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The productivity of Maize (Zea mays L.) water using efficacy and consumptive use under different irrigation systems

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ABSTRACT

Under conditions of freshwater scarcity in Iraq, farmers are looking to adopt more effective irrigation methods compared with conventional. In 2016 and 2017, a field experiment was performed over two years to evaluate optimal irrigation method for maize *Zea mays L.* production using a Randomized Completely Bloke Design RCBD with five irrigation furrow treatments I0, surface drip I1, and subsurface drip with three depths of emitter 10cm I2, 20 I3, and 30cm I4 respectively. These treatments were irrigated when 50- 55% of the available water was depleted; then, a sensor system was utilized to identify the required water amount to bring the soil in the crop root area to the capacity field. The results indicated that the consumptive water use of furrow 707.91 and 689.69 mm surface drip 558.65 and 529.66 mm and subsurface drip with emitter deep at 10 cm 400.38 and 380.83 mm, 20cm 313.93 and 293.50 mm and 30cm 345.61 and 325.28 mm for 2016 and 2017 respectively. Subsurface drip irrigation increases crop yield; the greatest yield grain was optioned under the treatment subsurface drip irrigation with 20 cm emitter depth and the lowest under surface drip irrigation.

Keywords: Consumptive use, Maize Production, Subsurface Drip, and Furrow irrigation.

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1. Introduction

Like many semi-arid and arid zones of the world, Iraq faces a critical shortage of fresh water suitable for irrigation. This shortage is due to climatic change, an increase in water use for municipal and industrial purposes, and water policies of neighboring countries that limit the water flow in the Tigris and Euphrates Rivers. All these reasons lead to a decrease in the share of agriculture from that water [1]–[3]. This threatens crops' cultivation and, thus, the supply of food [4]–[6]. All these factors are pushing farmers to adopt more appropriate irrigation methods than the traditional ones to achieve more water using efficacy, which is the main goal of irrigation in arid regions [7], [8]. Maize *[Zea mays L.]* is one of the most produced cereal crops in Iraq. It is the fourth important one after wheat, barley, and rice. The cultivated areas were [57259 and 75992 ha] with production [182340 and 259546 ton ha^{-1}] in 2015 and 2016, respectively [9]. Maize is a summer crop that belongs to C4 plants, and it is characterized by fast growth and their potential in dry matter accumulation. Thus, it is a high water consumer [10]–[12]. Thus, underwater scarcity, the cultivated area will have little productivity causing a shortage in the produced amount. Iraqi farmers have been practicing traditional irrigation methods [raised - bed, furrow, basin, border…. etc.] for maize production, the growing season coincides with the hottest months [July, August, and September]. This raises their seasonal water requirements, in the range from 600 to 900 mm [13], [14]. Recently, controllable irrigation systems such as drip [surface and subsurface] have received increased attention in scientific research or/and farming practices to reduce the amounts of water, fertilizer, and herbicides spread on the crop [15]. Consequently, the results of many previous studies [enumerate the studies] that drip irrigation practices [surface and subsurface] indicated that the water use of maize was 300 – 600 mm [16]–[18]. Therefore, this reduction in the amount of water use compared to the traditional method lead to a significant increasing in water using efficacy [WUE] of the maize as it increased from 1.42 kg/m^3 under furrow irrigation to 3.2 kg/m^3 under sub-surface drip irrigation [19]–[21]. This project aims to assess the subsurface drip as an alternative comparative with traditional methods and determine its effect on growth, yield, consumptive use, and water using the maize's efficacy under the situations of the typical region in Iraq.

2. Materials and work methodologies

2.1. Location description

The field experiments were carried out during 2016 – 2017, the growing season in Al-Yousifya, 15 km southwest of Baghdad - Iraq at the geographic coordinates: 44° 18' 75'' E and 33° 07' 84''Nand 34m altitude as in Figure 1. The soil of the field is classified as Typic-Torriflovent, and the texture is silt clay. The climate in the middle of Iraq is arid - semi arid. It is very hot, and no rain falls during the summer [a crop growing season]. The weather data of Al-Yousifya Region are given from Al-Raeed weather station located 5000 m away from the investigational location; The Berman-Monteith equation was used to measure total Evapotranspiration ET_o [22] using the Cropwat program [23]; typical measurements are illustrated in Figure 2.

