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Research Article

ASSESSMENT OF WATER USE EFFICIENCY USING SURFACE AND SUBSURFACE DRIP IRRIGATION SYSTEM ON YIELD OF TOMATO IN SOUTHERN PROVINCE OF RWANDA

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Abstract

Surface and subsurface drip irrigation methods can play a significant role in overcoming the scarcity of water mostly in water shortage areas. The average annual rainfall of 1200mm per year is suitable for the growth of crops grown in in the country. However, it is erratic and unevenly distributed throughout the year within the agriculture seasons. In addition, it may be too little or not available at the time needed resulting into drought. These problems have adverse effect on crops grown in rainfed agriculture. Therefore, study was conducted to assess water use efficiency using Surface and Subsurface drip irrigation system on yield of tomatoes at IPRC Huye farm located in Ngoma Sector, Huye district in southern province of Rwanda as the main objective. An area of 308.76m^2 (16.6 m × 18.6m) was allocated for the experiment. The soil in experimental field was found as sandy clay loam with the Bulk density between (1.0 -1.32) g/cm^3. The infiltration rate of the soil was found to be 20mm/hour. Using CROPWAT 8.0 software, the peak water requirement of the tomato crop was estimated and found to be 4.24mm/day. The experiment contained five irrigation treatments viz., 90%, 80%, 70%, 60%, and 50% Crop water use (ETc) and the control (100% ETc) was laid out in RCBD design with three replications. Seedlings of tomato (Solanum lycopersicum) were raised in nursery bed (30days). Vigorous, strong and healthy ones were selected for transplanting at a spacing of 0.80 m x 0.80 m. Irrigation schedule was prepared in accordance with crop water requirement and was applied at allowable soil moisture depletion (p = 0.40) of the total available soil moisture throughout the crop growth stages. The discharge of one emitter was 0.5 l/h. Statistical analysis has been performed using Microsoft excel and GenStat software. The result showed that there is a significant difference in plant height among treatments at 20DAT while at 50 and 85 DAT a highly significant difference was found among them at 5% level of probability. The highest fruit head volume was observed from treatment received 80% ETc of subsurface drip irrigation system followed by 90% ETc of the same system while the highest yield (25.90t/ha) was found to be in control (100%ETc). Base on this study, I suggest that in an area with no water shortage, full irrigation water supply of subsurface drip irrigation system could be used for the production of tomato.

Keywords: Drip irrigation, surface drip irrigation, subsurface drip irrigation, tomato, Huye.

INTRODUCTION

Irrigated agriculture accounts for two-thirds of the water withdrawn from the earth's rivers, lakes, and aquifers and produces approximately 40% of total food production. Demand for water to satisfy the needs of industry and population is increasing (Taylor and Zilberman, 2017). On a global scale, agriculture will be obliged to give up water for higher-value uses in cities and industries. Water to satisfy these demands can be found by irrigated agriculture becoming more efficient. The challenge is to sustain irrigated food production with less water (Mancosu, Snyder, Kyriakakis, and Spano, 2015). Tomatoes (Solanum lycopersicum) are one of the most common and important types of vegetables in the world, and they have high water requirements. In Rwanda, tomato crops are usual grown during the agriculture seasons A, B or C and are considered to be the second after potato (Ndereyimana, Nyalala, Murerwa, and Gaidashova, 2020). Improved irrigation methods can conserve water without compromising yield or quality (Basset-Mens, Rhino, Ndereyimana, Kleih, and Biard, 2019). Drip irrigation refers to the application of water at a slow rate drop by drop through perforations in pipes or nozzles attached to tubes spread over the soil to irrigate a limited area around the irrigation (Jägermeyr, Pastor, Biemans, and Gerten, 2017). Surface and subsurface drip irrigation are the ones of the water-saving irrigation methods that reduce the amount of irrigation provided to crops (Umair *et al.,* 2019). They are the irrigation systems that require the ability to control both the amount and the placement of irrigation water, in order to maintain a desired soil moisture deficit for all or part of the crop-growing season (Odhiambo, 2017). The overall objective is to assess water use efficiency using Surface and Subsurface Drip Irrigation System on yield of tomato at IPRC Huye farm located in Ngoma Sector, Huye district in southern province of Rwanda. For the completion of the main objective, we determined the weather parameters of the study area, the soil physical properties, water requirement for tomato and the effect of water deficit of 10 to 50% on tomato crop growth and yield for both surface and subsurface drip irrigation systems.

