J. Soils and Crops 34(1) 29-39, June 2024

ISSN 0971-2836 (Print)
ISSN 2582-2756 (Online)

WATER USED BY SOYBEAN AND MAIZE INTERCROPPING PATTERNS AS AFFECTED BY DIFFERENT SOYBEAN CULTIVARS AND PLANT POPULATION

Ahmed M. Taha[1] and Eman I. Abdel-Wahab[2]

ABSTRACT

A-two year study was carried out at Giza Agricultural Experiments Station, Agricultural Research Center, Egypt during the two successive summer seasons of 2021 and 2022.The objectives of this study were i) To compare between water used by three patterns of three soybean cultivars intercropped with maize planted on raised beds ii) To determine the highest water equivalent ratio of the studied patterns and iii) To estimate water consumptive use of the three soybean cultivars, as well as determine local crop coefficients values under furrow and raised beds cultivation methods. The study included nine treatments including the combination between three intercropping systems (100% soybean+100% maize; 75% soybean+100% maize; and 50% soybean+100% maize) and three soybean cultivars (Giza 21, Giza 82 and Giza 11) planted on raised beds.Sole planting of soybean and maize was done on both furrows and raised beds.The experimental design was randomized complete block design with three replications.The applied irrigation water and water consumptive use (WCU) were measured and water equivalent ratio (WER) was calculated. Soybean crop coefficients (Kc) were calculated underfor sole planting under furrows and raised beds. The results indicated that the highest yield of intercropped soybean and maize were obtained from 100 % soybean+100 % maize intercropping pattern. Giza 111 soybean cultivar gave the highest yield under both sole and intercropped planting. The applied irrigation water depths were 922 and 927 mm in the first and the second season, respectively. The highest WCU was obtained under 100% soybean + 100% maize intercropping pattern in both seasons. The results also showed highest WER_{total} values of 1.22 and 1.30 in the 1st and 2ndseasons, respectively. These were obtained under 100 % soybean + 100 % maize intercropping pattern. The results also showed that soybean cultivars planted on furrows had lower Kc values compared to the values on raised beds. The highest values of Kc were found for Giza 111 under both cultivation methods. It is recommended to implement soybean and maize intercropping system with 100% of its planting density using Giza 111 soybean cultivar to obtain the highest yield and WER values from the crops.

(Key words: Intercropping systems, water equivalent ratio, water consumptive use, crop coefficient)

INTRODUCTION

Increasing water use efficiency by the cultivated crops in Egypt is raising a lot of concerns these days. Producing more crop yield with lower applied amount of irrigation water is the aim that any new research on on-farm irrigation should focus on. One of the methods that proved to increase water use efficiency is cultivation on raised beds. Raised beds cultivation proved to reduce the applied water to wheat by 20% (Abouelenein *et al*., 2009). Ahmad *et al.* (2009) reported that raised beds can save 20-25% of irrigation water, which increased water use efficiency by 15%. 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). Sing *et al.* (2010) found lower water consumption and higher wheat yield raised beds planting than under conventional flat planting due to decrease in irrigation amount. Raised beds cultivation significantly and substantially increased maize growth, microbial functional groups and enzyme activities compared to flat planting, thus it increasing availability of essential crop nutrients by stimulating microbial activity (Zhang *et al.,* 2012). Beds planting also created better soil physical environment throughout the crop growth period, which led to higher crop productivity (Aggarwal and Goswami, 2003).

Agriculture is the producer of food using the available natural resources, namely soil, water and weather resources. Increasing the efficiency of using these resources can increase food production and availability, as well as reduce food insecurity. Under the condition of lands limitation and/or water limitation implementing intercropping

1. Asstt. Professor, Water Requirement and Field Irrigation Research Department; Soils, Water and Environment Research Institute; Agricultural Research Center, Egypt
2. Asstt. Professor, Food Legumes Research Department, Field Crops Research Institute; Agricultural Research Center, Egypt

systems can increase land productivity, where two crops share the same area occupied by one of them (Gallaher, 2009).Furthermore, implementing intercropping systems can contribute in increasing water use efficiency, where two crops share the applied irrigation water to one of them (Tolera, 2003).Intercropping increases the use efficiencies of land, light, water and nutrients (Brooker *et al.*, 2015). Intercropping of plants with 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 mono cultures (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 (Zhank *et al.,* 2019). Intercropping system is generally could be a way of irrigation water saving (Tsubo *et al.,* 2005).

In Egypt, there is a decline in area under soybean in Egypt, where it reached to about 7,812 ha in 2016, while, maize had about 4,877,829 ha in 2016 (Anonymous, 2016). One of the important intercropping systems implemented in Egypt is soybean intercropping with maize. It can increase the cultivated area of soybean without using extra lands (Sherif and Gendy, 2012).In addition to that, this system has numerous benefits. It can improve soil fertility and health maize based intercropping system with legume helps in improving soil health as well as its yield (Beedy *et al.*, 2010).Maize plant development is strongly dependent on the abundant of soil nitrogen and nitrogen use efficiency for biomass production and yield (Sonnewald, 2012). On the other hand, soybean is a legume plant, which has the ability to fix atmospheric nitrogen when properly modulated (Flynn and Idowu, 2015), and it can provide maize with some of nitrogen needs if both are intercropped. In addition, Waktola *et al*. (2014) reported that the productivity of maize-soybean intercropping showed a higher relative yield advantage over sole cropping. Also, Sani *et al*. (2014) found that the maize yield was higher in intercropping system than in monoculture. In general, increased productivity in cereal-legume intercropping compared to sole crops are noticed due to increases in resource use efficiency and improved soil fertility in the long term resulting from biological N fixation by the legume (Rivest *et al.,* 2013).

