Water management of maize-cowpea intercropping system under surface irrigation

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Abstract

A two-year study was carried out at Giza Agricultural Experiments Station, Agricultural Research Center, Egypt during 2020 and 2021 to study the effect of three irrigation treatments (120, 100 and 80% ETo) on yields, amounts of applied irrigation water (AIW), water equivalent ratio (WER), of intercropped maize-cowpea, sole maize and cowpea cultivations. Water use efficiency (WUE) and water productivity (WP) were evaluated for sole cultivation of maize and cowpea. Results indicated that the AIW depths under 120, 100 and 80% ETo were respectively 1081, 926 and 772 mm in the 1st season and 1036, 889 and 742 mm in 2nd. There were no significant differences between yields of intercropped maize and cowpea irrigated with 120 and 100% ETo. Adopting the 100% ETo treatment will save 14% of irrigation water, however the highest WER values were obtained from 80% ETo treatment, namely 1.21 and 1.26 respectively in the 1st and 2nd seasons. For sole cultivation of maize and cowpea, the highest WUE and WP were obtained under 100% ETo. The two-season average local Kc values for maize and cowpea under 120% ETo were 0.73 and 0.70, respectively. It could be concluded that irrigating cowpea intercropped with maize with 100% ETo irrigation treatment resulted in insignificantly less yield than that obtained under 120% ETo treatment, but with 14% less applied irrigation water.

Keywords: Maize, cowpea, intercropping, Irrigation water amounts, Water equivalent ratio, Water productivity, Water use efficiency, Crop coefficients

INTRODUCTION

Increasing crops productivity and saving on the applied irrigation water are two interrelated issues raising a lot of concern these days in Egypt. Producing more crop yield with lower applied amount of irrigation water should be the aim of any new research. One of the methods that proved to increase water use efficiency is cultivation on raised beds. Beds planting also created better soil physical environment throughout the crop growth period, which led to higher crop productivity (Aggarwal and Goswami, 2003). Ahmad *et al.,* (2009) reported that raised beds cultivation could save between 20-25% of irrigation water, which increased water use efficiency by 15%. Sing *et al.* (2010) found lower water consumption and higher crop yield under raised beds planting than under conventional flat planting due to decrease in irrigation amount. Raised beds planting contributed significantly in improving water distribution and efficiency, increased fertilizer use efficiency and reduced weed infestation, lodging and seed rate without sacrificing yield (Hobbs *et al.,* 2000). Zhang *et al.* (2012) stated that raised beds cultivation significantly and substantially increased maize growth, microbial functional groups and enzyme activities compare to flat planting, thus increasing availability of essential crop nutrients by stimulating microbial activity. Raised beds cultivation significantly and substantially increased maize growth, microbial functional groups and enzyme activities compare to flat planting, thus it increased availability of essential crop nutrients by stimulating microbial activity (Zhang *et al.,* 2012).

One way to improve water use for crops and reduce losses of irrigation water to groundwater is the calculation of seasonal crop coefficients (Kc) to apply the amount of irrigation that the crop needs (Djaman *et al.,* 2017). Crop coefficient is defined as the ratio between crop evapotranspiration (ETc) and reference evapotranspiration (ETo), from a well-watered (not limiting) reference surface (Allen *et al.,* 1998). Crop Kc plays an important role in the exact calculation of ETc and consequently water requirements (Jensen *et al.*, 1990). Thus, correct knowledge of ETc allows improving water management by changing the volume and frequency of irrigation to meet crop requirements and to adapt to soil characteristics (Katerji and Rana, 2008). Furthermore, it was reported that the Kc is affected by all the factors that influence soil water status, for instance, the irrigation method and frequency (Wright 1982), the weather and soil characteristics (Snyder *et al.,* 2004), and the agronomic techniques that affect crop growth (Annandale *et al.*, 1994). Consequently, the reported values of crop coefficients in the literature can vary significantly from the actual measured values in a location, if growing conditions differ from those where these coefficients were experimentally obtained (Annandale *et al.*, 1994). Thus, performance of experiments that seek the determination of Kc at the regional scale is quite significant. In Egypt, there were no attempts made to study the effect of cultivation method (raised beds cultivation) on Kc values of cowpea and maize under field conditions.

