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Evaluating the Effects of Deficit Irrigation and Mulch Type on Yield and Water Productivity of Tomato in Fogera, Ethiopia

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Abstract

Water scarcity is a significant challenge facing Ethiopia's irrigated agriculture, prompting the need for innovative on-farm irrigation management strategies to ensure the sustainable utilization of limited water resources. In 2021, a study was conducted at the Fogera National Rice Research and Training Center (FNRRTC) to assess the yield and water productivity (WP) of tomato crops under water stress conditions. The experiment involved testing three deficit irrigation levels (100%ETc, 75%ETc, and 50%ETc) based on ETc, along with three mulch types: No Mulch (NM), White Plastic Mulch (WPM), and Rice Straw Mulch (RSM) using a Randomized Complete Block Design (RCBD) with three replications. Rice Straw Mulch was applied at a rate of 6t/ha, while White Plastic Mulch had a thickness of 25 microns. Results showed that the yield of tomatoes and WP were significantly influenced by deficit irrigation and mulch types at a 0.05% significance level. Specifically, tomatoes under 75%ETc had higher marketable yields compared to 100%ETc and 50%ETc; while WP was highest at 50%ETc. RSM demonstrated superior performance, enhancing both yield and WP when compared to No Mulch and WPM. Overall, utilizing RSM with 75%ETc proved to be an effective strategy for conserving water while optimizing tomato yields in Ethiopia.

Keywords: Deficit irrigation; Mulch; Crop; Water Productivity; Water stress; Tomato

Introduction

The escalating global population and the escalating challenges posed by climate change necessitate an increase in food production to ensure food security worldwide (Page et al., 2020; Wendimu, 2021). Smallholder agriculture serves as the primary income source for rural communities in sub-Saharan African (SSA) countries such as Ethiopia. However, these smallholder agricultural systems heavily rely on rainfed production, making them vulnerable to the adverse effects of rainfall variability and drought, leading to food insecurity and low agricultural productivity (Assefa et al., 2022). The inadequacy of traditional farming techniques exacerbates the challenges faced by small-scale farmers, resulting in insufficient food production to meet the demands of the growing population (Tadesse et al., 2021; Yimam et al., 2020; Gizaw, 2020; Feleke et al., 2020; Belay et al., 2019). Therefore, enhancing agricultural productivity is crucial to addressing food security issues and sustaining the livelihoods of Ethiopian communities (Tewabe et al., 2020) [1].

To address the growing food demands, it is imperative to transition from rainfed production to irrigation-supported agriculture (Belay et al., 2019). Irrigation plays a pivotal role in mitigating the impact of rainfall variability and irregularity on agricultural productivity (Mekonen et al., 2022) . Small-scale irrigation initiatives are crucial for poverty reduction, food security, and enhancing rural livelihoods in Ethiopia (Assefa et al., 2022; Terefe, 2021; Ahmed, 2019; Tewodros, 2017). However, the scarcity of available water resources poses a significant challenge to irrigated agriculture in many regions, including Ethiopia (Belay et al., 2019) [2]. Climate change further exacerbates water scarcity issues, leading to droughts, moisture stress, and inadequate water management practices that strain water resources and hinder crop productivity (Tewabe et al., 2020). Insufficient water availability for irrigation results in low crop yields, conflicts over water allocation, and challenges in sustaining agricultural productivity (Dirirsa et al., 2017) [3]. Currently irrigated agriculture takes place under water scarcity and insufficient water supply for irrigation due to these crop productivity is low are (Kifle and Gebretsadikan, 2016). Enhancing water productivity (WP) and water savings are a major challenge for sustainable crop production in irrigated agricultural (Mubarak and Hamdan, 2018). In the context of Ethiopia, traditional irrigation systems dominate crop production, resulting in low water and crop productivity levels (Hordofa et al., 2008). Poor irrigation water management practices further compromise the sustainability of crop production, leading to crop failures, water disputes, and reduced household incomes. To address these challenges, innovative water-saving technologies and efficient irrigation strategies are essential for enhancing water productivity and ensuring sustainable crop production (Al-ghobari & Dewidar, 2017; Chai et al., 2016; Mashnik et al., 2017; Hashem et al., 2018) [4]. Therefore, deficit irrigation and conservation agriculture practices emerge as critical strategies to optimize water use efficiency and enhance crop productivity in water-limited regions [5].

Deficit irrigation (DI) represents a water-saving strategy that aims to maximize net returns by reducing irrigation water without compromising crop yields (Capra and Consoli, 2015). By implementing water-saving techniques like DI, water productivity can be improved, leading to enhanced overall yields (Asmamaw, et al., 2021; Hashem et al., 2018; Ismail, 2010). Conservation agriculture practices, such as mulching, have proven effective in boosting water and crop productivity while reducing production costs (Erkossa et al., 2018; Adimassu et al., 2017). Mulching, in particular, plays a crucial role in improving water and crop productivity under deficit irrigation conditions (Rop et al., 2016). Evaluating various water-saving techniques, including deficit

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irrigation and mulching, is essential for enhancing water productivity and crop yields in water-limited environments (Khan et al., 2015) [6,7].

Combining mulching with optimal deficit irrigation practices offers a promising approach to increasing crop yields and water productivity in water-scarce regions (Wen et al., 2017). Previous studies have demonstrated the positive effects of deficit irrigation combined with mulching on crop productivity (Razaq et al., 2019; Biswas et al., 2017). The objective of this study is to assess the impact of different mulch types and deficit irrigation practices on water and crop productivity in tomato production in the Ethiopian highlands [8].

