

Research Article

Evaluating the Effects of Deficit Irrigation and Mulch Type on Yield and Yield Components of Onion in Fogera, Ethiopia

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Abstract

Water scarcity is a challenge for current irrigated agriculture globally. Under these circumstances, new on-farm irrigation management strategies should be established. An experiment was conducted at Fogera in 2021 to evaluate the effects of deficit irrigation (DI) and mulch type on onion yield and yield components. A factorial combination of three levels of DI (100%ETc, 75%ETc, and 50%ETc) and three mulch types No Mulch (NM), White Plastic Mulch (WPM), and Rice Straw Mulch (RSM) were evaluated in RCBD with three replications. Monthly ETo, ETc, and irrigation scheduling were computed using CROPWAT 8.0 model. These studies showed that the onion yield and yield components were significantly affected by the main and the interaction effects. The maximum average plant heights (PH), leaf heights (LH), and number of leaves per plant (LNP) of 51.7 cm, 38.0cm, and 10.4 respectively, were recorded from 100%ETc whereas the minimum PH, LH, and LNP of 39.5 cm, 29.0cm, and 6.9 were recorded from 50%ETc treatment respectively. The highest average bulb weight (BW), bulb diameter (BD), and bulb height (BH) were 117.9gr, 6.4, and 5.7 cm recorded from 100%ETc treatment respectively. In contrast, the minimum average BW, BD, and BH were 79.9gr, 4.8, and 5.0cm recorded from 50%ETc respectively. The highest PH, LH, and LNP of onions were 51.9cm, 40.6cm, and 10.1 respectively recorded from RSM treatments. In contrast, the minimum PH, LH, and LNP of onions were 41.5cm, 31.1cm, and 7.5 respectively, recorded from WPM treatments. Similarly, the highest mean BW, BH, and BD 106.2gr, 5.8cm, and 6.0cm were obtained from the treatments of RSM respectively. In contrast, the lowest mean BW, BH, and BD 100.7gr, 5.0cm, and 5.3cm were obtained from NM treatments respectively. The interaction effects of DI and mulch showed that the onion yield at 100%ETc with RSM was 7.5% higher than that at 100%ETc with NM and 15.1% higher than the yield at 100%ETc with PM. The highest BW, BH, and BD of the onion 121.8 gr, 6.2, and 6.8 were obtained when the onions received 100%ETc and mulched with RS while the lowest average BW, BH, and BD of the onion were 77.3gr, 4.6cm and 4.1cm were obtained from 50%ETc with NM treatment combination. These results showed that RSM with 75%ETc improves onion yield and yield components.

Keywords

Deficit Irrigation, Mulch Types, Onion, Yield and Yield Components

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1. Introduction

Population growth, combined with the emerging challenges of climate change, means that the world's agricultural systems will need to produce more food [1]. And food security around the globe will face great challenges [2]. Smallholder agriculture is the main source of income for rural people in sub-Saharan African (SSA) countries like Ethiopia. However, smallholder agricultural production relies heavily on rainfall, and as drought becomes more common, many people have repeatedly been exposed to hunger and famine [3, 4]. Rainfall variability and irregularity are major concerns in a rainfed production system, and smallholder farmers are vulnerable to frequent droughts in crop production [5]. As a result of these factors, the land's production and productivity have declined significantly and are insufficient to feed the current population [6]. Therefore, improving agricultural productivity is critical for ensuring food security [7].

Small-scale irrigation is the leading strategy for reducing poverty, ensuring food security, and improving the Ethiopian community's livelihood [3]. Rainfed production should be supplemented with irrigation to meet the food needs of the growing human population [6, 8, 9, 10]. Small-scale irrigation is one of the most valuable farming systems and leading strategy to reduce poverty, ensure food security, and improve the livelihood situation by increasing production and productivity in the Ethiopian community [3, 11-13]. Drought, moisture stress, and poor irrigation water management pose a challenge to Ethiopia's current irrigated agriculture [6, 7]. This resulted in yield reduction and substantial conflict in freshwater allocation among irrigation users [14, 15, 16]. Enhancing water productivity (WP) and water savings are major challenges for sustainable crop production in irrigated agriculture [17]. Traditional irrigation systems dominate crop production in Ethiopia, contributing to low water and crop productivity [14, 19]. In the Ethiopian highlands, water is insufficient to allow sustained vegetable production due to an expansion of irrigated land, excessive water abstraction, and poor water management practices. This has led to crop failure and caused conflict among irrigation water users. Irrigation water shortage impacts the yield of vegetable crops and household income. Water-saving and enhancing WP technologies are most important for current irrigated agriculture [16]. Those technologies play an important role in boosting agricultural production by improving the efficiency of irrigation water use in small-scale irrigation [17]. Innovative technologies are needed for smallholder farmers to use the available irrigation water efficiently [18, 23]. Deficit irrigation and conservation agriculture are among the technologies used to increase the efficient use of the available water.