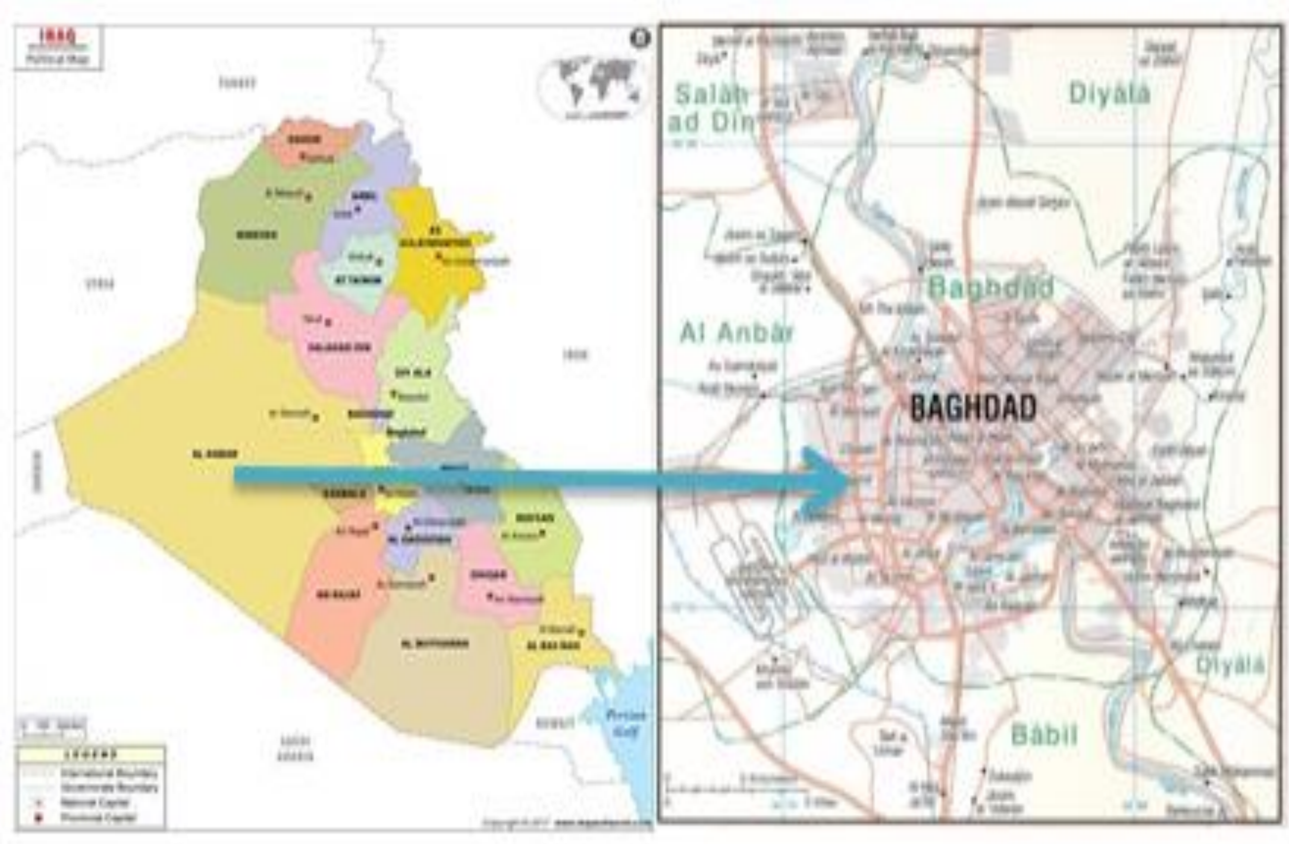
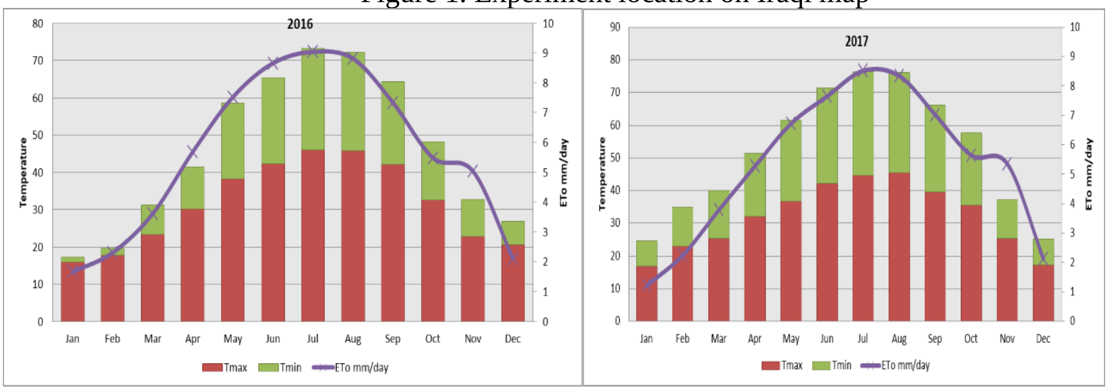


Figure 1. Experiment location on Iraqi map



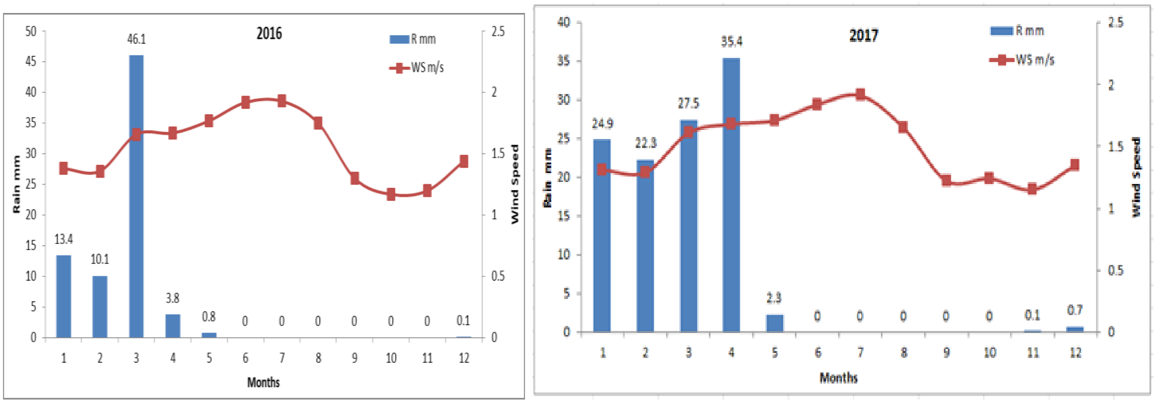


Figure 2. Temperature, total evapotranspiration rain and wind speed for seasons of Maize in 2016 and 2017

2.2. Land preparation and soil sampling

Residual of the previous crop [wheat] was removed from the field by a hay collector and then plowed twice perpendicularly by using a moldboard plow harrowed and then leveled. The basic soil properties [chemical, physical, and hydraulic] were determined by randomly taking soil samples for depth [0-30cm]. The soil analysis results have been listed in Table 1.

Table 1. Selected Physical and Chemical characteristics of Investigational Soil

Characteristics		**2016**	**2017**
		Soil depth 0 -30 cm	**Soil depth 0 -30 cm**
EC	DSM-1	3.2	3.6
pH		7.6	7.8
Sand	%	122	115
Silt		624	648
Clay		254	237
Texture		Silt Clay	Silt Clay
Organic Matter	%	4.50	3.73
Bulk Density	$mg.m^{-3}$	1.38	1.39
Particle Density		2.58	2.60
Porosity	%	48	49
Water Amount at 33 kPa	cm^3cm^{-3}	0.3361	0.3368
Water Amount at 1500 kPa		0.1777	0.1779
Existing Water		0.1584	0.1589

3. Experimental Remediation

The experiment has been carried out using a completely Randomized block design [RCBD] with three tries that included five irrigation method treatments to become fifteen experimental units. The experimental unit area was $20m^2$ (4m wide X 5m long). The irrigation treatments were as irrigation of surface drip [I_1], furrow [I_0], and irrigation of subsurface drip with three patterns of emitter depth [10, 20=and 30 cm], which was assigned I_2, I_3, and I_4, respectively. The experimental units were separated by 2 m wide to prevent water leakage between them as in Figure 3.