Tomatoes are a vital crop in Ethiopia, contributing significantly to the country's agricultural sector and economy. In the Fogera region specifically, tomato production plays a crucial role in providing livelihoods for farmers and meeting the local demand for fresh produce. However, tomato cultivation in Fogera faces various challenges, with water scarcity being a major concern. The erratic rainfall patterns and limited access to irrigation water pose significant obstacles to sustainable tomato farming in the region [9]. In light of these challenges, the adoption of efficient water management practices is essential to enhance tomato yield and water productivity in Fogera. Deficit irrigation, which involves supplying water to crops below their full water requirements, can help optimize water use efficiency and mitigate the impact of water scarcity on tomato production. Similarly, the use of mulching, such as plastic or organic materials, can aid in conserving soil moisture, suppressing weed growth, and regulating soil temperature, thereby improving crop yields in water-limited environments. This study aims to fill the gap in knowledge regarding the optimal water management strategies for tomato production in this region, considering factors such as water scarcity, climate variability, and sustainable agricultural practices. Therefore, this research aims to address the research gap in understanding how deficit irrigation and mulching impact tomato yield and water productivity in the specific context of Fogera, Ethiopia [10]. By investigating the effects of these practices on tomato crops, the study seeks to provide valuable insights into sustainable water management strategies for farmers in the region and to contribute to the development of tailored recommendations and interventions to support tomato farmers in Fogera in achieving higher yields and improved water productivity and promoting sustainable agricultural practices [11].

Materials and Methods

Study area description

The field experiment was conducted at the Fogera National Rice Research and Training Center (FNRRTC) experimental site [12]. It is located at 11°19′ N and 37°03′ E at an altitude of 1815 m.a.s.l during the 2020/21 irrigation season. Fogera is found in the South Gonder Zone of the Amhara regional state (figur1). Which is found at a distance of 657 km from Addis Ababa and 57km from Bahir Dar. It is predominantly classified as woinadega agro-ecology (ILRI, 2005). The climatic data of the experimental site, which is situated in the middle of Fogera Plain, show that the mean annual minimum, maximum and mean temperatures of the area are 14.0°C, 27.7°C, and 20.8°C, respectively. Rainfall in the area is uni-modal, usually occurring from June to October, and its mean annual rainfall is 1216.3mm and ranges from 1103 to 1336mm (Aleminew et al., 2019). The land in Fogera shows that 44.2% is arable and another 20% is irrigated, 22.9% is used for pasture, 1.8% has shrubland, 3.7% is covered with water, and the remaining 7.4% is considered degraded or other (System, 2006). The dominant soil type in the Fogera is black clay soil (ferric vertisols), while the mid and high-altitude areas are predominantly orthic Luvisols (Figure 1) [13,14].

Experimental design and layout

Two main factors were considered: the first factor was mulch types and the second factor was deficit irrigation level based on crop water requirement (ETc) and each factor had three levels. Three levels of deficit irrigation are; 100%ETc, 75%ETc, and 50%ETc while three mulch types: No Mulch (NM), Rice Straw Mulch (RSM), and White Plastic Mulch (WPM) were evaluated. The non-deficit and non-mulch treatments were used as controls. The application of rice straw mulch at the rate of 6tha−1, while 25 micron thickness was used for white plastic mulch. A factorial combination of three levels of deficit irrigation and three mulch types was evaluated in a randomized complete block design (RCBD) with three replications and treatments were randomly assigned (by chance) to the experimental block. The field experiment has a total of nice treatment combinations and 27 plots [15]. The plot size was 4.2m × 4m=16.8m2 area. To minimize the influence of the lateral flow of water into the plots, the block distance should be sufficient. Then, the distance between blocks and plots was 3m and 2m receptively. In this experiment, the furrow irrigation method was used (Table 1) [16].

Agronomic practices of the experimental

Tomato Roma VF variety seeds were used as seed material. The nursery bed was prepared and the seed was sown on 01 December 2020 for tomato. Watering, weeding, fertilizer, chemical spray, and other agronomic activities were applied in the nursery. The seedling was transplanted to experimental plots on 01 January 2021 tomato. Furrow spacing and plant space were done according to the agronomic recommendation of the area. This was done with the spacing between rows being 1m for tomato while the plant spacing being 30cm transplanted was done. Each plot has four single planting rows for tomatoes, each row accommodating about 14 plants for tomato [17].

Each experimental plot was fertilized with one application of NPSB during transplanting only and a split application of urea at transplant and 30 days after transplanting as top dressing with the agronomic recommendation rate NPSB and urea for tomato [18]. Chemical spray was applied to prevent the experiment from disease and pests. Each experimental plot was equally treated with fertilizer rate, chemicals, and weed. For all treatments without treatment variation, one common irrigation was applied at a depth of 25.5 mm for tomatoes based on irrigation scheduling to ensure good seedlings establishment. All

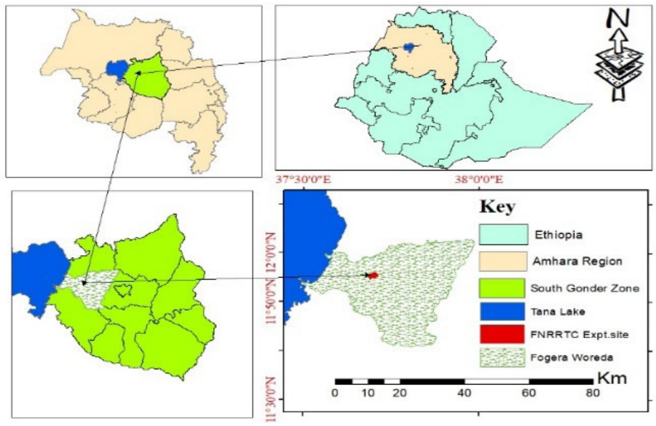

Figure 1: Map of the study area.

Table 1: Treatment combinations.

