attainable yield of herbaceous crops as a function of water consumption [17]. Its major advantages over other models lie in its accuracy, simplicity and robustness [17]. The main menu provides access to a whole set of menus where input data is displayed and can be updated. Input data comprise those of weather, crop, irrigation, field management, soil, groundwater characteristics, planting or transplanting date, simulation period and conditions at the start of the simulation period. The simulations were carried out with AquaCrop model, version 6.0.



Climate — (None) — Specify climatic data when Running AquaCrop

Growing cycle: Day 1 after sowing: 22 March - Maturity: 24 July
Crop — DEFAULT.CRO — a generic crop
Calendar mode

Irrigation — (None) — Rainfed cropping
Field — (None) — No specific field management

Soil profile — DEFAULT.SOL — deep loamy soil profile
Groundwater — (None) — no shallow groundwater table

Simulation period — Simulation period: from 22 March - to 24 July
Initial conditions — (None) — Soil water profile at Field Capacity
Off-season — Simulation period linked to cropping period
Project — (None) — No specific project
Field data — (None) — No field observations

Figure 1. AquaCrop start menu

Study Area

The study was carried out at the experimental farm of the Federal College of Forestry Mechanization, Afaka, Kaduna, Nigeria, on latitude 10º36'N and longitude 07º25'E.

The rainy season lasts from mid-April to early October. Kaduna has an annual mean rainfall of 1206 mm and its temperature range is 31^0C to 33^0C for the maximum scale and 14^0C to 19^0C for the minimum scale [18].

Description of the Field Experiment

The research was carried out as growth-stage based deficit irrigation trials in the 2017/2018 and 2018/2019 irrigation seasons. The field trial spanned from 12th December to 11th March, in both seasons. The experiment was preceded by the nursery stage, which lasted for thirty days. The experiment was laid in randomized complete block design (RCBD) and replicated three times. The treatment factors are three deficit irrigation levels (80, 60 and 40% of reference evapotranspiration, ETo) and three crop growth stages, namely, vegetative stage (V), flowering stage (F) and maturity stage (M). Full irrigation (100% ETo) at the three growth stages is the control. A fixed 3-day irrigation interval was used throughout the experiment as recommended by [19]. Table 3.1 describes the field treatments.

AquaCrop Prediction of Yield and Water Productivity under Different Scenarios

Consequent upon satisfactory simulation of yield, crop water use and water productivity of UC 82B tomato in Afaka, Kaduna, Nigeria [20], the model was used for scenario analyses to evaluate the management practices for drip-irrigated tomato in the study area. The scenario analyses explain the implication of using the model under varied irrigation conditions. The following scenarios were considered: irrigation depths at one of three growth stages; irrigation depths at two of three growth stages; irrigation depths at all three growth stages and irrigation methods (drip, basin and furrow).

Scenario 1: Deficit application at one of three growth stages, in successions

Scenario 1 was created based on the field treatment which gave the highest water productivity in the field trials of 2017/18 and 2018/19. The treatment, designated as T_7 (Table 1) gave the highest water productivity of 0.45 kg/m^3, with a corresponding fruit dry yield of 1.59 kg/m^3 and crop water use of 369 mm. T_7 was described as the irrigation schedule where the crop was fully irrigated at the vegetative and flowering stages but 60% ETo at the maturity stage. Hence, T_7, tagged $V_{100}F_{100}M_{60}$ was selected. The water productivities of T_7 were 4.94 kg/m^3 and 0.45 kg/m^3 on fruit fresh and dry yield basis, respectively. The scenarios hence created are with respect to varied irrigation depths during the maturity growth stage as described in Table 2.

Scenario 2: Deficit application at two of three growth stages, in successions

Scenario 2 comprises four irrigation depths, and deficit application at two of three growth stages in successions. The irrigation depths were 100, 80, 60 and 40% of the mean ETo of the study area.

Each irrigation depth was successively imposed at two crop growth stages, the third stage being fully irrigated (Table 3).

Scenario 3: Deficit application at all three growth stages

In scenario three, each irrigation depth is applied all through the entire crop growth stages (Table 4). The irrigation interval was fixed at 3 days.