Deficit irrigation (DI) is an optimization strategy that maximizes net returns by reducing the amount of irrigation water and increasing WP without imposing a yield penalty [24]. These water-saving strategies are aimed at improving WP [21, 22]. Expanding irrigated areas using the water con-

served could increase overall production and allow for WP increment [26]. Conservation practices have become one of the most effective strategies for improving water and crop productivity while reducing production costs [24, 25, 27, 30]. Due to greatly increased yields and water savings under conservation agriculture in smallholder plots, farmers applied grass mulch and used no-tillage practices [6]. Mulching is one of the important CA strategies to improve water and crop productivity [28]. The benefits of CA under different irrigation scheduling on smallholder irrigated farms have not been adequately investigated in the Ethiopian [6]. Most of the previous studies evaluated the impacts of DI and mulch practices mainly on cereals. Individually, the effect of DI and mulch type on onion yield and growth and yield components has been tested in the drip but not in furrow irrigation systems, by different researchers in different parts of the world [29]. Also, experimental field measurements on vegetable production systems and the combined effect of irrigation levels with mulching practices in furrow irrigation systems have been limited. The effects of white plastic and rice straw mulch with DI on onion and growth and yield components in furrow irrigation were not evaluated. Different mulch types had different responses in different crops and agroecology [13]. Therefore, evaluating different water-saving techniques is most important to improve WP and yield under deficit irrigation and mulch [33].

Combining mulch with optimal DI effectively increases crop yield and growth and yield components in water-limited regions [30]. Mulching with a 20% deficit irrigation improved water and yield productivity [31, 32]. DI with mulching gave better yield and growth and yield components for onion crops compared to non-mulched conditions (36). A combination of 80%ETc with straw mulch had a high marketable bulb yield of onion [33]. The combination of DI with mulch had pronounced effects on the growth and yield productivity of onion [34]. Then, effective and economical utilization of water resources by low-cost technologies is sensible and adaptable, directly contributing to the sustainability of the livelihoods of smallholder farmers.

2. Materials and Methods

2.1. Study Area Description

During the 2020/21 irrigation season, the field experiment was conducted at the Fogera National Rice Research and Training Center (FNRRTC) experimental site. Fogera is found in the South Gonder Zone of the Amhara regional state (figure 1). It is located at 11°19' N and 37°03' E at an altitude of 1815 m.a.s.l. and is found at a distance of 657 km from Addis Ababa and 57 km from Bahir Dar. It is predominantly classified as Woinadega agroecology [35]. 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 1216.3 mm and ranges from 1103 to 1336mm [36]. The land in Fogera consists of 44.2% rainfed,

20% irrigated, 22.9% pasture, 1.8% shrubland, 3.7% covered with water, and the remaining 7.4% degraded land or other [37,38, 39, 40, 41]. The dominant soil type in the Fogera is black clay soil (ferric vertisols), while the mid and high-altitude areas are predominantly orthic Luvisols.

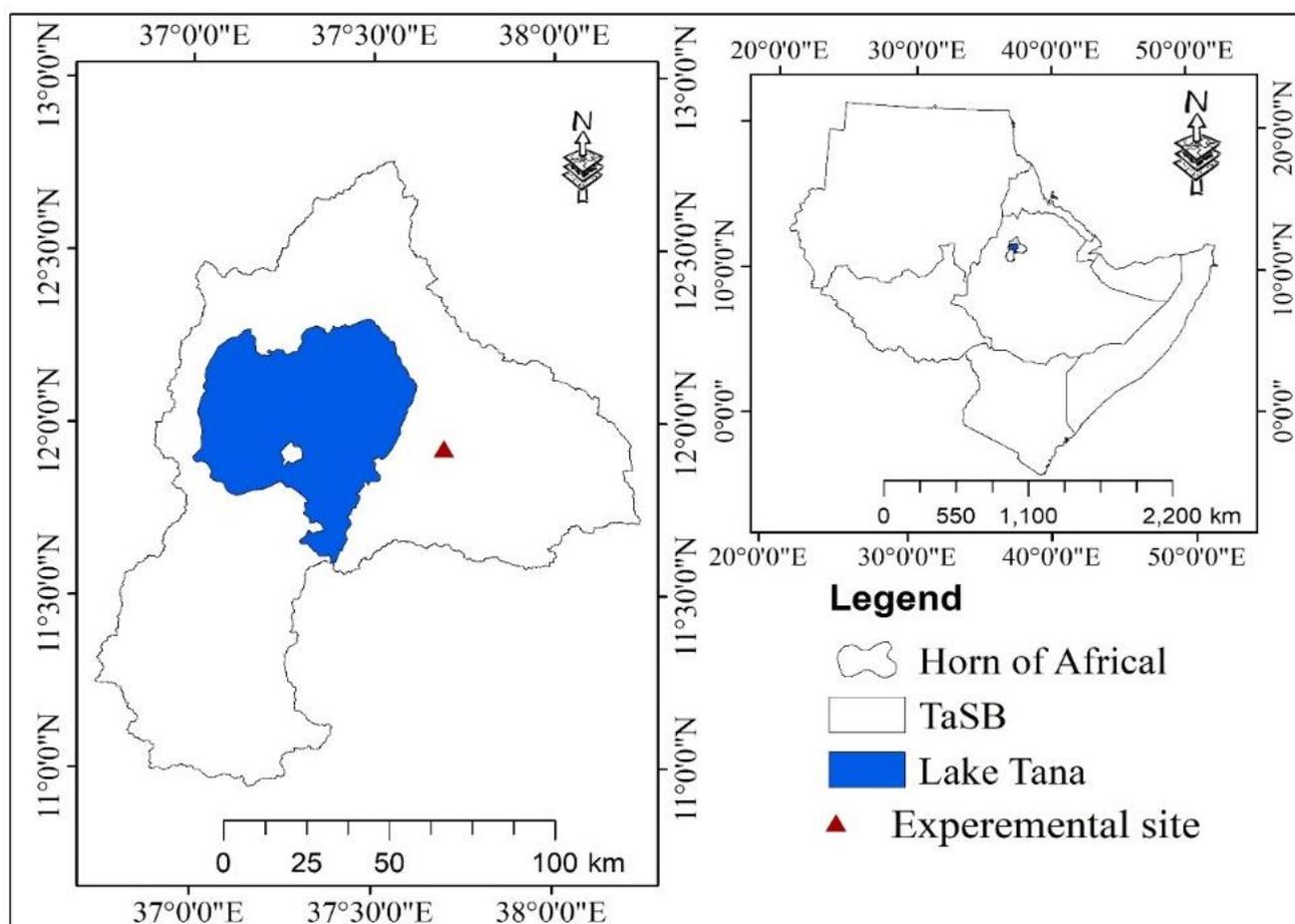


Figure 1. Map of the study area.