Using intercropping systems can be another method to increase water use efficiency (Yildirim and Guvenc, 2005). Intercropping is a type of mixed cropping and defined as an agricultural practice of cultivating two or more crops in the same space of land at the same time (Hauggard-Nielson *et al.,* 2001; Tsubo *et al.,* 2003). Intercropping systems can provide many benefits through increased efficiency of land use, enhancing the capture and use of light, water and nutrients, and controlling weeds, insects and diseases (Dhima *et al.,* 2007). Intercropping increases the use efficiencies of land, light, water and nutrients (Brooker *et al.,* 2015). Intercropping plants of different rooting patterns permits greater exploitation of a larger volume of soil, where greater root concentrations of the soil profile occur and that improves access to relatively immobile nutrients as well as soil moisture (Gebru, 2015). As a result, intercropped plants tend to absorb more nutrients than those in monocultures (Ouda *et al*., 2007). Advantageous intercropping in semi-arid region might be achieved by the combination of one crop that requires less water and another that requires more (Zhang Yue *et al.,* 2019).

In Egypt, there is a shortage in forage crops for livestock feeding during summer season, from May until November. Cowpea has been introduced to Egyptian agriculture as a promising double purpose forage and a seed crop used in animal feed as a primary source of protein (Al-Dakheel *et al*., 2009). It is a semi-erect legume, fast growing and high yielding fodder suitable for cultivation all over the country. It fixes atmospheric nitrogen and contributes to soil fertility improvement, particularly in smallholder farming systems where little or no fertilizer is used (Iqbal *et al*., 2015). It can be harvested for fodder in 60-70 days and yields 35-40 ton/ha of green fodder with 17.5-19.0% of crude protein. Cowpea has a wide range of compatibility with other crop species in intercropping systems.

Maize is an important cereal crop in Egypt. It is one crop that provides opportunity for inclusion in intercrops because of its wider row spacing and plasticity to row spacing (Kamanga *et al.,* 2010). Intercropping cowpea with maize is one of the most popular mixed cropping combinations for smallholders. Intercropping cowpea with maize can attain higher maize grain yield, maximum water and land use utilization and it can improve soil fertility (Dahmardeh *et al*., 2010). Ouda *et al.,* (2020) indicated that intercropping cowpea with maize increased maize yield by 8%, compared to sole maize cultivation. In addition to that, it can attain higher farmer' net returns than the sole cropping (Abdulai *et al.,* 2018).Because cowpea has high level of protein content (about twice than maize), its intercropping with maize can improve forage protein content. Several authors have documented the efficiency of maize/cowpea intercropping system on increasing maize yield (Ouda *et al.,*2020; Abdel-Wahab *et al*., 2021). However, there was no research on the efficiency of this system for the use of irrigation water under raised beds cultivation in clay soil.

To assess the efficiency of water use by the intercrops, water equivalent ratio can be used. It is defined as the total water use that is needed in sole crops to produce the equivalent of the species yields on a unit area of intercrop with the associated water use (Mao *et al.,* 2012). Few researchers in Egypt used water equivalent ratio to evaluate intercropping systems from water use point of view. Abd El-Alim *et al.* (2017) and Ouda *et al.* (2018) found that the value of water equivalent ratio for sunflower intercropping with peanut system was greater than that of sole crops. Zohry and Ouda (2019) indicated that the value of water equivalent ratio was the highest when onion was intercropped with sugar beet, compared to fababeen intercropped with sugar beet and chickpea intercropped with sugar beet systems. However, no research in Egypt was conducted to study water equivalent ratio for cowpea intercropped with maize system. Thus, the objective of this study is to evaluate the effect of three irrigation treatments (120, 100 and 80% ETo) on the yields of intercropped maize/cowpea (50% cowpea intercropped with 100% maize) and sole maize and sole cowpea cultivations, amounts of applied (AIW) and consumed irrigation water (CU), water use efficiency (WUE), water productivity (WP) and water equivalent ratio (WER). The study aims also to develop local crop coefficient (Kc) of cowpea and maize cultivated on raised beds under experimental conditions.

MATERIALS AND METHODS

Experimental site description

A two-year field experiment was carried out at Giza Agricultural Research Station (Lat. 30°00'30" N, Long. 31°12'43" E, 26 m a.s.l), ARC, Egypt in 2020 and 2021 summer seasons.

Soil samples from the upper 60 cm soil surface were collected at 15 cm interval to determine the main soil physical and chemical properties, soil-moisture constants, available nitrogen (N) and phosphors (P). Physical and chemical soil analyses were conducted by the standard methods as described by Tan (1996). The obtained values are presented in Table 1. Samples of irrigation water at the experimental site were also collected for analysis. The EC and pH values of the irrigation water were 1.20 and 7.50 dS m^{-1}, respectively.