Table 1. Treatment descriptions of the field experiment

Treatment Number	Treatment Tag	Treatment Description
T_1	$V_{100}F_{100}M_{100}$	Full irrigation (100% ET_o) at all crop growth stages (control)
T_2	$V_{80}F_{100}M_{100}$	Irrigating with 80% ET_o at vegetative stage, full irrigation at flowering and maturity stages
T_3	$V_{100}F_{80}M_{100}$	Irrigating with 80% ET_o at flowering stage, full irrigation at vegetative and maturity stages
T_4	$V_{100}F_{100}M_{80}$	Irrigating with 80% ET_o at maturity stage, full irrigation at vegetative and flowering stages
T_5	$V_{60}F_{100}M_{100}$	Irrigating with 60% ET_o at vegetative stage, full irrigation at flowering and maturity stage
T_6	$V_{100}F_{60}M_{100}$	Irrigating with 60% ET_o at flowering stage, full irrigation at vegetative and maturity stage
T_7	$V_{100}F_{100}M_{60}$	Irrigating with 60% ET_o at maturity stage, full irrigation at vegetative and flowering stage
T_8	$V_{40}F_{100}M_{100}$	Irrigating with 40% ET_o at vegetative stage, full irrigation at flowering and maturity stage
T_9	$V_{100}F_{40}M_{100}$	Irrigating with 40% ET_o at flowering stage, full irrigation at vegetative and maturity stages
T_{10}	$V_{100}F_{100}M_{40}$	Irrigating with 40% ET_o at maturity stage, full irrigation at vegetative and flowering stages

Table 2. Treatment descriptions for deficit irrigation at maturity stage

Treatment Number	Treatment Tag	Treatment Description
$T_{7(30)}$	$V_{100}F_{100}M_{30}$	Full irrigation (100% ET_o) at vegetative and flowering stages, 30% ETo at maturity stage
$T_{7(40)}$	$V_{100}F_{100}M_{40}$	Full irrigation at vegetative and flowering stages, 40% ETo at maturity stage
$T_{7(50)}$	$V_{100}F_{100}M_{50}$	Full irrigation at vegetative and flowering stages, 50% ETo at maturity stage
$T_{7(60)}$	$V_{100}F_{100}M_{60}$	Full irrigation at vegetative and flowering stages, 60% ETo at maturity stage
$T_{7(70)}$	$V_{100}F_{100}M_{70}$	Full irrigation at vegetative and flowering stages, 70% ETo at maturity stag
$T_{7(80)}$	$V_{100}F_{100}M_{80}$	Full irrigation at vegetative and flowering stages, 80% ETo at maturity stage
$T_{7(90)}$	$V_{100}F_{100}M_{90}$	Full irrigation at vegetative and flowering stages, 90% ETo at maturity stage

Table 3. Irrigation depth – growth stage based scenario (deficit at two of three growth stages, full irrigation at one growth stage)

Treatment Number	Treatment Tag	Treatment Description
$T_{2,3}$	$V_{80}F_{80}M_{100}$	Irrigating with 80% ET_o at vegetative and flowering stages, full maturity stage
$T_{2,4}$	$V_{80}F_{100}M_{80}$	Irrigating with 80% ET_o at vegetative and maturity stages, full irrigation at flowering stage
$T_{3,4}$	$V_{100}F_{80}M_{80}$	Irrigating with 80% ET_o at flowering and maturity stages, full irrigation at vegetative stage
$T_{5,6}$	$V_{60}F_{60}M_{100}$	Irrigating with 60% ET_o at vegetative and flowering stages, full irrigation at maturity stage
$T_{5,7}$	$V_{60}F_{100}M_{60}$	Irrigating with 60% ET_o at vegetative and maturity stages, full irrigation at flowering stage
$T_{6,7}$	$V_{100}F_{60}M_{60}$	Irrigating with 60% ET_o at flowering and maturity stages, full irrigation at vegetative stage
$T_{8,9}$	$V_{40}F_{40}M_{100}$	Irrigating with 40% ET_o at vegetative and flowering stages, full irrigation at maturity stage
$T_{8,10}$	$V_{40}F_{100}M_{40}$	Irrigating with 40% ET_o at vegetative and maturity stages, full irrigation at flowering stage
$T_{9,10}$	$V_{100}F_{40}M_{40}$	Irrigating with 40% ET_o at flowering and maturity stages, full irrigation at vegetative stage

V: Vegetative, F: Flowering, M: Maturity

Table 4: Irrigation depth – growth stage based scenario (deficit irrigation at all growth stages)

Treatment Number	Treatment Tag	Treatment Description
$T_{2,3,4}$	$V_{80}F_{80}M_{80}$	Irrigating with 80% ET_o at V, F and M stages.
$T_{5,6,7}$	$V_{60}F_{60}M_{60}$	Irrigating with 60% ET_o at V, F and M stages.
$T_{8,9,10}$	$V_{40}F_{40}M_{40}$	Irrigating with 40% ET_o at t V, F and M stages.