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MATERIALS AND METHODS

Description of experimental site

This study was conducted at Integrated Polytechnic Regional College (IPRC) – Huye farm land located in Huye district, southern province of Rwanda. The experimental site is located at 2° 5691' S latitude and 29° 7194'E longitude with an altitude of 1749m m.a.s.l. The site received a mean annual rainfall of 1182mm with an average minimum and maximum temperature of 12.8 and 26.2^{0}C, respectively. The soil textural class of the experimental area is sand clay loam.

Climatic characteristics

The average climatic data (maximum and minimum temperature, relative humidity, wind speed, sunshine hours) on of the study area were collected from the nearest meteorological station. The reference evapotranspiration ETo was estimated using CROPWAT software version 8.

Experimental design

An area of 308.76m^2 (16.6 m × 18.6m) was allocated for the experiment. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replicates. The treatments consisted of five soil moisture levels for each system, viz., 90% ETc; 80% ETc; 70% ETc; 60% ETc and 50% Etc and a control of 100% ETc., The experimental field was ploughed and made ready for transplanting. A surface and subsurface drip irrigation systems were installed to the established field. Grassland mulch materials was applied to cover the experimental plots. Seedling of tomato were prepared at suitable site by preparing bed on which seeds was raised. After germination, vigorous, strong and healthy ones were selected for transplanting at a spacing of 0.80 m x 0.80 m. The distance between the blocks was 1m and that between plots was also 1m. Each plot has two planting rows with two driplines of 16mm in diameter with on line emitters spaced 0.80 m apart with the capacity to deliver 0.5L/h at an operating pressure of 1bar controlled by one valve.

DATA COLLECTION

Weather data

Weather data such as maximum and minimum temperatures, relative humidity and rainfall, average daily wind speed and sunshine hours of Rubona station which is representatives of IPRC farm were collected from CLIMWAT2 Database.

Soil texture

The particle size distribution of the soil profile was done using the hydrometric method as described by Bouyoucos (1927). The disturbed soil samples on the experimental field from the 5 locations (X- direction system) at five different depths viz: 20,40,60,80 and 100 cm were collected with soil auger. Soil laboratory facilities of University of Rwanda, Huye Campus was used for analysing the particle size distribution in the soil profile. From the percentage of sand, silt and clay, the textural triangle diagram was used to determine the texture class of the soil. The reagents such as Amyl alcohol, Hydrogen peroxide, 30% (100 volumes) and Sodium hexametaphosphate were used.

Soil bulk density

Soil bulk density was determined from undisturbed soil sample by core sampling method in the field at five different depths viz: 20,40,60,80 and 100cm. The weight of the representative soil sample taken to laboratory was measured using an electronic balance in gram. oven dried for 24 hours at 105^{o}C and weighed for dry density using the following formula pb = Wd/Vc Where: pb is soil bulk density (g/cm^3), Wd is weight of dry soils (g) and Vc is volume of core sampler (cm^3).