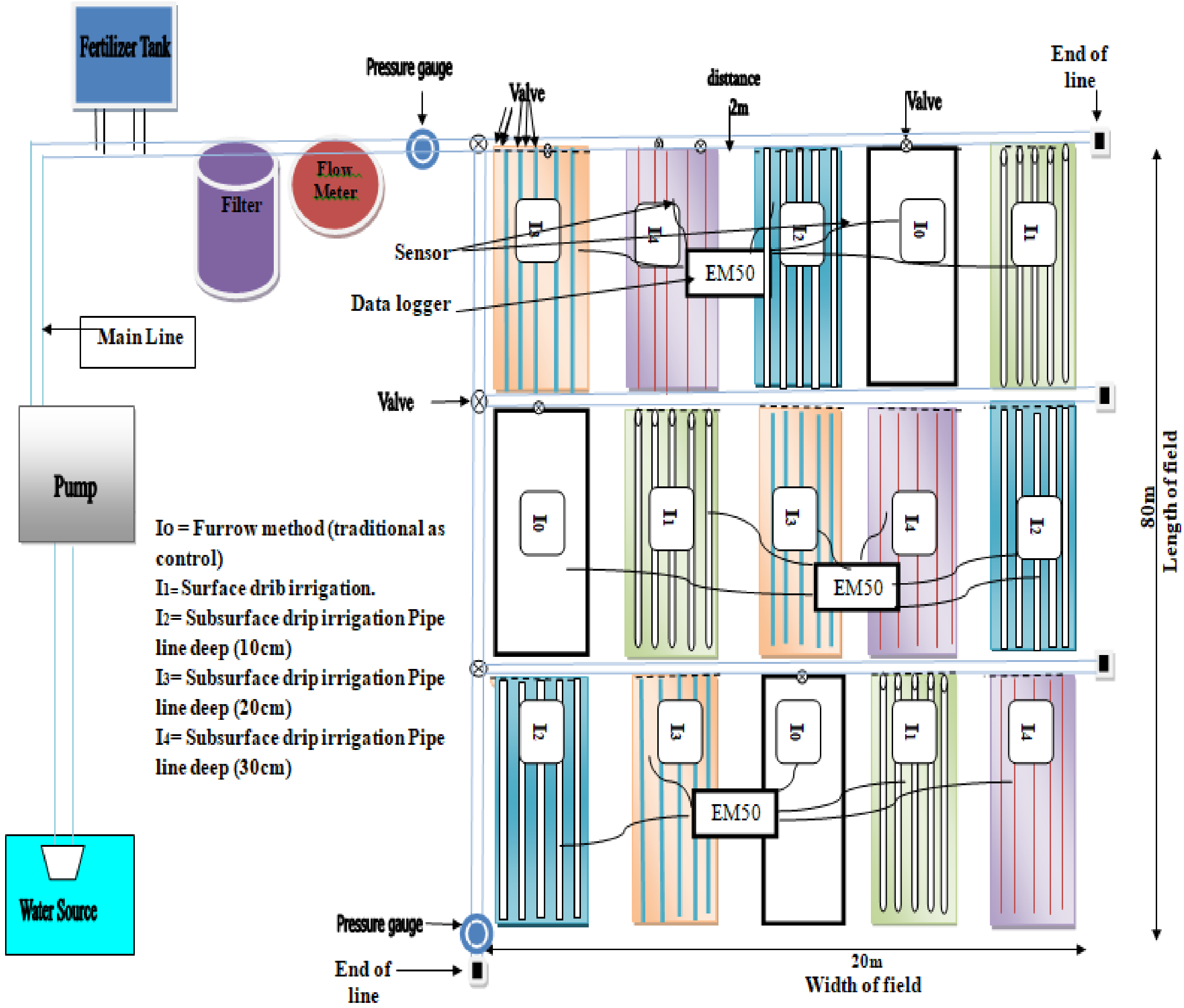


Figure 3. Layout of experimental treatments that includes five irrigation methods [I_0, I_1, I_2, I_3, and I_4] and distribution of irrigation systems

3.1. Agronomic practices

The experimental units were fertilized according to the agricultural extension recommendation of the experiment region by adding 200 kg/ha[1] of Diammonium phosphate [DAP] fertilizer [18: 46: 0], while nitrogen fertilizer was added as urea [46% N], and in the amount of 200 kg/ha[1] and two equivalent shares, the first at V_6 stage and the second at V_{12} stage the growth stages were determined according to [24]–[26]. Maize seeds [Kalimeras hybrid F1] were planted on the 7th August 2016 and 2017 seasons, respectively, by planting two seeds per hole; after an emergency, and established well. It was thinned to one seedling per hole. The planting distances were 0.7m between the rows and 0.2 m between plants in every row. Weeding was handily done; whenever needed, insect [*Sesamia cretica*] was truncated using granular diazinon [10%]. The harvest was performed about 122 days after planting.

3.2. Irrigation treatments and Scheduling

The irrigation scheme consisted of a furrow, surface drip, and subsurface drip [10, 20, and 30 cm emitter deep]. Initially, the furrow plots are irrigated because they were sown on rows of a flat plot, and after thirty days, the furrowing was performed between rows of plants using a furrower machine. The tube system applied the irrigation with valves and flow-meter to determine the water amounts applied to each experimental unit. In contrast, surface [DI] and subsurface [SDI] drip irrigation treatments were irrigated by drip system [Ro drip the desired spacing 10cm which controls the release of the desired quantity of water 1.5 L.h^{-1} under 1.5 bar pressure that manufactured by John Deer company the USA]. The system consisted of a PVC main supply pipe of 2 inches and a sub-main of 1.5 inches. The sub-main pipe of SDI was divided into five lateral lines buried beside the plants' rows for surface and buried under plants rows for subsurface [at three depths 10, 20, and 30 cm]. Each line had fifty emitters. The uniformity parameters chosen to evaluate the drip irrigation system are statistical Distribution Uniformity [DU] and Coefficient Uniformity [CU], which have been determined by utilizing the following equations [27]:

$$Cu = 100\left[1 - \frac{\Sigma x}{Mn}\right] \qquad 1($$

Where: Cu% = Uniformity coefficient as a percentage,

$\sum x$ = total deviations from the discharge rate [h cm^{-3}]

M = Average discharge raster's [h cm^{-3}]

n = Number of raster

Uniformity distribution [DU] using the following equation [28]:

$$DU\left(\frac{1}{4}\right) = \left(\frac{D_{iq}}{D_{ac}}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: DU [1/4] = Uniformity distribution for the lowest quarter [%]

