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USING AQUACROP MODEL TO DERIVE DEFICIT IRRIGATION SCHEDULES FOR IMPROVED IRRIGATION WATER MANAGEMENT FOR TOMATO PRODUCTION IN ZIMBABWE

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ABSTRACT

Increasing scarcity and unreliability of rainfall, and the absence of irrigation schedules are challenges to decision-making, particularly for viable tomato (*Lycopersicon esculentum* Mill) production in Zimbabwe. The objective of this study was to determine water requirements of tomato as a basis for developing generic calendar guidelines for a more efficient irrigation management in Harare, Zimbabwe. We explored the options of improving the traditional, dry and supplementary wet season irrigation practices. By considering the archived climate data of thirty years (1991-2021) for Harare; and model-simulated consumptive water use from 2014 to 2017 at Thornpark Research Station, together with the crop and soil characteristics; and the irrigation method; an irrigation calendar was developed using the AquaCrop model 5.0. The improved irrigation schedule for dry season tomato cultivation at 60% ETc, resulted in water use of 471.6 mm, with a yield of 3.40 t ha^{-1}; compared to water use of 820 mm and a yield of 1.118 t ha^{-1}; for the wet season. Through this model, we have been able to estimate the time interval between the previous irrigation and the next irrigation for any date in the growing season. Therefore, year-round irrigated tomato production may be feasible with an added yield advantage of 2.28 t ha^{-1} obtainable using water and rainy periods.

Key Words: Irrigation calendar, *Lycopersicon esculentum*

RÉSUMÉ

La rareté croissante et le manque de fiabilité des précipitations, ainsi que l'absence de calendriers d'irrigation sont des défis pour la prise de décision, en particulier pour la production viable de tomates (*Lycopersicon esculentum* Mill) au Zimbabwe. L'objectif de cette étude était de déterminer les besoins en eau de la tomate comme base pour développer des directives de calendrier génériques pour une gestion plus efficace de l'irrigation à Harare, au Zimbabwe. Nous avons exploré les options d'amélioration des pratiques d'irrigation traditionnelles, sèches et supplémentaires en saison humide. En considérant les données climatiques archivées de trente ans (1991-2021) pour Harare ; et la consommation d'eau simulée par modèle de 2014 à 2017 à la station de recherche de Thornpark, ainsi que les caractéristiques des cultures et des sols ; et la méthode d'irrigation; un calendrier d'irrigation a été développé en utilisant le modèle AquaCrop 5.0. Le programme d'irrigation amélioré pour la culture de la tomate en saison sèche à 60 % d'ETc a entraîné une consommation d'eau de 471,6 mm, avec un rendement de 3,40 t ha^{-1} ; par rapport à une consommation d'eau de 820 mm et un rendement de 1.118 t ha^{-1} ; pour la saison des pluies. Grâce à ce modèle, nous avons pu estimer l'intervalle de temps entre l'irrigation précédente et la prochaine irrigation pour n'importe quelle date de la saison de croissance. Par conséquent, la production de tomates irriguées toute l'année peut être réalisable avec un avantage de rendement supplémentaire de 2,28 t ha^{-1} pouvant être obtenu en utilisant l'eau et les périodes pluvieuses.

Mots Clés : Calendrier d'irrigation*, Lycopersicon esculentum*

INTRODUCTION

The intensity, distribution and frequency of rainfall in Zimbabwe are quite variable, yet their seasonal pattern is too complex to enable a viable cropping system (Mamombe *et al.*, 2017). Although traditionally the rainy season in Zimbabwe stretches from November to March, with the highest recorded in December, January and February (Mamombe *et al.*, 2017); the onset and cessation dates of the rainy seasons are unpredictable, sometimes starting in October and ending in April (Torrance, 1981). Rainfall in Zimbabwe is mainly dependent on the orientation and behavior of the Inter-Tropical Convergence Zone (ITCZ), which is influenced by the change in pressure patterns to the north and south of the country (Beilfuss, 2012); and the passage of the upper westerly waves of mid-latitude origin which enhance the intensity of rainfall during a given wet period (Mamombe *et al.*, 2017). However, the influence of the upper westerly waves is sometimes hindered by a strong seasonal high-pressure system over Botswana (Ismail, 1987); which may cause or induce a dry-spell in the area. In addition, there has been projections of increased precipitation variability and hydro-meteorological hazards such as floods, droughts and erratic rainfall due to global warming (Mushore, 2013).