Average monthly meteorological data at the experimental site during 2020 and 2021 seasons are presented in table 2.

Experimental design and tested treatments

A split plot statistical design with three replicates was used to implement the field experiment. The tested treatments were:

Irrigation treatments (main plots):

- I1: Irrigation with amounts of water equal to 120% ETo
- I2: Irrigation with amounts of water equal to 100% ETo
- I3: Irrigation with amounts of water equal to 80% ETo

Cropping systems (sub-plots):

- Cowpea (50%) intercropped with maize (100%)
- Solid maize
- Solid cowpea

Table 1: Main physical and chemical properties and soil moisture constants of the soil at the experimental site

Soil properties	Soil depth (cm)			
	0-15	15-30	30-45	40-60
Physical parameters				
Coarse sand, %	2.98	2.95	2.93	2.88
Fine sand, %	13.0	13.0	13.0	13.1
Silt, %	30.1	29.9	29.7	29.1
Clay, %	53.9	54.1	54.3	54.9
Texture class	Clay	Clay	Clay	Clay
Bulk density, Mg m^{-3}	1.16	1.25	1.24	1.28
Field capacity, % w/w	42.1	34.6	29.4	28.1
Permanent wilting point, % w/w	18.7	16.6	15.9	15.5
Available water, %	23.4	18.0	13.4	12.5
Chemical parameters				
pH (1:2.5)	7.15	7.36	7.60	7.64
ECe, soil paste extract, dS m^{-1}	0.79			
Soluble cations, meq L^{-1}				
Ca^{2+}	3.54	3.42	3.7	3.35
Mg^{2+}	1.15	1.3	1.45	1.50
Na^{+}	2.36	2.44	2.75	2.88
K^{+}	0.38	0.44	0.51	0.66
Soluble anions, meq L^{-1}				
CO_3^{2-}	nd*	nd	nd	nd
HCO_3^{-}	2.10	2.25	2.38	2.64
Cl^{-}	2.22	2.35	2.48	2.66
SO_4^{2-}	2.40	3.70	3.10	3.40
Available (N, ppm)	38.0	42.0	46.6	50.2
Available (P, ppm)	16.5	17.9	20.2	22.4

nd: not detected

Cultural practices

At the experimental site, a surface irrigation system was used and the amounts of irrigation water applied to each treatment during the growing seasons were measured using a calibrated flow-meter connected to the irrigation pump.

Maize crop

Maize (hybrid T.W.C. 321)was sown on the 16th and 21st of May in 2020 and 2021 seasons, respectively. In intercropping and sole systems, maize grains were sown in both sides of raised beds, 140 cm width, by sowing one grain/hill distanced 25 cm apart (Figure 1 a,b). Solid cultivation was used to estimate the water equivalent ratio.

In each season, calcium super phosphate (15.5% P_2O_5) at rate of 357 kg per ha was applied during soil preparation. N fertilizer was added at a rate of 286 kg N per ha as ammonium nitrate (33.5% N) in two equal doses applied before the first and the second irrigations, respectively. Maize plants were harvested on the 22nd and 27th September 2020 and 2021 seasons, respectively.

Ten maize plants were taken randomly at harvest from each sub plot to determine plant height (cm), number of green leaves $plant^{-1}$, number of ears $plant^{-1}$, ear weight (g) and grain yield $plant^{-1}$ (g). Grain yield ha^{-1} (t) was determined from grain weight of each sub plot and converted to ton per hectare.

Cowpea

Cowpea (Cream 1 cultivar) was sown on the 16th and 21st of May 2020 and 2021 seasons, respectively. Two rows of cowpea were grown in middle of the raised beds, where plants were distanced 20 cm apart. Cowpea plants were thinned to two plants per hill distanced at 20 cm between hills under intercropping and sole planting. In solid culture of cowpea, four rows were grown on the raised beds. This pattern was expressed as 100% soybean (Figure 1.c). Solid cultivation was used to estimate the water equivalent ratio only.