Diq= Average water depths for the lowest quarter

Dac = The average of water depths

The proportion of variance conjugations emitters also measured by using the following equation [29]:

$q_{Net} = [q_{Max} - q_{Min}] / q_{Max}$ (3)

Where: q_{Net}% = proportion of variance conjugations drippers

q_{Max}= maximum discharge, [L/h]

q_{Min}= less discharge [L/h]

The evaluation system results indicated that the adoption of pressure 150 kPa gave the highest coefficient of homogeneity that was 97.4%, uniformity distribution for the lowest quarter and was 99.3% at the lowest rate variation in the discharge of drippers was 9.8%. Irrigation arrangement is depending on the depletion of 50% existing water at three depths of soil [0 - 10, 10 – 20 and20 - 30 cm] depending on the plant growth stages in which the root depth is associated; the first depth was 0-10 cm which coincides with initiation stage, 0-20 cm with vegetative stage and 0-30 cm with reproductive. The moisture depletion was monitored by a sensors system [manufactured by Decagon Devices Company, USA], which is consisted of two data loggers connected to five sensors [type GS3]. The sensors were buried inside the experimental units' soil and reading and recording volumetric, and this was done every three hours. Irrigation frequency after depletion of 50 % of available soil water that determined according to the following equation [30]:

$$Aw = \theta fc - \theta wp \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Whereas: AW = Available Water content in the soil [cm ^{3}cm^{-3}]

θfc=Volumetric water amount at capacity field [cm^{3}cm^{-3}]

θwp= Volumetric water amount at point wilting [cm^{3}cm^{-3}]

While the water amount of furrow irrigation treatment was calculated according to the following equation [31]:

$$d = (\theta_{FC} - \theta_w)D \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where d = irrigation depth [mm]

θ_{FC} = Volumetric moisture at field capacity

θ_W = Volumetric moisture before re- irrigated [depletion 50% of available water]

D = Effective root depth [mm].

The applied water amount to experimental plots by an organization of drip irrigation was calculated according to the following equation [32]:

$$NDI = RZD \ x\ WHC \ x\ Pd \ x\ \ pw \qquad \ldots\ldots\ldots\ldots\ldots (6)$$

Whereas: NDI = Net Depth of Irrigation [cm]
RZD =Depth of Root Zone [cm]
WHC= Water Holding Capacity [mm of water. cm^{-1}] = FC—WP
Pd = Percentage depletion, Pw =Percent of wetting [%].
Water Consumptive use [evapotranspiration] of the crop has been determined by utilizing the following water balance formula [22]:

$$(I + P + C) - (ET_a + D + R) = \mp \Delta s \ldots \ldots (7)$$

$$I + P - ET_a = \pm \Delta s \ldots \ldots (8)$$

In this study, the soil-water amount at the start of the study is close to its amount at the end of the experiment ΔS=0. Furthermore, the total amount of precipitation throughout the Maize's growing seasons (Fig. 2) is insignificant (up to 1 mm). With such an amount, precipitation did not affect the corn yield; the water consumptive use equation becomes as follows:

$$I = ET_a \ldots \ldots \ldots \ldots \ldots (9)$$

Water use efficiencies were calculated according to the following equation [33]:

$$WUE_f = \frac{Y}{ETa} \ldots \ldots \ldots \ldots (10)$$

Where: WUE_f= water using efficacy
Y= yield grain [kg ha^{-1}]
ETa= actual evapotranspiration [mm].

3.3. Statistics Analysis:

The data have been analyzed utilizing a single parameter variance analysis [Anova] for RCBD by least significance differences [LSD] where p higher than 0.05 table 2. The SAS program [34] was used to achieve statistical analysis.

Table 2. Variance Analysis (mean square) of investigated characters of maize with irrigation methods in 2016, 2017 seasons

Variation Source	d.f	Height of Plant	Area of Leaf	Leaf area index	Root dry weight	Grains' number per ear	Weight of 500 grains	Yield's Grain
2016								
Blocks	**2**	1.40*	24360.26*	0.05*	0.22	0.95	0.38*	0.15*
Irrigation	**4**	816.50*	1590409.24*	0.33*	284.00*	5839.42*	151.03*	5.77*
Error	**8**	1.65*	22039.29*	0.01*	1.69*	19.87*	0.06*	0.04*
Total	**14**							
CV		0.55	2.86	2.80	3.01	0.44	0.17	2.06
Sȳ		1.04	121.21	0.08	1.06	3.63	0.2	0.1
2017								
Blocks	**2**	32.06*	482.02*	0.02*	0.10	14.68	0.22*	0.03*
Irrigation	**4**	838.58*	1380479.22*	0.38*	307.80*	6453.75*	124.71*	6.02*
Error	**8**	5.78	579.85	0.02	0.51	18.77	0.01	0.02
Total	**14**							
CV		1.70	0.38	5.82	2.46	0.94	0.16	2.90
Sȳ		1.96	19.66	0.11	0.58	3.53	0.08	0.11
Note	**C.V: Coefficient of Variation** **Sȳ: Standard Error** *** : Significant at 0.05**							

4. Results and discussion

The amounts of water given to the maize plants under different irrigation methods are presented in this study in figures 4 and 5. The lowest amounts of water given to crop seasonally followed the subsurface drip irrigation method when emitters were placed at a depth of 20 cm [I_3]. It was recorded as 313.93 and 293.5 mm for the 2016 and 2017 seasons, respectively. The amount of water that given increased when the emitters are placed in the depth of 30 cm was 345.61 and 325.28 mm Because the plants' roots are concentrated in the surface layers of the soil, especially in the early growing stages, and since the presence of emitters at a depth of 30cm was required to increase the irrigation's number and the water quantities to ensure the delivery to the surface layers where the roots are spread compared with I_3 treatment and 10cm 400.38 and 380.83 mm for the 2016 and 2017 seasons; respectively. Many previous studies indicated that compared to traditional irrigation methods, irrigation water for maize production could be reduced by 35-55 % [15], [35]. The greatest water amount has been furrow irrigation [I_0] 707.91 and 689.96 mm and surface drip irrigation 558.65 and 529.66 mm for the seasons 2016 and 2017, respectively. The overall amount of water added in 2016 was slightly more than in 2017, and this is probably because the maximum temperature in September was [42.11C°] for the 2016 season, higher than the 2017 season that was [39.61c°] in addition to wind speed [1.30 and 1.22ms^{-1}] and then referenced ET0 850.5 and 790.1 mm for 2016 and 2017 seasons respectively. All these facts are presented in the meteorological data in figure 2. In September, there is much effective maize growth and increases the rate of accumulation of dry matter, and the plant reaches the flowering stage to require the maximum daily water usage. The soil characteristics determine the crop's water irrigation amount and its frequency, climatic factors, plant growth stage, and anatomical and morphological characteristics [36]. The amount of water taken by the roots from the soil to be transferred to the shoot is determined by soil moisture content and its distribution in the rhizosphere, the size and depth of those roots, their ability to absorb water growth rate, and the size of the shoot [37]. The amount of water transpired by stomata is determined by the level of deficit evaporation pressure in the atmosphere surrounding the plant. The subsurface drip irrigation provides good moisture uniformity at the rhizosphere. It decreases the evaporation loss and runoff and deep percolation with furrow irrigation compared with surface drip [38], and this led to a decrease in the water requirements for the subsurface, especially I_3 treatment.