The rainfall pattern from 2011 to 2020 exhibited considerable spatial and temporal variability, characterised by shifts in the onset of rains; and increases in the frequency and intensity of heavy rainfall events. There are also increases in the proportion of low rainfall years, decreases in low intensity rainfall events, and increases in the frequency and intensity of mid-season dry-spells (Unganai, 2009; Brown *et al.*, 2012). In Harare region, precipitation has been irregular, typically ranging from 200-800 mm in total, and often insufficient for tomato production. Although a range of irrigation scheduling methods have been developed for many countries, to assist farmers and irrigators to apply water more efficiently, considering crop evapotranspiration and rainfall (Jensen, 1980), small scale farmers in Zimbabwe cannot use such methods because they require sophisticated monitoring equipment and data processing. Therefore, indicative irrigation calendars have proven to be useful to small holder farmers using climatic data and standardised crop and soil data; such as fixed irrigation intervals and application depths; with or without some empirical adjustments to actual weather conditions (Raes *et al.*, 2002). The inefficiencies detected in the irrigation systems have induced the development of tools that help farmers in irrigation scheduling such as practical decision-support in management. Simulation models are also tools that provide a low-cost means of investigating a wide range of management options that have been produced (Wellens *et al.*, 2017).

Crops require water balance such that rainfall or irrigation water should be equal to the water lost through evapotranspiration (Zirebwa *et al.*, 2012). Hence, accurate irrigation scheduling plays an important role in deciding productivity of and income obtained from tomatoes. Proper irrigation scheduling will not only affect yield and quality of crops like the tomato, but also greatly optimise scheduling of other cultural and commercial activities (Raes *et al.*, 2002). Currently, there is paucity of site-specific drip irrigation guidelines or calendar for tomato production in Zimbabwe. Moreover, evaporative demand is known to differ between locations and over-time for a specific location; and as crop canopy cover varies. Therefore, a rigid guideline of the amount of irrigation water per day can lead to over- or under-irrigation (Fessehazion *et al.*, 2014). Therefore, there is need for information on irrigation requirements for tomatoes, by developing site specific irrigation calendars, which are simple guidelines or charts that indicate when and how much to irrigate.

Calendar based irrigation scheduling provides farmers with an inexpensive and convenient way to estimate the irrigation timing and amount; and hence the irrigation requirements developed can be flexible by deducting measured rainfall since the last irrigation event (Fessehazion *et al.*, 2014). However, fixed calendars are less reliable in conditions of variable climatic pattern and location; hence the corresponding irrigation applications are often characterised by periods of over- and under-irrigation (Raes *et al.,* 2002). Excessive irrigation leads to water logging, loss of valuable nutrients and soil salinisation; while withholding irrigation, during crop sensitive periods, can result in limited growth and a reduction in crop yield (Raes *et al.*, 2002).

Tomatoes are the number one field vegetable in 'farm value' in Zimbabwe and the transplanted tomatoes are a long-season crop with high water requirements. An average cultivar requires about 40 cm^3 of water over the growing season (LeBoeuf *et al.*, 2008). When deficit irrigation is applied, tomatoes can result in higher and more consistent yields, better quality, larger fruit, less blossom-end rot and less cracking (LeBoeuf *et al.*, 2008). Recent research has shown tomato yield increases of up to 80% with the use of properly timed and scheduled irrigation (LeBoeuf *et al.*, 2008). Correct scheduling of irrigation will provide maximum benefits from tomato production; however, proper scheduling is vital for optimal outputs (LeBoeuf *et al.*, 2008). The objective of this study was to develop an irrigation calendar that can guide tomato farmers on to the routines of proper irrigation during the wet and periods of water scarcity or dry conditions; using the AquaCrop model.