Factors		
Mulching type	**deficit irrigation**	**Treatment combination**
No Mulch (NM)	100%ETc (0%DI)	100%ETC with NM
		75%ETC with NM
		50%ETC with NM
		100%ETC with RSM
Rice Straw Mulch (SM)	75%ETc (25%DI)	75%ETC with RSM
		50%ETC with RSM
		100%ETc with WPM
Plastic Mulch (PM)	50%ETc (50%DI)	75%ETC with WPM
		50%ETC with WPM

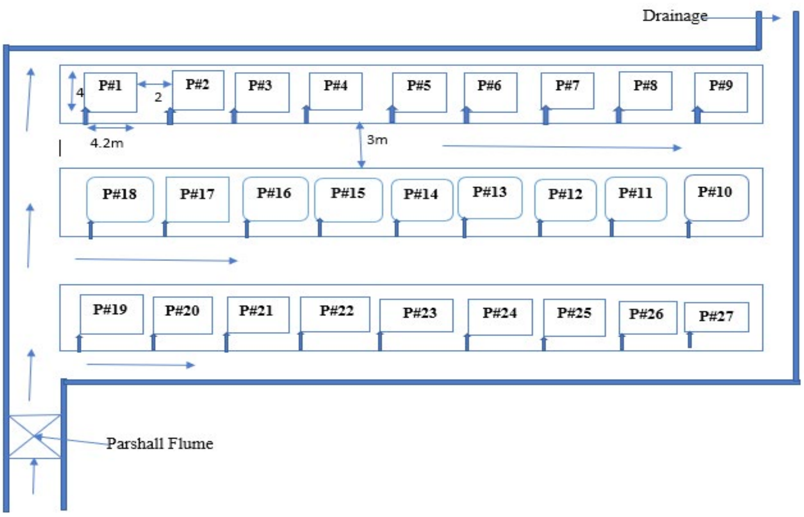

Figure 2: The experimental layout.

Table 2: Agronomic management of tomatoes throughout the growing period.

Crop	Management activities	Date	Methods and tools
	Nursery and seedling	1-Dec-20	Water can
Tomatoes	wedding of the seedlings	15-Jan-21	Handpick
(Roma VF)	Fertilizer application for nursing	15-Jan-21	Hand
	Tillage	10-20 December 2020	Draught animal
	Planting and fertigation	1-Jan-21	manual
	Irrigation	01 January – 18 April	Furrow irrigation
	Weeding	15-Jan-21	Sickle
	Mulch application	15-Jan-21	Manual
	Harvesting	01-30 April 2021	Hand

treatments were weeded only once before mulch was applied. Fifteen days after transplanting, treatments were started because seedings were started root development and were well performed. All treatments were irrigated on the same day because the only difference was the depth of water based on deficit levels. The harvesting time of tomato five harvesting times were done and tomato yield was weighed from each plot during harvest and converted to t/ha (Figure 2) (Table 2) [19-23].

Soil sampling and analysis

Soil samples were collected before crops were planted. Five soil depths were sampled from the top to the respective root depth (0-20, 20-40, 40-60, 60-90, and 90-120cm) using a soil auger at three locations at the representative site of the experiment. Composite samples were made by mixing five sub-samples from the same treatment and depth. About 1 kg of soil was used to determine the physical and chemical properties such as soil textural class, field capacity (FC) and permanent wilting point (PWP), soil pH, and EC analysis at the Amhara Design and Supervisory Works Enterprise. Whereas the soil bulk density was determined from undisturbed soil samples using a cylinder, a drop-hammer core sampler with a size 5 cm in diameter and 5 cm in height was driven into the soil with a hammer [24]. The core sampler was driven to 20 cm depth for the upper 0–20 cm soil layer and to 40 cm depth for the next 20 cm layer. The cylinder containing an undisturbed soil core was removed and trimmed. The weight of the soil core was determined after drying it in an oven at 105 °C for 24 hours. The mass of the soil per volume determined the bulk density (Terzaghi et al., 1996). Soil samples were air-dried, sieved by a 2 mm sieve, and analyzed using standard laboratory procedures. The major soil properties included pH (H2O), electrical conductivity, exchangeable Na, K, Ca, Mg, CEC, and Exchangeable Na %(ESP) was determined using ammonium acetate. The soil textural class analysis of clay, silt, and sand was determined using the hydrometer method [25]. The pH meter was standardized with 4.0 and 9.2 pH buffer solutions and accordingly, the pH of the sampled soil was measured. For soil electrical conductivity determination, an extract was obtained from the saturated soil paste with the help of a vacuum pump. Then with the help of the digital electrical conductivity meter, ECe was measured. The pH and EC of water were also measured for irrigation water quality. Field capacity and permanent wilting points were determined in the laboratory using pressure-plate apparatus by applying 1/3 bars pressure to a saturated soil sample for field capacity and applying 15 bars pressure to determine the permanent wilting point. The soil moisture was determined gravimetrically [26].

Determination of crop water requirement

Monthly ETo was computed using CROPWAT model version 8.0 with the Penman-Monteith method based on the 28-year long-term climate data (Tmax. Tmin, RH, Sh, and U) collected from the West Amhara National Metrology Agency in Bahir Dar for onions and tomatoes during the growing season. Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (ETo*Kc) (Allen, 2006) [27]. The crop coefficient was used for the growth stages of the onion and tomato crop for the experimental years explained. Irrigation water to be applied to the tomato was determined based on the allowable constant soil moisture depletion fraction (p = 0.4) of the total available soil water (TAW), where TAW was determined from the permanent wilting point, field capacity, root depth, and bulk density variables [28]. The depth of water applied during each irrigation event was the net irrigation requirement estimated by the Penman-Monteith method using the long-term climate data. Considering conveyance and other losses for a surface furrow irrigation system, an application efficiency of 60% was assumed (Chandrasekaran et al., 2010). Successive irrigation depth was applied based on the readily allowable water for the root depth on that day. The different amount of water was applied with different irrigation scheduling. Because the amount of water applied to the crop depends on the crop growth stage and the monthly weather conditions [29]. The daily crop evapotranspiration was deducted from the net irrigation depth for the control treatment (100% ETc) until the cumulative subtraction from the net irrigation depth applied approached zero. Further irrigation was applied when the cumulative ETC approach to net irrigation depth was applied to control treatment and applied to stress treatments based on their proportion to non-stressed treatment. The effective root depth for mid-season and the late season was taken as a constant 1.1m for tomato. During the experiment, there was no rainfall, and all the water required by crops had to be supplied by irrigation, due to this, the net irrigation requirement and the readily available water were equal. The gross irrigation was calculated based on application efficiency and readily available water (FRENKEN, 2002). Once the amount of water that needs to be given during one irrigation application is estimated and applied, then the next determines the irrigation interval by dividing the net irrigation depth (mm) by daily crop water requirement (mm/day) (Table 3) [30-33].