Table 2: Meteorological data and the measured class A pan values at Giza site during 2020 and 2021 seasons

Month	Tmax (°C)	Tmin (°C)	Ws (m s^{-1})	RH (%)	SS (h)	SR ($cal/cm^2/day$)	Epan (mm/month)
2020							
May	34.6	19.1	3.4	38.7	13.4	731	11.26
June	38.6	22.5	2.0	31.7	13.9	776	12.73
July	36.6	24.3	2.1	46.3	13.8	778	12.74
August	37.2	23.8	3.5	44.3	13.0	758	12.01
September	35.4	22.3	1.9	44.3	12.2	741	11.68
October	32.4	19.8	2.0	56.7	11.4	722	10.55
2021							
May	34.6	19.4	2.0	34.0	13.4	732	10.40
June	36.7	16.0	2.0	23.3	13.9	720	11.51
July	38.2	24.5	1.6	42.3	13.8	765	11.83
August	37.1	24.6	2.0	46.3	13.1	742	10.62
September	34.9	22.3	2.9	46.0	12.2	725	10.54
October	31.0	18.5	1.9	46.7	11.40	718	10.38

Tmax= Maximum temperature; Tmin= minimum temperature; Ws= wind speed; RH= relative humidity; SS= Actual sunshine duration; SR= Solar radiation; Epan= Evaporation pan.

Cowpea seeds were inoculated with *Rhizobium melitota* and Arabic gum was used as a sticking agent. N-fertilizer was added for cowpea at a rate of 35.7 kg N per ha as ammonium nitrate (33.5% N) before the first irrigation under intercropping and sole cultural practices. Cutting of cowpea plants were done on the 2nd and 5th of August 2020 and 2021, respectively. At harvest, ten plants were randomly taken from each sub plot to determine plant height (cm) and number of branches plant^{-1}. Forage yield per ha was determined from forage weight of each sub plot and converted to ton per ha.

The conventional agricultural practices performed in the surrounding area for maize and cowpea crops were used to ensure proper growth and yield.

Crop water relations

Reference crop evapotranspiration (ETo)

The ETo values were calculated based on Class-A-pan measurements using the following equation (Doorenbos and Pruitt, 1979):

$$ETo = Epan\ X\ Kpan$$

where:

ETo = Reference evapotranspiration (mm/day)
Epan = Pan evaporation (mm/day)
Kp = Pan coefficient (= 0.75 at the experimental site)

Applied irrigation water (AIW)

The depth of applied irrigation water (AIW) to the experimental plots was calculated according to the following equation:

$$AIW = \frac{ETo\ X\ I}{Ea}$$

where:

AIW = depth of applied irrigation water (mm)
ETo = reference evapotranspiration (mm/day)
I = irrigation interval (days)
Ea = application efficiency (fraction) = 0.6 for surface system at the site

Water consumptive use (WCU)

Crop water use was estimated by soil moisture depletion method according to Majumdar (2002) given as follows:

$$WCU = \sum_{i=1}^{i=4} \frac{\theta 2 - \theta 1}{100} \times Bd\ x\ d$$

where:

WCU = water consumptive use or crop evapotranspiration (mm)
i = number of soil layer
θ2 = soil moisture content after irrigation, (%, by mass)
θ1 = soil moisture content just before irrigation, (%, by mass)
Bd = soil bulk density, (g cm^{-3})
d = depth of soil layer, (mm).

Figure 1: Maize and cowpea cropping systems:(a) cowpea intercropped with maize (50% cowpea+100% maize), (b) solid maize (100%) and (c) solid cowpea (100%)

Crop coefficient (Kc)

The local crop coefficient values for sole cowpea and maize grown on raised beds were estimated according to Allen *et al.* (1998):

$$Kc = \frac{\mathrm{ETc}}{\mathrm{ETo}}$$

where:

ETc = crop evapotranspiration (mm/d) ≈ water consumptive use (WCU)
ETo = reference evapotranspiration (mm/d)

The local crop coefficient values for cowpea and maize were estimated for all growth stages

Water equivalent ratio (WER)

The water equivalent ratio is used to quantify system level water use efficiency (Mao *et al.*, 2012).The WER is determined by calculating the total water use that is needed in sole crops to produce the equivalent of the specific yield on a unit area of intercrop with the associated water use as:

$$\mathrm{WER} = \frac{\left(\frac{Y_{int,c}}{WU_{int}}\right)}{\left(\frac{Y_{mono,c}}{WU_{mono,c}}\right)} + \frac{\left(\frac{Y_{int,m}}{WU_{int}}\right)}{\left(\frac{Y_{mono,m}}{WU_{mono,m}}\right)}$$

Where: $Y_{int,c}$ and $Y_{int,m}$ are the yield of intercropped cowpea and maize, respectively. WU_{int} is water consumptive use by the intercropped crops. $Y_{mono,c}$ and $Y_{mono,m}$ are the yields of mono cowpea and maize, respectively. $WU_{mono,c}$ and $WU_{mono,m}$ are water consumptive use by mono cowpea and maize crops, respectively. If WER is higher than 1.0, it implies advantage of the intercropping system.