The suitable planting density for soybean and maize in an intercropping system were studied before. Increasing soybean plant density under intercropping systems from 50 to 100% of solid culture achieved high seed yield without reduction on maize grain yield under raised beds cultivation (Abd El-Alim *et al.,*2017). However, very few studies studied the most suitable soybean cultivar to be intercropped with maize, with respect to its yield and water use. One of the important methodologies to evaluate water use by intercropping systems is to calculate water equivalent ratio. Water equivalent ratio is defined by the total water use that is needed in sole crops to produce the equivalent of the species yields on a unit area of intercropped with the associated water use.The water equivalent ratio was used to quantify system level water use efficiency and it is value is between zero and one (Mao *et al.*, 2012).Few researchers in Egypt used water equivalent ratio to evaluate intercropping systems from water use point of view. AbdEl-Alim *et al.* (2018) and Ouda *et al.* (2018) found the value of water equivalent ratio for the intercropped yield was greater than that of sole crops and was greater than unity under sunflower intercropping with peanut system. Zohry and Ouda (2019) indicated that the value of water equivalent ratio was highest when onion was intercropped with sugar beet, compared to faba been intercropped with sugar beet and chickpea intercropped with sugar beet systems.

One way to improve water use crops and reduce losses of irrigation water to groundwater is the calculation of seasonal crop coefficients (Kc). Crop coefficient is defined as the ratio between crop evapotranspiration (ETc) and reference evapotranspiration (ETo), from a well-water (not limiting) reference surface (Allen *et al*., 1998). Crop Kc plays an important role in the exact calculation of ETc and consequently water requirements. 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 factors, the soil characteristics (Snyder *et al.*, 2004), and the agronomic techniques that affect crop growth (Annandale *et al.,* 1994). The Kc is crop specific and growth stage specific and results from the combination effects of crop characteristics, soil moisture status and soil type, crop management practices, canopy and aerodynamic resistance, climatic conditions such as the available energy, surrounding air content in vapor, air vapor, deficit evapotranspiration, etc..(Jensen *et al.*,1990 and Djaman *et al.*, 2017).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 the said coefficients were experimentally obtained (Annandale *et al.,* 1994).In Egypt, no attempts were done before to calculate Kc values of different soybean cultivars under surface irrigation on a field level.

The objectives of this study were i) To compare between the water used by three soybean cultivars in an intercropping (soybean/maize) patterns cultivated on raised beds ii) To determine the water equivalent ratios of the studied patterns and iii) To estimate water consumptive use of the three soybean cultivars, as well as developing crop coefficients under furrow and raised beds cultivation methods.

MATERIALS AND METHODS

Experimental site description

A two-year study was carried out at Giza Agricultural Research Station (Lat. 30°002 303 N, Long. 31°122 433 E, and 26 m a.s.l.), ARC, Giza, Egypt. Average monthly meteorological data and the measured evaporation pan (Epan) values at the experimental site during the 2021 and 2022 growing seasons are presented in Table 1.

Table 1. Average monthly meteorological data and Epan values at Giza station during 2021 and 2022 growing seasons

Season			2021			
Month	Tmax(°C)	Tmin(°C)	Ws(m s^{-1})	RH(%)	SS(h)	Evaporation pan(mm day^{-1})
May	33.9	19.2	3.3	35.9	13.3	6.90
June	37.7	22.9	2.1	36.7	13.8	7.40
July	38.2	24.1	2.2	46.8	13.7	8.60
August	38.6	23.7	3.30	44.7	12.9	8.80
September	37.9	22.3	2.3	44.0	12.1	7.66
Season			2022			
Month	Tmax(°C)	Tmin(°C)	Ws(m s^{-1})	RH(%)	SS(h)	Evaporation pan(mm day^{-1})
May	33.4	19.1	3.2	34.1	13.3	6.87
June	37.2	22.6	2.2	35.7	13.8	7.18
July	37.9	22.8	2.4	42.5	13.7	7.92
August	38.8	24.5	3.2	46.6	13.0	8.67
September	37.6	23.1	2.5	46.8	12.1	7.55

Tmax= Maximum temperature; Tmin= Minimum temperature; Ws= Wind speed; RH= Relative humidity; SS= Sunshine duration

Chemical and physical properties of the collected soil samples were analyzed according to the standard methods as described by Tan (1996). The obtained values are presented in Table 2. In addition, electrical conductivity (dS m^{-1}) and pH values of the irrigation water were 1.20 and 7.50, respectively.

Table 2. Main physical, hydro-physical and chemical properties of the soil at the experimental site

Soil properties	Soil depth (cm)			
	0-15	15-30	30-45	40- 60
Particle size distribution:				
Coarse sand, %	2.98	2.95	2.93	2.88
Fine sand, %	12.97	13.00	13.02	13.07
Silt, %	30.10	29.95	29.74	29.15
Clay, %	53.95	54.10	54.31	54.90
Textural class	clay	clay	clay	clay
Bulk density, Mg m^{-3}	1.16	1.25	1.24	1.28
Field capacity, % w/w	42.10	34.60	29.40	28.10
Permanent wilting point, % w/w	18.70	16.60	15.95	15.55
Available water, %	23.40	18.00	13.45	12.55
pH (1:2.5)	7.15	7.36	7.60	7.64
ECe, soil paste extract, dS m^{-1}		0.95		
Soluble cations, meq l^{-1}				
Ca^{2+}	3.54	3.42	3.70	3.35
Mg^{2+}	1.15	1.30	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	38.00	42.00	46.60	50.20
Available (P) ppm	16.50	17.88	20.20	22.40

*nd: not detected

Cultural practices

The field study consisted of nine treatments as follows: three soybean planting densities (2, 3 and 4 rows ridge^{-1} representing 50, 75 and 100% of the recommended sole planting density, respectively), and three soybean varieties (Giza 21, Giza 82 and Giza 111) intercropped with one maize cultivar (TWC 321). For comparison purpose, the sole soybean and maize were cultivated on raised beds and on furrows. Plot area was 12.6 m^2. Each plot consisted of three raised beds, 1.4 m wide and 3.0 m long under intercropping systems and sole planting. Under sole planting on furrows, each plot consisted of six furrows, 0.7 m wide and 3.0 m long.