The predetermined amount of irrigation water for each plot was measured using a 3-inch standard Parshall flume. The required amount of irrigation water was applied to each experimental plot based on the deficit level of the treatment. The volume of water applied for all treatments was determined from the plot area and depth of irrigation requirement. The time required to irrigate each plot was measured from the ratio of the volume of applied water to the discharge-head relation of the 3-inch Parshall flume. The time required to deliver the desired depth of water into each furrow was calculated using the below equation 2.1 the help stopwatch (Geremew et al., 2008).

$$T = (A*d)/6q \quad (2.1)$$

Where A = (irrigated area) in m^2 d = irrigation depth in cm T = (time) in min. q = (Parshall flume discharge) in l/s

Agronomic data collection

Marketable yield

The experimental data on the fruit yield of tomato in each experimental plot was harvested and the yield obtained after picking the tomato fruit. Marketable yield (kg/ha) was measured for healthy

Table 3: Long-term (from 1990 to 2017) means climate data.

Month	RF (mm)	Tmin. °c	Tmax. °c	RH %	Ws (U) m/s	sunshine (hr)	ETo mm/day
Jan	0	11	27	49.5	0.66	9.5	3.6
Feb	0	12.2	28.7	44.4	0.74	9.65	4.15
Mar	0.3	13.7	29.9	42.4	0.91	9.06	4.67
Apr	3	14.1	30.3	42.6	1.01	9.03	4.97
May	16.2	14.3	29.4	53.6	0.94	8.31	4.64
Jun	121.7	13.7	27.5	66.7	0.93	6.99	4.08
Jul	314.2	13.7	24.3	76.1	0.76	4.65	3.25
Aug	274.4	13.8	24.6	78.1	0.72	4.58	3.22
Sep	144	13.2	25.7	72.8	0.72	6.45	3.65
Oct	37.9	12.8	26.7	64.3	0.73	8.55	3.93
Nov	0.9	11.4	26.9	57	0.68	9.45	3.72
Dec	0	10.9	26.7	53.8	0.62	9.81	3.5

Table 4. Tomato parameters used for crop water estimation.

Growth stage					
	Initial	Development	Mid	Late	Total
Tomato					
Depletion fraction (P)	0.4	0.4	0.4	0.4	
Crop Coefficient (Kc)	0.5	0.8	1.1	0.8	
Growth stage (days)	15	30	35	40	120
Source: Allen et al., (1998)					

Table 5: Results of physical properties of soil of the experimental site.

Soil depth (cm)	FC (%)	PWP (%)	Bulk density (gm/cm^3)	Textural status (%)			Textural class	TAW
	(0.33 bar)	(15 bars.)		sand	Silt	clay		(mm)
0-20	35.1	21.5	1.22	13	22	65	heavy clay	33.18
20-40	35.6	22.3	1.24	21	16	63	heavy clay	32.98
40-60	37.5	23.6	1.31	19	18	63	heavy clay	36.428
60-90	37.8	24.8	1.28	21	16	63	heavy clay	49.92
90-120	38.6	25.7	1.33	19	16	65	heavy clay	51.858
Total available water (TAW)				204mm/1.2m=170mm/m				

Table 6: Analysis of chemical properties of soil and water.

Soil depth (cm)	0-20cm	20-40cm	40-60cm
pH-H2O (1:2:5)	5.38	5.73	6.17
EC (mS/cm)	0.1	0.1	0.1
Exch. Na (meq. /100gm of soil)	1.25	2.23	1.07
Exch. K (meq. /100gm of soil)	0.26	0.34	0.31
Exch. Ca (meq. /100gm of soil)	30.1	37.09	26.66
Exch. Mg (meq. /100gm of soil)	9.58	15.62	7.62
CEC (meq. /100gm of soil)	42.13	55.7	48.12
Sum of cations (meq. /100gm of soil)	41.18	55.27	35.65
Exchangeable Na %(ESP)	2.96	4	2.22
PH of water	7.28		
EC (dS/m) of water	0.24		

and non-diseased, non- rotten, tomato fruit recorded from the sampled plant. Marketable bulb yield was expressed as kg per plot [34]. Finally, the yield obtained from the sample area was converted to per hectare using equation 2.2 (Demisie and Tolessa, 2018).

$$\text{Tomato yield}\left(\frac{kg}{ha}\right)=\frac{\text{weight of sample yield(kg)}}{\text{Net harvested area(m2)}}*10000\text{m2} \quad (2.2)$$

Water productivity was determined based on the ratio of the yield of tomato (yield per hectare) to the amount of water used from the establishment to harvest expressed as kg of yield per m3 of water. It was calculated based on the formula using equation 2.3.

$$WP=\frac{Ya}{ETa} \quad (2.3)$$

Where: WP -Water productivity (kg/m3) Ya-Actual yield (kg/ha) ETa -Seasonal applied amount of water (m3 /ha)

The crop yield response factor (Ky) was determined from the experimental data. The yield response factor (Ky) was one of the important parameters that indicated whether moisture stress due to deficit irrigation was advantageous or not in terms of enhancing water productivity. The yield response factor relates relative yield reduction to the corresponding relative deficit in evapotranspiration (ETc). It was an indication of the response of yield to water use reduction. The yield response factor was determined based on the ratio of relative yield decrease to relative evapotranspiration deficit expressed in decimals, using equation 2.4 (Smith et al., 2002) [35].

$$\left(1-\frac{Ya}{ym}\right)=\text{ky}*(1-\frac{ETa}{ETm} \quad (2.4)$$

Where: Ya = actual harvested yield in kg/ha, Ym = maximum harvested yield in kg/ha, ky = yield response factor, ETa = actual evapotranspiration in mm/growing period, and ETm = maximum evapotranspiration in mm/growing period.