Water use efficiency (WUE)

Water use efficiency for sole maize was calculated according to Stanhill (1986) as:

$$WUE = \frac{Yield\ \left(\frac{kg}{ha}\right)}{Consumed\ water,\ WCU\ \left(\frac{m^3}{ha}\right)}$$

where:

Yield = Maize and cowpea yields (kg ha^{-1})
WCU =Water consumed by the crop during entire growing season (m^3 ha^{-1})

Crop water productivity (WP)

Crop water productivities for sole maize and cowpea were calculated according to Zhang (2003):

$$WP = \frac{Yield\ \left(\frac{kg}{ha}\right)}{Applied\ irrigation\ water, AIW\ \left(\frac{m^3}{ha}\right)}$$

Statistical analysis

The data were statistically treated using the analysis of variance (ANOVA) for the split plot design, and least significant difference (LSD)was used for means separation (P ≤ 0.05) according to Freed (1991).

RESULTS AND DISCUSSION

Effect of irrigation treatments and cropping system on cowpea and maize yields

The results in table 3 showed that there was a significant effect of irrigation treatments on the obtained yield. Results of the effect of irrigation treatments indicated that there were no significant differences between yields obtained from 120 and 100% ETo irrigation treatments, while the two treatments differed significantly with the 80% ETo treatment in the two seasons. The recorded yields for maize crop, under maize/cowpea system, were 9.29 and 9.64 t/ha, 9.2 and 9.56 t/ha, and 4.94 and 5.79 t/ha for 120, 100, and 80% ETo irrigation treatments in the first and second growing seasons, respectively. The recorded yields for cowpea crop, under maize/cowpea system, were 14.0 and 12.8 t/ha, 12.8 and 11.8 t/ha, and 8.63 and 7.75 t/ha for 120, 100, and 80% ETo irrigation treatments in the first and second growing seasons, respectively.

As for the effect of intercropping systems, results indicated that there were no significant differences between maize yields under maize/cowpea system (7.82 and 8.24 t/ha) and sole maize yields (7.80 and 8.42 t/ha) in the 1st and 2nd growing seasons, respectively. It was noticed from the results that maize yields under intercropped system were 2.41 and 1.59% higher than those of sole maize, which could be due to the fact that the intercropping with cowpea can benefit from N-fixed by the leguminous crops and more efficient utilization of irrigation water. Results showed also that there were significant

Table 3: Effect of the interaction between irrigation treatments and cropping system on cowpea and maize yields in both growing seasons

Irrigation treatments	Cropping systems	Maize yield (ton/ha)		Cowpea yield (ton/ha)	
		Fist season	Second season	Fist season	Second season
120% ETo	Maize/cowpea system	9.40	9.71	8.80	7.76
	Sole maize	9.18	9.56	----	----
	Sole cowpea	----	----	19.2	17.9
	Average	**9.29**	**9.64**	**14.0**	**12.8**
100% ETo	Maize/cowpea system	9.28	9.62	8.20	7.25
	Sole maize	9.12	9.49	----	----
	Sole cowpea	----	----	17.5	16.4
	Average	**9.20**	**9.56**	**12.8**	**11.8**
80% ETo	Maize/cowpea system	4.78	5.38	6.05	5.40
	Sole maize	5.10	6.20	----	----
	Sole cowpea	----	----	11.2	10.1
	Average	**4.94**	**5.79**	**8.63**	**7.75**
Average Cropping systems	Maize/cowpea system	**7.82**	**8.24**	**7.68**	**6.80**
	Sole maize	**7.80**	**8.42**	----	----
	Sole cowpea	----	----	**16.0**	**14.8**
LSD 5% Irrigation treatments		2.23	2.86	1.87	1.81
LSD 5% Cropping systems		NS	NS	1.49	1.36
LSD 5% Interaction		NS	NS	2.22	2.03

differences between cowpea yields under maize/cowpea system (7.68 and 6.80 t/ha) and sole cowpea yields (16.0 and 14.8 t/ha) in the 1st and 2nd seasons, respectively. The obtained result is supported by what was reported by Pal and Sheshu (2001), Rivest *et al.*(2013), Sani *et al.* (2014), Feng *et al.* (2016) and El-Mehy *et al.* (2018), who reported that yield of intercropped maize was higher than the sole maize, and water used by the intercrops was 25% higher as compared with sole cultivation. Results were in line with those reported by Adigbo *et al.*(2013), who indicated that maize/cowpea intercrops had no effects on the performance of maize and enhanced the productivity of the cowpea without reducing maize yield. Results were also in line with those reported by Adigbo *et al.*(2013), who indicated that maize/cowpea intercrops had no effects on the performance of maize and enhanced the productivity of the cowpea without reducing maize yield.

