
Open Access Journal

**Journal of Sustainable Research in Engineering Vol. 6 (2) 2020, 47-55**

Journal homepage: http://sri.jkuat.ac.ke/ojs/index.php/sri

**ISSN (Online)**: 2409-1243

# Yield Response, Water Use and Water Productivity of Tomato under Deficit Sub-Surface Drip Irrigation and Mulching

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**Abstract**: The greatest challenge in the agricultural sector is to produce more food with less water. The problem facing tomato growers in Njoro Sub County is the unfavourable conditions for tomato growth which includes very low rainfall during the dry periods. This requires maximizing yield per unit of water used. However, there is limited information on water management strategies, or deficit irrigation that would maximize tomato crop yield and additionally improve on the quality of fruit when drip irrigation is used. The objective of this study was to evaluate the effect of deficit sub – surface drip irrigation and mulching systems on water productivity of tomato (*Lycopersicon esculentum* mill) crop in Njoro Sub County. The study was carried out on experimental plots measuring 4 $m^2$ in a shade at Egerton University's Tatton farm. Factorial experimental design was used in this study where the treatments were three water levels (100 % $ET_{C.}$ 80% $ET_C$ and 60 % $ET_C$) and four grass mulch densities (0, 0.5, 1 and 1.5 $kg/m^2$ ) replicated three times. The sub – surface drip lines were laid at a depth of 5 cm below the ground surface. An estimated crop water requirement was applied to the respective plots based on various irrigation levels guided by the four main tomato crop development stages. The agronomic parameters and yield was monitored on weekly basis over a period of twenty weeks. The tomato water productivity under the interactive effect of deficit sub – surface drip irrigation and grass mulch densities was determined to be highest at 60 % $ET_C$ and 1 $kg/m^2$ of grass mulch and lowest at 100 % $ET_C$ and 1.5 $kg/m^2$. The study provides information on optimum application rates that can be adopted for production of more tomato yields by farmers with less water thus leading to poverty reduction by improving the agri-business in Njoro Sub County.

**Keywords:** crop water requirement, deficit irrigation, water management, water productivity

## 1. Introduction

Worldwide, tomato is one of the most commonly grown vegetable crop. However, due to unfavourable weather conditions which include high/low rainfall and high/low temperatures, there is need to minimize water use in order to maximize crop yields under water deficit conditions. Varying tillage and mulching practices are some of the agronomic measures that could increase water productivity [1].

Irrigation is a process of providing regulated amount of water to plants, agricultural crops, orchards and landscapes at required intervals. The common distinct water application methods include sprinkler irrigation, surface irrigation (basin, wild flooding, border and furrow), sub-surface irrigation and drip irrigation [2]. The possibility of drip irrigation system applying water at very slow rates offers the means to deliver water to the soil in small and frequent quantities at a relatively low cost when compared to other pressurized systems such as sprinkler irrigation [3] .

It is very critical to make efficient use of water by converting more area to irrigation through the available limited water resources. This could be achieved by introducing advanced methods of irrigation with improved water management practices. Efficient utilization of water, land and other resources increases productivity and promotes sustainable development in irrigated agriculture [4]. Deficit irrigation is a regulated irrigation technique that reduces water use, with little impact on crop yield and quality to ensure sustainable agricultural productivity [5]. Mulching involves placing a covering material on the ground surface around plants for conservation of soil moisture, improving fertility and health of the soil, reducing weed growth and enhancing the visual appeal of the area [6].

Drip irrigation in combination with mulch is an appropriate system, which could significantly improve the crop water productivity. Surface mulch has been used to improve soil water retention, reduce soil temperature and wind velocity at the soil surface. For commercial production of vegetable crops in many regions of the world, the use of mulch has become an important cultural practice that maximizes water use efficiency by the plant and as a result, improves crop growth. When mulch is spread over the soil surface, a favourable soil-water-plant relation is generated [7].