V: Vegetative, F: Flowering, M: Maturity

Scenario 4: Deficit irrigation across three irrigation methods

Drip and surface (basin and furrow) irrigation methods were considered under this scenario, the latter representing the irrigation practice of most of the tomato farmers in the area.

Drip irrigation wets a fraction of the soil surface (30%), basin irrigation wets the entire soil surface (100%) and furrow (every furrow, narrow bed) wets an average of 80% of the soil surface [21].

RESULTS AND DISCUSSION

Effects of Irrigation Depths on Fruit Dry Yield, crop Water Use and Water Productivity

The effects of varied irrigation deficits at one growth-stage (maturity) on the fruit dry yield (Y_{dry}), crop water use (CWU) and water productivity (WP) are presented in Table 5. The highest simulated Y_{dry} and CWU were 1.71 t/ha and 375.3 mm, respectively, and these occurred in $T_{7(90)}$ while the least Y_{dry} and CWU were 1.06 t/ha and 287.9 mm, respectively. The Y_{dry} range is about 50% lower than that obtained in a similar study in Harare, Zimbabwe, using galina and shanty varieties [21]. The yield differences are attributable to a number of factors ranging from environmental to agronomic; yield and water productivity can vary substantially among species and genotypes (cultivars) [23] and also in response to location, stress patterns, planting dates, and other factors [24].

The WP ranged between 0.37 and 0.46 kg/m^3 in the treatments examined with $T_{7(70)}$ having the highest value (WP=0.46 kg/m^3) and $T_{7(30)}$ having the least (WP = 0.37 kg/m^3). Hence, it can be implied from the model that tomato fruit yield is more productive when irrigated with 70% ETo value at the maturity stage than 60% ETo at maturity as observed in the field. Compared to the full irrigation treatment about 69 mm of seasonal water applied (equivalent to 13% of full irrigation) was saved in $T_{7(70)}$ and this can be used to cultivate additional 0.15 ha, with the potential to produce additional 0.25 t/ha. Total derivable dry yield from $T_{7(70)}$ will be 1.89 t/ha which is well above the yield of the fully irrigated treatment.

Table 5. Effects of deficit irrigation at one of three growth stages (Scenario 1)

Treatment	SWA, mm	Y_{dry}, t/ha	CWU, mm	WP, kg/m^3
$T_{7(30)}$	355	1.06	288	0.37
$T_{7(40)}$	370	1.10	277	0.40
$T_{7(50)}$	408	1.31	325	0.40
$T_{7(60)}$	481	1.5	369	0.45
$T_{7(70)}$	461	1.64	361	0.46
$T_{7(80)}$	488	1.65	324	0.44
$T_{7(90)}$	515	1.71	375	0.45

Effects of deficit application at two of three growth stages, in successions

The effects of irrigation depths on simulated fruit dry yield, crop water use and water productivity for scenario 2 are presented in Table 6. The highest simulated Y_{dry} and CWU were obtained as 1.69 t/ha and 373 mm, respectively in $T_{2,3}$ while the least Y_{dry}, CWU and WP were obtained in $T_{9,10}$ as 1.02 t/ha, 254 mm and 0.40, respectively.

The highest crop water productivity was obtained in $T_{5,6}$, with Y_{dry} value of 1.62 t/ha, CWU of 357 mm and WP of 0.46. Water saved in $T_{5,6}$ was 72 mm, which is 13.6% of the water applied in the fully irrigated treatment.

The amount of water hence saved can be used to cultivate additional 0.157 ha, with the potential to produce additional 0.255 t/ha. The additional yield adds up to give a yield potential of 1.875 t/ha which is an advantage over the yield obtained from the fully irrigated treatment.