Maize was sown using one seed hill^{-1} with 25 cm distance between hills under both intercropping and sole planting. Soybean plants were thinned to two plants hill^{-1} with 15 cm distance between hills under both intercropping and sole cultures (Figures1, 2 and 3). Soybean seeds were inoculated with *Bradyrhizobium japonicum* and *Arabic gum* was used as a sticking agent. Soybean seeds were sown on the 20th and 25thof May in 2021 and 2022 seasons, respectively. Maize (TWC.321 cultivar) was sown 15 days after soybean sowing. In the two seasons, calcium super phosphate (15.5% P_2O_5) at rate of 476 kg ha^{-1} was applied during soil preparation. Nitrogen fertilizer was added for maize at a rate of 285.6 kg N ha^{-1} as ammonium nitrate (33.5% N) in two equal doses under intercropping and sole planting. Furthermore, nitrogen fertilizer was added for soybean at a rate of 35.7 kg N ha^{-1} as ammonium nitrate (33.5% N).

All normal agricultural practices were performed and no insecticide treatments were applied. Soybean Giza 21 and Giza 111 cultivars were harvested on the 29th and 30st of September in 2021 and 2022 seasons, respectively. Meanwhile, soybean Giza 82 cultivar was harvested on the 29th and 31stof August 2021 and 2022 seasons, respectively. Maize plants were harvested on the 25th and 28thof September 2021 and 2022 seasons, respectively. Surface irrigation system was used at the experimental farm.

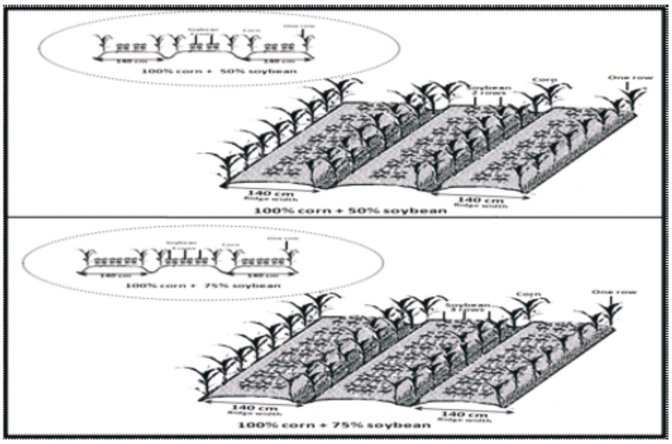

Figure 1.Intercropped soybean (two rows, 50% and three rows, 75%) with maize(100%) on raised bed

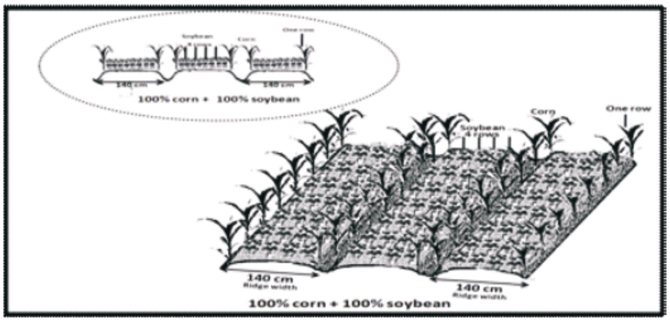

Figure 2. Intercropped soybean (four rows, 100%) with maize (100%) on raised bed

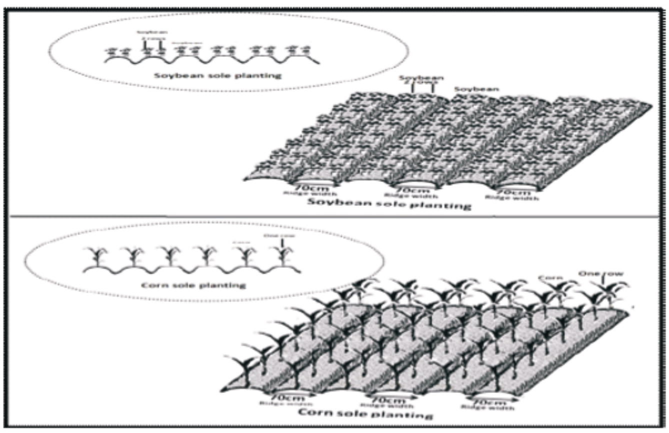

Figure 3.Sole maize and soybean cultivated on furrows

Crop-water relations

Reference crop evapotranspiration, water consumptive use and the amounts of applied irrigation water were calculated as followed:

Reference evapotranspiration (ETo)

Reference crop evapotranspiration values were determined using the Class-A-pan and were calculated according to the following equation (Doorenbos and Pruitt, 1979):

$$ETo = Epan \ X \ Kpan$$

where:

ETo = Reference crop evapotranspiration (mm day^{-1}).

Epan = Pan evaporation (mm day^{-1}).

Kp = Pan coefficient (Kp value of 0.75was used under the current experimental conditions).

Water consumptive use (WCU)

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

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

where:

WCU = water consumptive use or crop evapotranspiration (ETc), (mm).

i = number of soil layers.

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).

Applied irrigation water (AIW)

Irrigation amounts were calculated using the following equations (Doorenbos and Pruitt, 1992):

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

where:

AIW =depth of applied irrigation water (mm).

Ea = application efficiency of surface irrigation system (68% and 65% in the first and second seasons, respectively at the experimental farm).

Crop coefficient (Kc)

Local crop coefficient values for sole soybean and maize grown on raised beds and furrows were estimated according to Allen *et al.*(1998) as follows:

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

where:

ETc = crop evapotranspiration (mm day^{-1}) ≈ water consumptive use (WCU)

ETo = reference evapotranspiration (mm day^{-1}).