In Kenya, Studies on drip irrigation and mulching have been carried out under open field conditions suggesting the need to conduct further studies under controlled conditions as was the case in this study [8]. Protected cultivation is an improved agricultural method used to increase production of crops. The ratio of open field to greenhouse tomato production is 2:3 [9] .In Njoro Sub County, tomato is one of the most grown vegetable crop. The crop is largely grown in the open-field under rain-fed conditions. The vulnerability of tomatoes to weather conditions has several consequences. For instance low crop production, high food demand and consequently high food prices. Similarly, unfavorable weather may lead to reduced farm returns. With changing weather conditions, greenhouse tomato production is likely to become more popular as crops grown under controlled environment like in a greenhouse, provides protection against unfavorable weather conditions [10]. However, there was need for further studies on water productivity of tomato in a shade under both deficit drip irrigation and mulching systems as was the case in this study.

Protected cultivation is an alternative new technique for seasonal and off-seasonal vegetable cultivation and can be successfully practiced for niche areas of agriculture. Use of organic, or inorganic, mulch may improve crop yield by conserving soil water [11]. The protected cultivation techniques include; shade net house, greenhouses and polyhouse [12]. Deficit irrigation is rarely practiced because farmers are not aware of the improvement of crop water productivity under deficit irrigation for sensitive crops like tomato.

Reference evapotranspiration ($ET_O$) can be estimated using different methods depending on the availability and reliability of climatic data. The different methods of ETo estimation include; FAO-24 Penman –Monteith, FAO-24 Blaney-Criddle, Hargreaves and Christiansen Pan methods [13].

The Penman - Monteith method is considered as a standard and the most accurate method to estimate reference evapotranspiration and was therefore the most ideal for use in this study [14]. The method is shown in Equation 1.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma(900/T + 273)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where,

$ET_0$ = grass reference evapotranspiration (mm day$^{-1}$),

$\Delta$ = the slope of the saturated vapor pressure curve (kPa $^oC^{-1}$),

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T + 237.3}\right)\right]}{(T + 237.3)^2} \quad (2)$$

$R_n$ = the net radiation (MJ $m^{-2}$ $day^{-1}$),
G = the soil heat flux density (MJ $m^{-2}$). It is null for daily estimates,
T = daily mean air temperature (°C) at 2 m based on the average of maximum and minimum temperature

$$T = \frac{T_{\max} + T_{\min}}{2} \quad (3)$$

$U_2$ = average wind speed at 2 m height ($ms^{-1}$)

$$U_2 = U_Z \frac{4.87}{\ln(67.8z - 5.42)} \quad (4)$$

where;
$U_2$ = wind speed at 2 m above ground surface (m/s)
$U_Z$ = measured wind speed at z m above ground surface (m/s)
z = height of measurement above ground surface (m)
$e_s$ = the saturation vapour pressure (kPa)

$$e_s = \frac{e^o(T_{\max}) + e^o(T_{\min})}{2} \quad (5)$$

$$e^o T_{\max} = 0.6108 \exp\left[\frac{17.27 T_{\max}}{T_{\max} + 237.3}\right] \quad (6)$$

$$e^o T_{\min} = 0.6108 \exp\left[\frac{17.27 T_{\min}}{T_{\min} + 237.3}\right] \quad (7)$$

$e_a$ = the actual vapour pressure (kPa)

The actual vapour pressure was determined using the actual vapour pressure calculator from the relative humidity and the saturated vapour pressure.
($e_s$ - $e_a$) = the saturation vapour pressure deficit ($\Delta e$, kPa )
γ = the psychometric constant (0.0677 kPa $^oC^{-1}$)

$$\gamma = \frac{C_P P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P \quad (8)$$

P = Atmospheric pressure (kPa)
λ = Latent heat of vaporization 2.45 (MJ/kg)
$C_p$ = Specific heat at constant pressure $1.013 \times 10^{-3}$ (MJ/kg/°C)
Ɛ = Ratio molecular weight of water vapour/dry air = 0.622

$$P = 101.3 \left[\frac{293 - 0.0065z}{293}\right]^{5.26} \quad (9)$$

P = Atmospheric pressure (kPa)
z = elevation above sea level (m)

The crop water requirement of tomato for Njoro Sub County was estimated using the function presented in Equation 1.

