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Impact of irrigation regimes on productivity and profitability of maize + peanut intercropping system in Upper Egypt

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ABSTRACT: Good management of soil and water use is one of the most important factors in agricultural sustainability, and intercropping systems are an important component of good agricultural practices. Thus, a field experiment was conducted at the Experimental Farm of Arab Al-Awamer Research Station, Assiut Governorate, Agriculture Research Center, Egypt, during the summer seasons of 2021 and 2022 to investigate the effect of maize (M) + peanut (P) intercropping system on productivity, water use efficiency, and profitability at varying irrigation regimes. The experiment was laid out in a randomized complete block design using a split-plot arrangement with three replicates. Irrigation regimes (120, 100 and 80% ETc) were assigned to the main plots, while the intercropping systems (100% P + 25% M, 100% P + 33% M and 100% P + 50% M) were allocated to the sub-plots. The results showed that most traits of peanut and maize decreased substantially under the 80% ETc irrigation regime. While the largest values of traits were associated with the 120 % ETc. Averaged across the two seasons, the highest values of net return (1,441 US$/ha) were obtained when 100% peanut plants were intercropped with 25% maize at 120% ETc irrigation regime. Therefore, we recommend intercrop maize (25%) with peanut (100%) irrigated with 120% ETc to achieve higher yields and net return.

Keywords: Intercropping systems; Sole; Land equivalent ratio; Water use efficiency; Drip irrigation.

1. INTRODUCTION

Water is essential for the expansion and sustainability of crop production in Egypt. The country's ability to supply the water needed for that expansion is related to horizontal agricultural expansion. High water resources management issues in Egypt are symbolized by an imbalance between high water demands and low supply. Thus each unit of water must be saved and efficiently use to enhance food production. The drip irrigation system has immense potential to save water and enhance water productivity. For higher sunflower yield on newly reclaimed soils in the Assiut Governorate, Egypt the crop required 679.9 mm of water under a sprinkler irrigation system and merely 590 mm under a drip irrigation system [1,2]. Metwally et al. [3] showed that compatible intercropping systems increased the light use efficiency, water conservation, and yield advantages over the monoculture. El-Mehy et al. [4] indicated that all intercropping systems had water-equivalent ratios and land-equivalent ratios that were greater than unity. It is thus clearly established that the intercropping systems can result in higher water and land productivity.

Egyptian agriculture needs to become less dependent on irrigation inputs to enhance the sustainability of crop production. Achieving sustainable agriculture opportunities are provided by several cropping systems, including crop rotations, relay intercropping and intercropping systems [5]. Intercropping is an agricultural system used for cultivating more than one crop in one field simultaneously during part or the same of their growing time [6,7]. Due to the temporal and spatial complementarity between cultivated crops, it has been proved that intercropping systems enhance productivity through efficiently using agricultural lands and input resources [8,9].

Maize is one of the most important and major cereal grain crops used for food and as livestock fodder, but its continuous cropping often leads to poor soil fertility, thus increase the risk of crop failure [10]. Accordingly, it makes economic sense to grow a low water and fertilizers-requiring crop in the intercropping system with maize. In this regard, peanut is a low-water consumption and high-value crop, as well as a source of cooking oil and protein [11, 12] and also fixes atmospheric nitrogen providing it to the following crops, thus supporting the circular economy principle.

Based on the values of the land equivalent ratio (LER), the results showed the yield advantage of the maize+peanut intercropping system [13,14], where maize was the superior competitor and its productivity dominated the intercropping system yield. Recently, Pourjani et al. [15] reported that the highest grain yields of peanut were observed in 100% peanut + 50% maize intercropping system plots (2631.2 kg/ha), while the highest grain yield of maize was observed in 50% peanut + 100% maize intercropping system plots (6449.5 kg/ha).