Effects of deficit application at all three growth stages

The simulated fruit dry yield, crop water use and water productivity as affected by irrigation depths and growth stage based deficit irrigations for scenario 3 are presented in Table 7. The highest simulated Y_{dry}, CWU and WP were obtained in $T_{2,3,4}$ as 1.67 t/ha, 365 mm and 0.46 kg/m^3, respectively in while the least were obtained in $T_{8,9,10}$ as 0.97 t/ha, 233 mm and 0.41, respectively. $T_{2,3,4}$ is the treatment with the highest water productivity, and hence, the recommended deficit water application strategy across the entire crop growth cycle. Irrigation water saved in $T_{2,3,4}$ is 83 mm, which is 13.7% of the water applied in the fully irrigated treatment. Potentially, this can be applied to cultivate additional 0.19 ha to produce additional 0.31 t/ha. The additional yield adds up to give a yield potential of 1.98 t/ha which is greater than the yield from the full irrigation.

Table 6. Effects of deficit irrigation at **two** of three growth stages (Scenario 2)

Treatment	SWA, mm	Y_{dry}, t/ha	CWU, mm	WP, kg/m^3
$T_{2,3}$	500	1.69b	373b	0.45b
$T_{2,4}$	471	1.66c	367c	0.45b
$T_{3,4}$	464	1.66c	368c	0.45b
$T_{5,6}$	458	1.62d	357d	0.46a
$T_{5,7}$	401	1.59e	351e	0.45b
$T_{6,7}$	386	1.53f	337f	0.45b
$T_{8,9}$	417	1.32g	301g	0.44b
$T_{8,10}$	330	1.20h	289h	0.41c
$T_{9,10}$	308	1.02i	254i	0.40c
SE±		0.080	14.00	0.0069
Significance		*	*	*

Table 7. Effects of deficit irrigation at **all three** growth stages (Scenario 3)

Treatment	SWA, mm	Y_{dry}, t/ha	CWU, mm	WP, kg/m^3
$T_{2,3,4}$	447	1.67a	365a	0.46a
$T_{5,6,7}$	351	1.50b	333b	0.45b
$T_{8,9,10}$	257	0.97c	233c	0.41c
SE±		0.19	35.31	0.013
Significance		*	*	*

Generally, the fruit yields and crop water use decreased with increase in moisture deficit (percentage water withheld) and growth stage progression (vegetative to flowering to maturity). This confirms the findings that yield reduction increases as deficit levels increase, especially at the reproductive growth stages [8], [25], [16].

The yield reduction due to moisture stress was evident from observed reduction in plant growth and development in the moisture stressed plots. In moisture stressed plants, there is reduction of the photosynthetic process as the stomata close to reduce transpiration [26].

Also, translocation of assimilates are known to be affected by water stress which hence limits photosynthesis.

Comparison of deficit irrigation scenarios

The irrigation treatments with the highest irrigation water productivities among the deficit scenarios were compared among themselves as depicted in Table 8. The highest crop water productivity value of 0.46 was obtained in $T_{7(70)}$, $T_{5,6}$ and $T_{2,3,4}$ among the three deficit irrigation scenarios examined. However, $T_{2,3,4}$ should be the most preferred deficit treatment, having the least seasonal water applied (SWA = 447 mm) and highest fruit dry yield (1.67 t/ha). The results showed that while the highest yield may be obtained under full irrigation, the highest water productivity may occur under deficit irrigation. Similar results were obtained in the deficit irrigation on tomato (Galila 555) in Silte Zone, Rift Valley, Ethiopia [27]. The water saved under the deficit irrigation would translate into additional cultivated land, the latter being the opportunity cost of the water saved during deficit irrigation. The increase in water productivity justifies the use of regulated growth deficit irrigation under the condition of limited water availability.

Table 8. Comparison of deficit irrigation scenarios

Treatment	SWA, mm	SWs, mm	Y_{dry}, t/ha	CWU, mm	WP, kg/m^3	Y_e, t/ha
T_1	530	0	1.72	384	0.45	1.72
$T_{7(70)}$	461	69	1.64	361	0.46	1.89
$T_{5,6}$	458	72	1.62	357	0.46	1.88
$T_{2,3,4}$	447	83	1.67	365	0.46	1.98

SWs = Seasonal water saved (mm), Ye = expected yield (t/ha)

Effects of Deficit Irrigation across Three Irrigation Methods

The effects of irrigation methods on the model outputs are presented in Table 9. The irrigation method scenarios comprise the drip irrigation system, which was used in conducting the field study and surface irrigation (basin and furrow) systems, which are the farmers' practice in the study area.