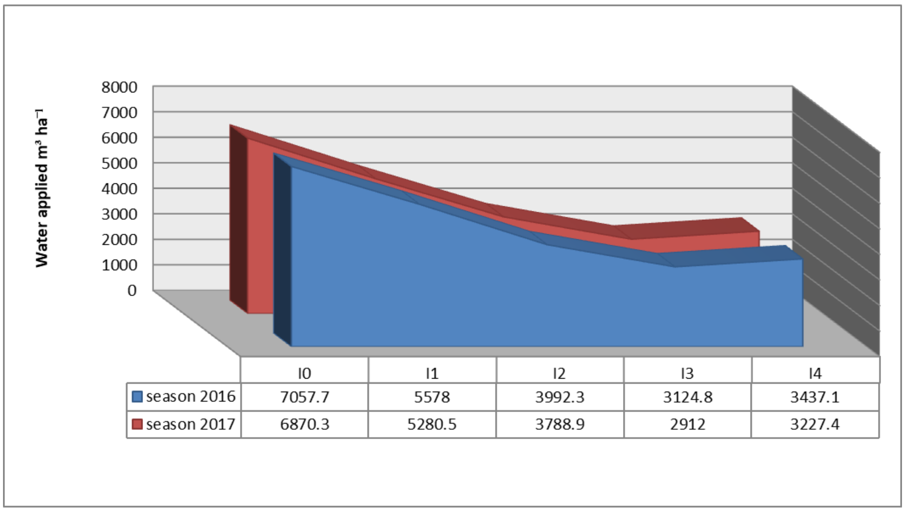


Figure 4. Water applied [m^3 ha^{-1}] of maize with irrigation methods in different seasons of 2016 and 2017

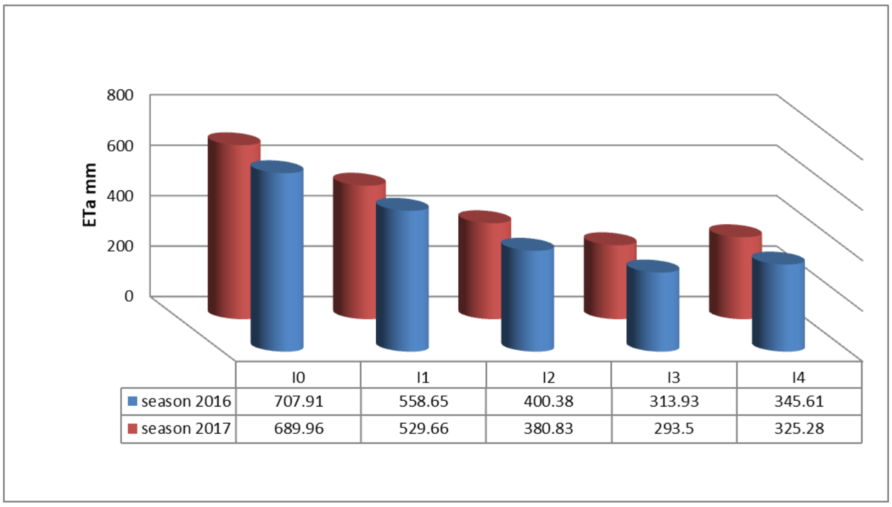


Figure 5. ETa [mm] of maize with irrigation methods in different seasons of 2016 and 2017

4.1. Factors of growth

Index of leaf zone, leaf zone, plant height, and roots dry weight in the two seasons of an experiment had significant effects of irrigation methods on an index of leaf zone, leaf zone, plant height, and roots dry weight. Figures 6, 7, 8, and 9 show that [I_3] gave the highest mean of plant height 191.6 and 196.6 cm leaf zone 5591 and 5485cm^2 index of leaf zone 2.93 2.86 and roots dry weight 45.58 and 46.81 gm plant^{-1} for 2016 and 2017 seasons; respectively. [I_1] showed the lowest value could be attributed to the application of subsurface drip irrigation, especially [I_3], which can provide conditions with high soil moisture content and good uniformity in the rhizosphere. In exchange, this eliminates the detrimental effects of water scarcity on plant growth that can accrue with other irrigation methods with good soil moisture content and distribution; the growth will be increased, followed by an accumulation of dry matter [39], [40].

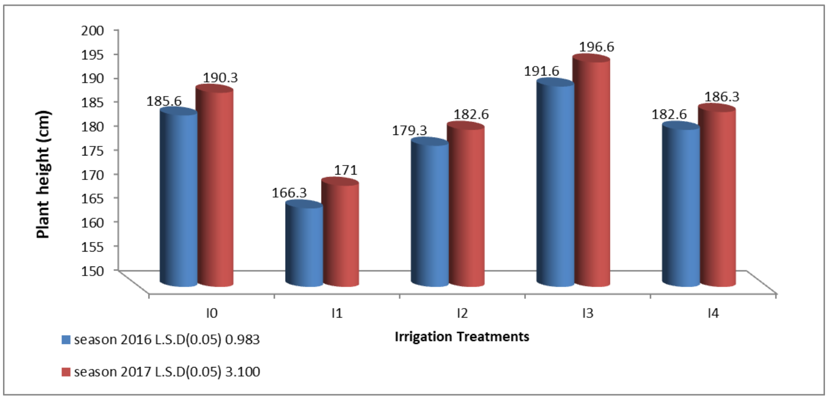


Figure 6. Plant height [cm] of maize with irrigation methods in different seasons of 2016 and 2017