Water equivalent ratio (WER)

The WER is determined by measuring the total crop water used in sole crops to produce the equivalent of the species yields on a unit of intercropped area with the associated water use. It is used to quantify system level water use efficiency (Mao *et al.*, 2012).The WER is calculated as follows:

$$WER = \frac{\left(\frac{Y_{int,s}}{WCU_{int}}\right)}{\left(\frac{Y_{mono,s}}{WCU_{mono,s}}\right)} + \frac{\left(\frac{Y_{int,m}}{WCU_{int}}\right)}{\left(\frac{Y_{mono,m}}{WCU_{mono,m}}\right)}$$

where: $Y_{int,s}$ and $Y_{int,m}$ are the yields of intercropped soybean and maize. WCU_{int} is water consumptive use by the intercropped crops. $Y_{mono,s}$ and $Y_{mono,m}$ are the yields of mono soybean and maize crops. $WCU_{mono,s}$ and $WCU_{mono,m}$ are water consumptive use by mono soybean and maize crops, respectively.

Statistical analysis

The data were statistically treated using the analysis of variance (ANOVA) for randomized complete block design and the least significant difference (LSD) according to Freed (1991). The LSD was used for means separation (P d" 0.05) following the T test (0.05) to compare between soybean cultivars under intercropping and sole cultures according to Snedecor and Cochran (1980).

RESULTS AND DISSCUSSION

Maize yield as affected by intercropping patterns

Results in Table 3 indicated that maize yield insignificantly affected by the studied soybean/maize intercropping patterns. Moreover, soybean cultivars had no effect on maize yields under the studied intercropping patterns. Similarly, the sole maize yield was within the same range as the yields of the intercropped maize. These results were the same in both growing seasons. It can be also noticed that maize yield in the second season was higher than that recorded in the first season. This result could be attributed to the improved soil fertility in the long term resulting from biological N fixation by the legume in the second season compared to first season. These results were quite homogeneous with those reported by Waktola *et al.* (2014),who indicated that the productivity of maize-soybean intercropping showed a higher relative yield advantage over sole cropping. Also, Sani *et al.* (2014) found that the maize yield was higher in intercropping than monoculture crops. Increasing the productivity in cereal-legume intercropping compared to sole cultivation can be due to increases in resource use efficiency and improved soil fertility in the long term resulting from biological N fixation by the legume (Rivest *et al.*, 2013).

Results in Table 3 also showed that soybean yield was significantly and negatively affected by reducing planting density from 100% to 50% under the studied intercropping patterns. The highest soybean yield was obtained from Giza 111 cultivar, which makes it a good candidate to be used in implementing intercropping systems. The results also showed that soybean yields either sole or intercropped were less in the second season compared to the first season. This is attributed to the repetition of soybean cultivation in same place. In addition, the sole soybean was the highest compared to the yields under intercropping patterns.

Table 3. Intercropped and sole maize and soybean yields as affected by the intercropping patterns, soybean varieties in the two growing seasons

Intercropping pattern	Soybean cultivars	Maize yield (t ha^{-1})		Soybean yield (t ha^{-1})	
		2021	2022	2021	2022
100% soybean +100% maize	Giza 21	8.26	9.08	1.99	1.66
	Giza 82	8.23	8.92	2.39	2.12
	Giza 111	8.25	9.07	2.72	2.41
	Mean	**8.24**	**9.02**	**2.36**	**2.06**
75% soybean +100% maize	Giza 21	8.26	9.08	1.35	1.11
	Giza 82	8.20	8.91	1.67	1.45
	Giza 111	8.22	9.06	1.88	1.63
	Mean	**8.22**	**9.01**	**1.63**	**1.39**
50% soybean+100% maize	Giza 21	8.11	9.01	1.10	0.83
	Giza 82	8.45	9.14	1.21	0.99
	Giza 111	8.23	9.08	1.49	1.19
	Mean	**8.26**	**9.07**	**1.26**	**1.00**
Average of soybean cultivars	Giza 21	8.21	9.05	1.48	1.20
	Giza 82	8.29	8.99	1.75	1.52
	Giza 111	8.23	9.07	2.03	1.74
L.S.D. 0.05 Soybean plant density		N.S.	N.S.	0.22	0.16
L.S.D. 0.05 Soybean cultivars		N.S.	N.S.	0.08	0.12
L.S.D. 0.05 Interaction		N.S.	N.S	0.21	0.21
Recommended solid culture of maize		8.33	9.17	—	—
Recommended solid culture of Giza 21		—	—	3.03	2.70
Recommended solid culture of Giza 82		—	—	3.69	3.43
Recommended solid culture of Giza 111		—	—	3.90	3.71

Applied irrigation water and water consumption under soybean and maize intercropping patterns

The applied irrigation water, calculated based on class-A pan measurements, were 922 mm (9220 m^3 ha^{-1}) and 927 mm (9720 m^3 ha^{-1}) in the first and the second seasons, respectively for the studied intercropping patterns, and sole maize and sole soybean cultivars. The results in Table 4 indicated that water consumptive use values were the highest under 100 % soybean intercropped with 100 % maize in both growing seasons. Different rooting patterns between soybean and maize (deep versus shallow roots) permitted greater exploitation of a larger volume of soil and improve access to soil water, which maximize water use efficiency (Gebru, 2015).This result implied better use of the applied water, which cause low water losses by deep percolation under this intercropping pattern. It is also attributed to the large established ground cover by this intercropping system, which minimized soil evaporation. These results were similar to what was obtained by Abd El-Alim *et al.* (2017), who found that recommended applied irrigation water was 809 mm (8090 m^3 ha^{-1}) under intercropping soybean with maize on raised beds with 140 cm width and increased soybean plant density from 50 to 100% of solid culture, which achieved high seed yield without reduction on maize grain yield. On the other hand, intercropping soybean with maize increased land and net equivalent ratios (Metwally *et al.*, 2008 and 2012, and Abdel-Wahab and Abd El-Rahman, 2016).

Furthermore, Hobbs *et al.* (2000) demonstrated that raised beds planting contributed significantly in improving water distribution uniformity and water use efficiency, which reflected on higher water consumption. The results also showed that lowest water consumptive use was found for 50% soybean intercropped with 100% maize.