Table 9. Effect of irrigation methods on yield, crop water use and water productivity

Irrigation methods	Fruit dry yield, t/ha					
	T_1	T_7	T_1	T_7	T_1	T_7
Drip	1.69	1.53	322.8	290.0	0.52	0.53
Basin	1.69	1.53	365.3	337.2	0.46	0.45
Furrow	1.69	1.53	366.2	328.3	0.47	0.47

The simulation results showed that the fruit dry yields were similar irrespective of the irrigation method for each of T_1 (1.69 t/ha) and T_7 (1.53 t/ha).

Under field conditions, however, studies have shown that irrigation methods have effect on the yields of crops. [28], [29] reported that drip irrigation yielded 19% and 50% more fruit yield, respectively, than furrow irrigation. Hence, the model response to the effects of different irrigation methods for the same irrigation depth is inadequate with respect to the fruit dry yield.

The model however, showed different crop water use and crop water productivity values in response to the irrigation methods. For each treatment the lowest crop water use was obtained under drip irrigation compared to the basin and furrow systems.

This corroborates the reports for off-season vegetables under drip and furrow irrigation systems [30]. In $T_{1,}$ the drip system was 12% more efficient than both basin and furrow. Also, in T_7, the drip system was 14% and 12% more efficient than the basin and furrow systems, respectively. The differences are attributable to the percentage of soil surface wetted under irrigation. It has been indicated that 30%, 80% and 100% of soil surfaces are wetted under drip, furrow and basin irrigation systems, respectively [21]. On the average, water productivity was highest under drip irrigation system (0.53 kg/m^3) compared to both basin and furrow systems (0.46 kg/m^3). This is because under the surface systems more seasonal water application is required without a significant improvement in the crop yield. Hence, under water-limiting conditions drip irrigation should be preferred to the surface systems for more efficient irrigation water management and higher water productivity.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The conclusions made from this study are as follows:

1. The application of the validated AquaCrop 6.0 is innovative as it was able to adequately simulate the effects of varied irrigation depths at different growth stages on fruit yield, crop water use and water productivity in both seasons. The model is found to be valuable in aiding decision making for effective irrigation management strategies and prediction of tomato yield in the study area and other areas of similar environmental conditions.
2. The three deficit irrigation scenarios evaluated showed that irrigation water productivity was highest when deficit irrigation was applied at 80% ETo value across the three growth stages than when applied at either one or two of the growth stages. Hence, an appropriate deficit irrigation strategy can proceed through the entire crop growth stages to achieve the highest irrigation water productivity of UC 82B tomato.

Recommendations

1. The model scenario study under varied irrigation depths showed that the tomato yield decreased as the deficit levels increased, with the highest water productivity occurring when the crop was irrigated with 80% ETo amount across the entire crop growth cycle.

This is, therefore, the recommended regulated deficit irrigation schedule for UC 82B tomato under water limiting condition in the study area.

2. In comparison to surface methods, drip irrigation is recommended for improvement of water productivity as crop water use was found to be lower under the drip method.

REFERENCES

[1]. IAEA. 2017. Agricultural water management, *International Atomic Energy Agency publication.* https://www.iaea.org/topics/agricultural-water-management

[2]. English M.J., Musick J.T. and Murty V.V. 1990. Deficit irrigation. In: Management of farm irrigation systems, Hoffman, G.J., Towell T.A.and Solomon K.H. (eds.), St. Joseph, Michigan, USA, ASAE.

[3]. Kirda C. 2002. Deficit irrigation scheduling based on plant growth stages showing water tolerance. In: Deficit Irrigation Practice, FAO (ed.), Rome, Italy, pp. 3-10

[4]. Mannini P. 2004. Le buone pratiche agricole per rispamiare acqua. A cura di Pirani P., Regione Emilia-Romagna. *Agricultura*, 5, suppl. 18, 177 pp.

[5]. FAO 2000. Socio- Economic Impact of Smallholder irrigation Development in Zimbabwe, Food and Agr. Organization (FAO) Sub-Regional Office for East and Southern Africa, Harare.

[6]. Kirda, C., Kanber, R. and Tulucu, K. 1999. Yield response of cotton, maize, soybean, sugar beet, sunflower and wheat to deficit irrigation. The Netherlands, Kluwer Academic Publishers.