Results showed also that the intercropped maize yield in the second season was higher than yield in the first season. This result could be attributed to improved soil fertility resulting from biological N fixation by the legume in the second season compared to first season. The results agreed with those reported by Shen and Chu (2004), who stated that legumes can transfer fixed-N, which is very important nutrient for intercropped cereals during their joint growing period. The results are also quite homogeneous with Kabita Mishra (2019) who found that intercropping maize with cowpea in 1:1 mixture row cropping was found suitable for higher yield and also producing better quality forage crops, compared to both sole crops of maize and cowpea.

As for the interaction effect, results indicated that there was a significant effect of irrigation treatments with intercropping systems only on cowpea yields. Results revealed that the highest maize yields of 9.40 and 9.71 t/ha were obtained from the 120% ETo and maize/cowpea treatment in the 1st and 2nd seasons, respectively. The highest cowpea yields of 19.2 and 17.9 t/ha were obtained from 120% ETo and sole cowpea treatment in the 1st and 2nd seasons, respectively.

Effect of the tested treatments on applied irrigation water (AIW) and water saved

Results showed that, the depths and amounts of applied irrigation water under 120, 100 and 80% ETo irrigation treatments were 1081 mm (10807 m^3/ha), 926 mm (9260 m^3/ha), and 772 mm (7724 m^3/ha) in the first season, and were 1036 mm (10357 m^3/ha), 889 mm (8890 m^3/ha),and 742 mm (7424 m^3/ha) in the second season, respectively (Table 4). Results indicated also that, applying the 100 and 80%ETo treatments saved,on average, 14 and 28% of the applied water, respectively as compared with the 120% ETo treatment.

Effect of tested treatments on water consumptive use (CU) of maize/cowpea intercropped system, sole maize and sole cowpea crops

Results in table 5 indicated that, the 2-year average water consumed by maize/cowpea crops were 8692, 7260 and 5682 m^3/ha for the 120, 100, and 80% ETo treatments, respectively. Average consumed water represented 82, 80 and 75% of the AIW for the 120, 100, and 80% ETo treatments, respectively. Results showed that the 2-year average CU values for the sole maize crop were 6503, 5680 and 5022 m^3/ha for the 120, 100, and 80% ETo irrigation treatments, respectively. The same respective values for the sole cowpea crop were 6533, 5648 and 4855 m^3/ha. Results indicated that increasing the amounts of applied water increased water consumption. These results agreed with those reported by Feng *et al.* (2016) and El-Mehy *et al.* (2018).The consumed water by sole maize varied from 61.5 to 66.0% of the applied water, while for the sole cowpea crop the same values were about 60% of the applied irrigation water. The obtained results implied better use of the applied water, which cause low water losses by deep percolation under this intercropping system. It is also attributed to the wide established ground cover by cowpea, which minimized soil evaporation. Furthermore, difference in rooting patterns between cowpea and maize (deep versus shallow roots) improved the access to soil water and permitted greater exploitation of a larger volume of soil, which maximize water use efficiency as stated by Gebru (2015).

Table 4: Applied irrigation water depths (mm), amounts (m^3/ha), and saved water (%) as affected by irrigation treatments during 2020 and 2021 growing seasons

Irrigation treatments	First season		Second season	
	Applied water (mm) &(m^3/ha)	% saved	Applied water (mm) & (m^3/ha)	% saved
120% ETo	1081 (10807)	---	1036 (10357)	---
100% ETo	926 (9260)	14	889 (8890)	14
80% ETo	772 (7724)	29	742 (7424)	28

Table 5: Water consumption (m^3 ha^{-1}) by maize/cowpea intercrop system, sole maize and sole cowpea during 2020 and 2021 growing seasons

Intercropping systems	First season			Second season		
	120% ETo	100% ETo	80% ETo	120% ETo	100% ETo	80% ETo
Maize/cowpea	8835	7420	6790	8550	7100	5570
Maize (sole)	6486	5660	4994	6520	5700	5050
Cowpea (sole)	6545	5595	4660	6271	5396	4483