We still need more information for linking the irrigation regimes and intercropping system effects on the vegetative growth characters and grain yield in maize+peanut intercropping system [16]. In this respect, Morris and Garrity [17] reported that during the entire growth period in the intercropping system, water consumption becomes greater compared to the monoculture with a small difference than sole cropping water consumption weighted mean value. Also, Han et al. [18] determined that although the intercropped maize in the maize+peanut rotational strip intercropping system consumed more moisture, however, it achieved several economic benefits and less N_2O emissions than sole maize. [19] have grown groundnut (peanut) under different intercropping systems i.e. sole groundnut, sesame, castor, blackgram, and pearl millet, and found that the sole groundnut recorded 5.11 kg/ha/mm water use efficiency comparing with 5.49 kg/ha/mm for groundnut+blackgram intercropping system. As different component crops in intercropping systems need different amounts of water, hence the optimization of irrigation for intercropping systems becomes imminent to increase crop yields and water productivity. Therefore, this study was carried out to explore the production potential of maize+peanut intercropping system at different irrigation regimes and thereby quantify the water use efficiency.

2. MATERIALS AND METHODS

2.1. Study Site

A field experiment was conducted in 2021 and 2022 at the Experimental Farm of Arab El-Awammer Research Station of Egypt, Agricultural Research Center (ARC) (latitude 27°, 03′ N, longitude 31°, 01′ E and 71 m above sea level) at Assiut Province, Egypt. The weather data of the experimental area during the 2021 and 2022 growing seasons are presented in Table 1.

Table 1. Average monthly meteorological data of Assiut weather station during 2021 and 2022 growing seasons.

Date	Temperature Min (C°)	Temperature Max (C°)	Relative Humidity (%)	Wind Speed km/h	Solar Radiation (MJ/m²/day)
			2021		
May	21.1	38.0	28.9	18.0	27.7
June	22.3	36.9	29.1	19.3	29.6
July	24.6	38.9	27.9	14.7	28.8
Aug.	24.2	39.1	28.1	14.5	27.4
Sept.	21.4	35.2	39.5	18.1	24.1
Oct.	17.6	32.4	44.2	14.9	20.4
			2022		
May	19.3	35.2	25.0	18.1	29.4
June	23.1	37.7	29.4	16.2	29.7
July	23.4	37.9	30.1	16.1	28.8
Aug.	24.4	38.1	34.7	15.6	26.9
Sept.	22.3	36.9	36.0	15.4	24.0
Oct.	17.6	30.2	48.8	15.7	19.7

Experiments were conducted on the type of soil classified as Arid sol, having a sandy texture (89.9% sand, 7.1% silt and 3.0% clay). The soil pH was 8.37, soil organic matter 0.21%, total N 0.005% and available phosphorus 8.32 ppm in the top 30 cm of the soil profile. The preceding crops were wheat and Egyptian clover (Berseem) in the first and second seasons, respectively.

2.2. Experimental design

The experiment was laid out in a randomized complete block design (RCBD) using a split-plot arrangement with three replicates. Irrigation regimes were assigned to the main plots, while three intercropping systems were allocated to the sub-plots.

Three Irrigation regimes (IR)included:

1. Irrigation with amounts of water equal to 120% ETc.
2. Irrigation with amounts of water equal to 100% ETc.
3. Irrigation with amounts of water equal to 80% ETc.

Three intercropping systems (IS), included:

1. 100% peanut + 25% maize (growing maize on one side of one row and leaving three rows without intercropping).
2. 100% peanut + 33% maize (growing maize on one side of one row and leaving two rows without intercropping).
3. 100% peanut + 50% maize (growing maize on one side of one row and leaving one row without intercropping) and peanut was grown on one side of all rows.

In addition, pure stands for (a) sole peanut (SP) (*Arachis hypogaea* L. cv. Giza 6) was maintained. The peanut seeds were treated by *Rhizobium* spp. before sowing and. Like for peanut, the (b) sole maize (SM) stand (*Zea mays* L. cv. Giza, single cross 131) was also maintained.