2.2. Experimental Design and Layout

The experiment was designed by selecting two factors, which are mulch types, and 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, and the three mulch types are No Mulch (NM), Rice Straw Mulch (RSM), and White Plastic Mulch (WPM). The non-deficit and non-mulch treatments were used as control. Rice straw mulch was applied at a rate of 6 t ha⁻¹, for

the white plastic mulch 25-micron thickness was applied. 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. Treatments were randomly assigned (by chance) to the experimental block. The field experiment has a total of 9, treatment combinations and 27 plots. The plot size was 4.2 m × 4 m=16.8 m² area. To minimize the influence of the lateral water flow into the plots, we kept sufficient distance between blocks, and the plots (i.e., 3 m and 2 m, respectively). In this experiment, the furrow irrigation method was used.

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 (RSM)	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

2.3. Agronomic Practices of the Experimental Site

The seed variety used in this experiment is Onion (*Allium cepa* L) Bombay red. The nursery bed was prepared, and the seed was planted on November 10, 2020. Watering, weeding, fertilizer, and chemical spray were applied in the nursery. The onion seedlings were transplanted to the experimental plots on January 1, 2021. Furrow spacing and plant space were done according to the agronomic recommendation of the area. The spacing between rows is 0.6m, (0.2m between ridges and furrow is 0.4m), and the plant spacing is 0.07m for onion. Each plot has seven double rows, and each row accommodates about 60 plants of onions.

NPSB fertilizer was applied at transplanting only for each

experimental plot. In addition, urea fertilizer was applied during transplanting and 30 days after transplanting with the recommendation rates of NPSB and urea fertilizer for onion. Chemical spray was applied to prevent the experiment from disease and pests. All treatments without treatment variation two common irrigation were applied at the depth of 14.5mm and 17mm respectively before the treatment started for onion based on the irrigation scheduling to ensure good seedlings establishment. All treatments were weeded once before mulch was applied. Fifteen days after transplanting treatments were started because seedlings started root development and were well performed. All plots were irrigated on the same days because the only difference was the depth of water based on deficit levels. The harvesting time of onion was April 30 and onion yield was weighed from each plot during harvest and converted to t/ha.

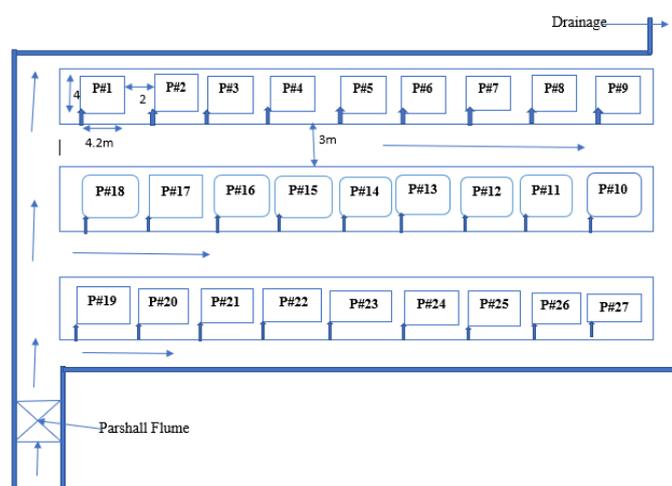
**Figure 2.** The experimental layout.

Table 2. Agronomic management of onions throughout the growing period.

Crop	Management activity	Date	Methods and tools
Onion (Bombe red)	Nursery and seedling	10 November 2020	Water can manual
	1 st wedding of the nursery	25 November 2020	Hand pick-up
	Fertilizer application for nursery	5 December 2020	Hand application
	Chemical application for seedlings and 2 nd weddings of nursery	10 December 2020	Knapsack, hand pick-up
	Chemical application and 3 rd wedding of nursery	25 December 2020	Knapsack, hand pick-up
	Tillage	10-20 December 2020	Draught animal
	Planting and fertigation	01 January 2021	Manual with hand
	Irrigation	01 January – 20 April	Furrow irrigation
	Weeding	15 January 2021	Sickle
	Mulch application	15 January 2021	Manual with hand
Harvesting	27-30 April 2021	Sickle	

2.4. Soil Sampling and Analysis

Soil samples were collected before crops were planted. Samples were taken using a soil auger at three representative locations from five soil depths (0-20, 20-40, 40-60, 60-90, and 90-120cm). Composite samples were prepared by mixing five sub-samples from the same treatment and depth. About 1 kg of soil was used for determining the soil's physical and chemical properties, such as soil textural class, field capacity (FC) and permanent wilting point (PWP), Soil pH, and EC. The soil bulk density was determined from undisturbed soil samples taken using a cylinder core sampler with a size 5 cm in diameter and 5 cm in height. The weight of the soil core was determined after drying in an oven at 105 °C for 24 hours. The bulk density was determined by the mass of the soil per volume [44, 46, 47, 48]. 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) determined using ammonium acetate. The soil textural class analysis of clay, silt, and sand was determined using the 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, EC_e was measured. The pH and EC of water were also measured for irrigation water quality. Field capacity and permanent wilting point were determined in the laboratory using a 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. The samples were analyzed at the Amhara Design and Supervisory Works Enterprise soil laboratory.