Statistical analyses

The collected data were statistically analyzed using statistical software in the procedure of a general linear for the variance analysis model. Analyses of variance (ANOVA) were used for the yield and water productivity of tomatoes. All data collected were managed and compared with Least Square of Differences (LSD) and when the effect of the treatments was found significant, mean comparisons were tested using the Tukey test at 5% probability. Results of growth, yields, and yield component parameters were analyzed using the statistix computer package version 10 [36].

Results and Discussions

Soil and water analysis

The soil texture laboratory analysis results showed that the average proportion of sand, silt, and clay percentages were 18.6, 17.6, and 63.8, respectively. Thus, according to the USDA soil textural classification, the soil textural class of the experimental site was heavy clay soil. The result of soil bulk density (BD) in the experimental field has a slight variation in its depth [37]. The BD of the experimental site varied from 1.22 g/cm3 in the upper soil (0-20 cm) to 1.33 g/cm3 in the lower soil layer (90-120 cm). The average bulk density of the experimental site was 1.28 g/cm3. The BD of 1.2 g/cc may be expected for clay soil but it can vary from around 1.0-1.4 g/cc (Hazelton & Murphy, 2019). The soil moisture content on the weight base at FC showed varying variation within depths of 0-20, 20-40, 40-60, 60-90 and 90-120 cm were 35.1, 35.6, 37.5,37.8 and 38.6 %, respectively. Whereas the soil moisture content on weight base at PWP also showed a vary within depths of 0-20, 20-40,40-60,60-90 and 90-120 cm were 21.5, 22.3, 23.6,24.8, and 25.7%, respectively. The average moisture content on the weight base at FC (1/3 bar) and PWP (15 bar) were 36.92% and 23.58%, respectively [38]. The total available water (TAW) which was the amount of water that a crop can extract from its root zone was directly related to variations in FC and PWP. Based on the laboratory results of ADSW the experimental TAW also showed a variation within depths of 0-20, 20-40,40-60,60-90 and 90-120 cm were 33.2, 33.0, 36.4,49.9, and 51.9mm, respectively. The volumetric TAW of the experimental site was 170mm/m. The analysis of applied irrigation water showed that a pH value of 7.28 and ECw value of 0.24 dS/m was obtained (Table 5,6) [39].

Crop water requirement of tomato

The total irrigation water applied to tomato crops was 438.5 mm for non-stressed treatment (100%ETc) respectively. The result was in agreement with Doorenbos and Kassam (1986) who reported that the seasonal crop water requirement of tomato ranges from 400-600 respectively using furrow irrigation. All treatments were irrigated on the same day because the only difference was the depth of water on deficit levels (Table 7) [40].

The effects of deficit irrigation on yield and water productivity of tomato

The effects of deficit irrigation on yield components of tomato

Deficit irrigation had no significant effect on the fruit diameter and

Table 7: Seasonal irrigation water applied to the tomato.

Treatments	Total CWR, (mm)	Total IWR (mm)
100%ETc	438.5	438.5
75%ETc	335.3	335.3
50%ETc	232	232

Table 8: The effects of deficit irrigation on yield components of tomato.

Deficit level	Fruit diameter (cm)	Fruit length (cm)
100%ETc	3.60^a	5.8^a
75%ETc	3.63^a	5.78^a
50%ETc	3.58^a	5.7^a
LSD (0.05)	NS	NS
C.V	1.9	1.8

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance. ** =significant at P < 0.01

fruit length of tomatoes ($p < 0.05$). Fruit diameter and fruit length were not significantly affected by deficit level. Even with a minimal amount of water, we can get reasonable growth and yield components. However, the maximum fruit diameter and fruit length (3.63 and 5.8cm) were recorded from 75%ETc and control (100%ETc) respectively. On the other hand, the minimum fruit diameter and fruit lengths were 3.58 and 5.7cm recorded in the application of 50%ETc respectively. According to Berihun, (2011), amount of water applied did not have a significant effect on the growth and yield components of tomatoes. These results are consistent with the findings of Shahein et al., (2012) who reported that water stress for the whole growing season does not significantly affect fruit length and diameter compared to fully irrigated treatment. A similar result was also reported by Selamawit Bekele, (2017) who reported that deficit levels had no significant effect on growth and yield components. No significant difference in fruit diameter was observed under full irrigation and 70%ETc (Randhe et al., 2019) (Table 8) [41].