Field Capacity (FC), Permanent Wilting Point (PWP), Bulk density (BD) **and Available Soil water (ASW**

Field capacity (FC), Permanent Wilting Point (PWP), Bulk Density (BD) and Available Soil water of the study area were determined using 3 undisturbed soil samples collected by using core samples from the soil pit at the depth interval of 0 – 20 cm; 20 – 40 cm 40-60cm, 60-80 and 80-100cm from the surface. Soil samples were saturated for one day and a pressure of 1/3 bar (field capacity) and 15 bars (for permanent wilting point) were exerted until no more change in weight of sample was observed. After getting moisture values available, water availability to crops from this soil was calculated. The total available water (TAW) for the plant use in root zone was computed as the difference in moisture content between field capacity (FC) and permanent wilting point.

Infiltration rate

The infiltration rate was determined experimentally using the double ring infiltrometer following the procedure of Anon (1991)

Agronomic parameters

Plant height (cm), Fruit head volume (cc), fruit head weight (Kg/plant) and Total head yields (tons/ha) were collected and measured.

Statistical Analysis

Statistical Analysis for each measured response data variables of analysis of variance (ANOVA) were computed. Data were analyzed for variability using the GenStat software. Mean separation were done using the Least Significance Difference (LSD) method at 5% level of probability.

RESULTS AND DISCUSSION

Weather analysis

The data of Rubona meteorological station were collected through CLIMWAT.2 (FAO) database. The mean monthly maximum and minimum temperatures were plotted in graph for the months and are shown in figure 1 and 2. It was found that the highest average temperature of 26.2 ^{o}C occurred in September whereas the lowest temperature of 12.8 ^{o}C occurred in June.

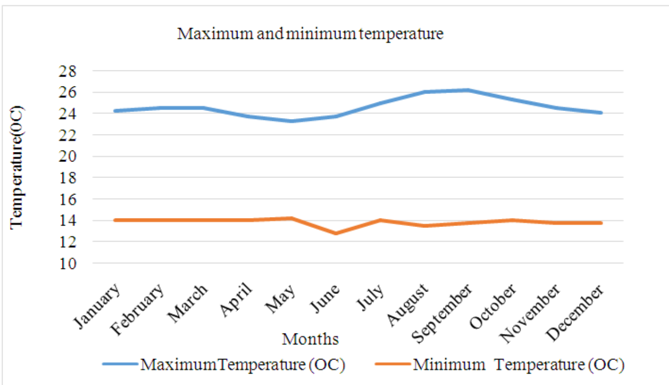


Figure 1. Maximum and minimum temperature

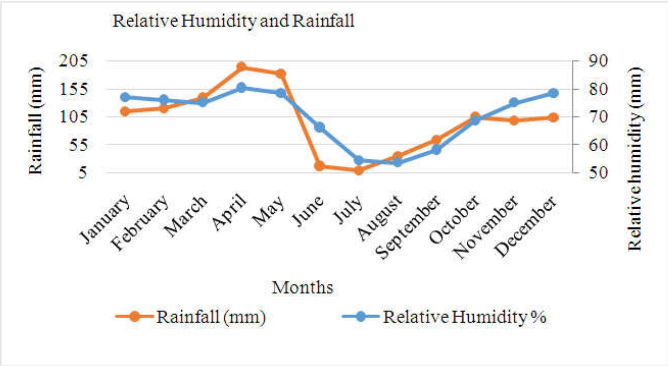


Figure 2. Relative Humidity and Rainfall

According to relative humidity, it was found that the high relative humidity of 80.43, 78.49 and 78.51% was found for the period of April, May and December respectively. It was also high for the period of January (77.04%) and February (76.08 %). Low relative humidity was found for the period of July (54.47%) August (53.6%) and September (58.23%).

Wind speed and sunshine

The mean monthly wind speed and sunshine were plotted in graph and are shown in figures 3. The average monthly wind speed was found to be 7.02 Km/hour and its range varies from 6.47to 7.95Km/hour. The difference between maximum and minimum wind speed is only 1.48 Km/hour. It indicates that there is no much difference in wind speed throughout the year. The longest durations of sunshine occurred in May (8.2hours/day) followed by June (8.9hours/day) and July (8.1hours/day) while the shortest sunshine duration of 6.48 hours observed in October. The monthly average sunshine hours was as 7.4 hours per day. The range of sunshine duration in a day varies from 6.4 to 8.9 hours. The difference between maximum and minimum sunshine hours is 2.4 hours.