There are several water saving irrigation techniques which include deficit irrigation, mulching systems, managed full season drought management and partial season drought management [15]. In this study a combination of deficit irrigation and mulching was used.

This study therefore worked to improve the agro-business management by determining the optimal tomato water requirement that resulted in increased water productivity.

## 2. Materials and methods

### 2.1. The study area

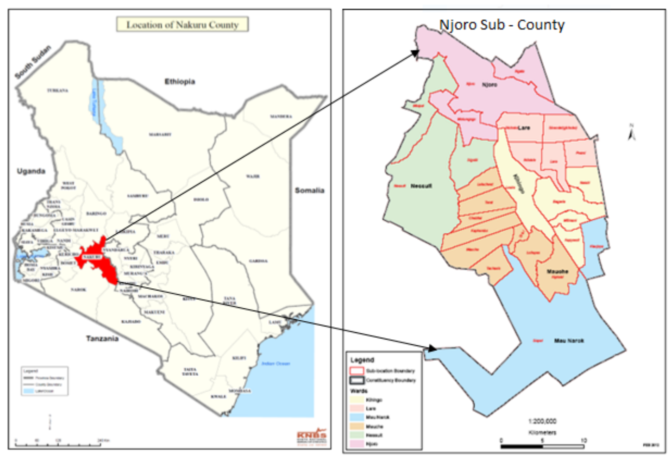


**Figure 1:** Location of Njoro Sub County

The study was carried out in Njoro Sub - county, Nakuru County. Njoro Sub - county covers an area of about 780 $km^2$. On average it has an altitude of 2400 meters above sea level and lies between Latitude 0° 15”0 and 0° 42’ 30 south and Longitude 35° 45”0 and 36° 10” 0 East.

Njoro area has a trimodal rainfall pattern with the peaks in April, August and November. The average mean annual temperature for the area is 21 °C being highest on average in March, at around 17.3 °C while August is the coldest month, with temperatures averaging 15.1 °C.

### 2.2. Experimental Set Up and Data Acquisition

A total area of 220 $m^2$ was used for the drip irrigation system study. Experimental plots measuring 2 m by 2 m were used. Twelve treatments were administered in the plots using factorial experimental design with three replications, giving the total number of plots as thirty six as described in Table 1.

**Table 1:** Treatment allocation to the plots

| | | | |
|---|---|---|---|
| Plot1 100% $ET_C$ 0.5 kg | Plot 2 60% $ET_C$ No mulch | Plot 3 80% $ET_C$ 1 kg | Plot 4 100% $ET_C$ 0.5 kg |
| Plot 5 80% $ET_C$ 0.5 kg | Plot 6 100% $ET_C$ No mulch | Plot 7 60% $ET_C$ 1.5 kg | Plot 8 80% $ET_C$ 0.5 kg |
| Plot 9 60% $ET_C$ 0.5 kg | Plot 10 80% $ET_C$ No mulch | Plot 11 100% $ET_C$ 1 kg | Plot 12 60% $ET_C$ 0.5 kg |
| Plot 13 100% $ET_C$ 1 kg | Plot 14 60% $ET_C$ 1.5 kg | Plot 15 80% $ET_C$ No mulch | Plot 16 100% $ET_C$ 1 kg |
| Plot 17 80% $ET_C$ 1 kg | Plot 18 100% $ET_C$ 1.5 kg | Plot 19 60% $ET_C$ No mulch | Plot 20 80% $ET_C$ 1 kg |
| Plot 21 60% $ET_C$ 1 kg | Plot 22 80% $ET_C$ 1.5 kg | Plot 23 100% $ET_C$ No mulch | Plot 24 60% $ET_C$ 1 kg |
| Plot 25 100% $ET_C$ 1.5 kg | Plot 26 60% $ET_C$ 0.5 kg | Plot 27 80% $ET_C$ 1.5 kg | Plot 28 100% $ET_C$ No mulch |
| Plot 29 80% $ET_C$ 1.5 kg | Plot 30 100% $ET_C$ 0.5 kg | Plot 31 60% $ET_C$ 1.5 kg | Plot 32 80% $ET_C$ No mulch |
| Plot 33 60% $ET_C$ 1.5 kg | Plot 34 80% $ET_C$ 0.5 kg | Plot 35 100% $ET_C$ 1.5 kg | Plot 36 60% $ET_C$ No mulch |