METHODOLOGY

Irrigation scheduling. This research was conducted in the Harare region, located at -17.83^{O} S latitude and 31.05^{O} E longitude, at Thornpark station University of Zimbabwe with soil characteristics as shown in Table 1. The region receives unimodal rainfall, commencing from October and ending late April. Temperatures are usually in the range of 8 to 29 ^{o}C. Tomato production during dry seasons, as well as during drought incursions in a wet season is done using traditional irrigation methods such as the sprinkler and terraced structures.

In the present study, the AquaCrop model (Crop water productivity model version 5.0, 2015) developed by the Land and Water Division of FAO, United Nations, was used to develop an Irrigation Calendar. This was done using monthly rainfall data (Fig. 1), Monthly average temperatures (Table 2) and evapotranspiration for the period 2016-2019, obtained from the Meteorological Services Department of Zimbabwe; and crop and soil characteristics. Tables 3 - 5 shows the dependable rainfall, weather conditions and the crop growth in relation to water stress as experienced at the research site. The procedure was executed a number of times, with different values of irrigation amounts, ranging from

TABLE 1. Soil characteristics at the University of Zimbabwe research site (Thornpark Farm)

Parameter	Description
Soil classification	Zimbabwe: 5 EI FAO: Haplic Lixisol
Depth	80 cm
Texture	Course sandy clay loam
Bulk density	1.3 - 1.6 g cm^{-3}
Available water content	12 (%v/v)
Final infiltration rate	18 cm hr^{-1}

Adapted from (Mhizha, 2010)