Monoculture peanut seeds were drilled in one side of row (50 cm width) spaced at 10 cm between hills. Monoculture maize seeds were drilled in one side of the row (50 cm width), with one plant/hill and 25 cm between hills. The individual plot area was 18 m^2, each intercropping and monoculture plot consisted of 12 rows of 3 m length, and 0.5 m width. Potassium sulfate and calcium superphosphate were applied to sub-plots during soil preparation at planting. Potassium fertilizer (48 % K_2O) was added at the rate of 120 kg K_2O/ha and Calcium super phosphate (15.5% P_2O_5) at a rate of 360 kg /ha during the two growing seasons for peanut and maize. Nitrogen fertilizer was added at the rate of 180 kg N/ha for peanuts in sole and intercropping systems and 358 kg N/ha for maize in sole and intercropping systems, in the form of ammonium nitrate (33.5% N). Peanut was planted on 1 and 3 June in the first and second seasons, respectively. Whereas maize was planted 15 days after peanut planting during both seasons. For irrigation, the drip irrigation system was used in this study; the drip system was set up of GR polyethylene pipe of 16 mm in diameter with auto emitter every 30 cm on the pipe and 50 cm between laterals with a flow rate of 4 liter /hour at 1.5 bars. Other cultural practices were followed as per the recommended schedule.

2.3. Agronomic management

At harvesting, 10 guarded plants were taken randomly from each sub-plot to estimate:

Peanut traits: plant height (cm), 100 pods weight (g), 100 seed weight (g), pods and fodder yields (ton/ha) were measured as all harvested plants from each sub-plot then the total weight of pods and fodder/ha.

Maize traits: plant height (cm), number of grains/row, grains weight/ear (g), 100- kernels weight (g) and grain yield (kg/ha) were measured as all harvested maize plants of every sub-plot then the total number of ears were collected and weighed and the adjusted yield of grains to 15% moisture were measured as (ton /ha).

2.4. Estimation of water uses of indicators

2.4.1. Crop evapotranspiration (ETc)

Crop evapotranspiration (ETc) was calculated according to Allen et al. [20]:

$$ET_c = ET_0 \times Kc$$

Where: ETc = Crop evapotranspiration, ET_0 = Reference evapotranspiration. CROPWAT model (version 8), Kc = Crop coefficient for main crop (peanut), from FAO paper 56.

2.4.2. Applied irrigation water

The amounts of actual irrigation water applied under each irrigation treatment were determined using the following equation [21]:

$$I.Ra = \frac{ETc + Lf}{Er}$$

Where: I.Ra = total actual irrigation water applied mm/ interval, Etc = Crop evapotranspiration for main crop (peanut), Lf = leaching factor 10%, Er = irrigation system efficiency.

2.4.3. Irrigation water use efficiency (IWUE)

The irrigation water use efficiency (IWUE) values were calculated as follows [7]:

$$IWUE = \frac{Grain\ \ or\ Seed\ \ yield\ (Kg\ /\ ha.)}{Irrigation\ \ water\ applied\ (m^3\ /\ ha.)}$$

2.4.4. Economic productivity of irrigation water (EPIW)

Enhancing economical productivity of irrigation water by product value addition and can be expressed according to Molden [22]. It was calculated as follows:

$$Economic\ productivity\ of\ irrigation\ water = \frac{Net\ returns}{Applied\ irrigation\ water}$$

Where: Net returns in USD/ha, applied irrigation water in (mm/ha).

2.4.5. Water equivalent ratio (WER)

The water equivalent ratio quantifies the amount of water that would be needed in sole crops to achieve the same yield as produced with one unit of water in an intercropped situation and it is calculated according to the formula [23]:

$WER=WER_P + WER_M= WUE_{int\ p}/WUE_{sole\ P} + WUE_{int\ M}/WUE_{sole\ M}$

Where: $WUE_{int\ P} = (Y_{int\ P} /WU_{int})$, $WUE_{sole\ P} = (Y_{sole\ P}/WU_{sole\ P})$,

$WUE_{int\ M} = (Y_{int\ M} /WU_{int})$ and $WUE_{sole\ M} = (Y_{sole\ M} /WU_{sole\ M})$