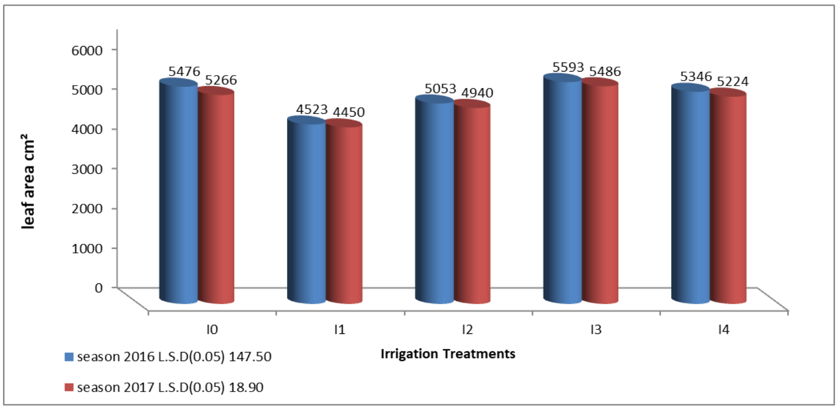


Figure 7. Leaf area [cm^2] of maize with irrigation methods in different seasons of 2016 and 2017

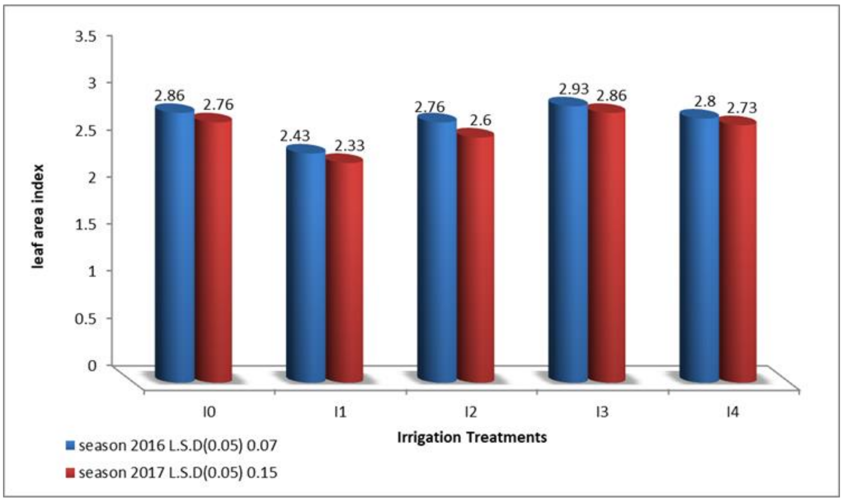


Figure 8. Leaf area index of maize with irrigation methods in different seasons of 2016 and 2017

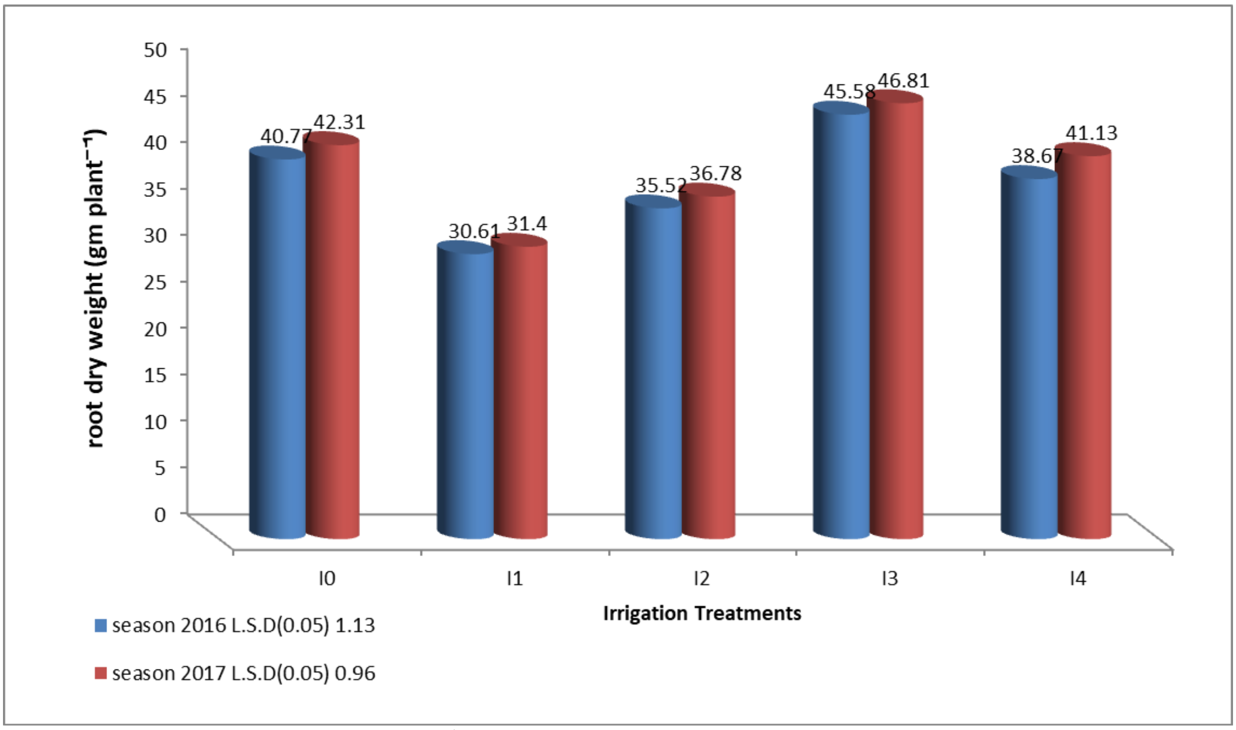


Figure 9. Root dry weight [gm plant^{-1}] of maize with irrigation methods in different 2016 and 2017