The effects of deficit irrigation on yields and water productivity of tomato

The analysis of variance (ANOVA) results showed that the marketable yield of tomato was significantly ($p < 0.05$) affected by irrigation levels. the highest and the lowest marketable yield of tomato (37.7t/ha) and (29.5t/ha) were obtained from the 75%ETc and 50%ETc respectively. This shows that the marketable yield of tomato in 75%ETc was 27.8% higher than 50%ETc and 4.1% higher than 100%ETc, i.e., 75%ETc could save 25% of water without affecting yield. This result is consistent with the suggestion of Biswas et al., (2015) reported that the yield of tomatoes with the increasing amount of irrigation water. The trend was reversed when irrigation was coupled with mulches there was a decrease in tomato yield with the increase in irrigation regime. This result was in line with Audu et al., (2020) who reported that the high tomato yield was obtained at 80%ETc than 100ETc. A similar result was also Randhe et al, (2019) stated that, the yield of tomatoes was higher under 70%ETc than full irrigation. For tomatoes production applying 85% and 70% of ETc was recommended with a minimum reduction of yield (Kifle, 2018). This result was also in line with Ya-dan et al., (2017) reported that tomato yield increased with the amount of applied irrigation water at 75%ETc and then decreased at 100%ETc [42].

Similarly, the highest WP of tomato 12.7 and 11.2kg/m3 was obtained from 50%ETc and 75%ETc respectively while the lowest WP 8.3kg/m3 was obtained from 100%ETc. This shows that the WP of tomato in 50%ETc was 13.4% higher than 75%ETc and 53.0 % higher than 100%ETc. This shows that WP in 100%ETc was lower than 50% and 75%ETc. The 100%ETc had a significant difference on WP from all other deficit treatments. This was because the amount of water applied in the full irrigation treatment was significantly higher than in the deficit treatment. WP for tomato was increased in deficit treatment compared to non-stressed treatment. This result was in line with Guangcheng et al., (2017) who stated that DI significantly increased the WP compared to the full irrigation regime. A similar result was also reported by Ragab et al., (2019) that DI improved WP for tomatoes. This result was also in line with Selamawit Bekele, (2017) reporting that the maximum WP was recorded from 50%ETc and the minimum was recorded at 100%ETc. The highest WP of tomato was found at 50%ETc, while 100%ETc showed the least WP (Asmamaw et al., 2021). The highest WP of tomatoes was obtained in 50%ETc (Ya-dan et al., 2017). The highest WP was observed at 60%ETc while the lowest was observed at 100%ETc (Sang et al., 2020) (Table 9) [43].

The effects of mulch types on yield and water productivity of tomato

The effects of mulch on yield components of tomato

The analysis of variance showed that the fruit diameter of tomato was significantly affected by the main effects of mulch type ($p < 0.05$), while the fruit length of tomato was not significantly affected by the mulch type. The highest fruit diameter was obtained from rice straw mulch 3.66cm and plastic mulch 3.60cm while the lowest fruit diameter was obtained from no mulched treatment 3.56cm. Whereas the fruit length of tomato was not significantly different among treatments. This result agreed with the results of Karaer et al., (2020) who stated fruit diameter was found to be higher in mulch applications [44]. This result agreed with the results of Goel et al., (2020) reported that the trend of the favorable effect produced by mulches on growth parameters was rice straw mulch higher than no mulch. The application of different mulch types had no significant effect on the growth and yield parameters of tomatoes (Mn et al., 2017) (Table 10) [45].

Table 9: The effects of deficit irrigation on yield and water productivity of tomato.

Deficit level	Yield of tomato (t/ha)	Water productivity of tomato (kg/m^3)
100%ETc	36.2^b	8.3^c
75%ETc	37.7^a	11.2^b
50%ETc	29.5^c	12.7^a
LSD (0.05)	1.1	0.3
P	**	**
C.V	2.6	2.7

Where, LSD = Least Significant Difference at 5% level; CV =Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01

Table 10: The effects of mulch type on fruit diameter and length of tomato.

Mulch types	Fruit diameter (cm)	Fruit length (cm)
No mulch	3.56^b	5.76^a
Rice straw mulch	3.66^a	5.79^a
Plastic mulch	3.60^{ab}	5.77^a
LSD (0.05)	0.08	NS
P	*	
C.V	1.9	1.8

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01

The effects of mulch types on yields and water productivity of tomato

The analysis of variance showed that the marketable yield of onion and tomato was significantly affected by mulch type at ($p < 0.01$). The marketable yield of tomatoes was 36.9, 35.1, and 31.1 t/ha, respectively, in RSM, WPM, and NM treatments. This implies that the marketable yield in RSM was 17.1% higher than NM and 5.1% higher than WPM treatment. The result indicated that mulch application significantly improves the yield of the tomato. This result was in line with the results of Audu et al., (2020) reported that the yields of tomatoes obtained from RSM were higher than the yield obtained from WPM. The results were also consistent with the findings reported in Goel et al., (2020) that increase in tomato yield with mulches RSM was 25.6% as compared to NM. RSM increased the fruit yield of tomatoes (Pandey & Mishra, 2012). These results agree with Robel Admasu and Zelalem Tamiru, (2019) who reported that the maximum marketable yield was obtained due to plastic mulch than no mulch for tomatoes. The application of straw mulch is found to be economically and agronomically feasible (Berihun, 2011). The application of mulch types significantly influences tomato fruit yield (Tegen et al., 2016). Crop yield significantly increased with the application of rice straw mulch (Dossou-yovo et al., 2016). These results suggest that straw mulching has great potential for improving onion yield (Tao et al., 2015) [46].

Similarly, the WP of tomatoes was 11.4, 11.0, and 9.8 kg/m3 in RSM, WPM, and NM treatments, respectively. It implies that the WP in the RSM treatment was 16.3% higher than NM and 3.6% higher than the WPM treatment. The results indicated that mulching applications significantly improve the WP of the tomato. This result was in line with the results of Goel et al., (2020) who reported that RSM increased WP by 26.6 % over no mulch. The results were also consistent with the findings reported in tomato Robel Admasu and Zelalem Tamiru, (2019) that the maximum WP was obtained due to PM than NM for tomatoes. The result indicated that mulching was one of the important water management strategies used to improve WP. This result showed that straw mulch increased WP and decreased evapotranspiration (Table 11) [47].