Where: $WUE_{sole\ P}$ and $WUE_{sole\ M}$ are the water use efficiencies of sole peanut and maize. $WUE_{int,P}$ and $WUE_{int\ M}$ are water use efficiencies of peanut and maize in the intercropping. These WUE_m are calculated as the yield of crop peanut or maize per unit of total water used in the intercropping Y is the yield, WU_{int} is the actual evapotranspiration of the whole cropping system, $WU_{sole\ P}$ and $WU_{sole\ m}$ are the actual evapotranspiration of crops peanut and maize in sole crops.

2.5. Intercropping indices

2.5.1. Land equivalent ratio (LER)

Land equivalent ratio (LER) verifies the effective ability of intercropping to use the resources of the environment compared to monoculture as suggested by Willey and Osiru [24]. The LER values were calculated as: $LER = (LER_p + LER_m)$, where $LER_p = YI_p/Y_p$ and $LER_m = YI_m/Y_m$, where Y_P and Y_M are the yields of peanut and maize as monoculture while YI_p and YI_m are the yields of peanut and maize as intercrops, respectively.

2.5.2. Relative crowding coefficient (RCC or k)

The relative crowding coefficient (RCC or k) is the measure of the relative dominance of one crop/types over the other in an intercropping or mixed culture [25]. The association of 'a' and 'b' and vice versa, the coefficient is given as:

$$K_{pm} = \frac{Y_{pm}}{Y_{pp} - Y_{pm}} \times \frac{Z_{mp}}{Z_{pm}}$$

$$K_{mp} = \frac{Y_{mp}}{Y_{mm} - Y_{mp}} \times \frac{Z_{pm}}{Z_{mp}}$$

Where, K_{pm} and K_{mp} are the relative crowding coefficient of crop 'p' and 'm' intercropped with crop 'm' and 'p', Y_{pm} and Y_{mp} are the yield per unit area of crop 'p' and 'm' intercropped with crop 'm' and 'p' (expressed over the area occupied by both crops), Y_{pp} and Y_{mm} are the yield per unit area of the sole crop 'p' and 'm', Z_{pm} and Z_{mp} are the proportion of intercropped area initially allocated to crop 'p' and 'm', respectively. It has further been suggested that K_{pm} x $K_{mp} = K$. If the product of the coefficients of component crops (K) is greater than, equal to or less than unity, it indicates there is 'yield advantage', 'no effect' or 'yield disadvantage' for intercropping, respectively.

2.5.3. Competitive ratio (CR)

It gives more desirable competitiveness for the crops. The CR represents simply the ratio of individual LER_p of the two component crops and considers the proportion of the crops on which they are initially sown as indicated by Willey and Rao [26]. The CR index was calculated using the following formula:

$CR_p = (LER_p / LER_m) (Zl_m / ZI_p)$ while $CR_m = (LER_m / LER_p) (ZI_p / ZI_m)$.

2.6. Economic evaluation

The total return from each treatment was calculated in (US$): 750 and 320 US$/ton for peanut and maize, respectively, as an average for the two seasons [27]: Net returns = Gross returns – Gross variable costs

2.7. Statistical analysis

Data were analyzed by SAS program version 9.2 (2009) [28] software package. Means were compared by Least Significant Difference (LSD) at 5% level of significance, where significance was indicated by the F-test [29].

3. RESULTS

3.1. Effect of irrigation regimes

3.1.1. Growth and yield attributes of peanut

All vegetative parameters, viz. plant height, 100 pods weight and 100 seed weight of peanut were significantly affected by the irrigation regimes in the two growing seasons (Table 2). Results also showed that all the studied parameters of peanuts increased with the increasing irrigation treatments from irrigation 80% ETc to irrigation with 120 % ETc.