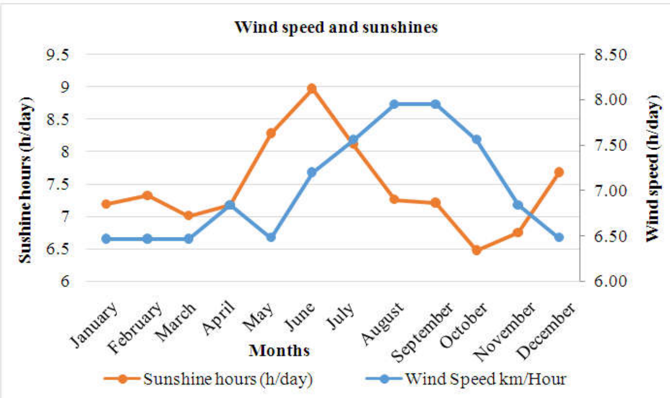


Figure 3. Wind speed and sunshine

Table 1. Soil physical characteristics at the experimental site

Soil texture	Bulk density (g/cm^3)	Field capacity (%)	Permanent Wilting Point (%)	Total available water (mm)
Sand clay loam	1.11	38.5	22.3	39.35

Total available water (TAW) which is the amount of water that the crop can extract from its root zone is directly related to variation in field capacity and permanent wilting point. High volume of TAW were found in subsurface soil; whereas lower volume was found in the top soil. The average total available water of the soil was 35.95 mm (Table 1).

Infiltration rate of soil in experimental field

The infiltration rate of the study area which refers to the vertical intake of water to the soil was determined experimentally using the double ring infiltrometer following the procedure of Anon (1991). The average infiltration rate of the experimental field was found to be 2cm/hour as shown in (Figure 4). Adopting the method of Majumdar (2000), classification of infiltration rates of the soil of the study area, was found to be moderate as it is in range of 12.7-25.4 mm/hr.

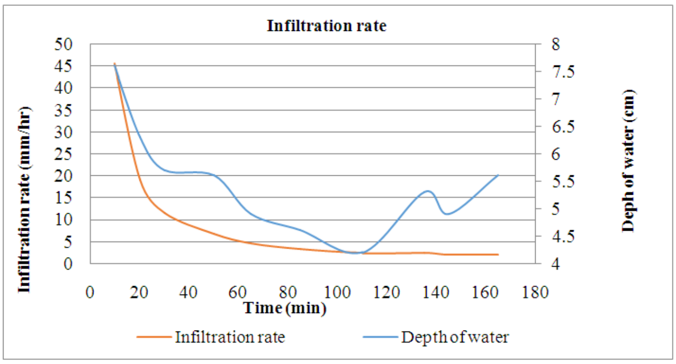
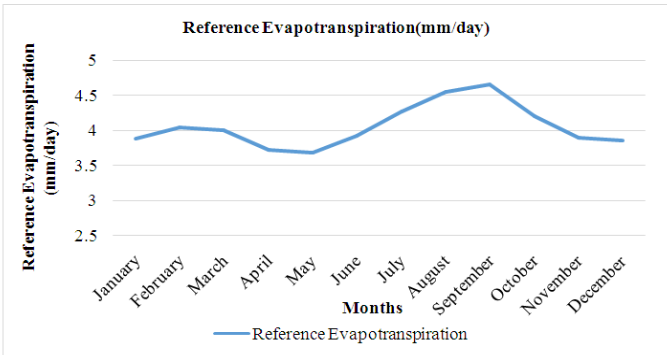


Figure 4. Infiltration rate

Potential Evapotranspiration

The maximum reference evapotranspiration (ETo) of 4.06 mm/day was in September while the minimum was 3mm/day in May. Figure 5 shows the reference crop evapotranspiration (ETo) of the experimental area.