2.5. 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 (T_{max}, T_{min}, RH, Sh, and U) collected from West Amhara National Metrology Agency at Bahir Dar for onions and tomato during the growing season (Table 3). Crop water use (ET_c) was determined by multiplying ETo by the crop coefficient (ETo*K_c) [46]. The crop coefficient was used for the growth stages of the onion crop for the experimental years explained in (Table 4). Irrigation water to be applied to the onion and tomato was determined based on allowable constant soil moisture depletion fraction ($p = 0.25$ and 0.4 respectively) 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 [49, 50]. 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. The daily crop evapotranspiration was deducted from the net irrigation depth for the control treatment (100% ET_c) until the cumulative subtraction from the net irrigation depth applied approached zero. Next

irrigation was applied when the cumulative ET_c approach to net irrigation depth was applied for the control treatment and applied for 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 0.5m for onion. During the experiment, there was no rainfall, and all the water required by crops had to be supplied by irriga-

tion, 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 [42]. Once the amount of water that needs to be given during one irrigation application is estimated and applied, determine the irrigation interval by dividing the net irrigation depth (mm) by daily crop water requirement (mm/day).

Table 3. Long-term (1990 to 2017) means climate data for Woreta meteorological station.

Month	RF (mm)	Tmin. °C	Tmax. °C	RH %	Ws (U)m/s	sunshine (hr)	ET _o mm/day
Jan	0.0	11.0	27.0	49.5	0.66	9.50	3.60
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	274.4	13.8	24.6	78.1	0.72	4.58	3.22
Sep	144.0	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	0.68	9.45	3.72
Dec	0.0	10.9	26.7	53.8	0.62	9.81	3.50

Table 4. K_c and growth stages of onion crop.

	Growth stage				
	Initial	Development	Mid	Late	Total
Onion					
Depletion fraction (P)	0.25	0.25	0.25	0.25	
Crop coefficient (K _c)	0.5	0.8	1.0	0.9	
Growth stage (days)	15	30	40	35	120

Source: Allen et al (1998).

The predetermined amount of irrigation water to 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 [43].

$$T = \frac{A*d}{6q} \quad (1)$$

where A = (irrigated area) in m² d = irrigation depth in cm T = (time) in min. q = (Parshall flume discharge) in l/s

2.6. Agronomic Data Collection

Marketable Yield

The experimental data on the yield of onion in each experimental plot was harvested and the yield was obtained after manually removing roots and stock from the onion bulb by sickle. Marketable yield (kg/ha) was measured for healthy and non-diseased, non-rotten, non-white (different varieties), non-split, marketable-sized 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 [51, 52]

$$\text{Bulb yield} \left(\frac{\text{kg}}{\text{ha}} \right) = \frac{\text{weight of sample yield (kg)}}{\text{Net harvested area (m}^2)} * 10000 \text{m}^2 \quad (2)$$

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 decimal, using equation 2.4 [45].

$$\left(1 - \frac{Y_a}{Y_m} \right) = ky * \left(1 - \frac{ET_a}{ET_m} \right) \quad (3)$$

Where: Y_a = actual harvested yield in kg/ha, Y_m = maximum harvested yield in kg/ha, ky = yield response factor, ET_a = actual evapotranspiration in mm/growing period, and ET_m = maximum evapotranspiration in mm/growing period.

3. Data 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 onions. All

data collected were managed and compared with the 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 version 10.

4. Results and Discussions

4.1. 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 was found in heavy clay soil. The result of soil bulk density (BD) showed a slight variation in its along the soil depths (0 to 120 cm). It 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 was found 1.28 g/cm³ (Table 5). On average, a BD of 1.2 g/cm³ is expected for clay soil but it can vary from around 1.0-1.4 g/cm³ [46]. The soil moisture content on weight base at field capacity (FC) showed variation along the soil depths (i.e., 0-20, 20-40, 40-60, 60-90, and 90-120 cm) which resulted in a value of 35.1, 35.6, 37.5, 37.8, and 38.6 %, respectively (Table 5). 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 at FC (1/3 bar) and permanent wilting point, PWP, (15 bar) was 36.92% and 23.58%, respectively. The total available water (TAW) was directly related to variations in FC and PWP. It showed a variation along the soil depths (i.e., 0-20, 20-40, 40-60, 60-90, and 90-120 cm) and the values were 33.2, 33.0, 36.4, 49.9, and 51.9mm, respectively. The volumetric TAW of the experimental site was 170mm/m. The chemical analysis of applied irrigation water showed that it has a pH, potential hydrogen, value of 7.28, and ECw, electrical conductivity, value of 0.24 dS/m was obtained (Table 6).

Table 5. Physical properties of soil of the Fogera experimental site at different soil depths.

Soil depth (cm)	FC (%) (0.33 bar)	PWP (%) (15 bars.)	Bulk density (gm/cm ³)	Textural status (%)			Textural class	TAW (mm)
				sand	Silt	clay		
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. Chemical properties of soil and water for Fogera experimental site at different soil depths.