3.1.2. Pods and fodder yields of peanut

Irrigation regime treatments significantly affected the fodder and pod yields of peanuts during both seasons. Irrigation with 120% ETc gave the highest fodder yield (5.83 and 6.38 tons/ha) over the 100 and 80% ETc in the first and second seasons, respectively. In addition, the seed yield of peanuts increased by irrigation applied, where irrigated plants with 120% ETc gave higher values (2.89 and 3.02 tons/ha) over the irrigation regime with 100% ETc (2.69 and 3.01 tons/ha) and 80% ETc (2.10 and 2.29 tons/ha) in the first and second seasons, respectively.

3.1.3. Growth, yield attributes and yield of maize

In general, increasing the seasonal values of applied water for irrigation treatments affected all the studied traits of maize significantly ($P < 0.05$) (Table 3). Plant height, no. of kernel/row, kernel weight/ear, 100-kernel weight, and grain yield significantly increased with the increasing water irrigation regime to 120% ETc during the two successive seasons. Irrigation regime 120 ETc exceedingly performed better than 100% and 80% of ETc, particularly with respect to the plant height, no. of kernels/row, kernel weight/ear, 100- kernel weight, and grain yield of maize during both the seasons. The highest values of grain yield 2.65 and 2.95 tons/ha were obtained under the irrigation regime 120% ETc, while the lowest values were of 1.97 and 2.16 tons/ha were obtained under the irrigation regime of 80% ETc in the first and second seasons, respectively.

3.2. Effect of intercropping systems

3.2.1. Growth and yield attributes of peanut

Peanut plant height, 100-pod weight and 100-seed weight were significantly influenced by the intercropping systems during the seasons 2021 and 2022 (Table 2). The peanut plant height of the intercropping treatment 100% P + 50% M was the highest, being significantly higher as compared to all intercropping treatments during the two experimental years. However, the peanut 100-pod weight and 100-seed weight in the treatment 100% P + 25% M was greater than that of treatments 100% P + 33% M and 100% P + 50% M during the two experimental years.

3.2.2. Pods and fodder yields of peanut

The results in Table 2 showed the significant impact of intercropping on fodder and pod yields of peanuts. For the intercropping treatment 100% P + 25% M, the peanut fodder and pod yields were highest in 2 years as compared to all other intercropping treatments. Averaged across the two seasons, the data demonstrated that the average fodder yields of 5.23, 5.06 and 4.86 ton /ha were obtained for the intercropping systems of 100% P + 25% M, 100% P + 33% M and 100% P + 50% M, respectively**.** The highest pod yield of 2.75 and 2.95 tons/ha was found in 100% P + 25% M in the 2021 and 2022 seasons, respectively while the minimum pod yield of 2.29 and 2.54 tons/ha was obtained in the case of 100% P + 50% M in 2021 and 2022 season, respectively.

3.2.3. Growth, yield attributes and yield of maize

The intercropping systems affected the plant height, no. of kernel/row, kernel weight/ear, 100- kernel weight and grain yield significantly during both seasons, except for 100- kernel weight during the second season (Table 3). The highest values of plant height, no. of kernels/row, kernel weight/ear, 100- kernel weight and grain yields were obtained under the intercropping system 100% P + 50% M, whereas, the minimum values of these traits were recorded with the 100% P + 25% M. The data clearly demonstrated that the grain yields of 2.94 and 3.17 ton /ha were obtained during the 2021 and 2022 seasons for the 100% P + 50% M, respectively.

Table 2. Effect of irrigation regimes and intercropping systems on growth, yield attributes, fodder yields and pods yields of peanut.