[7]. Oiganji E., Igbadun H.E., Mudiare O.J. and Oyebode M.A. 2017. Water use efficiency of maize crop under deficit irrigation scheduling using gravity drip system in Samaru, Nigeria. *Global J. of Science Frontier Research: (D) Agriculture and Veterinary*. 17(1), pp. 74-82

[8]. Igbadun H.E. 2012. Impact of methods of administering growth stage deficit irrigation on yield and soil water balance of maize crop (SAMAS TZEE). *Nigerian Journal of Basic and Applied Sciences*, 20(4), pp. 357-367

[9]. Halilu, A. G., Othman M.K., Ismail H., and Shanono N.J. 2014. Effects of deficit irrigation and mulch on yield and water use efficiency of watermelon in Samaru, Nigeria. *Nigerian Journal of Soil and Environmental Research*, 12, pp. 13–17.

[10]. Ismail, H., Abubakar, S.Z., Oyebode, M.A., Halilu, A.G., and Shanono, N.J. 2014. Effect of irrigation regimes on growth and yield of tomato under high water-table conditions. *Journal of Soil and Environmental Research*, 12, pp. 43–57

[11]. Oiganji, E., Igbadun H., Mudiare O.J., and Oyebode M.A. 2016. Calibrating and validating AquaCrop model for maize crop in Northern zone of Nigeria. *Agricultural Engineering International: CIGR Journal*, 18(3), pp. 1-13

[12]. Igbadun, H.E. 2008. A model for generating water management responses indices use in assessing impact of irrigation scheduling strategy. *Nigerian Journal of Engineering*, 14(2)

[13]. Kumar, V., and Ahlawat I.P.S. 2004. Carry-over of bio-fertilizers and nitrogen applied to wheat and direct applied nitrogen in maize in wheat-maize cropping system. *Indian Journal of Agronomy*, 49(4), pp. 233-236.

[14]. Jones J.W., Antle J.M., Basso B., Boote K.J., Conant R.T. 2017. Brief history of agricultural systems modeling. *Agricultural Systems*, 155, pp. 240-254

[15]. Souza J.L.M., Oliveira C.T., Rosa S.L.K. and Tsukahara R.Y. 2020. Calibration and validation of the AquaCrop model to estimate maize production in Campos Gerais, Paraná State,Brazil.*Revista Brasileira de Meteorologia*, 35(2), pp. 243-253.

[16]. Liu, J., Wiberg, D., Zehnder, A., Yang, H., 2007. Modeling the role of irrigation in winter wheat yield, crop water productivity, and production in China. *Irrig. Science,* 26, pp. 21–33.

[17]. Steduto P., T.C. Hsiao, E. Fereres and D. Raes (2012). Crop yield response to water. Irrigation and Drainage Paper No. 66, FAO Rome

[18]. NIMET 2015. Climate of Kaduna, Nigeria, 1986 – 2015, Nigerian Meteorological Agency.

[19]. Zhai Y.M., Shao X.H., Xing W.G. and Wang Y. 2010. Effects of drip irrigation regimes on tomato fruit yield and water use efficiency. *Journal of Food, Agriculture and Environment*, 8(3), pp. 709-713.

[20]. Onwuegbunam D.O., Oyebode M.A., Igbadun H.E. and Ismail H. 2022. Simulation of response of field-grown drip-irrigated tomato to water stress using Aquacrop model, Unpublished PhD. Thesis, Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria, Nigeria.

[21]. Raes D., Steduto P., Hsiao T.C. and Fereres E. 2018. Annexes: AquaCrop 6.0 - 6.1 Reference Manual, Food and Agriculture Organization of the United Nations, Rome, May 2018

[22]. Muroyiwa G., Mhizha T., Mashonjowa E. and Muchuweti M. 2022. Evaluation of FAO Aquacrop model for ability to simulate attainable yields and water use for field tomatoes grown under deficit irrigation in Harare. *African Crop Science Journal*, 30(2), pp. 245 – 269.

[23]. Sheshshayee, M.S., Bindumadhava, H., Shankar, A.G., Prasad, T.G. and Udayakumar, M. 2003. Breeding strategies to exploit water use efficiency for crop improvement. *Journal of Plant Biology*, 30(2), pp. 253-268.

[24]. Fereres E. and Soriano M.A. 2007. Deficit irrigation for reducing agricultural water use, *Journal of Experimental Botany.* 58(2), pp. 147-158.