Sub - surface drip lines were placed at a depth of 5 cm below the ground surface because at a depth of 20 cm there was high root concentration. The drip lines were placed at the shallow depth to accommodate the water conservation by grass mulch on the soil surface. Tomato was planted on 12th January, 2019 at a spacing of 50 cm between rows and 60 cm between plants [16].One type of mulch (dry Guinea grass) of three densities (0.5, 1 and 1.5 kg/m$^2$) and three levels of deficit irrigation were used which are 100% $ET_c$, 80% $ET_c$, and 60% $ET_c$ to account for water saving through deficit irrigation that is 20 to 40% irrigation water at yield reductions below 10%.

From the past studies grass mulch of densities 0.75 kg/m$^2$ by [17] 1.2 kg/m$^2$ by [18] and 3 kg/m$^2$ by [19] have been used. In this study grass mulch densities within the recommended range of 0.5, 1 and 1.5 kg/m$^2$ were used to determine their effect on tomato growth. A lower mulch density was used to determine the tomato water productivity

Both the mainline and the sub mainlines were made of PE pipes each of internal diameter of 25 mm while the lateral line was made of same pipe with 10 mm internal diameter and 0.50 m lateral spacing. The emitter discharge was 1.2 litres/second. A 1000 litre tank was raised at a height of 2m above the ground for supplying water to the 100 litre tanks which were raised at a height of 1.5 m above the ground that supplied water to the experimental plots through the mainline, sub mainlines and the laterals.

DAP fertilizer was applied at 200 kg/ ha and urea at 100 kg/ha. 25g of Karate pesticide was applied two days after transplanting to control cutworms. Early and late blight diseases were controlled using 50g Ridomil in 20 litres of water at weekly intervals. Aphids, white flies and mites were controlled using Actara at 10g in 20 liters of water.

The reference evapotranspiration was estimated using the FAO Penman Monteith method and the $ET_O$ Calculator and the crop coefficient using the FAO Kc tables. The weather parameters used were monthly reference evapotranspiration, minimum and maximum temperature and wind speed. The crop coefficients used were as shown in Table 2.

**Table 2:** Tomato crop coefficients

| Stages | Initial | Development | Middle | Late |
|---|---|---|---|---|
| Days | 30 | 40 | 40 | 25 |
| $K_c$ | 0.45 | 0.75 | 1.15 | 0.9 |

### 2.3. Crop Water Requirement

The Crop Water Requirement ($ET_c$) is the amount of water required to meet the water extracted from land through evapotranspiration or the amount of water needed by the various crops to grow optimally [20]. The crop water requirement of tomato for Njoro Sub County was estimated using Equation 1 [21].

$$ET_c = ET_o \times k_c \quad (10)$$

where,

$ET_C$ = Crop evapotranspiration (mm day$^{-1}$)

$ET_o$ = Reference evapotranspiration (mm day$^{-1}$)

$K_c$ = Crop coefficient (dimensionless)

### 2.4. Water Productivity

Tomato water productivity was determined based on the yield per unit of water used. The water productivity based on the yield was evaluated by the water productivity function [22]. The water productivity based on the tomato yield was determined using Equation 11.

$$WP = \frac{Y_T}{I_W} \quad (11)$$

where,

WP = Water productivity ($kg/m^3$)

$Y_T$ = Total yield ($kg/m^2$)

$I_W$ = Irrigation water used ($m^3/m^2$)

Tomato fruits were harvested at an interval of one week from the maturity period to the end of harvest period. The mass of tomatoes was measured using a digital Electronic Balance after every harvest and the readings recorded to determine the yields. The total mass was then determined at the end of the harvesting period and the total yield expressed in units of mass per unit area of crop field. The yield from each treatment was determined for estimation of the water productivity at every water level and to analyze the differences in production.