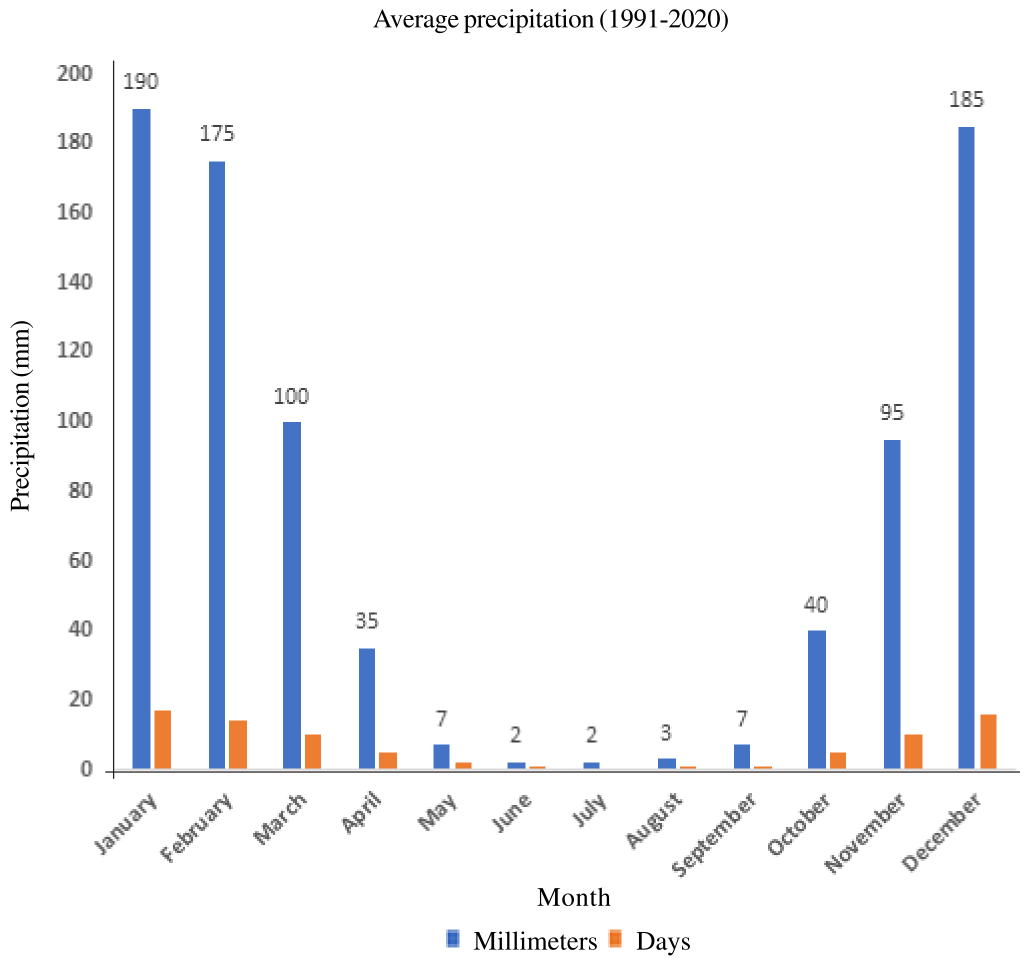

Figure 1. Dependable rainfall for Harare showing the average precipitation for a period of 30 years (1991-2020). The rainfall is obtained from December to March and the period between April and October is relatively dry with very little rainfall.

TABLE 2. Harare - Average temperatures (1991-2020) Meteorological Services Department

Month	Minimum (°C)	Maximum (°C)	Mean (°C)
January	17	27	21.8
February	16	27	21.7
March	16	27	21.2
April	13	25	19.4
May	10	24	17
June	8	22	14.8
July	8	21	14.5
August	9	24	16.8
September	12	28	20
October	15	29	22
November	16	28	22.4
December	17	27	21.8
Yearly average	13.1	25.8	19.4

TABLE 3. Dependable rainfall for the experimental site (Thornpark)

80 %	December, January, February and March
50 %	November and March
20 %	October and April

TABLE 4. Weather conditions experienced from 1991 to 2021 at Harare in Zimbabwe

Weather conditions	Amount of rainfall	Month
Dry	80% no rain	April - September
Normal	50% no rain	September and May
Humid	20% no rain	October - April
Hot and dry	100% no rain	August

(50-100%) Crop Water Requirements (ETc); and hence the optimum results were retrieved after a predefined number (11 times) of iterations at 60% ETc. Total seasonal irrigation water, monthly irrigation water, weekly irrigation water and daily quotas for chosen months were determined and in this respect, AquaCrop generated an irrigation file which contained irrigation dates and the corresponding irrigation amounts.

Based on the methodology above, the crop received water according to the irrigation dates with corresponding amounts generated by the AquaCrop as indicated in the generated irrigation charts (Tables 6 - 9). A detailed description of the profiles about the AquaCrop and how it works is provided in Muroyiwa *et al*. (2022).

Calendar development. Complete climate and irrigation files for four cropping seasons were created from data obtained during field work (2014-2017); and these were entered into the AquaCrop model as input data. Eleven

TABLE 5. Crop growth in relation to water stress and the Crop factor (Kc)

Growth stage	Initial stage	Canopy development	Mid-season stage	Late-season stage		
Crop factor	0.45	0.75	1.15	0.80		
Days	23	42	27	20		
Water stress	Very sensitive	Moderate sensitivity	Very sensitive	Sensitive…not sensitive		
Growth recovery	Flowering	Max canopy cover	Max rooting depth	Canopy senesense	Maturity	
Days	6	36	65	62	92	112

FAO (2012), AquaCrop Water Irrigation and Drainage Paper

TABLE 6. Irrigation calendar: Drip irrigated tomato on sandy-clay-loamy soil at Harare in Zimbabwe

	Cropping season				
	April	May	June	July	August
Irrigation intervals (days)	5	31	30	31	10
Water supply (mm)	38.6	158.7	186.6	199.2	77.9
Growing stage	Germination	Vegetative development	Flowering	Yield formation and maturity	
Days	23	42	27	20	
Sensitivity to water-stress	Very	Moderate sensitive	Very sensitive	Not sensitive	

