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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 poses a significant challenge to current irrigated agriculture, necessitating the development of new on-farm irrigation management strategies to ensure sustainable utilization of limited water resources. In 2021, an experiment was conducted at the Fogera National Rice Research and Training Center (FNRRTC) experimental site with the objective of analyzing the yield and water productivity of tomato crops under water stress conditions. A factorial combination of three levels of deficit irrigation (100%ETc, 75%ETc, and 50%ETc) based on ETc, and three mulch types: No Mulch (NM), White Plastic Mulch (WPM), and Rice Straw Mulch (RSM) were evaluated in 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. Monthly Reference Evapotranspiration (ETo), Crop Evapotranspiration (ETc), and irrigation scheduling were calculated using the CROPWAT 8.0 model based on climate, soil, and crop data. The results of the study revealed that both the yield of tomatoes and water productivity were significantly influenced by the main and interaction effects of deficit irrigation and mulch types at a significance level of 0.05%. The marketable yield of tomatoes at 75%ETc was 4.1% higher than at 100%ETc and 27.8% higher than at 50%ETc, while the water productivity at 50%ETc was 13.4% higher than at 75%ETc and 53.0% higher than at 100%ETc. Additionally, the marketable yield of tomatoes with Rice Straw Mulch was 17.1% higher than with No Mulch and 5.1% higher than with White Plastic Mulch, while the water productivity of tomatoes with Rice Straw Mulch was 16.3% higher than with No Mulch and 3.6% higher than with White Plastic Mulch. Furthermore, the marketable yield of tomatoes at 75%ETc with Rice Straw Mulch was 8.0% higher than at 100%ETc with Rice Straw Mulch and 9.7% higher than at 75%ETc with White Plastic Mulch. The water productivity of tomatoes at 50%ETc with White Plastic Mulch was 3.2% higher than at 50%ETc with Rice Straw Mulch and 8.5% higher than at 75%ETc with Rice Straw Mulch. These findings highlight that Rice Straw Mulch with 75%ETc enhances both yield and water productivity by conserving water without compromising tomato yields.

Keywords: Deficit Irrigation; Mulch; Crop and Water Productivity; Water Stress; Tomato

Abbreviations: FNRRT: Fogera National Rice Research and Training Center; NM: No Mulch; WPM: White Plastic Mulch; RSM: Rice Straw Mulch; RCDB: Randomized Complete Block Design; ETO: Monthly Reference Evapotranspiration; ETC: Crop Evapotranspiration; SSA: Sub- Saharan African; WP: Water Productivity; DI: Deficit Irrigation; BD: Bulk Density; RCBD: Randomized Complete Block Design; FC: Field Capacity; PWP: Permanent Wilting Point; TAW: Total Available Soil Water; BD: Bulk Density; TAW: The Total Available Water

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. [1,2]). 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. [3]). 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. [4-8]). Therefore, enhancing agricultural productivity is crucial to address food security issues and sustain the livelihoods of Ethiopian communities (Tewabe, et al. [9]). To address the growing food demands, it is imperative to transition from rainfed production to irrigation-supported agriculture (Belay, et al. [8]). Irrigation plays a pivotal role in mitigating the impact of rainfall variability and irregularity on agricultural productivity (Mekonen, et al. [10]).

Small-scale irrigation initiatives are crucial for poverty reduction, food security, and enhancing rural livelihoods in Ethiopia (Assefa, et al. [3,11-13]). However, the scarcity of available water resources poses a significant challenge to irrigated agriculture in many regions, including Ethiopia (Belay, et al. [8]). 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. [9]). Insufficient water availability for irrigation results in low crop yields, conflicts over water allocation, and challenges in sustaining agricultural productivity (Dirirsa, et al. [14]). Currently irrigated agriculture take place under water scarcity and insufficient water supply for irrigation due to these the crop productivity are low are (Kifle, et al. [15]). Enhancing Water Productivity (WP) and water savings are a major challenge for sustainable crop production in irrigated agricultural (Mubarak, et al. [16]). In the context of Ethiopia, traditional irrigation systems dominate crop production, resulting in low water and crop productivity levels (Hordofa, et al. [17]). 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, et al. [18-21]).

Therefore, deficit irrigation and conservation agriculture practices emerge as critical strategies to optimize water use efficiency and enhance crop productivity in water-limited regions. 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. [21-23]). Conservation agriculture practices, such as mulching, have proven effective in boosting water and crop productivity while reducing production costs (Erkossa, et al. [24,25]). Mulching, in particular, plays a crucial role in improving water and crop productivity under deficit irrigation conditions (Rop, et al. [26]). Evaluating various water-saving techniques, including deficit irrigation and mulching, is essential for enhancing water productivity and crop yields in water-limited environments (Khan, et al. [27]). 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.