Table 4. Water consumptive use of soybean intercropped with maize patterns in the two growing seasons.

Intercropping pattern	Soybean cultivars	Water consumptive use (mm)	
		2021	2022
100% soybean+100% maize	Giza 21	729	633
	Giza 82	760	710
	Giza 111	788	750
	Mean	**759**	**698**
75% soybean +100% maize	Giza 21	692	598
	Giza 82	625	704
	Giza 111	640	615
	Mean	**652**	**639**
50% soybean+100% maize	Giza 21	656	556
	Giza 82	575	570
	Giza 111	615	518
	Mean	**615**	**548**

Water equivalent ratio of the pattern of soybean intercropping with maize

The results in Table 5 indicated that water equivalent ratio values for soybean ($WER_{soybean}$) under the three intercropping patterns were lower in the second growing season compared with the first growing season as a result of lower soybean yield in the second growing season. Giza 111cultivar attained the highest WER value under the three intercropping patterns in both the seasons as a result of higher yield as compared with the other cultivars. Furthermore, the values of WER for soybean were reduced by the reduction of its planting density from 100% to 50% of its recommended density. On the other hand, the WER values for maize (WER_{maize}) under the three intercropping patterns 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, Giza 21 under the 100 % intercropping pattern attained the highest WER values. Under the 75% intercropping pattern, the WER values for either Giza 21 or Giza 82 in the first and second seasons, respectively were higher compared to the Giza 111 cultivar. For the 50% intercropping pattern, the highest values of WER were attained for Giza 82 and Giza 111 in the first and second seasons, respectively which implied that there was no superiority of one soybean cultivar on the other with respect to obtaining higher WER value. The highest WER values for maize were obtained under the 50 % intercropping pattern, where soybean planting density was the lowest. The WER_{total} values for the three intercropping patterns were the highest under intercropping 100% soybean with 100% maize regardless of the used soybean cultivar in both growing seasons. TheWER_{total} values were 1.22 and 1.30 in the 1st and 2ndseasons, respectively.

Results clearly showed that there is higher advantage in cultivating maize with soybean because higher values of WER were obtained for maize under the three intercropping patterns. However, there were 22 and 30% increase in WER_{total}values in the first and the second season, respectively showing an advantage translated in increasing water use of the intercropping systems over the sole planting of either soybean or maize. These results were confirmed by the findings of Mao *et al.* (2012) and Zhang *et al.* (2019).Coll *et al.* (2012) indicated that the great yields attained by the intercrops are only as a consequence of low water losses. Furthermore, Miao *et al.* (2016) found that actual evapotranspiration and irrigation water use under intercropping systems were higher than those of the sole crops, which led to significantly higher land and water equivalent ratios of intercropping than those of single crops.

Table 5. Water equivalent ratios (WER) for soybean cultivars intercropped with maize in the growing seasons

Intercropping pattern	Cultivars	$WER_{soybean}$		WER_{maize}		WER_{total}	
		2021	2022	2021	2022	2021	2022
100% soybean +100% maize	Giza 21	0.50	0.49	0.69	0.88	1.19	1.37
	Giza 82	0.56	0.46	0.66	0.77	1.22	1.24
	Giza 111	0.60	0.54	0.64	0.75	1.24	1.29
Mean		**0.55**	**0.50**	**0.67**	**0.80**	**1.22**	**1.30**
75% soybean +100% maize	Giza 21	0.36	0.35	0.73	0.94	1.09	1.28
	Giza 82	0.48	0.32	0.80	0.78	1.28	1.10
	Giza 111	0.51	0.45	0.79	0.91	1.30	1.36
Mean		**0.45**	**0.37**	**0.77**	**0.87**	**1.22**	**1.25**
50% soybean+100% maize	Giza 21	0.31	0.27	0.76	0.96	1.06	1.23
	Giza 82	0.38	0.24	0.90	0.89	1.27	1.14
	Giza 111	0.42	0.34	0.82	0.94	1.24	1.27
Mean		**0.37**	**0.28**	**0.83**	**0.93**	**1.19**	**1.21**

Effect of cultivation method on water consumption by sole soybean cultivars

The sole soybean cultivars were cultivated on furrows and on raised beds. The results in Table 6a showed that, in the first growing season, the cultivation methods of soybean cultivars affected both yields and water consumptive use. The results in the table showed that the raised beds cultivation method resulted in higher yield and water consumptive use compared to cultivation on furrows. On average, raised beds cultivation resulted in 4% increase in the yield and 12% increase in water consumption. Similar results were obtained in the second growing season (Table 6b). Cultivation on raised beds resulted in increasing in average soybean yield by 4%, water consumptive use was by 18% as compared to furrow cultivation.

Limon-Ortega *et al.* (2002) indicated that raised beds cultivation improves soil quality; increases root length density in the upper 45 cm in beds due to porous soil, which led to enhanced root growth. Results by Dey *et al.* (2015) showed that cultivation on raised beds produced higher yields. Furthermore, Hobbs *et al.* (2000) demonstrated that raised beds planting significantly contributed in improving water distribution and efficiency.

Table 6 a. Effect cultivation method on the yields of sole soybean cultivars, water consumption use (WCU) in 2021 growing season

Soybean cultivars	Furrow	Yield (t ha^{-1}) Beds	Increase inyield (%)	WCU (mm) Furrow	Beds	Increase in WCU (%)
Giza 21	3.03	3.11	3	552	636	15
Giza 82	3.69	3.81	3	658	714	9
Giza 111	3.90	4.09	5	680	755	11
Average	**3.54**	**3.67**	**4**	**630**	**702**	**12**

Table 6 b. Effect cultivation method on the yields of sole soybean cultivars, water consumption use (WCU) in 2022growing season

Soybean cultivars	Furrow	Yield (t ha^{-1}) Beds	Increase inyield (%)	WCU (mm) Furrow	Beds	Increase in WCU (%)
Giza 21	2.70	2.80	4	504	656	30
Giza 82	3.43	3.63	6	532	584	10
Giza 111	3.71	3.76	1	628	714	14
Mean	**3.28**	**3.40**	**4**	**555**	**651**	**18**