The total irrigation water used was determined considering the water application levels in the different plots. The total daily irrigation water used in the different water levels was evaluated using Equation 12.

$$I_w = ETo \times K_c \times I_l = ET_c \times I_l \quad (12)$$

where,

$I_w$ = Total irrigation water used (mm/day)

$ETo$ = Reference evapotranspiration (mm/day)

$K_c$ = crop coefficient (dimensionless)

$I_l$ = Irrigation level (dimensionless)

$ET_c$ = Crop evapotranspiration

The irrigation levels $I_l$ were 100% $ET_c$, 80% $ET_c$ and 60% $ET_c$. The water productivity at every water level was then determined and conclusions made on the treatment with the highest water productivity.

## 3. Results and discussion

### 3.1. Weather pattern

The trimodal rainfall pattern for Njoro Sub – County was determined using 30 year (1987 -2016) average rainfall data from Egerton University, department of Agricultural Engineering weather station and the results are shown in Figure 2.

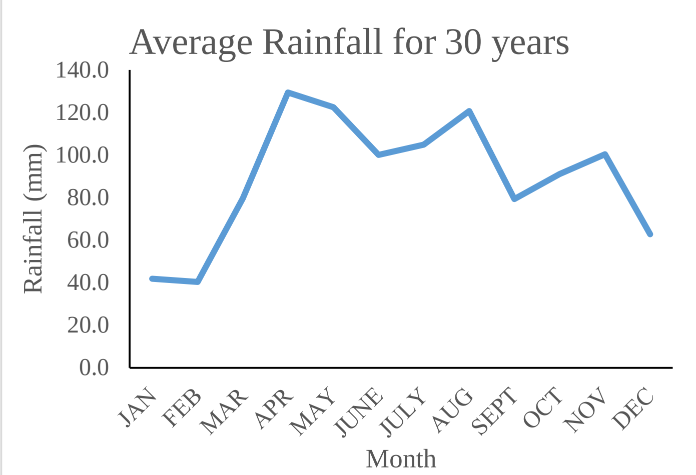


**Figure 1:** Rainfall pattern for Njoro Sub–county

From Figure 2, the rainfall peaks are April, August and November.

### 3.2. Reference Evapotranspiration

Ten year average reference evapotranspiration (ETo) distribution estimated from the FAO Penman Monteith method Equation 2, for the tomato growing period (January to May 2019) was as shown in Figure 3.

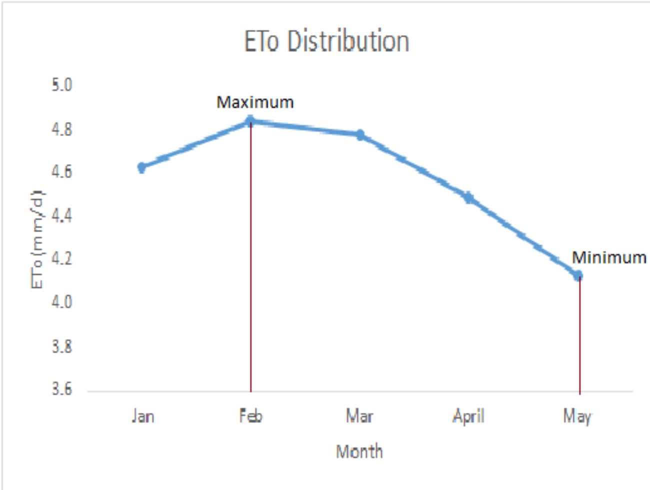


**Figure 3:** Ten year average $ET_O$ distribution for the growing period

From figure 3, the highest reference evapotranspiration was observed in February while the lowest in the month of May. This was because of the lowest rainfall amount and the highest temperatures experienced in the month of February than in the month of May where there was significant rainfall amount. The trend concur with that of [23]where the reference evapotranspiration reduced drastically from the month of February to May.