4.2. The grain yield and the yield components

The yield components [i.e., number of grain per ear and weight of grain] are presented in figures 10 and 11. The irrigation method affected yield component [i.e., number of grain and grain weight] for two seasons of this study, considering that each hybrid plant gives one ear. The results in figures 10, 11, and 12 show [I_3] gave the highest mean of the number of grains per ear [559.56 and 566.45], and for 500-grain weight [121.50 and 123.30 gm]; while, treatment I_1 gave the lowest mean of the number of grains per ear [450.29 and 464.31] and 500-grain weight [113.10 and 115.13 gm] for 2016 and 2017 seasons respectively. The available moisture to the plant is sufficient through the growing season and not exposed to water stress, especially in the critical stage of growth, which are the initiation and development of The number of grains, and their weight yield components, rows' number per ear is determined in the early vegetative stages [V8_ V11]. The ear takes its potential size in the V12 stage; in this stage [V8-V12] [41], [42], the potential number of rows and the number of grain site will be determined while the grain weight is determined from fertilization until physiological maturity that means filling duration [43]. The availability of nutrients enhances the plant's growth and the initiation and improvement of grain yield components associated with moisture availability. This is achieved with I_3, where the yield components are correlated with growth characteristics such as leaf area index and plant height. These are related to intercepted light and dry matter accumulation by photosynthesis. They differ according to the amount of assimilating allocated to the leaf development and the leaf area produced per leaves, dry of matter, and then affected to initiation and development of grain yield components [44]. Thus, the grain yield is related to its components [45], which were the best in I_3 treatments. Figures 10, 11, and 12. I_3 gave the highest mean of grain yield [8.50 and 8.76 t ha^{-1}] for the 2016 and 2017 seasons, respectively. The lowest mean of grain yield was with surface drip irrigation [I_1] was [6.36 and 6.66 t ha^{-1}] for the 2016 and 2017 seasons, respectively, due to the high temperature and the increase in the evaporation rates, figure 2. Increasing the rate of evaporation from the drop from the emitters instead of infiltration into the soil, therefore, the moisture provides the emitter on the soil surface is subject to the evaporation rather than their infiltration in the soil surface in addition to the increase in the moisture area in the rhizosphere which encages the root growth and spread over a wider area this confirmed by figure 9. that shows the dry weight of the roots in different irrigation treatments which is reflected in their efficacy in absorbing water and nutrients [46].

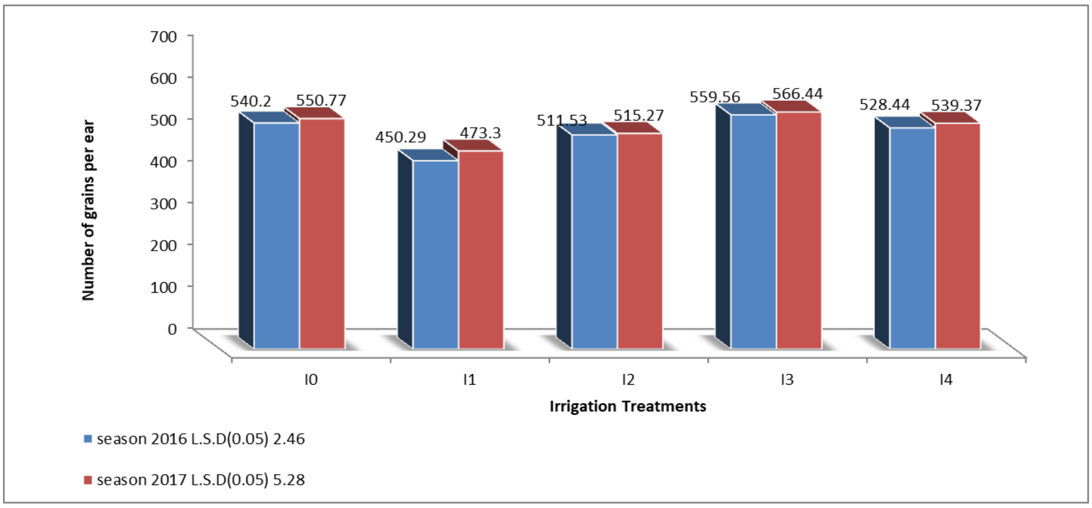


Figure 10. A number of grains per ear of maize with irrigation methods in different seasons of 2016 and 2017

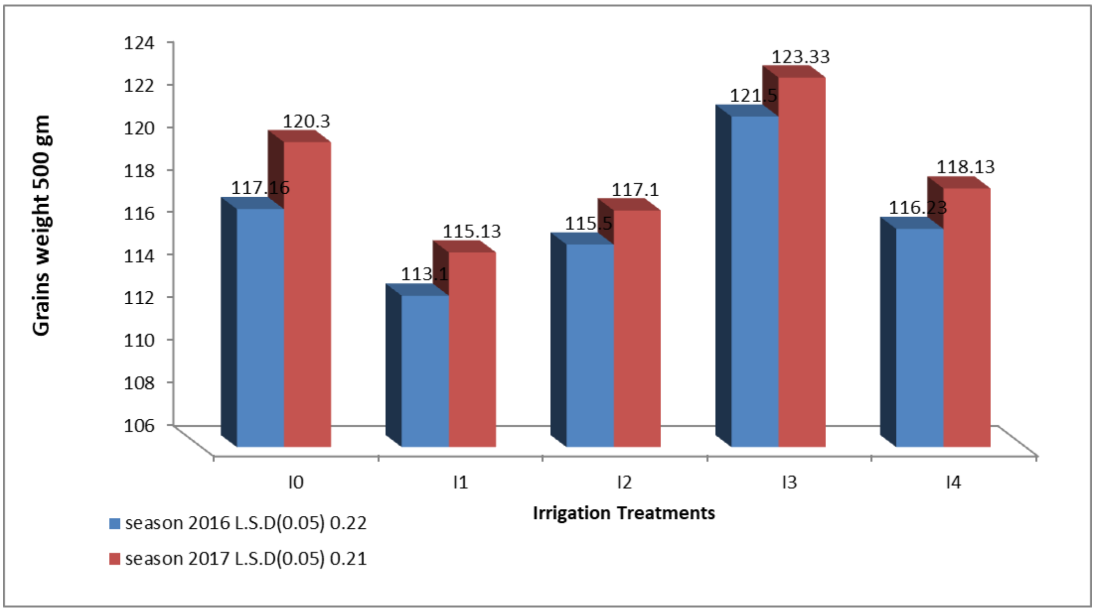


Figure 11. Grains weight 500 [gm] of maize with irrigation methods in different seasons of 2016 and 2017