Effect of cultivation methods on sole soybean crop coefficient

The highest yield of sole soybean under either furrow or raised beds cultivation was obtained from Giza 111 cultivar in both the growing seasons (Tables 6a and 6b). Therefore, the monthly values of crop coefficients (Kc)for this cultivar were individually graphed in Figure 4. The figure showed that, under raised bed cultivation, the Kc values where higher than the values under furrow cultivation. These monthly values were 0.47, 0.91, 1.01, 0.96 and 0.44 for the period from May to September, respectively. Whereas, monthly Kc values under furrow cultivation were 0.42, 0.88, 1.02, 0.90 and 0.40, for the same period. This result implied that Kc values were affected by weather conditions prevailed at the experimental site. It was also affected by the cultivation methods. The obtained results can also be attributed to better distribution of water and fertilizers under raised bed cultivation which resulted in better growth condition. These results are in harmony with those obtained by Jagtap and Jones (1989) and Kamble *et al* .(2010), who stated that the crop coefficients were found to vary with the percentage of the ground covered by crops, rate of crop development, time to achieve full ground cover**.**

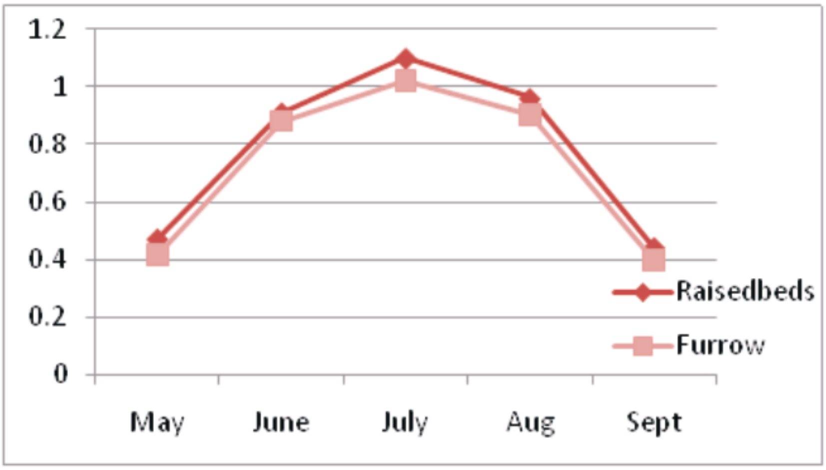

Figure 4.Average monthly crop coefficient (Kc) values for Giza111 soybean cultivar under raised bed and furrow cultivation methods

Comparison between Kc values of soybean cultivars grown on raised beds

Figure (5) showed that the lowest average monthly Kc values of 0.52, 0.98, 1.02, and 0.48 were recorded for Giza 82 cultivar as a result of low growing season from May to August. Whereas, the highest average monthly Kc values of 0.40, 0.86, 1.02, 0.88 and 0.41, for the period from May to September were found for Giza 111 cultivar.

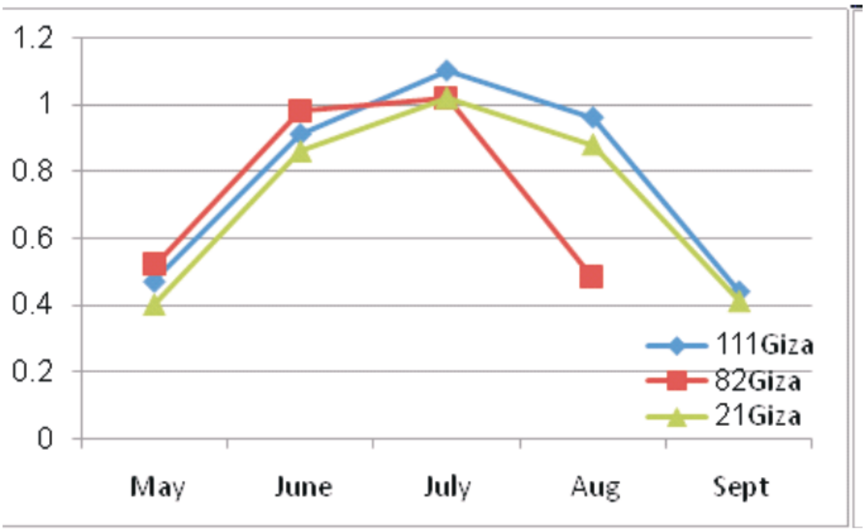

Figure 5. Average monthly crop coefficient (Kc) values for soybean cultivars grown on raised beds

Comparison between the values of Kc for soybean cultivars grown on furrows

Figure (6) showed similar trend in the values of monthly Kc values of the three cultivars. The Kc values under furrow cultivation were lower than those under raised bed. The lowest average monthly Kc values of 0.46, 0.96, 1.00, and 0.44 were found for Giza 82 cultivar as a result of shorter growing season from May to August. Whereas, the highest average monthly Kc values were found for Giza 111 cultivar. The values of monthly crop coefficients of Giza 21 were 0.38, 0.83, 0.97, 0.85 and 0.37, respectively for the period from May to September.

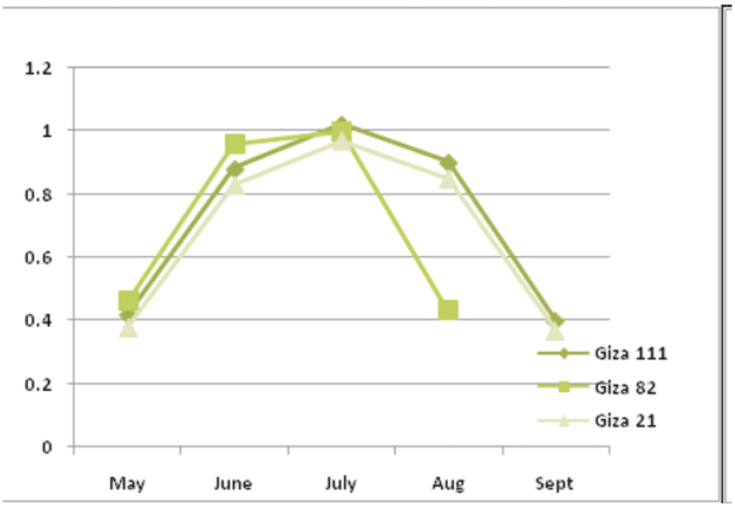

Figure 6. Average monthly crop coefficient (Kc) values for soybean cultivars grown on furrows

REFERENCES

Abd El-Alim A.M., S.A.Safina, R. EL-Killany, and N.A.Saleh, 2017. Growing corn and soybean in solid and intercropping systems under different levels of irrigation water. Bio. Sci. Res.**14**(3): 532-541.