Soil depth (cm)	0-20cm	20-40cm	40-60cm
pH-H ₂ O (1:2:5)	5.38	5.73	6.17
EC (mS/cm)	0.10	0.10	0.10
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)	30.10	37.09	26.66
Exch. Mg (meq. /100gm of soil)	9.58	15.62	7.62
CEC (meq. /100gm of soil)	42.13	55.70	48.12
Sum of cations (meq. /100gm of soil)	41.18	55.27	35.65
Exchangeable Na % (ESP)	2.96	4.00	2.22
PH of water	7.28		
EC (dS/m) of water	0.24		

4.2. Crop and Irrigation Water Requirement of Onion

The total irrigation water applied to onion crops was 413.7 mm for non-stressed treatment (100%ETc) respectively (Table 7). The result was in agreement with [53, 54, 55] who reported the seasonal crop water requirement of onion ranges from 350 - 550 mm using furrow irrigation. All treatments were irrigated on the same days because the only difference was the water depth on deficit levels.

Table 7. Seasonal irrigation water was applied to the onion.

Treatments	Total CWR, (mm)	Total IWR (mm)
	Onion	
100%ETc	413.7	413.7
75%ETc	318.2	318.2
50%ETc	222.6	222.6

4.3. The Effects of Deficit Irrigation on Yield, Growth, and Yield Components of Onion

4.3.1. The Effects of Deficit Irrigation on Growth Components of Onion

The effects of deficit irrigation results showed there were significant differences in growth parameters when tested at the 5% level. The maximum plant and leaf heights and num-

ber of leaves per plant of 51.7 cm, 38.0cm, and 10.4 respectively, were recorded from 100%ETc whereas the minimum plant and leaf heights and leaf number per plant of 39.5 cm, 29.0cm, and 6.9 were recorded from 50%ETc treatment respectively (Table 8). The results revealed onion growth parameter was directly associated with the amount of irrigation water applied. This result showed that onion growth components decreased with an increase in levels of water deficit. These results are in agreement with the findings of [49] who reported that the highest growth components of onions were recorded from full irrigation, and the lowest heights were recorded from high-stressed treatment. The current result was also in line with [59] who stated that 100%ETc resulted in the highest values of growth parameters, while 50%ETc led to the lowest, with intermediate values recorded at 75%ETc. [60] also reported the lowest plant heights obtained from treatments receiving a low amount of water of 50%ETc. In general, the results indicated growth components of onion decreased as irrigation depth decreased from optimum irrigation (100%ETc) to low soil moisture level (50%ETc). This indicated that the growth parameters of onions were taller at maximum applied water than onions that received a minimum amount of water (Table 8). Similar results were also obtained by [65] that decreasing deficit levels (stresses) increased the plant height and leaf height and number.

Table 8. The effects of deficit irrigation on growth components of onion.

Deficit level	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
100%ETc	51.7 ^a	38.0 ^a	10.4 ^a

Deficit level	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
75%ETc	47.6 ^b	37.8 ^a	8.9 ^b
50%ETc	39.5 ^c	29.2 ^b	6.9 ^c
LSD (0.05)	2.9	2.8	0.6
P	**	**	**
C.V	5.1	6.7	5.5

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 $P < 0.01$.

4.3.2. The Effects of Deficit Irrigation on Yield and Yield Components of Onion

The analysis of variance (ANOVA) results showed that the marketable yield of onion was significantly ($p < 0.05$) affected by irrigation levels. The highest marketable yield 34.8 t/ha was obtained from 100%ETc and the lowest marketable yield 21.8 t/ha was obtained from 50%ETc (Table 9). The marketable yield of onion was 34.8, 30.9, and 21.8 t/ha, respectively, in 100%ETc, 75%ETc, and 50%ETc. It implies that the marketable yield of onion in 100%ETc was 12.6% higher than 75%ETc and 59.6% higher than 50%ETc. The results showed that the marketable yield of onion decreased proportionally with the amount of irrigation water applied from 100%ETc to 50%ETc. There was a linear relationship between the marketable yield of onion and the amount of irrigation water applied. These results agreed with the findings of [56] and [57] who stated that the minimum yield was recorded from 50%ETc. Similarly, [58] and [14] stated that

the marketable bulb yield from non-stressed treatments (100 ETc) was the highest while the most stressed treatment (50 ETc) had the lowest marketable bulb yield of onion. At the same time, the highest average bulb weight, bulb diameter, and bulb height were 117.9gr, 6.4, and 5.7 cm recorded from full irrigation treatment respectively. In contrast, the minimum average bulb weight, bulb diameter, and bulb height were 79.9gr, 4.8, and 5.0cm recorded from 50%ETc respectively. Results showed that onion yield components decreased with an increase in levels of water deficit. This indicated that the yield components of plots that received maximum applied water were higher than plots that received a minimum amount of applied water (Table 9). The result shows that, there was a linear relationship between bulb size and the quantity of irrigation water applied. This means that water stress affects negatively the weight of individual bulbs. The results revealed yield components are directly associated with the amount of irrigation water applied. These results were in line with the result of [27] who reported that the highest mean yield components were obtained from treatment with the highest supply of water while the treatment with the lowest quantity produced the least mean yield components. This finding is also consistent with the result of [49] who reported that the highest yield components were obtained from treatment that received the highest supply of water while that received the lowest quantity produced the minimum average bulb weight of onion. In general, yield components were reduced significantly with decreasing applied irrigation, which might be due to water shortage. This shows the response of the crop to deficit irrigation and as applied water increased the average weight of onion bulbs increased [32]. [27] also reported that the highest yield components were obtained from 100%ETc which received the maximum amount of water while 50%ETc gave the smallest diameter which received the least amount of water.

Table 9. The effects of a deficit on the yield and yield components of onions.