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. Therefor 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. 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.

Materials and Methods

Study Area Description

The field experiment was conducted at the Fogera National Rice Research and Training Center (FNRRTC) experimental site. It is located at 11º19' N and 37º03' 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 (Figure 1). 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, et al. [28]). 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 14.0ºC, 27.7ºC, and 20.8ºC, 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. [29]). 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, et al. [30]). The dominant soil type in the Fogera is black clay soil (ferric vertisols), while the mid and high-altitude areas are predominantly orthic Luvisols.

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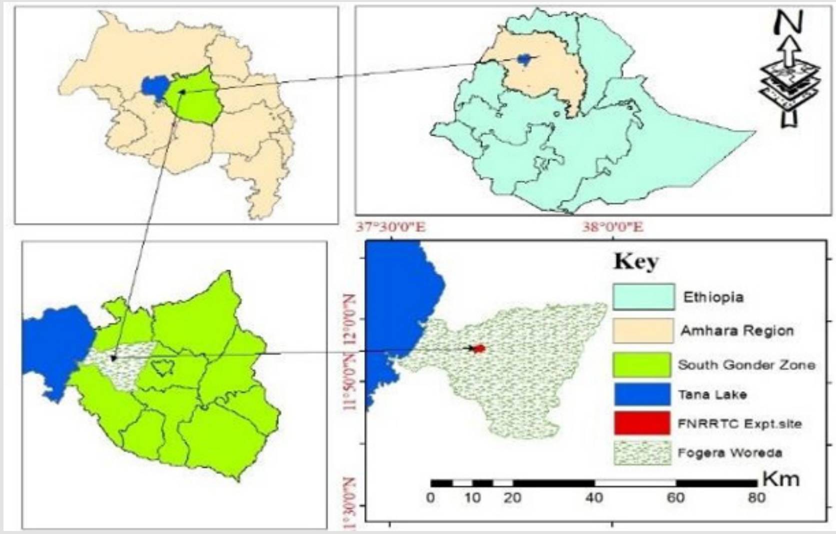

Figure 1: Map of the study area.

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 25micron 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. 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 (Figure 2).

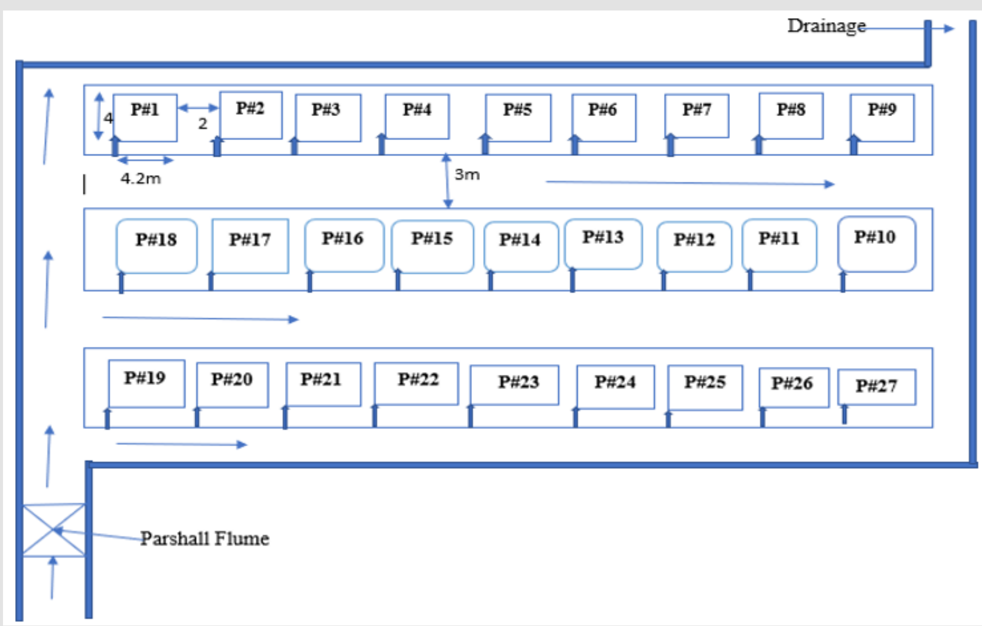

Figure 2: The experimental layout.

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 being1m 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. 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. 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 treatments were weeded only once before mulch was applied. Fifteen days after transplanting, treatments were started because seedings were start root development and was 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.