[25]. Jiang, X., Zhao, Y., Wang, R., & Zhao, S. 2019. Modeling the Relationship of Tomato Yield Parameters with Deficit Irrigation at Different Growth Stages. Hortscience, 59(4), pp. 1492-1500

[26]. Singh V., Sasode S., Patel R., Kumar S. and Ahirwal A. 2020. Moisture stress and their effects on crops. Kirshi Science, eMagazine for Agricultural Science, 1(6), pp. 1-4, December, 2020, www.krishiscience.in/storage/app/finalpdf/rDxQlkd0ONjIgIXDhH

[27]. Bekele T., Wabela K. and Abebo M. 2022. Effect of deficit irrigation on tomato (Galila 555) yield and water productivity in Silte Zone, Rift Valley, Ethiopia. *International Journal of Plant Biotechnology*, 8(1), pp. 1-7.

[28]. Pruitt W.O., Fereres E., Henderson D.W. and Hagan R.M. 1984. Evapotranspiration losses of tomatoes under drip and furrow irrigation. California Agriculture, May-June 1984, pp. 10-11. www.calag.ucanr.edu/download_pdf.cfm?article=ca.v038n05p10

[29]. Kahlon M.S., Josan A.S. Khera K.L. and Choudhary O.P. 2007. Effect of drip and furrow methods of irrigation on tomato under two irrigation levels. *Indian Journal of Agricultural Research*, 41, pp. 282-286.

[30]. Musa M., Iqbal M., Tariq M., Sahi F.H., Cheema N.M. and Jahan F.N. 2014. Comparative water use efficiency of drip and furrow irrigation systems for off-season vegetables under plastic tunnel. *SAARC J. Agric.*, 12(1), pp. 62-71.

PREDVIĐANJE PRINOSA PARADAJZA I POTROŠNJE VODE PO SCENARIJU SA DEFICITOM NAVODNJAVANJA UPOTREBOM MODELA AQUACROP, U AFAKI, KADUNA, NIGERIJA

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Apstrakt: Poboljšanje potrošne vode za navodnjavanje kod deficita postalo je glavni cilj za održivu poljoprivredu zbog globalnog pada pristupačnosti vode.

Studija je procenila prinos, upotrebu vode za useve i potrošnju vode kod paradajza gajenog u polju navodnjavanjem sistemom kap po kap kao odgovor na regulisano navodnjavanje u slučaju deficita vode, i naknadnu simulaciju pod različitim scenarijima deficita i metoda navodnjavanja, koristeći AquaCrop model, za uslove pokrajine Afaka, Nigerija.

Eksperiment na terenu, postavljen u randomizovanom kompletnom blok dizajnu, sastojao se od tri različita nivoa deficita navodnjavanja (80, 60 i 40% referentne evapotranspiracije, ETo) postavljenih u fazama vegetativnog razvoja: cvetanja i zrelosti, sa 100% ETo u tri faze porasta useva, kao kontrole.

Najveći prinos svežeg paradajza (19,0 t/ha) dobijen je navodnjavanjem sa 100% ETo vrednošću u svim fazama rasta, ali je najveća potrošnja vode svežeg paradajza (4,94 kg/m^3) dobijena navodnjavanjem sa 60% ETo u fazi zrelosti, zatim puna navodnjavanje u vegetativnim i cvetnim fazama.

Na osnovu prinosa paradajza (slučaj kada nije navodnjavano), najveća simulirana potrošnja vode kod (0,46 kg/m^3) za scenarije deficita dobijena je navodnjavanjem sa normom od 80% ETo kod sve tri faze rasta, sa najvećim (ne navodnjavano) prinosom paradajza (1,67 t/ha) i najmanja sezonska primena vode (447 mm).

Kod scenarija metode navodnjavanja (kap po kap, nalivanje i brazda), prinos paradajza (ne navodanjavano) je bio sličan za svaki tretman, ali je potrošnja vode bila najveća (0,53 kg/m^3) kod sistema kap po kap.

Navodnjavanje sa 80% ETo tokom celog ciklusa rasta useva paradajza sorte UC 82B preporučuje se za najveću produktivnost navodnjavanja.

Ključne reči: *Predviđanje, prinos paradajza, produktivnost vode, deficit navodnjavanja, scenariji, AkuaCrop, Nigerija*

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