TABLE 7. Irrigation schedule: Drip irrigated tomato for the dry period (April - September) at Harare in Zimbabwe

Date	Stage	Rain (mm)	Depletion (%)	Irrigation application (mm)
25 April	Initial	0.0	68	9.36
9 May	Initial	0.0	62	11.5
21 May	Development	0.0	63	14.0
31 May	Development	0.0	61	15.5
9 June	Development	0.0	64	18.1
17 June	Development	0.2	63	19.5
25 June	Middle	0.0	61	19.2
3 July	Middle	0.3	61	19.3
11 July	Middle	0.0	62	19.4
19 July	Middle	0.0	61	19.3
27 July	Middle	0.3	62	19.6
4 August	Middle	0.0	64	20.0
12 August	Middle	0.0	64	20.3
20 August	End	0.0	65	20.5
29 August	End	0.0	63	19.8
8 September	End	0.0	61	19.1

simulations for each season were run to obtain an average for each crop season. The model was run for the dry and wet season to evaluate crop yield; and total water use for each of the simulations. A specific day, 3-day, 10-day and a monthly interval were used for the irrigation scheduling; as these were generated from the model as outputs (Tables 6-9). During field work, there were four treatments for each trial (i.e. 100, 80, 60, 50% ETc), but for the AquaCrop model, eleven simulations were done at 5% intervals, with a range from 50-100% ETc. The following inputs for the model were used: Long-term historical climate data from 1991 -2020 and the weather data for a complete growing season: Total Rainfall (mm), Mean daily ETo (mm), daily Average Temperature (^{o}C) and the default CO_2 in ppm (Range 1902-2099).

Inputs for the soil characteristics included soil type and rooting depth. Crop characteristics involved inputs showing day of transplanting, growth cycle from transplant to maturity, maximum effective root zone, plant density and initial canopy cover. All the data generated were first used for calibration and validation of the model before the 11 simulations were done.

A file was selected from AquaCrop model data base for the irrigation schedule. This was created from field data at 60% Crop Water Requirements obtained as the optimum for Yield and high Water Use Efficiency. The irrigation method used was deficit since 60% ETc for dry season and 100% ETc for the wet season were used (Muroyiwa *et al.*, 2022). In the file for the irrigation events, time criteria were selected as the allowable percent depletion of the readily available water at 60 and 100% ETc. The model also required the depth criteria and the fixed net application in mm was used. The net application was obtained from the product of evapotranspiration ETo and the crop factor, *viz.* Kc. i.e. ETc = ETo x Kc

RESULTS

Soil characteristics of the research site. The site was relatively flat with moderately deep

TABLE 8. Irrigation calendar for dry season tomato production at Harare in Zimbabwe

Station:	Thornpark, Harare	Crop:	Tomato,
Planting date:	25 April	Harvest date:	11 September
Soil:	Sandy-clay-loam	Timing:	Irrigation at depletion
Total net irrigation	474.5 mm	Crop scheduling options	Specific days after transplanting
Expected yield	3.40 t ha^{-1}	Actual w ater use by crop	471.6 mm