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 for determining the soil 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, drop-hammer core sampler with size 5 cm in diameter and 5 cm in height was driven into the soil with a hammer. 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 bulk density was determined by the mass of the soil per volume (Terzaghi, et al. [31]).

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 hydrometer method. 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 15bars pressure to determine the permanent wilting point. The soil moisture was determined gravimetrically.

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 (Table 1). Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (ETo*Kc) (Allen, et al. 32). The crop coefficient was used for the growth stages of the onion and tomato crop for the experimental years explained in Table 2. Irrigation water to be applied to the tomato was determined based on 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. 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. [33]). 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 of the crop depends on the crop growth stage and the monthly weather conditions. 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.

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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
		75%ETC with WPM
Plastic Mulch (PM)	50%ETc (50%DI)	50%ETC with WPM

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

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

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, all the water required by crops has 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, et al. [34]). Once the amount of water that needs to be given during one irrigation application was estimated and applied, then the next determine the irrigation interval by dividing the net irrigation depth (mm) to daily crop water requirement (mm/day). 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. [35]).

$$T = \frac{A * d}{6q} \quad 2.1$$

where A = (irrigated area) in m2 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 weighing the yield obtained after picking the tomato fruit. Marketable yield (kg/ha) was measured for healthy and non-diseased, non- rotten, tomato fruit recorded from the sampled plant. Marketable bulb yield was expressed as kg per plot. Finally, the yield obtained from the sample area was converted to per hectare using equation 2.2 (Demisie, [36]).

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

Water productivity was determined based on the ratio of 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/m^3) Ya-Actual yield (kg/ha) ETa -Seasonal applied amount of water (m^3 /ha)

Crop yield response factor (Ky) was determined from the experimental data. The yield response factor (Ky) was one of the important parameters that indicate 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 the equation 2.4 (Smith, et al. [37])

$$(1-\frac{ya}{ym}) = ky*(1-\frac{ETa}{ETm} \quad 2.4$$

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 a statistical software in the procedure of a general linear for the variance analysis model. Analyses of variance (ANOVA) were used for 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 statistix computer package version10.

Results and Discussion

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 with its depth. The BD of the experimental site varied from 1.22 g/cm^3 in the upper soil (0-20 cm) to 1.33 g/cm^3 in the lower soil layer (90-120 cm). The average bulk density of the experimental site was 1.28 g/cm^3 (Table 3). 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 [38]). 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 (Table 3). 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 weight base at FC (1/3 bar) and PWP (15 bar) were 36.92% and 23.58%, respectively. 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 4).

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	0.0	11	27	49.5	0.66	9.5	3.6
Feb	0.0	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	3.0	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	2	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

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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

Note: Allen, et al., (1998).

Crop Water Requirement Of Tomato

The total irrigation water applied to tomato crops were 438.5 mm for non-stressed treatment (100%ETc) respectively (Table 5). 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 5: Results of physical properties of soil of the experimental site.

Soil Depth (cm)	FC (%) (0.33 bar)	PWP (%) (15 bars.)	Bulk Density (gm/cm^3)	Textural Status (%)			Textural	TAW
				Sand	Silt	Clay	Class	(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		

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 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, (Table 6). According to (Berihun, et al. [39]), amount of water applied did not have a significant effect on the growth and yield components of tomatoes. This results consistent with the findings of Shahein, et al. [40]) 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, et al. [41]) 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., [42]).

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		

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 (Table 6). This result is consistent with the suggestion of (Biswas, et al. [43]) 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. [44]) who reported that the high tomato yield was obtained at 80%ETc than 100ETc. A similar result was also (Randhe, et al. [42]) 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. [45]) reported that tomato yield increased with the amount of applied irrigation water at 75%ETc and then decreased at 100%ETc. Similarly, the highest WP of tomato 12.7 and 11.2kg/m^3 was obtained from 50%ETc and 75%ETc respectively while the lowest WP 8.3kg/m3 was obtained from 100%ETc (Table 7). 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 significantly different on WP from all other deficit treatments. This was because the amount of water applied in the full irrigation treatment was significantly higher than 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. [46]) who stated that DI significantly increased the WP compared to the full irrigation regime. A similar result was also reported by (Ragab, et al. [47]) 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. [22]). The highest WP of tomatoes were obtained in 50%ETc (Yadan, et al. [45]). The highest WP was observed at 60%ETc while the lowest was observed at 100%ETc (Sang, et al. [48]).

Table 7: Seasonal irrigation water applied to tomato.

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

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 (Table 8). Whereas the fruit length of tomato was not significantly different among treatments. This result agreed with the results of (Karaer, et al. 49]) who stated fruit diameter was found to be higher in mulch applications. This result agreed with the results of (Goel, et al. [50]) 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. [51]).