Deficit level	Bulb Weight (gr)	Bulb Height (cm)	Bulb Diameter (cm)	Yield of onion (t/ha)
100%ETc	117.9 ^a	5.7 ^a	6.4 ^a	34.8 ^a
75%ETc	110.3 ^b	5.4 ^b	5.9 ^b	30.9 ^b
50%ETc	79.9 ^c	5.0 ^c	4.8 ^c	21.8 ^c
LSD (0.05)	1.3	0.2	0.2	1.5
P	**	**	**	**
C.V	1.0	2.9	3.4	4.2

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 $P < 0.01$.

4.4. The Effects of Mulch Types on Growth, Yield, and Yield Components of Onion

4.4.1. The Effects of Mulch Types on Growth Components of Onion

Analysis of variance showed that significant all growth parameters of onion were significantly affected by mulch types ($P < 0.01$). All growth parameters of onion were highest in RSM treatment compared to WPM and NM treatments. The highest plant heights, leaf height, and leaf numbers of onions were 51.9cm, 40.6cm, and 10.1 respectively recorded from RSM treatments. In contrast, the minimum plant height, leaf heights, and leaf number of onions were 41.5cm, 31.1cm, and 7.5 respectively, recorded from WPM treatments (Table 10). It could be the white plastic mulch increase the surface temperature and reflect solar energy above the optimal level. Due

to this the plant leaf was burned and dry. It was observed that straw mulch prevented the emergence and regrowth of weeds. It, therefore, reduced the competition for nutrients while plastic mulch was observed to accelerate the emergence and regrowth of weeds. It, therefore, increases the competition for nutrients. This result agreed with the result of [66] who reported that maximum plant height and maximum leaf height are observed in plots mulched with straw. This result agrees with the results of [67] which indicates that the negative impacts of plastic mulch decrease growth components and reduce the activity of soil microorganisms. In improving the soil nutrient status straw mulch is more effective than plastic mulch [68]. This result agreed with the results of [69] stated that white plastic mulch gave the minimum number of leaves compared with other mulch types. Straw mulches significantly increased the net photosynthetic rate of leaves more than other mulch types during the whole growth season [70].

Table 10. The effects of mulch types on growth components of onion.

Mulch types	Plant Height (cm)	Leaf Height (cm)	Leaf Number (No.)
No mulch	45.4 ^b	33.4 ^b	8.6 ^b
Rice straw mulch	51.9 ^a	40.6 ^a	10.1 ^a
Plastic mulch	41.5 ^c	31.1 ^b	7.5 ^c
C.V	5.1	6.7	5.5
P-level	**	**	**
LSD (0.05)	2.9	2.8	0.6

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 $P < 0.01$

4.4.2. The Effects of Mulch Types on Yields and Yield Components of Onion

The analysis of variance showed that the marketable yield of onion was significantly affected by mulch type at ($p < 0.01$). The maximum marketable yield of onion was recorded at rice straw mulch (RSM) and it was statistically superior to plastic and no mulch (NM). On the other hand, the lowest marketable yield of onion was obtained at no mulch (NM), and this was statistically similar to that of white plastic mulch (WPM) for onion (Table 11). The marketable yield of onion was 31.7, 28.3, and 27.5 t/ha, respectively, in RSM, WPM, and NM treatments. It implies that the marketable yield in RSM treatment was 15.3 % higher than NM and 12.0% higher than WPM treatment. The result indicated that mulching with RSM did significantly improve the yield of onion. These results show that the onion yields significantly increased with the application of rice straw mulch. This result was in line with the result of [71, 72] who reported that

the RSM increased the bulb yield of onion. Crop yield significantly increased with the application of rice straw mulch [62]. This result agreed with the result of [73] who stated that mulching with plastic material gave an onion yield increase of about 12–15% compared to a no-mulch condition. These results suggest that straw mulching has great potential for improving onion yield [64]. In contrast, the analysis of variance showed that the yield components of onion were significantly affected by mulch type. Greater bulb weights and sizes were achieved from RSM. The highest mean bulb weight, bulb height, and bulb diameters 106.2gr, 5.8cm, and 6.0cm were obtained from the treatments of mulched RS respectively. Whereas the lowest mean bulb weight, bulb height, and bulb diameters 100.7gr, 5.0cm, and 5.3cm were obtained from NM treatments respectively. However, there was no significant difference between WPM and NM on the average bulb weight of onion (Table 11). This result is in line with [74] who reported maximum bulb weight in straw mulch followed by plastic mulch and no mulch treatment. The rice straw mulch increased all previous yield components [75]. This study was

in line with the result of [76] who stated that plants grown with straw mulch gave higher yield components. This result agreed with the result of [77] who reported that organic

mulching can improve bulb quality due to enhancing higher nutrient availability to the plants.

Table 11. The effects of mulch type on yield and yield components of onion.

Mulch types	Bulb Weight (gr)	Bulb Height (cm)	Bulb Diameter (cm)	Yield of onion (t/ha)
No mulch	100.7 ^b	5.0 ^c	5.3 ^c	27.5 ^b
Rice straw mulch	106.2 ^a	5.8 ^a	6.0 ^a	31.7 ^a
Plastic mulch	101.1 ^b	5.3 ^b	5.7 ^b	28.3 ^b
C.V	1.0	2.9	3.4	4.2
P-level	**	**	**	**
LSD (0.05)	1.3	0.2	0.2	1.5

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 5% level of significance. ** =significant at P < 0.01