Month	Decade	Stage	Kc	ETc mm day^{-1}	ETc mm dec^{-1}	Eff rain mm dec^{-1}	Irr. req mm day^{-1}	Irr. req mm dec^{-1}
April	3	Init	0.45	1.76	10.6	5.5	0.06	6.0
May	1	Deve	0.45	1.60	16.0	5.8	1.02	10.2
May	2	Deve	0.56	1.81	18.1	2.3	1.58	15.8
May	3	Deve	0.73	2.48	27.3	1.8	2.55	25.5
June	1	Deve	0.91	3.23	32.3	1.4	3.09	30.9
June	2	Mid	1.07	3.92	39.2	0.4	3.88	38.8
June	3	Mid	1.12	4.09	40.9	0.5	4.04	40.4
July	1	Mid	1.12	4.09	40.9	0.6	4.02	40.2
July	2	Mid	1.12	4.09	40.9	0.6	4.03	40.3
July	3	Mid	1.12	4.17	45.8	0.6	4.52	45.2
August	1	Mid	1.12	4.24	42.4	0.5	4.20	42.0
August	2	Late	1.11	4.29	42.9	0.4	4.25	42.5
August	3	Late	1.00	3.81	41.9	1.2	4.07	40.7
September	1	Late	0.85	3.23	32.3	1.5	3.98	30.8
September	2	Late	0.78	2.92	29.0	0.2	2.90	29.0
Interval in days:			Initial 23		Development 42		Mid 27	Late 20

Irrigation calendar for the dry cropping season at 60% ETc showing irrigation requirements per day and per decade

N.B. Record rainfall before irrigation

Subtract rainfall from water requirements to obtain the irrigation amount

TABLE 9. Irrigation calendar (October–February) at Harare in Zimbabwe

Station:	Thornpark, Harare	Soil:	Sandy-clay-loam
Crop:	Tomato (Galina)	Efficiency Irri Sched:	100% ETc
Planting date:	01 October	Harvest:	17 February
Applic ation:	Refill soil to field capacity	Timing:	Irrigate at critical depletion
Water use			820 mm
Supplementary irrigation:			22.3 mm
Yield:	1.118 t ha^{-1}	Total rain/dec	442 mm

Month	December	Stag	Kc coeff	ETc mm day^{-1}	ETc mm dec^{-1}	Eff rain mm dec^{-1}	Irr req mm dec^{-1}
October	1	Init	0.45	1.61	16.1	7.9	8.1
October	2	Dev	0.47	1.64	16.4	10.4	6.0
October	3	Dev	0.62	2.04	22.4	16.4	6.1
November	1	Dev	0.79	2.43	24.3	23.0	1.2
November	2	Dev	0.94	2.73	27.3	28.8	0.0
November	3	Mid	1.07	2.95	29.5	33.0	0.0
December	1	Mid	1.07	2.84	28.4	37.9	0.0
December	2	Mid	1.07	2.71	27.1	42.7	0.0
December	3	Mid	1.07	2.80	30.8	43.2	0.0
January	1	Mid	1.07	2.90	29.0	44.2	0.0
January	2	Mid	1.07	2.99	29.9	45.7	0.0
January	3	Late	1.03	2.99	32.9	42.8	0.0
February	1	Late	0.89	2.68	26.8	39.7	0.0
February	2	Late	0.77	2.42	16.9	26.1	0.0
Total					357.9	441.8	21.4

Interval in days: Initial 23 Development 42 Mid 27 Late 20

N.B. Record rainfall before irrigation
Subtract rainfall from water requirements to obtain the irrigation amount

well drained sandy clay loam. The soil has a typical water holding capacity within 0.80 m, with an infiltration rate of about 0.18 m h^{-1} and an available water content of 12 (%v/v).

Average temperatures for Harare from (1991-2020). The average minimum temperature was 13.1 °C, with a maximum of 25.8 °C and a mean average of 19.4 °C. The lowest temperatures were obtained in June, July and August *versus* high temperatures obtained in September, October and November.

Dependable rainfall for the experimental site (Thornpark). The area receives most of its rainfall for the year from December to March. Half of the amount is obtainable in November and March and 20% of the total in October and April.

Table 4 shows the weather conditions experienced from 1991 to 2020 in Harare. From April to September the area was dry with approximately 80% of no rain. Normal conditions prevailed in November and March with 50% no rain. The period between October and May displayed humid conditions and August was 100% no rain and was a hot and dry period.

Crop growth in relation to water stress, growth stage and the Crop factor (Kc). The crop factor is important as it determines the crop water requirements for a particular stage showing higher values (0.75 and 1.15) for the canopy development and mid-season stage, respectively; and this coincides with maximum canopy cover growth and the rooting depth.