Treatment	Plant height (cm)		100-pod weight (g)		100-seed weight (g)		Fodder yield (ton/ha)		Pod yield (ton/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation regimes										
120% ETc	71.27[a]	72.20[a]	219.41[a]	239.13[a]	79.79[a]	87.11[a]	5.83[a]	6.38[a]	2.89[a]	3.02[a]
100% ETc	67.36[a]	68.40[b]	199.62[b]	216.25[b]	75.64[b]	82.54[b]	4.85[b]	5.31[b]	2.69[b]	3.01[a]
80% ETc	59.42[b]	62.56[c]	162.08[c]	178.28[c]	67.36[c]	72.97[c]	3.78[c]	4.13[c]	2.10[c]	2.29[b]
LSD $_{(0.05)}$	7.32	3.61	5.84	3.90	3.68	1.97	0.04	0.07	0.18	0.12
Intercropping systems										
100% P + 25% M	62.58[b]	65.14[c]	199.60[a]	217.34[a]	76.48[a]	83.67[a]	4.99[a]	5.47[a]	2.75[a]	2.95[a]
100% P + 33% M	65.72[ab]	67.62[b]	195.12[b]	212.41[b]	74.11[b]	80.93[b]	4.83[b]	5.28[b]	2.64[a]	2.83[b]
100% P + 50% M	69.74[a]	70.39[a]	186.38[c]	203.91[c]	72.20[c]	78.01[c]	4.64[c]	5.07[c]	2.29[b]	2.54[c]
LSD $_{(0.05)}$	5.73	2.34	2.53	3.52	0.80	0.90	0.03	0.05	0.11	0.09
Sole peanut	68.23	70.33	233.10	241.74	84.86	90.01	6.23	6.84	3.18	3.30

3.2.4. Interaction effect of irrigation regimes and intercropping systems

The results given in Table 4 showed that the interaction effects between the irrigation regimes and intercropping systems (peanut and maize) were not significant for all the studied characters or parameters, except the pod yield (ton /ha) of peanut in the second season and kernel weight/ear (g) of maize in the first season. The highest pod yield of peanut (3.19 ton/ha) in the second season was obtained under the irrigation regime of 120% ETc with 100% P + 25% M. Whereas, the highest mean value of kernel weight/ear of maize was obtained with 100% P + 50% M under the irrigation regime of 120% ETc (218.20 g) in the first season.

Table 3. Effect of irrigation regimes and intercropping systems on growth, yield attributes and grain yield of maize.

Treatment	Plant height (cm)		No. of kernels/row		Kernel weight/ear (g)		100- kernel weight (g)		Grain yield (ton/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation regimes										
120% ETc	216.22[a]	225.11a	41.67[a]	42.33[a]	210.63[a]	210.32[a]	34.22[a]	35.14[a]	2.65[a]	2.95[a]
100% ETc	211.67[b]	223.33a	39.56[ab]	40.11[b]	202.67[b]	205.59[b]	32.38[b]	34.30[b]	2.33[b]	2.58[b]
80% ETc	196.81[c]	214.44b	38.67[b]	39.22[b]	197.90[c]	201.09[c]	31.99[b]	32.13[c]	1.97[c]	2.16[c]
LSD (0.05)	3.29	2.95	2.30	2.09	4.64	2.34	0.66	0.80	0.01	0.03
Intercropping systems										
100% P + 25% M	203.78[b]	216.67[b]	38.67[c]	39.78[b]	198.21[c]	203.00[b]	31.84[b]	33.33[a]	1.72[c]	1.99[c]
100% P + 33% M	206.78[ab]	221.92[ab]	40.00[b]	40.22[b]	204.99[b]	205.56[b]	32.79[b]	33.72[a]	2.29[b]	2.52[b]
100% P + 50% M	214.14[a]	224.30[a]	41.22[a]	41.67[a]	208.01[a]	208.44[a]	33.96[a]	34.52[a]	2.94[a]	3.17[a]
LSD (0.05)	9.44	6.62	0.86	1.06	2.02	2.65	1.04	NS	0.10	0.18
Sole maize	209.17	216.17	43.33	44.00	219.35	220.18	35.83	36.49	5.19	5.41

NS meaning; Not significant.

Table 4. Interaction effect of irrigation regimes and intercropping systems on kernel weight/ear of maize in 2021 and pod yield of peanut in 2022 season.