The interaction effects of deficit irrigation and mulch types on yield and water productivity of tomato

The effects of deficit irrigation and mulch on yield components of tomato

The analysis of variance showed that the fruit diameter and fruit length of tomatoes were not significantly affected by the interaction effects of deficit irrigation and mulch types ($p < 0.01$). There was no significant difference was observed between treatments in fruit diameter and fruit length of tomato at all deficit irrigation and mulch types. Even we applied a minimum amount of water to get a reasonable fruit size tomato. This may be due to the canopy covers of tomato used as a mulch. This result agreed that the results of Kere et al., (2003) the yield attributes of tomato were not significantly affected by either irrigation amount and mulch type. According to Berihun, (2011), the interaction effect of the amount of water and mulch was not significant in fruit length and fruit diameter. According to Aliabadi et al., (2019) the interaction effect of mulch and the amount of water on fruit length and diameter was not significant. A similar result was also reported by Selamawit Bekele, (2017) who reported that deficit levels have no significant effect on plant and fruit height. No significant difference in fruit diameter was observed under full irrigation and 70%ETc (Randhe et al., 2019) (Table 12) [48].

Table 11: The effects of mulch type on marketable yield tomato.

Mulch types	Yield of tomato (t/ha)	water productivity of tomato (kg/m³)
No mulch	31.5[c]	9.8[c]
Rice straw mulch	36.9[a]	11.4[a]
Plastic mulch	35.1[b]	11.0[b]
C.V	2.6	2.6
P level	**	**
LSD (0.05)	1.1	0.3

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01

Combine effects of mulch and deficit irrigation on yields and water productivity of tomato

The ANOVA results showed that the marketable yield of tomato was significantly affected by the interaction effects of deficit irrigation and mulch types at ($p < 0.05$). The highest marketable yield of tomato (41.7t/ha and 38.6 t/ha) was achieved from 75%ETc and 100%ETc with RSM treatments, respectively. However, no significant yield difference was observed between 75%ETc with WPM and 100%ETc with RSM treatment combinations. The lowest marketable yield obtained from 50%ETc with NM treatment was 26.6t/ha. The marketable yield of tomato was 41.7, 38.6, and 38.0, t/ha, respectively, in 75% and 100%ETc with RSM, and 75%ETc with WPM treatment combinations. This implies that the marketable yield of tomato in 75%ETc with RSM was 8.0% higher than 100%ETc with RSM and 9.7% higher than 75%ETc with WPM treatment combinations. This result showed that RSM and WPM increased the yield of tomatoes by 21.2% and 10.5% compared with the NM treatment. These results also showed that there was no yield advantage observed using 100ETc with NM. RSM improves the yield of tomatoes compared to WPM and NM treatments. All the deficit treatments with mulch resulted in significantly higher yields than un-mulched irrigation-level treatments. The yield of tomatoes increased with the increase in water supply without mulch. The effect was reversed when the irrigation level was coupled with either plastic or straw mulch; there was a decrease in tomato yield with the increase in the irrigation regime. Irrigation at the same level without mulch produced the lowest yield. However, 100%ETc irrigation supply produced a lower yield than 75%ETc when mulched with plastic and mulched with straw. This may be due to excessive watering that has

Table 12: The interaction effects of mulch and deficit on yield components of tomato.

Treatments	Fruit diameter (cm)	Fruit length (cm)
100% ETc´NM	3.56[a]	5.83[a]
75% ETc´NM	3.55[a]	5.75[a]
50% ETc´NM	3.55[a]	5.71[a]
100% ETc´SM	3.68[a]	5.78[a]
75% ETc´SM	3.69[a]	5.82[a]
50% ETc´SM	3.60[a]	5.76[a]
100% ETc´PM	3.57[a]	5.79[a]
75% ETc´PM	3.66[a]	5.77[a]
50% ETc´PM	3.58[a]	5.74[a]
C.V	1.9	1.8
LSD (0.05)	NS	NS

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01 and NS =non-significant been shown to increase flower drops and reduce fruit set. Also, this may cause excessive vegetative growth and a delay in ripening. The water supply during and after the fruit set must be limited to a rate that will prevent the stimulation of new growth at the expense of fruit development (Doorenbos and Kassam, 1979). This result is in line with the findings of Audu et al., (2020) recommended that tomato producers adopt water application at 80%ETc and use RSM. These results were also consistent with the findings of Biswas et al., (2015) reported that with 100%ETc water application, the plastic-mulched treatment produced a lower yield than the straw-mulched treatment. The maximum marketable yield of tomatoes was observed at 80%ETc with mulch (Alebachew, 2017). The maximum fruit yield was recorded from the plants receiving deficit irrigation at 80%ETc with a straw mulching treatment combination (Samui et al., 2020). The best level of irrigation for tomato crops is 80%ETc and this corresponds to mulching practice of rice straw mulch (Zakari et al., 2020) [49].

Similarly, the highest WP of tomatoes (13.59 and 13.08 kg/m3) was achieved from 50%ETc with WPM and with RSM respectively . There was no significant difference observed between 50%ETc with WPM and with RSM treatment combinations. The lowest WP was obtained from 100%ETc with no mulch. However, there were no significant differences observed between in WP of 100%ETc with NM and 100%ETc with WPM treatment combinations. The WP of tomatoes was 13.59, 13.08, and 12.44, kg/m3, respectively, at 50%ETc with WPM, RSM, and 75%ETc with RSM treatment combinations. This implies that WP in 50%ETc with WPM was 3.2% higher than 50%ETc with RSM and 8.5% higher than 75%ETc with RSM treatment combinations. These results showed that RSM and WPM combined with DI improved tomato WP without yield penalty. At an irrigation level of 50%ETc, irrigated tomato plots mulched with WPM produced better WP than that of NM and NM treatment. The NM treatment remained always behind the mulched treatment. At a high irrigation level of 100%ETc, all mulched and un-mulched treatments performed almost similarly to produce WP. Mulches reduced the rate of water loss through evaporation from the soil surface. So, the soil-water-plant relationship was better in a low irrigation level than in a high irrigation level which might help produce higher WP. These results were consistent with the findings of, Biswas et al., (2015) reported that the higher WP were obtained from mulch treatments with a 50%ETc. This result is in line with the findings of Goel et al., (2020) who explained that mulching increased irrigation water use efficiency by 26.6 % in rice straw mulch over no mulch. The tomato WP under the interactive effect of deficit irrigation and mulch was determined to be highest at 60%ETc with mulch and lowest at 100%ETc (Sang et al., 2020) (Table 13).