Irrigation calendar for drip irrigated tomato on sandy-clay-loamy soil. Irrigation requirements according to AquaCrop model for the period between April to August are shown. In the last 5 days of April the irrigation requirements were at 38.6 mm, being on the higher side due to the high evapotranspiration. In the month of May, it was at 158.7 mm being lower than in June at 186.6 mm, as the month of May received more rains than in June which was relatively dry (Table 6). July was almost dry and, hence the higher irrigation requirements standing at 199.2 mm. The duration of various growth stages, in number of days from germination to maturity, together with the sensitivity of the plant to water stress for each stage is presented in Table 6.

Irrigation requirements for the different growth stages of the crop for the dry cropping season at 60% crop water requirements. Table 7 shows irrigation as generated by the AquaCrop model for specific days from 25 April to 08 September with approximate intervals (8-14) days for the dry cropping season. The net application depth is shown in mm for a depletion of 61-68%. The amount of precipitation received is zero for all the months, except for June and July receiving 0.2 and 0.3 mm, respectively.

Irrigation calendar for dry season tomato production. Daily and ten day irrigation water requirements are shown on the calendar for the period between April and August, displaying high water requirements from June to August due to high crop water requirements.

Ten-day irrigation water requirements for the period between October and February. There are crop water requirements from October to the first week of November (Table 9). The rest of November to mid-February there is excess rainfall and, hence no need for supplementary irrigation.

DISCUSSION

The sandy clay loam soils at the site gave good soil water retention characteristics, having a direct influence on the total available water. The maximum effective rooting depth at Thornpark was 0.8 m, a result which is consistent with the observed depth of the soil at Thornpark reported by Mhizha (2010).

Water retention characteristics indicate total available soil water content of 130 mm/m for the sandy clay loam soils. These results compare well with reported values of 127 mm m^{-1} for similar soils in Zimbabwe (Raes *et al.*, 2002).

The average temperatures for Harare from (1991-2020) for a period of 30 years (Table 2) showed an average minimum temperature of 13.1 ^{o}C, with a maximum of 25.8 ^{o}C and a mean average of 19.4 ^{o}C. The lowest temperatures were obtained in June-August; while the highest prevailed in September to November, constituting the wet period. The country experiences its rainy season along with relatively high temperatures during the wet period; and it encounters dry seasons with low temperatures from June to August. The rainfall data reveals a high inter- and intra-seasonal variability of rainfall and frequent dry spells (Fig. 1).

The rainfall in Harare as shown in Table 3 indicates that the area receives most its rainfall for the year from November to March, which is the wet season and half of the rainfall amount is obtainable in November and March and 20% of the total in April and October, the hot and dry months.

The weather conditions then experienced from April to September (Table 4) is relatively dry, with approximately 80% of no rain and; hence the need to develop a calendar for the hot and dry period. Normal conditions prevail in September and May, during which half of the rainfall is obtained and hence only supplementary irrigation is needed. The period between October and May displays humid conditions and August with 100% no rain, is hot and dry.

The crop factor (kc) in Table 5 is important as it determines the crop water requirements related to reference evapotranspiration (ETo) in mm/period, given by the crop factor (Kc) for different crop development stages. The canopy development and mid-season stage show high values of 0.75 and 1.15, respectively; and this coincides with maximum canopy cover growth and the rooting depth.

According to the AquaCrop model, the irrigation requirements for the period between April to August are shown in Table 6. In the last 5 days of April, the irrigation requirements stood at 38.6 mm. This is high due to high evapotranspiration, leading to higher crop water requirements. During the month of May ETc, was at 158.7 mm, being lower than in June with ETc at 186.6 mm as the month of May received more rains than in June, which is relatively dry (Table 1). July was almost dry and; hence the higher irrigation requirements standing at 199.2 mm. The amount of precipitation received rainfall zero for all the months, except for June and July which received 0.2 and 0.3 mm, respectively; and hence, the need for irrigation during the dry period.