The ten year average reference evapotranspiration estimated from the FAO Penman Monteith method was compared with that obtained from the Egerton University Department of Agricultural Engineering weather station (Number: 9035092) and the results are shown in shown in Figure 4.

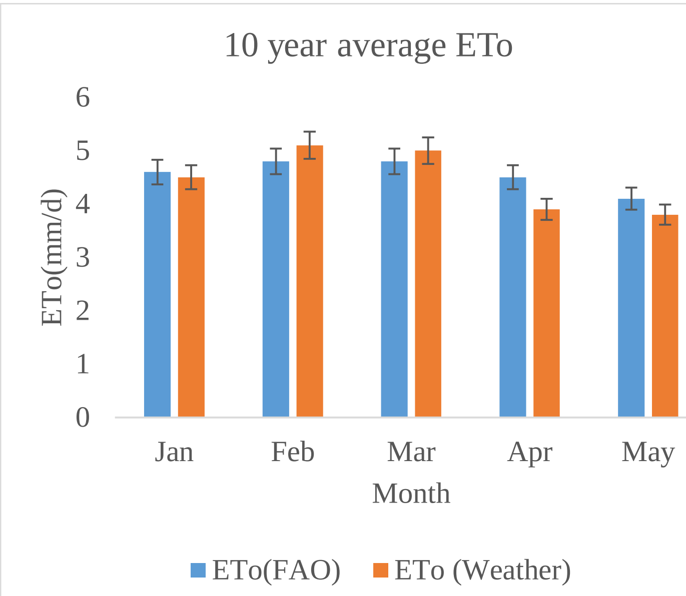


**Figure 4:** Comparison of the $ET_O$ calculated using the FAO Penman Monteith method and the $ET_O$ from the weather station

From Figure 4, it can be seen that there is no significant difference between the reference evapotranspiration estimated using the FAO Penman Monteith method and the one obtained from the weather station. This shows that the FAO Penman Monteith method was able to accurately estimate the reference evapotranspiration. The results concur with that of [24] who carried a study in Southern Ontario, Canada and their results revealed that the FAO Penman Monteith estimates the reference evapotranspiration accurately. The reference evapotranspiration was highest in the months of February and March and lowest in the month of May.

### 3.3. Crop water requirement

The tomato water requirement for Njoro Sub – county for the January – May growing period was calculated from the reference evapotranspiration ($ET_O$) and crop coefficients ($K_C$) in Table 2 using Equation 1 and the results are presented in Figure 5.

The four main stages of tomato described are initial, development, middle and late. The total depth of water applied during the growing period is 509 mm with the highest water requirement period being the middle stage. The depth of water applied to the 100 % $ET_c$, 80 % $ET_c$ and 60 % $ET_c$ treatments were 509 mm, 407 mm and 305mm respectively. The tomato crop water requirement for Njoro sub – county was thus estimated to be 3.77 mm/day. Deficit irrigation was introduced immediately after transplanting the tomato crops.