Table 13: The interaction effects of mulch and deficit on marketable yield tomato (t/ha).

Treatments	Marketable Yield of tomato (t/ha)	Water Productivity of tomato (kg/m^3)
100% ETc´NM	34.4^{d}	7.84^{f}
75% ETc´NM	33.4^{de}	9.97^{d}
50% ETc´NM	26.6^{g}	11.45^{c}
100% ETc´SM	38.6^{b}	8.81^{e}
75% ETc´SM	41.7^{a}	12.44^{b}
50% ETc´SM	30.3^{f}	13.08^{ab}
100% ETc´PM	35.6^{cd}	8.12^{ef}
75% ETc´PM	38.0^{bc}	11.34^{c}
50% ETc´PM	31.5^{ef}	13.59^{a}
C.V	2.6	2.6
P level	**	**
LSD (0.05)	2.6	0.5

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance. ** =significant at P < 0.01

Table 14: Effect of mulch type and deficit irrigation levels on tomato yield response factor.

Treatment	Yield (kg/ha)	ETa	$\frac{ETa}{ETm}$	$\frac{Ya}{Ym}$	$1-\frac{Y_a}{Y_m}$	$1-\frac{ET_a}{ET_m}$	$K_Y = \frac{1-(Y_a/Y_m)}{1-(ET_a/ET_m)}$
100%ETC´ NM	34375	438.5	1	0.8	0.2	0	-
75%ETC ´ NM	32097	335.3	0.8	0.8	0.2	0.2	1
50%ETC ´ NM	26563	232	0.5	0.6	0.4	0.5	0.7
100%ETC ´ SM	38646	438.5	1	0.9	0.1	0	-
75%ETC ´ SM	41701	335.3	0.8	1	0	0.2	0
50%ETC ´ SM	30347	232	0.5	0.7	0.3	0.5	0.5
100%ETC ´ PM	35625	438.5	1	0.9	0.1	0	-
75%ETC ´ PM	38021	335.3	0.8	0.9	0.1	0.2	0.4
50%ETC ´ PM	31528	232	0.5	0.8	0.2	0.5	0.5

The effect of mulch and deficit irrigation on yield response factor

The study revealed that a lower yield response factor (ky) of 0.0 was achieved from 75%ETc with RSM for tomato. The result indicated that the ky was associated with deficit level and mulch types. At 100%ETc were no recorded yield response factors . Because the actual amount of water applied at 100%ETc was similar to ETm, the result was one. In this study, the Ky of the tomato crop under no mulch condition was 1.0. The Ky values of the no mulch treatment were higher than the mulched treatment which implies that the proportional decrease in yield under the no mulch condition was much higher than in the mulched condition. Ky, which indicates the level of tolerance of a crop to water stress, approaching unity when yield declines proportionally to ET deficit (the greater Ky the lower the tolerance), was higher in no mulch compared to mulched treatment. This reveals a greater tolerance of this mulched treatment to water shortage. In this respect, Ky may be a valuable tool for water deficit tolerance and, thus, for deficit irrigation adaptability evaluation in tomato and onion production. Results among the treatments showed as the deficit increased, the sensitivity of yield increased (Table 14) [50].

Conclusion and Recommendations

Conclusion

Water scarcity is the main challenge in current sub-Saharan African countries including Ethiopia. To mitigate those challenge on farm water water-saving strategies should be implemented to increase yield and water productivity. The marketable yield of tomato in 75%ETc was 27.8% higher than 50%ETc and 4.1% higher than 100%ETc treatment. While the IWUE in 50%ETc treatment was 13.4% higher than 75%ETc and 53.0% higher than 100%ETc treatment. The marketable yield of tomato in RSM was 17.1% higher than in NM and 5.1% higher than WPM treatment while the IWUE of tomato in RSM was 16.3% higher than in NM and 3.6% higher than in the WPM treatment. In the combination effects of mulch and deficit irrigation, the marketable yield of tomatoes in 75%ETc with RSM was 8.0% higher than 100%ETc with RSM and 9.7% higher than 75%ETc with WPM treatment combinations. Similarly, the water productivity of tomatoes in 50%ETc with WPM was 3.2% higher than 50%ETc with RSM and 8.5% higher than 75%ETc with RSM treatment combinations.

Deficit irrigation strategies are recommended for use by farmers and extension workers to achieve optimum tomato yield and maximize

WP by applying at 75%ETc through growth phases while saving water 25% of the water requirement. Smallholder farmers should apply RSM practices to increased tomato yields and savings water under conservation agriculture. Tomato growers are highly advised to cover their crop with RSM and apply 25%deficit irrigation instead of full irrigation to achieve higher tomato yields and better WP. Adoption of water-saving strategies by smallholder farmers during the water scarcity time has economic benefits because less production cost was required for diesel, and labor for irrigation water application, and the saved water can potentially increase farm income to be used for bringing new areas under irrigation. Additional research is needed on the effect of mulch types on soil nutrient dynamics, soil temperature, and the occurrence of pests and disease while different irrigation levels of moisture stress to determine conclusively the influence of the same study on yields and water productivity. Such studies may result in a further improvement of the yield of tomato in water shortage areas of the country.

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