Table 7 is an irrigation schedule for drip irrigated tomato for the dry period (April - August) as generated by the AquaCrop model for specific days after transplant from 2 days in April and up to 10 days in August.

Table 8 is an Irrigation calendar for dry season tomato production in Harare, Zimbabwe. The calendar produced indicated an expected yield of 3.40 t ha^{-1} and actual water use by crop at 471.6 mm. The daily and ten day irrigation water requirements shown on the calendar displaying high crop water requirements from June to August are due to high evapotranspiration.

The irrigation requirements for the period between October and February (Table 9) show very low crop water needs. There is excess rainfall in the latter part of November to mid-February and hence there is no need for supplementary irrigation. During this period (October-February) when crop water requirements were at 100%, the yield obtained was at 1.118 t ha^{-1} as indicated by the calendar (Table 9) with effective rainfall at 442 mm being obtained. The values obtained were close to values produced by Sekyi-Annan *et al.*

(2018), showing that improved irrigation schedule for the dry season tomato cultivation can result in water savings of between 130 - 1325 mm, when compared with full irrigation practices, accompanied by approximately 4-14% increase in tomato yield.

The observed increases in tomato yield at 60% crop water requirements, under the improved irrigation schedule, could have resulted from the reduction of the negative effect of over-irrigation during the rainy season on crop yield, as the over-irrigated tomato fields showed lower yield *versus* the dry cropping season showing a higher increase in yield as also reported by Sekyi-Annan *et al.* (2018). Under improved irrigation schedules considerable, potential for water saving in the dry season showed water use of 471.6 mm *versus* the 820 mm during the wet season plus the supplementary irrigation water of 22.3 mm. The irrigation calendar for the wet season shows that we can avoid over-irrigation by practising supplementary irrigation when conditions are not favourable so as to avoid irrigation when water is adequate. The irrigation guidelines generated express indicative values for water supplies and intervals for the dry and wet season of drip irrigated tomato grown on sandy-clay-loam soil in Harare, Zimbabwe. Different intervals for irrigation scheduling generated show that the farmer can decide on the interval appropriate for weather conditions in the area such as dry, hot, humid or moderate conditions.

CONCLUSION

This study was designed to determine water requirements of tomatoes (*Lycopersicon esculentum* Mill) in Zimbabwe, using the AquaCrop model in order to develop generic calendar guidelines for a more efficient irrigation management. The irrigation schedule for dry season tomato cultivation at 60% ETc, resulted in water use of 471.6 mm per cropping season, with a yield of 3.40 t ha^{-1} compared to water use of 820 mm and a yield of 1.118 t ha^{-1} for the wet season. The model simulated the dry and wet weather conditions, and derived the best time interval for a net application depth of irrigation to avoid drought stress during the growth stages and to guarantee maximum water productivity. The calendars are in the form of simple readable charts, appropriate for use by small scale farmers and policy makers at local level. The charts are useful in adjusting irrigation scheduling during periods of moderate to high water stress and irrigation water can be saved, but adjusting irrigation scheduling during periods when the crop is sensitive to water stress should be avoided.

An analysis in the development of the calendar shows that input data for the climate, crop, soil, the sensors and management during the cropping season are required to provide optimal irrigation scheduling solutions and improved resource allocation under the hot and dry conditions. For the climate, Evapotranspiration (ETo) cannot be calculated within the model and hence the need for farmers to make use of automatic weather station set up in the field or to obtain data from meteorological services in the area. For adoption of the new water management technologies, the farmers need technical training and the willingness to accept irrigation calendars based on data-driven decision-making processes. Therefore, irrigation engineers, agronomists, extension officers and other stakeholders can play an effective role in driving this technology towards the development of an irrigation schedule. The calendar generated can help small holder farmers, and other stakeholders to plan effectively so as to ensure high water use efficiency and optimum crop yields being achieved.

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