Water equivalent ratio

The results in table 6 indicated that water equivalent ratio values for cowpea (WER_{cowpea}) under the three irrigation treatments were lower in the second growing season compared with the first growing season as a result of lower cowpea yield in the second growing season. On the other hand, the values of WER for maize (WER_{maize}) under the three irrigation treatments were higher in the second growing season, compared to the first growing season as a result of higher maize yield in the second growing season. In both growing seasons, irrigation with 80% ETo attained the highest values of total WER of 1.21 and 1.26 in the 1st and 2nd seasons, respectively as compared to 120 and 100% ETo treatments. This result implied that the efficiency of water utilization under this system was higher by 21 and 26% than the sole cultivation of either cowpea or maize. These results were similar to El-Mehy *et al.* (2018); Ouda *et al.* (2018) and Zohry *et al.*(2020).The obtained results were confirmed by the findings of Coll *et al.* (2012), Mao *et al.* (2012) and Zhang *et al.* (2019), they indicated that the greater yields attained by the intercrops are only as a consequence of low water losses. Furthermore, Miao *et al.* (2012 &2016) reported that actual evapotranspiration and irrigation water use under intercropping systems were larger than those of the sole crops, which led to significantly higher water equivalent ratio of intercropping than those of single crops, as well as there is higher water use under intercropping systems than those of the sole crops.

Water use efficiency (WUE) and water productivity (WP) of sole maize

The results in table 7 indicated that the highest water use efficiency values of 1.23 and 1.34 kg m^{-3} were obtained under the 100% ETo irrigation treatment in 1st and 2nd seasons, respectively. The lowest WUE values of 1.02 and 1.10 kg m^{-3} were obtained under the 80% ETo irrigation treatment in 1st and 2nd seasons, respectively. In addition, the highest water productivity values of 0.98 and 1.07 kg m^{-3} of applied water were obtained for the 100% ETo treatment in the respective seasons. The obtained results were in line with those reported by Ouda *et al.* (2020) and El-Mehy *et al.* (2018). They stated that decreasing the amounts of applied water increased water use efficiency and water productivity.

Water use efficiency (WUE) and water productivity (WP) of sole cowpea

Results in table 8 indicated that the highest water use efficiency values of 3.13 and 3.04 kg m^{-3} were obtained under application of 100% ETo irrigation treatment in the 1st and 2nd seasons, respectively. The lowest values of 2.40 and 2.25 kg m^{-3} were recorded from the 80% ETo treatment in the two respective seasons. Results showed also that the highest water productivity values of 1.89 and 1.84 kg m^{-3} of applied water were obtained from the 100% ETo irrigation treatment in both seasons. The obtained results were in agreement with those reported by Abdel-Wahab *et al.* (2021), who stated that increased

Table 6: Water equivalent ratio (WER) for cowpea intercropped with maize under irrigation treatments in both growing seasons

	WER_{cowpea}		WER_{maize}		WER_{total}	
Irrigation treatments	**Fist season**	**Second season**	**Fist season**	**Second season**	**Fist season**	**Second season**
120 % ETo	0.32	0.30	0.75	0.77	1.07	1.07
100% ETo	0.35	0.32	0.77	0.81	1.12	1.13
80% ETo	0.37	0.36	0.84	0.90	1.21	1.26

Table 7: Water use efficiency and water productivity of sole maize crop as affected by different irrigation treatments in 2020 and 2021 growing seasons

Irrigation treatments	WUE (kg m^{-3} consumed water)		WP (kg m^{-3} applied water)	
	Fist season	**Second season**	**Fist season**	**Second season**
120% ETo	1.04	1.12	0.85	0.92
100% ETo	1.23	1.34	0.98	1.07
80% ETo	1.02	1.10	0.66	0.84

Table 8: Water use efficiency and water productivity of sole cowpea crop as affected by different irrigation treatments in 2020 and 2021 growing seasons

Irrigation treatments	WUE (kg m^{-3} consumed water)		WP (kg m^{-3} applied water)	
	Fist season	**Second season**	**Fist season**	**Second season**
120% ETo	2.94	2.86	1.78	1.73
100% ETo	3.13	3.04	1.89	1.84
80% ETo	2.40	2.25	1.45	1.36

cowpea forage yields per ha, per land unit and water usages, as well as economic return were reported under optimum irrigation level.