Treatment	Kernel weight/ear of maize (g)			Pod yield of peanut (ton/ha)		
	100% P + 25% M	100% P + 33% M	100% P + 50% M	100% P + 25% M	100% P + 33% M	100% P + 50% M
	2021			2022		
120% ETc	199.63	214.07	218.20	3.19	3.03	2.83
100% ETc	201.00	202.90	204.13	3.12	3.03	2.87
80% ETc	194.00	198.00	201.70	2.54	2.43	1.91
LSD (0.05)		3.50			0.15	

3.3. Indicators of water use by peanut and maize crops

The results presented in Table 5 indicate that the seasonal irrigation water applied, irrigation water use efficiency, economic productivity of irrigation water and water equivalent ratio of maize+peanut during both seasons were affected significantly for the irrigation regimes and intercropping systems treatments, except the economic productivity of irrigation water during both the seasons and water equivalent ratio of peanut in the first season. The values of applied irrigation water under the 120, 100, and 80% ETc for the studied irrigation regimes treatments were 792 and 767 mm/ha, 665 and 640 mm, and 549 and 526 mm, in 2021 and 2022 seasons, respectively. The values of irrigation water use efficiency of sole peanut or maize were higher than the respective intercropping system treatments. The irrigation water use efficiency values of peanuts were higher than those of maize. The highest values of irrigation water use efficiency were obtained under the irrigation regime 80% ETc with 100% P + 50% M of maize (0.47 and 0.52 kg/m^3) in the first and second seasons, respectively. The economic productivity of irrigation water in the agricultural production system was focused on gross returns (USD/ha). The value of economic productivity of irrigation water increased when irrigated with 100% ETc compared to 80 and 120% ETc. The highest economic productivity of irrigation water was 0.46 and 0.52 USD/ha under 100% ETc in the 2021 and 2022 seasons, respectively. The highest water equivalent ratio values (1.24 and 1.23) were obtained under 120% ETc with 100% P + 25% M. While, the lowest values (0.86 and 0.84) were obtained with 100% P + 33% M and 100% P + 50% M when irrigated with 80% ETc, in the first and second seasons, respectively.

Table 5. Interaction effect of irrigation regimes and intercropping systems on applied irrigation water (AIW), irrigation water use efficiency (IWUE), the economic productivity of irrigation water (EPIW) and water equivalent ratio of maize+peanut (WER)

Treatment		AIW (mm)		IWUEP (kg/m^3)		IWUEM (kg/m^3)		EPIW (USD/m^3)		WER	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation Regimes	Intercropping Systems										
120% ETc	100% P + 25% M	792	767	0.39	0.41	0.26	0.31	0.39	0.43	1.24	1.23
	100% P + 33% M	792	767	0.38	0.39	0.34	0.38	0.39	0.43	1.24	1.23
	100% P + 50% M	792	767	0.33	0.37	0.41	0.46	0.40	0.44	1.24	1.22
100% ETc	100% P + 25% M	665	640	0.43	0.49	0.26	0.31	0.43	0.48	1.04	1.03
	100% P + 33% M	665	640	0.41	0.47	0.34	0.39	0.45	0.50	1.04	1.03
	100% P + 50% M	665	640	0.38	0.45	0.45	0.50	0.46	0.52	1.04	1.02
80% ETc	100% P + 25% M	549	526	0.43	0.48	0.25	0.30	0.42	0.47	0.86	0.85
	100% P + 33% M	549	526	0.41	0.46	0.35	0.41	0.44	0.50	0.86	0.84
	100% P + 50% M	549	526	0.32	0.36	0.47	0.52	0.40	0.45	0.86	0.84
LSD $_{(0.05)}$ Irrigation (I)		-	-	0.02	0.02	0.01	0.01	0.02	0.02	0.003	0.003
LSD $_{(0.05)}$ Intercropping system (S)				0.02	0.01	0.02	0.03	NS	NS	NS	0.002
LSD $_{(0.05)}$ I x S		-	-	0.03	0.02	0.03	NS	NS	NS	NS	0.003
Sole peanut		630	606	0.50	0.54	-	-	0.37	0.42	1.00	1.00
Sole maize		650	640	-	-	0.80	0.84	0.24	0.29	1.00	1.00