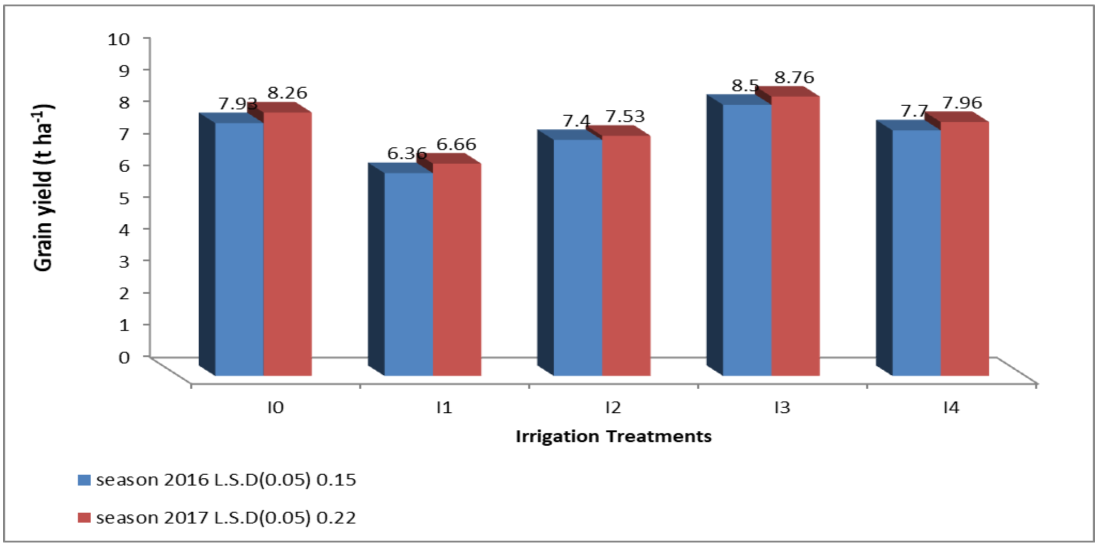


Figure 12. Grain yield [t ha^{-1}] of maize with irrigation methods in different seasons of 2016 and 2017

4.3. Water using efficacy [WUE]

Water using efficacy [WUE] in this study was presented in figure 13. There was a high difference between irrigation treatments for WUE. The 2- years results suggested that I_3 had WUE greater than other irrigation. [I_0, I_1, I_2, and I_4]. The mean value of WUE for [I_3] was 2.71 and 2.99 kg m^{-3} compared to I_0 [as a traditional method], which gave 1.12, 1.20 kg m^{-3} in 2016 and 2017, respectively. An increase in WUE is achieved by increasing grain yield or decreasing the amount of water used by a crop [47], [48]. In this study, I_3 used the lowest amount of water in the two seasons figure 5. Compared with the other treatments, the highest mean of grain yield was 8.50 and 8.76 t ha^{-1} in the 2016 and 2017 seasons, respectively. Besides, variations were found in the two seasons between the surface and sub-surface drip. Surface irrigation treatments I_1 gave the lowest mean of WUE 1.14 and 1.25 kg m^{-3} in the 2016 and 2017 seasons, respectively. This is since the high decrease of grain yield compared to subsurface treatments [I_2, I_3 and I_4], although I_1 used a high amount of irrigation water 558.65 and 529.66 mm ha^{-1} in 2016 and 2017 seasons, respectively. This result has the same trend as other results, as shown by [49], [50]. The results also showed that the emitter's depth was very The quantity of water consumption of the crop is important for determining and consequently the growth, grain yield, and finally WUE. Also, the results in figure 13. Although the furrow irrigation treatment I_0 as a traditional method gave a high mean of grain yield 7.93 and 8.26 t ha^{-1} it also gave a low WUE in the 2016 and 2017 seasons, respectively. Because the treatment used the highest amount of consumption water use since it was 707.91 and 689.96 mm ha^{-1} in 2016 and 2017 seasons, respectively comparison with comparison to subsurface drip irrigation treatments [I_2, I_3, and I_4] [51], [52].

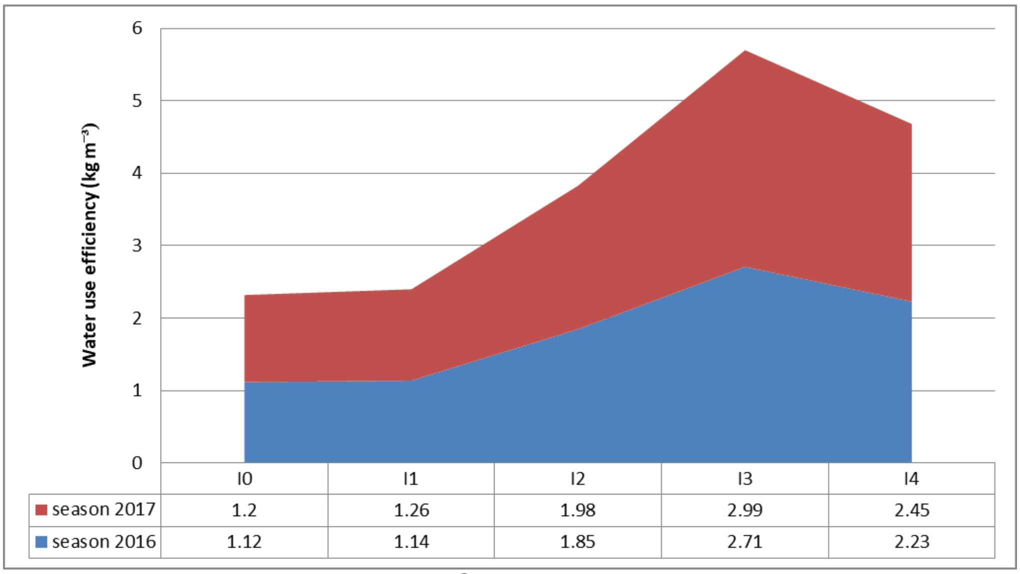


Figure 13. Water using efficacy (kg m^{-3}) for maize in different seasons of 2016 and 2017

5. Conclusion

This research evaluated the efficacy of the various irrigation techniques, the traditional [furrow] and drip systems [surface and subsurface]. It can be concluded that the maize irrigation requirements were the lowest when irrigation by drip systems was applied if compared with traditional methods. Maize under subsurface drip irrigation consumed a lesser amount of water during the growing seasons. This treatment decreases the amount of irrigation water used compared with the traditional furrow method by about 55- 57% in 2016 and 2017 seasons, respectively. The emitter 20 cm depth the best pattern was fond the highest mean of growth parameters, grain yield, and its components and performance in the use of water have been achieved. Under this region's condition, Iraqi farmers can be adopted a subsurface drip irrigation system as an alternative method to the furrow for maize production.

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