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

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

Note: 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 $P < 0.01$.

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 result of (Audu, et al. [44]) 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. [50]) that increase in tomato yield with mulches RSM was 25.6% as compared to NM. RSM increased the fruit yield of tomatoes (Pandey, et al. [52]). These results agree with (Robel Admasu, et al. [53]) 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, et al. [39]). The application of mulch types significantly influences tomato fruit yield (Tegen, et al. [54]). Crop yield significantly increased with the application of rice straw mulch (Dossou-yovo, et al. [55]). These results suggest that straw mulching has great potential for improving onion yield (Tao, et al., [56]). Similarly, the WP of tomatoes was 11.4, 11.0, and 9.8 kg/m3 in RSM, WPM, and NM treatments, respectively (Table 9). It implies that the WP in RSM treatment was 16.3% higher than NM and 3.6% higher than WPM treatment. The results indicated that mulching applications significantly improve the

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WP of the tomato. This result was in line with the result of (Goel, et al. [50]) 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 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

Note: 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 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 (Table 10). Even we applied minimum amount of water to get the reasonable fruit size of tomato. This may be due to the canopy covers of tomato use as a mulch. This result agreed that the results of (Kere, et al. [57]) the yield attributes of tomato were not significantly affected by either irrigation amount and mulch type. According to (Berihun, et al. [39]), the interaction effect of the amount of water and mulch was not significant in fruit length and fruit diameter. According to (Aliabadi, et al. [58]) the interaction effect of mulch and amount of water on fruit length and diameter was not significant. A similar result was also reported by (Selamawit Bekele, et al. [41]) 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. [41]).

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	3.60a^b	5.77^a
LSD (0.05)	0.08	NS
P	*	
C.V	1.9	1.8

Note: 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) were 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 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 (Table 11). This result showed that RSM and WPM increased the yield of tomatoes by 21.2% and 10.5% compared with 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 unmulched 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 irrigation regime. Irrigation at the same level without mulch produced the lowest yield.

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

Mulch Types	Yield of Tomato (t/ha)	water Productivity of Tomato (kg/m^3)
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

Note: 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.

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 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, et al. [59]). This result is in line with the findings of (Audu, et al. [44]) recommended that tomato producers to adopt water application at 80%ETc and use RSM. These results were also consistent with the findings of (Biswas, et al. [43]) 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, et al. [60]). The maximum fruit yield was recorded from the plants receiving deficit irrigation at 80%ETc with a straw mulching treatment combination (Samui, et al. [61]). The best level of irrigation for tomato crop is 80%ETc and this correspond to mulching practice of rice straw mulch (Zakari et al. 2020). Similarly, the highest WP of tomatoes (13.59 and 13.08 kg/m3) were achieved from 50%ETc with WPM and with RSM respectively (Table 11). 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 irrigation level of 50%ETc, irrigated to tomato plot 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. [43]) 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. [50]) 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. [48]).

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 [62-67] (Tables 12-14).

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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%ET×NM	3.55[a]	5.71[a]
100%ET×NM	3.68[a]	5.78[a]
75%ETC×SM	3.69[a]	5.82[a]
50%ETC×NM	3.60[a]	5.76[a]
100%ETC×NM	3.57[a]	5.79[a]
75%ETC×SM	3.66[a]	5.77[a]
50%ETC×NM	3.58[a]	5.74[a]
C.V	1.9	1.8
LSD (0.05)	NS	NS

Note: 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.

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×SM	33.4[de]	9.97[d]
50%ETC×NM	26.6[g]	11.45[c]
100%ETC×NM	38.6[b]	8.81[e]
75%ETC×SM	41.7[a]	12.44[b]
50%ETC×NM	30.3[f]	13.08[ab]
100%ETC×NM	35.6[cd]	8.12[ef]
75%ETC×SM	38.0[bc]	11.34[c]
50%ETC×NM	31.5[ef]	13.59[a]
C.V	2.6	2.6
P level	**	**
LSD (0.05)	2.6	0.5

Note: 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 $P < 0.01$.

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

Treatment	Yield (KG/HA)	ETA	$\frac{Ya}{Ym}$	$\frac{Ya}{Ym}$	$1-\frac{Y_a}{Y_m}$	$\frac{1-ETa}{ETm}$	$K_Y=\frac{1-(Y_a/Y_m)}{1-(ET_a/ET_m)}$
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

Conclusion and Recommendations

Conclusion

Water scarcity is the main challenge in current sub-Saharan African countries including Ethiopia. To mitigated those challenge on farm 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 NM and 5.1% higher than WPM treatment while the IWUE of tomato in RSM was 16.3% higher than 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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