4.5. The Interaction Effects of Deficit Irrigation and Mulch Types on Growth, Yield and Yield Components of Onion

4.5.1. The Interaction Effects of Deficit Irrigation and Mulch Types on Growth Components of Onion

The interaction effect of mulch type with deficit level on plant and leaf height was not significant, while leaf number per plant was significantly affected by the interaction effects of deficit levels with mulch type. The highest leaf number 12.5 was obtained from 100%ETc with RSM, while the lowest leaf number was obtained from 50%ETc with WPM treatment combinations. No significant difference was observed among treatments in plant height of onion from 100%ETc with NM, 100%ETc with RSM, and 100%ETc with

RSM. In addition, no significant effect was found in the plant height of onion treatments 100%ETc with RSM and 75%ETc with RSM (Table 12). Similarly, there is no statistically significant difference between 100%ET and 75%ETc with RSM. The result indicated that when treatments mulch with plastic plant and leaf height was lower whatever the irrigation depth was used. This may be due to the white plastic mulch reflecting the solar energy to the surface due to this reason the plant leaf was burned. This result agrees with the finding of [77] reported that the leaf height was not significantly affected by the interaction between mulching materials with deficit irrigation treatments. The results were also consistent with the findings reported by [78] plant height, which was not significantly affected by an interaction between mulching materials and irrigation level. These results were in line with the result of [75] stated that plastic mulch significantly affected the absolute growth rate of onions.

Table 12. The interaction effects of mulch and deficit on growth components of onions.

Treatments	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
100%ETc×NM	51.5 ^{ab}	36.1 ^{bc}	9.8 ^b
75%ETc×NM	45.9 ^c	35.5 ^c	9.1 ^{bc}
50%ETc×NM	39.0 ^{cd}	28.4 ^{de}	7.0 ^{de}
100%ETc×SM	57.9 ^a	43.6 ^a	12.5 ^a
75%ETc×SM	53.2 ^a	42.8 ^{ab}	9.9 ^b
50%ETc×SM	44.7 ^{bc}	35.4 ^b	7.9 ^{cd}
100%ETc×PM	45.9 ^{bc}	34.3 ^{cd}	8.9 ^{bc}

Treatments	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
75%ETc×PM	43.9 ^c	35.1 ^{cd}	7.7 ^{cd}
50%ETc×PM	34.7 ^d	23.9 ^e	5.9 ^e
C.V	5.1	6.7	5.5
P level	-	-	*
LSD (0.05)	NS	NS	1.4

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 $P < 0.01$

4.5.2. The Interaction Effects of Mulch Types and Deficit Irrigation on Yield and Yield Components of Onion

The ANOVA results showed that the marketable yield of onion and tomato was significantly affected by the interaction effects of deficit irrigation and mulch types at ($p < 0.05$). The highest and lowest marketable yield of onion (37.3t/ha) and (19.7t/ha) was obtained from 100ETc with RSM and 50%ETc with NM treatments respectively. However, 100ETc with RSM was no significant difference observed compared to 100% with NM and 75%ETc with the RSM treatment combination. On the other hand, no significant difference was observed between in marketable yield of onion at 100%ETc and 75%ETc with WPM, and 75%ETc with RSM treatment combinations. The marketable yield of onion was 37.3, 34.7, 32.4, and 33.9 t/ha, respectively, in 100%ETc with RSM, NM, WPM, and 75%ETc with RSM treatment combinations. It implies that the marketable yield of onion at 100%ETc with RSM was 7.5% higher than 100%ETc with NM, 15.1% higher than 100%ETc with WPM, and 10% higher than 75%ETc with RSM treatment combinations. These results showed that RSM improves yield productivity for onion without yield penalty at a 25% deficit level. These results showed that there was no yield advantage observed using 100ETc with no mulch. The yield improvement with RSM with deficit levels might be due to the enhanced availability and release of nutrients from decomposed rice straw mulched, improved soil properties, increased soil water holding capacity leading to good aeration and better root growth, and enhanced nutrient absorption by onion plants. However, the yield declined with white plastic mulch due to an increase in the emergency and the regrowth of weed population, poor aeration, and burned the leaf of the onion, these affect the photosynthetic activity, and due to this the weed population, there was higher nutrient competition in the WPM treatment. This result is in line with the findings of [49] who explained that RSM significantly improved onion bulb yields by 17% over no-mulch plots. The results were also consistent with the findings reported in [49] indicated that

straw mulch gave a higher marketable bulb yield while plastic mulch recorded a lower marketable bulb yield. The results were consistent with the results of [61] stated that the bulb yields of the treatments irrigated at 75%ETc with mulch were not statistically significantly different from those that were 100 ETc with mulch. These results also agreed with the result of [56] who stated that the minimum yield was recorded from 50%ETc with NM. This result also agreed with the result of [49] who reported that in terms of yield, irrigating up to 80%ETc with RSM can be recommended for the production of onion. This result is also consistent with the result of [17] who stated that the marketable yield of onion was significantly higher under 100%ETc with RSM being used. The bulb yields under WPM were not significantly different from a no-mulch condition [63]. The lowest yield of onion was recorded from 55%ETc with no mulch [56, 69]).