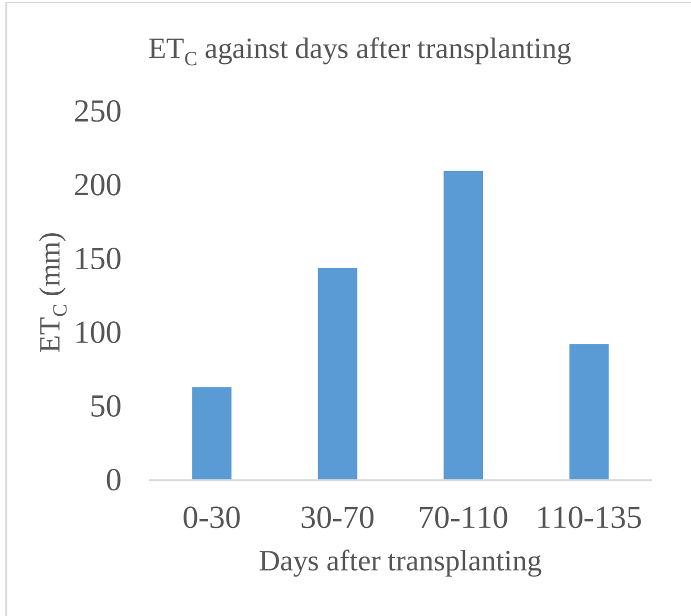


**Figure 5:** Graph of crop evapotranspiration ($ET_C$) against days after transplanting

### 3.4. Tomato yields and biomass

The tomato yields and biomass obtained from the different treatments in the field were as shown in Table 3. Table 4 and Table 5 shows the ANOVA for tomato yields and biomass respectively obtained from SPSS statistics.

**Table 3:** Actual biomass and yield obtained

| Treatment | Biomass (ton/ha) | Yield (ton/ha) |
|---|---|---|
| T1 | 3.18 | 2.46 |
| T2 | 2.97 | 2.07 |
| T3 | 3.05 | 2.02 |
| T4 | 3.3 | 2.19 |
| T5 | 3.72 | 2.19 |
| T6 | 3.46 | 2.07 |
| T7 | 3.23 | 2.67 |
| T8 | 3.61 | 2.40 |
| T9 | 3.85 | 2.74 |
| T10 | 4.53 | 2.04 |
| T11 | 3.45 | 2.26 |
| T12 | 2.90 | 2.08 |

**Table 4:** ANOVA for yield

ANOVA

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 21.037 | 1 | 21.037 | 1.725 | .218 |
| Residual | 121.963 | 10 | 12.196 | | |
| Total | 143.000 | 11 | | | |

**Table 5:** ANOVA for biomass

ANOVA

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 6.854 | 1 | 6.854 | .503 | .494 |
| Residual | 136.146 | 10 | 13.615 | | |
| Total | 143.000 | 11 | | | |

The significant difference between the treatment means was determined using IBM SPSS Statistics Version 27. From Table 4 and Table 5, it can be concluded with 95% level of confidence that there were significant difference in yield and biomass means in the different treatments as determined by the ANOVA using SPSS software. This is shown by the values of Fcalculated being greater than those of Fcritical. It can be seen from Table 3 that the highest and the lowest tomato dry yields were obtained at treatments 60 % $ET_c$, 1kg of mulch and 60 % $ET_c$, no mulch respectively. The yield at 60% $ET_c$, 1kg of mulch was higher than that at 100 % $ET_c$, no mulch by 11.4%. This shows the positive impact of mulching, which is reducing evaporation thus increasing yield. [25] carried out a study in Ogbomoso and Mokwa, Nigeria and their results revealed the highest tomato yields at grass mulch application rate of 1.5 kg/m$^2$, while in this study the highest yield was obtained at 1kg/m$^2$. This may be attributed to the sub - surface drip irrigation incorporated in this study unlike in their study where surface drip irrigation was practiced or due to the variations in the weather conditions in the different study areas. Sub – surface drip irrigation was able to reduce evapotranspiration significantly.

From Table 3, the highest and the lowest biomass production was at treatments 100 % $ET_C$ 1.5 kg of mulch and 60 % $ET_C$ 0.5 kg of mulch respectively. It can be seen that mulching has the potential of increasing the biomass production significantly.

### 3.5. Tomato water productivity

Tomato crop evapotranspiration and water productivity for the different treatments was estimated using Equations 1 and 11 respectively and the results are as presented in Figure 6 and Table 6 respectively.