Abd El-Alim A.M., S.A.Safina, R. EL-Killany and N.A.Saleh, 2017. Productivity, land equivalent ratios and water use efficiency of intercropping corn with soybean in Egypt.RJPBCS, **8**(4):328-344.

Abdel-Wahab, T.I., and R.A. Abd El-Rahman, 2016. Response of some soybean cultivars to low light intensity under different intercropping patterns with maize. Int. J. Appl. Agric. Sci.**2** (2): 21–31.

Abouelenein, R., T. Oweis, M. Sherif, H. Awad, F. Foaad, S. Abd El-Hafez, A. Hammam, F. Karajeh, M. Karo, and A. Linda, 2009. Improving wheat water productivity under different methods of irrigation management and nitrogen fertilizer rates. Egypt. J. Appl. Sci. **24** (12A):417-431.

Aggarwal, P. and B. Goswami, 2003. Bed planting system for increasing water use efficiency of Wheat *(T. aestibum)* grown in Inseptisol. Indian J. Agric. Sci.**73**:422-425.

Ahmad, I. M., B. Qubal., G, Ahmad and N,.H. Shah, 2009. Maize yield, plant tissue and residual soil N as affected by nitrogen management and tillage system. J. Agric. Biol. Sci. **1** (1): 19–29.

Allen, R., L. A. Percira, D. Raes, and M.Smith, 1998. Crop evapotranspiration. FAO Irrigation and Drainage, Paper No. 56 Food and Agricultural Organization of the United Nations, Rome, Italy. pp. 213.

Allen, R.G., L.S.Pereira,and D.M. Smith, 1998. Crop Evapotranspiration – Guidelines.

Annandale, J.G., and C.O. Stockle, 1994. Fluctuation of crop evapotranspiration coefficients with weather.A sensitivity analysis, Irri. Sci.**15**:1–7.

Anonymous, 2017. Bulletin of Statistical Cost Production and Net Return. Summer and Nili Field Crops and Vegetables and Fruit. Agriculture Statistics and Economic Sector, Ministry of Egyptian Agriculture and Land Reclamation, Part **(2)**, August, 2017.

Anonymous , 2016. Bulletin of Statistical Cost Production and Net Return. Summer and Nili Field Crops and Vegetables and Fruit, Agriculture Statistics and Economic Sector, Ministry of Egyptian Agriculture and Land Reclamation, Part **(2)**, August 2016.

Beedy, T. L., S. Snapp, F. K. Akinnifesi, and G.W. Sileshi, 2010. Impact of *Gliricidia sepium* intercropping system. Agricultural Ecosystem and Environment, **138** (3/4): 139-146.

Brooker, R.W., A.E.Bennett, W. Cong, T.J. Daniell, T.S.George, P.D. Hallett, C. Hawes, P. P. M. Iannetta, H. G. Jones, A.J. Karley, Li. L. Mckenzie, B.M. Pakeman, R.J. Paterson, E. Schöb, C. Shen, J. Squire, G. Watson, C.A. Zhang, C. Zhang, F. Zhang, and P.J.White, 2015. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology.New Phytol. **206** :107 117.

Coll, L., A. Cerrudo, R. J. P. Rizzalli and M. F. H. Andrade, 2012. Capture and use of water and radiation in summer intercrops in the south-east Pamp as of Argentina. Field Crop. Res.**134**:105- 113.

Djaman, K.,V. C. Mel, A.B.Balde, B. V. Bado, , L. Diop, B.Manneh, D. Mutiibwa, D. Rudnick, S. Irmak, and K. Futakuchi, 2017**.**Evapotranspiration, irrigation water requirement and water productivity of rice (*Oryza sativa* L.) in the Sahelian environment. Paddy Water Environ. **15**: 469 482.

Doorenbos, and Pruitt, 1979. Crop water requirement. FAO. Irrigation and drainage paper, 24, Rome, Italy.

El-Mehy, A. A., A. M. Taha and A. M. M. Abd-Allah, 2018.Maximizing Land and Water Productivity by Intercropping Sunflower with Peanut under Sprinkler Irrigation. Alexandria Sci. Exchange J. **39** (1) .

Flynn, R. and J.I.dowu, 2015 "*Nitrogen Fixation by Legumes*". Guide A-129, http://aces.nmsu.edu/pubs/_a/A129/for

Computing Crop Water Requirements. FAO Irrigation and drainage paper **56**, FAO, Viale Delle Terme di Caracalla, Rome, Italy.

Freed, R.D. 1991. MSTATC Microcomputer Statistical Program.Michigan State Univ. East Lansing, Michigan, USA.

Gallaher, R. N. 2009. Management of Agricultural Forestry and Fisheries enterprises.Vol. I: Multiple Cropping Systems Encyclopedia of Life Support Systems (EOLSS).

Gebru, H. 2015. A Review on the Comparative Advantages of Intercropping to Mono-Cropping System. Journal of Biology, Agriculture and Healthcare.**5**(9):215-219.

Hobbs, P.R., Y.Singh, G.S.Giri, J.G.Lauren and J.M. Duxbury, 2000.Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic plains of South Asia. IRRI workshop, Bangkok, Thailand, pp. 25-26.