Crop coefficient (Kc) of sole maize

The Kc values of sole maize under raised beds cultivation and application of 120%ETo irrigation treatment were 0.35, 0.98, 0.98-1.12, and 1.12-0.45 for initial, developmental, mid-season,and late-season growth stages, respectively. The average Kc for whole growing season was 0.73 (Figure 2). These results could be attributed to better distribution of water and fertilizers under raised beds cultivation, which resulted in better growth conditions. The obtained results agreed well with those reported by Tyagi *et al.*(2000), Giovanni *et al.*(2009), Kamble *et al.*(2010) and Mehta and Pandey (2016).They concluded that Kc values are not only affected by weather conditions prevailed in a region, but also affected by cultivation methods. There is a strong necessity for local calibration of Kc values under specific climatic conditions which ensures proper irrigation scheduling and efficient water management of crops on a regional scale. Maize Kc values varied from 0.2 to 1.2 and were directly affected by the percentage of the ground covered by crops, rate of crop development, and time to achieve full ground cover.

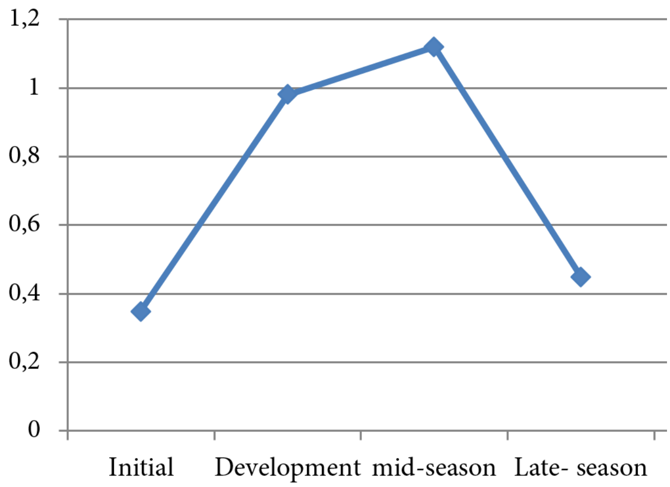

Figure 2: The 2-year average crop coefficient (Kc) values of maize (cultivar T.W.C. 321) during different growth stages

Crop coefficient (Kc) of sole cowpea

The calculated Kc values of sole cowpea crop under the 120% ETo irrigation treatment during different growth stage are illustrated in figure 3. The 2-year average Kc values were 0.49, 0.87, 1.02 and 0.42, for the initial, flowering, maturity and late season, respectively under raised beds cultivation. The 2-year average seasonal Kc value was 0.7.

The obtained results were in accordance with those reported by Farias *et al.* (2017), who stated that the Kc reached 1.4 during the reproductive phase and in the final stage attaining a mean value of 0.5 with a seasonal average cowpea Kc value of 0.8.

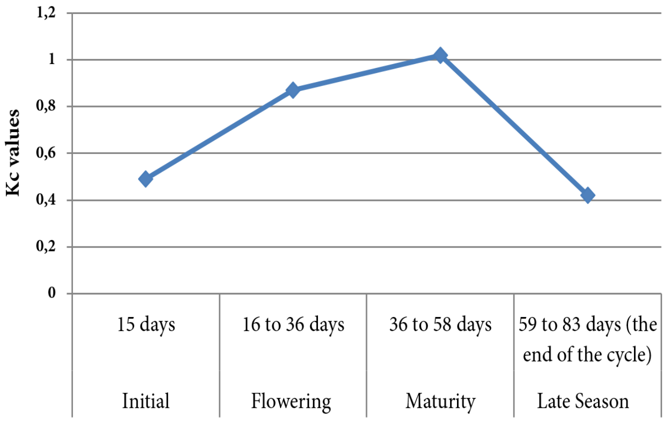

Figure 3: The 2-year average crop coefficient (Kc) values of cowpea (cultivar Cream 1) during different growth stages

CONCLUSION

Based on the results of the present study, it could be concluded that:

• Maize yields increased under intercropping systems by 2.41 and 1.59%, compared to sole planting.

• The 2-year average amounts of applied irrigation water under 120, 100 and 80%ETo irrigation levels were 10582, 9075, and 7575 m^3 ha^{-1}, respectively.

• Adopting the 100% ETo irrigation treatment will result in crop yields (9.95 ton maize/ha + 7.72 ton cowpea/ha) that are not significantly less than the yields from 120% ETo treatment, save 14% of irrigation water, achieve highest WUE values of 1.29 and 3.85 kg/m^3, highest WP values of 1.02 and 1.86 kg/m^3 for maize and cowpea crops, respectively.

• The 2-year local average Kc values of maize (cultivar T.W.C. 321) and cowpea (cultivar Cream 1) crops under irrigation with 120% ETo were 0.73 and 0.70, respectively.

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