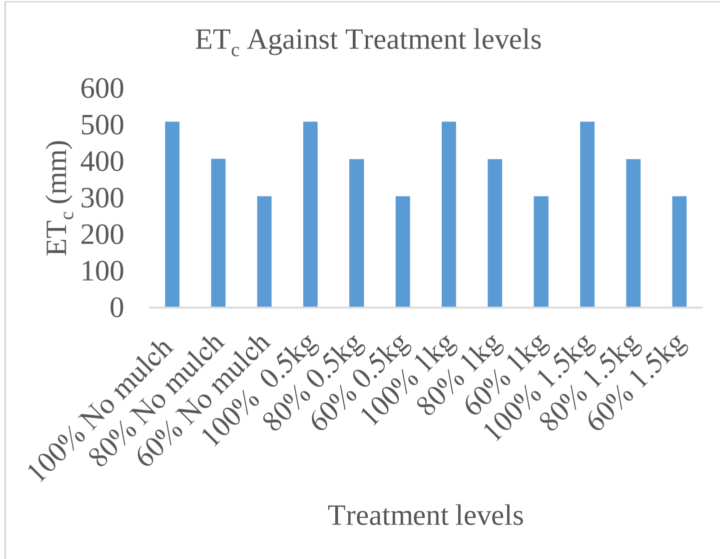


**Figure 6:** Graph showing crop evapotranspiration ($ET_C$) against treatment levels

**Table 6:** Water productivity obtained

| Treatment | Water productivity |
|---|---|
| T1 | 0.48 |
| T2 | 0.51 |
| T3 | 0.66 |
| T4 | 0.43 |
| T5 | 0.54 |
| T6 | 0.68 |
| T7 | 0.52 |
| T8 | 0.59 |
| T9 | 0.9 |
| T10 | 0.40 |
| T11 | 0.55 |
| T12 | 0.68 |

**Table 7**: Anova for water productivity

| SoV | df | SS | MS | Fcal | Fcrit |
|---|---|---|---|---|---|
| Total | 36 | 567886 | | | |
| Factor A | 4 | 45866.4 | 15288.8 | 3.79 | 3.01 |
| Factor B | 3 | 209223 | 104611 | 17.31 | 3.4 |
| Interaction AB | 6 | 22732.4 | 3788.73 | 1.88 | 2.51 |
| Error | 24 | 290065 | 12086 | | |

SoV = Source of variation; Factor A = Mulching density; Factor B = Water level

From Table 7 the Fcalculated values for mulching density, water level and their interactions are greater than the Fcritical values. It can therefore be concluded with 95% level of confidence that there were significant differences in the water productivity between the different treatment levels. It can be seen from Figure 6 that the highest water productivity was observed at 60 % $ET_C$ and 1 kg/m$^2$ of grass mulch while the lowest was observed at 100 % $ET_C$ and 1.5 kg/m$^2$ of grass mulch. This concurs with the results of [26] who conducted a study in Hitao Irrigation District, Inner Mongolia, China where they observed a higher processing tomato water productivity at 60 % $ET_C$ irrigation level. [27] carried out a study in Matinyani secondary school and Kyondoni location in Kitui county, Kenya and their results showed the highest water productivity at 80 % $ET_{C,}$ contrary to the highest water productivity at 60 % $ET_C$ in the present study. This is because of the reduced evapotranspiration as a result of sub – surface drip irrigation and mulching.

## 4. Conclusion

The highest biomass in the present study was obtained at 100 % $ET_C$ and 1.5 kg/m$^2$ of grass mulch while both the highest tomato dry yields and water productivity were obtained at treatments 60 % $ET_c$ and 1kg/m$^2$ of grass mulch. It can be seen that yield is not directly proportional to biomass produced and from the results therefore the best combination of management practices that increases the water productivity of tomato crop in Njoro Sub County was the application of 60 % $ET_C$ of water in combination to 1 kg/m$^2$of grass mulch. The combination should then be adopted by tomato farmers within Njoro Sub County in Nakuru County.

## Acknowledgement

The authors of people acknowledge the scholars whose articles are cited and referenced and also the staff of Egerton University, department of Agricultural Engineering. They also acknowledge AfDB – MOHEST for funding the research work.

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