Jagtap, S.S. and J.W. Jones, 1989. Stability of crop coefficients under different climate and irrigation management practices. J. Irrig. Sci. **10** : 231-244.

James, L. G. 1988: Principles of Farm Irrigation System Design. John Wiley & Sons, Inc. New York.

Jensen, M.E., R.D.Burman, and R.G. Allen, 1990 Evapotranspiration and Irrigation Water Requirements; ASCE Manual No. 70; American Society of Civil Engineers: New York, NY, USA.

Kamble, P.S., V.G. Maniyar and J.D. Jadhav, 2010.Crop coefficients (KC) of soybean [*Glycine max* (L.) Merrill] Asian J. Environ. Sci. **5** (2).

Katerji N. and G. Rana, 2008.Crop evapotranspiration measurement and estimation in the Mediterranean region.ISBN 978 8 89015 2412.INRA-CRA, Bari.

Limon-O. A., K.D.Sayre, R.A. Drijber, and C.A. Francis, 2002. Soil attributes in a furrow-irrigated bed planting system in northwest Mexico. Soil Till. Res.**63**:123–132.

Majumdar, D.K. 2002. Irrigation Water Management: Principles and Practice. 2nd ed. Prentice-Hall of India, New Delhi 110001.pp.487.

Mao, L.L., L.Z. Zhang,W.W. Li, W. V. D. Werf, J.H. Sun, H. Spiertz, and L. Li, 2012. Yield advantage and water saving in maize/pea intercrop. Field Crop Res.**138**:11-20.

Miao, Q., R.D. Rosa, H. Shi, P. Paredes, L. Zhu, J. Dai, J.M.Gonçalves, and L.S. Pereira, 2016. Modeling water use, transpiration and soil evaporation of spring wheat–maize and spring wheat–sunflower relay intercropping using the dual crop coefficient approach. Agri. Wat. Manag. **165**:211-229.

Ouda, S. A., M. TEl, E. F. Abdallah, and M.S.Gaballah, 2007.Effect of water stress on the yield of soybean and maize grown under different intercropping patterns. Aust. J. Basic and Appl.Sci.**1**(4): 578–85.

Ouda, S. and A. Zohry, 2018.Water requirements for prevailing cropping pattern.*In*: Cropping Pattern to Overcome Abiotic Stresses: Water, Salinity and Climate. Springer Publishing House.

Press, A. I., D.Rivest, M. Lorente, A. Olivier, and C. Messier, 2013. Soil biochemical properties and microbial resilience in agroforestry systems: effects on wheat growth under controlled drought and flooding conditions. Sci. Total Environ. **463** : 51–60.

Sani, Y.G., K. Jamshidi, and M.R. Moghadam, 2014. Evaluation of quality and quantity of corn and soybean grain yield in intercropping under deficit irrigation. J. Biol. Agric. and Healthcare, **4**(25): 13-14.

Sherif, S.A. and E. K. Gendy, 2012. Growing maize intercropped with soybean on beds. Egyptian J. Appl. Sci. **27**(9):409-423.

Sing , V. K., B.S. Dwivedi, A.K .Shukla and R.P Mishra, 2010. Permanent raised bed planting of the pigeonpea-wheat system on a Typic Ustoochrept: Effects on soil fertility, yield and water and nutrient use efficiencies. Field Crop Res. **116**:127-39.

Snedcor, R. L., G. W. and K. Cochran, 1980: Statistical Methods. 7th Edition, Iowa Stat. Univ.

Snyder, R. L., M. Orang Bali, S.Eching, 2004. Basic irrigation scheduling (BISm). http://www.waterplan. water.ca.gov/landwateruse/wateruse/Ag/CUP/Californi/Climate_Data_010804.xls

Sonnewald, U. 2012. "Plant Physiology Preview".www.plant.org, American Society of Plant Biologists.

Tan, K.H. 1996. Soil sampling, preparation and analysis. New York (NY): Marcel Dekker. Brockhaus, F. A. 1962. A B C der land wirtscheft B. and A-K 2 nd Edit VEB F. A. Brockhaus Verlay, Leipzg.

Tolera, A. 2003. Effects of nitrogen, phosphorus farmyard manure and population of climbing bean on the performance of maize (*Zea mays* L.)/climbing bean (*Phaseolus vulgaris* L.) intercropping system in Alfisols of Bako. An MSc Thesis Presented to the School of Graduate Studies of Alemaya University. pp.1-75.

Tsubo, M., S. Walker and H.O. Ogindo, 2005. A simulation model of cereal-legume intercropping system for semi-arid regions. Field Crop Res. **93**(1):10-22.

Vites, F. G. Jr. 1965. Increasing water efficiency by soil management. Amer. Soci.Agron. **26**:259-274.

Waktola, S.K., K. Belete, and T. Tana, 2014. Productivity evaluation of maize - soybean intercropping system under rain fed condition at Bench-Maji Zone, Ethiopia. Sky J. Agri Res. **3(9)**:158 - 164.

Wright, J. L. 1982.New evapotranspiration crop coefficients, Journal of Irrigation Drainage Div. ASCE **108** : 57–74.

Zhang, X., L. Ma, F. S. Gilliam and Q. W. C. Li, 2012. Effects of raised-bed planting for enhanced summer maize yield on rhizosphere soil microbial functional groups and enzyme activity in Henan Province, China. Field Crop. Res.**130**:28–37.

Zhang, Yue, Yu, Duan, J. Y. Jiayi Nie, R. Jianhong,V. W.Wopke, B. Jochem, B. E. J. Zhang, S. Zhicheng and L. Zhang, 2019 A lack of complementarity for water acquisition limits yield advantage of oats/vetch intercropping in a semi-arid condition. Agricultural Water Management. 225 : 105778.

Zohry , A. A. and S. A. Ouda, 2019 . Intercropping systems for Sugar beet to improved its land and water productivity. J. Soils and Crops. **29**(2) : 218-226.

Rec. on 15.06.2023 & Acc. on 06.09.2023