Fugure 5. Reference Evapotranspiration (ETo)

Effective rainfall

The maximum effective rainfall in April was 141 mm and the minimum was in July (12.7mm). The figure below **(Figure 6)** shows the effective rainfall within the area of study.

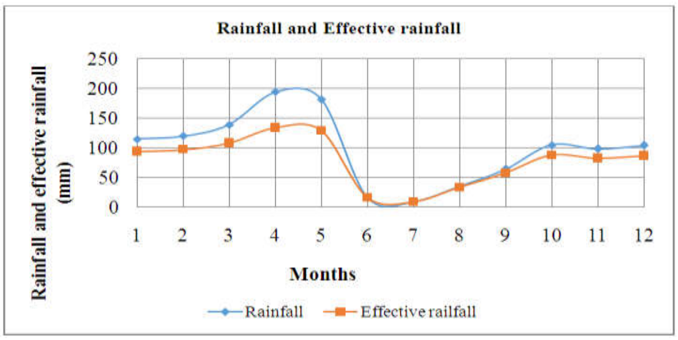


Figure 6. Effective rainfall in the study area

Crop water requirement and deficit irrigation level of tomato

The table below shows the irrigation water requirement and irrigation water levels. 4.16mm/day was applied as full irrigation during the month of July. During the month of April, less than 2mm/day irrigation water was applied due to the high rainfall (194mm) that was received. The net irrigation water requirement from 10% to 50% deficit was computed and presented in table 2

Table 2. Crop water requirement and irrigation level

ETc levels	April	May	June	July
Monthly ETc (mm/day)	1.95	2.96	4.0	4.16
90% ETc (mm/day)	1.75	2	3.6	3.7
80% ETc (mm/day)	1.56	2.4	3.2	3.3
70% ETc (mm/day)	1.22	2.1	2.8	2.9
60% ETc (mm/day)	1.17	1.77	2.4	2.5
50% ETc (mm/day)	1	1.5	2	2.1

Effect of irrigation levels on plant height

At 20DAT, the result showed that there was significant difference among treatments, whereas T1, T2, T3 and T4 showed a non-significant difference among them. The minimum plants height (16.63cm) was observed at T6 (50% ETc) while the maximum plant height (20.27cm) was observed at T2 (90% ETc). At 50 DAT, the results showed that there was a highly significant difference among treatments at 5% level of probability. The non-significant difference was observed on T5 and T6 of both surface and subsurface drip irrigation systems. The result also revealed that T2 and T3 there were not significantly different. The minimum plants height (36.55cm) was observed at T6 (50% ETc) while the maximum plant height (42.48cm) was observed at T3 (80% ETc). At 85 DAT, the minimum plants height (67.93 cm) was observed at T6 (50% ETc) while the maximum plant height (84.36cm) was observed at T3 (80% ETc). The result showed that there is highly significant difference among treatments. T6, T5 and T4 showed a significance difference at 5% level of probability while T3, T2 and T1 showed non significance difference. The deficit irrigation on subsurface drip irrigation system did not affect much tomato plant height. The plant height ranged from 16.63 and 20.27 cm for 20DAT; 36.55and 42.48 for 50DAT and 67.95 and 84.36cm for 85DAT.The highest and lowest plant height was observed from treatment receiving 90% and 50% ETc, respectively. This study outcome is in line with the research that has been done by Doorenbos J, Pruitt WO (1977). The increase in plant height with adequate soil moisture application is related to water in maintaining the turgid pressure of the plant cells which is the main reason for the growth.