Similarly, the highest bulb weight, bulb height, and bulb diameter of the onions 121.8 gr, 6.2, and 6.8 were obtained when the onions received full irrigation and mulched with RS while the lowest average bulb weight, bulb height, and bulb diameter of the onion 77.3gr, 4.6cm, and 4.1cm were obtained from 50%ETc with NM treatment combination (Table 13). No significant difference was observed among treatments in bulb weight of onion 100%ETc with NM and 75%ETc with RSM treatment combinations. Similarly, no significant difference was found in the bulb height of onion at 100%ETc and 75%ETc with RSM whereas no significant difference was observed among treatments in bulb diameter of onion 100%ETc with NM, 100%ETc with WPM, and 75%ETc with RSM treatment combinations. No significant difference was observed between treatments in bulb height of 100%ETc with WPM and 75%ETc with RSM treatment combinations. Also, no significant difference was observed in bulb height between the treatments of 100% and 75%ETc mulch with RSM treatments. The result indicated that the bulb size of the onion was affected by the amount of water applied and the mulch material. Even if we use any type of mulch, the bulb size will also decrease as the irrigation water depth decreases. This result is in line with [49] who reported maximum bulb size in straw mulch while minimum bulb was at 50%ETc with plastic mulch and no mulch treatment combinations. This result also

agreed with the result of [55] who stated that the interaction effects of deficit irrigation with mulch significantly influenced the bulb size of the onion. This result agreed with the result [44] who reported that organic mulching can improve bulb quality

due to enhancing higher nutrient availability to the plants. This result was in line with the result of [33] who stated the best quality of the onion bulb in respect of the maximum diameter of the bulb was obtained when mulching was done with rice straw.

Table 13. The interaction effects of mulch and deficit on yield and yield components of onions.

Treatments	Bulb Weight (gr)	Bulb Height (cm)	Bulb Diameter (cm)	Yield of onion (t/ha)
100%ETc×NM	114.9 ^{bc}	5.3 ^{cd}	6.1 ^b	34.7 ^{ab}
75%ETc×NM	110.0 ^d	5.0 ^{de}	5.5 ^{cd}	28.1 ^d
50%ETc×NM	77.3 ^f	4.6 ^e	4.1 ^e	19.7 ^f
100%ETc×SM	121.8 ^a	6.2 ^a	6.8 ^a	37.3 ^a
75%ETc×SM	113.6 ^c	5.9 ^{ab}	6.1 ^b	33.9 ^{abc}
50%ETc×SM	83.2 ^e	5.3 ^{cd}	5.2 ^d	24.0 ^e
100%ETc×PM	116.9 ^b	5.6 ^{bc}	6.1 ^b	32.4 ^{bc}
75%ETc×PM	107.3 ^d	5.2 ^{cd}	5.9 ^{bc}	30.7 ^{cd}
50%ETc×PM	79.2 ^f	5.1 ^d	5.0 ^d	21.7 ^{ef}
C.V	1.0	2.9	3.4	4.2
P level	**	*	*	*
LSD (0.05)	3.1	0.4	0.6	3.6

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 $P < 0.01$

4.6. The Effect of Mulch and Deficit Irrigation on Yield Response Factor

The study reveals that a lower yield response factor (ky) of 0.5 and 0.0 was achieved from 75%ETc with RSM for both onion and tomato respectively. The result indicated that the ky was associated with deficit level and mulch types. At 100%ETc were no recorded yield response factors (Table 14). Because the actual amount of water applied at 100%ETc was similar to ET_m, the result was one. In this study the Ky of the onion crop under no mulch condition was higher (1.0), this result agreed with [39] reported that Ky of the onion crop under no mulch condition was 1.1. 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. The result of the treatments showed as the deficit increased the sensitivity of yield increased.

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

Treatment	Yield kg/ha	ET _a	ET _a ET _m	Y _a Y _m	1- Y _a Y _m	1-ET _a ET _m	K _y = 1-(Y _a /Y _m) 1-(ET _a /ET _m)
100%ETC×NM	34722	413.7	1.0	0.9	0.1	0.0	-
75%ETC ×NM	28125	318.2	0.8	0.8	0.2	0.2	1.0

Treatment	Yield kg/ha	ET _a	ET _a ET _m	Y _a Y _m	1- Y _a Y _m	1-ET _a ET _m	K _y = 1-(Y _a /Y _m) 1-(ET _a /ET _m)
50%ETC × NM	19688	222.6	0.5	0.5	0.5	0.5	1.0
100%ETC × SM	37292	413.7	1.0	1.0	0.0	0.0	-
75%ETC × SM	33854	318.2	0.8	0.9	0.1	0.2	0.5
50%ETC × SM	23958	222.6	0.5	0.6	0.4	0.5	0.8
100%ETC × PM	32361	413.7	1.0	0.9	0.1	0.0	-
75%ETC × PM	30729	318.2	0.8	0.8	0.2	0.2	1.0
50%ETC × PM	21701	222.6	0.5	0.6	0.4	0.5	0.8

5. Conclusion and Recommendations

Water scarcity is the main challenge in current sub-Saharan African countries including Ethiopia. To mitigate those challenges on farms water saving strategies should be implemented to increase yield and water productivity. In the main effects of deficit irrigation, the marketable yield of onion in 75%ETc was 12.6% lower than 100%ETc, Whereas, the marketable yield of onion in RSM was 15.3% higher than NM and 12.0% higher than WPM. In the combined effects of mulch and deficit irrigation, the marketable yield of onion in 100%ETc with RSM was 7.5% higher than 100%ETc with NM, 15.1% higher than 100%ETc with WPM, and 10% higher than 75%ETc with RSM treatment combinations. On the other hand, 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. Deficit irrigation strategies are recommended for use by farmers and extension workers to achieve optimum onion yield and yield components by applying at 75%ETc through growth phases saving water 25% of the water requirement. Smallholder farmers should apply RSM practices to increase onion yields and save water under conservation agriculture. Onion growers are highly advised to cover their crops with RSM and apply 25% deficit irrigation instead of full irrigation to achieve higher onion yields. Adoption of water-saving strategies by smallholder farmers during 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 in the yield of onion and tomato in water shortage areas of the country.

Conflicts of Interest

The authors declare no conflict of interest.

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