Table 3. Mean value of tomato plant height

Irrigation water level	Plant height (cm)		
	20DAT	50AT	85DAT
T6	16.63a	36.55a	67.95a
T5	18.22ab	37.46a	75.9b
T4	18.97b	40.41b	78.58bc
T1	19.76b	41.46bc	83d
T3	20.24b	42.48c	84.36d
T2	20.27b	41.92c	82.44cd
Grand Mean	19.02	40.05	78.71
CV%	1.8	2.1	2.8
LSD	2.271	1.382	4.085
P (<0.05)	0.034	<.001	<.001

In the other side the shortening of plant height under less soil moisture stress may be associated due to the closure of stomata to conserve soil moisture evaporation, this leads to reduce uptake of CO2 and nutrient. Therefore, photosynthesis and other biochemical reactions are hindered, eventually affecting plant growth It is also in line with the research that has been done by (El-Noemani, Aboamera, Aboellil OM and Dewedar (2009) indicated that soil water supply is directly proportional with plant height growth. In a column, mean with the same letter are not significantly different according to fisher's protected LSD at 5% level of probability.

Effect of irrigation levels on both surface and subsurface drip irrigation systems on fruit head volume and yield

Mean value of fruit head volume and yield

Fresh fruit head volume and yield of tomato per hectare for the different irrigation treatments are shown in table4. T4, T1, T2 and T3 showed a significance difference at 5% level of probability while T5 and T6 showed non significance difference. The highest fruit head volume was observed from treatment received 80% ETc by subsurface drip irrigation system followed by 90% ETc of the same system. The highest (25.9 t/ha) tomato fruit yield was obtained under the control treatment of both irrigation systems, followed by treatment receiving 90% ETc (23.33t/ha) of subsurface drip irrigation system and this was not significantly different to treatment receiving 80% ETc (20.86 t/ha) of surface drip irrigation system. The lowest yield was recorded from treatment receiving 50% ETc and there was no significant difference with treatments receiving 60% ETc at $p<0.05$. Above 30% water deficit resulted tomato yields below mean value for the treatments; this reduction may be due to that the soil dries, consequently the rate of root absorption falls short of the transpiration rate of the plant; this creates an internal water deficit that affects photosynthesis and results in reduced leaf area, cell size, and intercellular volume, which reduces soil moisture accumulation. This internal water deficit had a greater effect on fruit growth stage, and at this time, the expanding fruit tissues require a great deal of water. A study done by Al- Moshileh (2007) revealed the similar findings with this result.

In addition, the results were consistent with the results obtained by Kassahun Alebachew, (2017) who reported that the highest tomato yields were observed with full irrigation.

Table 4. Mean value of fruit head volume and yield

Irrigation water levels	Fruit head volume	Yield (t/ha)
T6	26.97a	13.59a
T5	28.26a	16.97b
T4	31.92ab	18.92c
T1	35.78bc	25.90f
T2	40.47cd	23.33e
T3	42.24d	20.86d
Grand Mean	34.27	19.93
SE±	3.49	1.00
CV	5	5.1
LSD 0.05	6.366	1.833
P (<0.05)	<.001	<.001

In column, mean with the same letter are not significantly different according to fisher's protected LSD at 5% level of probability.

Conclusion

The soil type, weather parameters of the study area showed the variability of the crop water requirement through the year in the study area. The texture of experimental field is sandy clay loam. In this study, the application of 80% ETc using subsurface drip irrigation system gave highest plant height and head fruit volume. The maximum yield was found where 100% ETc irrigation water was applied on both irrigation systems and above 30% water deficit resulted tomato yields below mean value for the treatments; this may be due to water stress during fruit development and ripening which resulted a positive effect on fruit head volume, consequently result in smaller fruit. For further investigations chemical properties of soil need to be undertaken to confirm the benefits of the use of subsurface drip irrigation system. To validate the results of this finding and practically use the result by farmers, the experiment has to be repeated at different places and seasons so that findings could be developed. The experimental crop considered here is tomato but other vegetable crops especially long duration and crop sensitive to drought should be examined in this agro ecology with different types of irrigation level.

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