3.4. Intercropping indices

3.4.1. Land equivalent ratio (LER)

The total land equivalent ratio of all the intercropping systems was more than the unity indicating the yield advantage as compared to the sole peanut or maize crops (Table 6). The Relative yield of peanuts was higher than that of maize in all treatments. Averaged across the two seasons, the highest LER 1.49 was obtained when peanut plants intercropped 100% with 50% of maize plants under the highest irrigation water regime of 120% ETc. The lowest LER of 1.02 was recorded with the 100% P+ 25% M under 80% ETc treatment when averaged between the two seasons.

3.4.2. Relative crowding coefficient (K)

The data presented in Table 6 showed that the relative crowding coefficient exceeded one when peanuts intercropped with maize under all the intercropping systems when averaged across the two seasons. The relative crowding coefficient of peanut and maize was higher in 120% ETc as compared to 100 and 80% ETc if averaged between the two seasons. The maize coefficient (K) was almost higher than the peanut coefficient under the varying irrigation regimes. The relative crowding coefficient of maize was dominant while the peanut was dominant.

3.4.3. Competitive ratio (CR)

The competitive ratio is also a trend to know the extent of competition between the intercropped cropping components and the monoculture. Data presented in Table 6 revealed that the competitive ratio values of maize were higher as compared to the peanut when averaged between the two seasons. The competitive ratio of peanut and maize plants was higher in the irrigation regime 120% ETc as compared to the 100 and 80% ETc when averaged across the two seasons.

3.5. Economic evaluation

The net return is the best parameter to judge the profitability of sole crops and intercropping systems. The impact of irrigation regimes under different intercropping systems of peanut with maize in comparison to the sole peanut or maize has been shown in Table (6). It is clearly seen that the irrigation regime 120% ETc with 100% P + 25% M resulted in the highest net return (1,441 US$/ha), while the lowest net return (449 US$/ha), when irrigated 100% P + 50% M with 80% ETc treatment against the net return of peanut and maize monoculture, were (655 and 158 US$/ha), respectively.

Table 6. Effect of irrigation regimes and intercropping systems on intercropping indices and economic evaluation of peanut based maize in both seasons.

Treatment		L peanut	L maize	LER	K p	K m	K	CR p	CR m	Gross returns USD/ ha	Net returns USD/ ha
Irrigation Regimes	Intercropping Systems										
120% ETc	100% P + 25% M	0.96	0.42	1.38	6.43	2.90	18.65	0.57	1.74	3,159	1,441
	100% P + 33% M	0.93	0.52	1.45	4.16	4.37	18.20	0.59	1.71	3,189	1,424
	100% P + 50% M	0.84	0.64	1.49	2.71	7.23	19.63	0.66	1.52	3,264	1,407
100% ETc	100% P + 25% M	0.92	0.35	1.28	3.19	1.67	5.33	0.65	1.54	2,986	1,268
	100% P + 33% M	0.88	0.45	1.34	2.77	2.51	6.97	0.64	1.55	3,083	1,318
	100% P + 50% M	0.83	0.58	1.41	2.57	4.22	10.85	0.71	1.41	3,178	1,321
80% ETc	100% P + 25% M	0.75	0.27	1.02	0.76	0.76	0.57	0.69	1.46	2,404	686
	100% P + 33% M	0.72	0.39	1.10	0.84	1.26	1.06	0.61	1.63	2,514	749
	100% P + 50% M	0.56	0.51	1.07	0.64	2.05	1.32	0.56	1.80	2,306	449
Sole peanut		1	-	1						2430	655
Sole maize		-	1	1						1696	158

4. DISCUSSION

In Egypt, improving irrigation water use efficiency is a major goal in agricultural management under conditions of limited water resources and the use of cropping systems is one of the solutions to raise irrigation water use efficiency [4,7,30,31]. The main reason for smallholders to practice intercropping systems is that it can increase profitability and land productivity. Intercropping systems improved productivity and resource acquisition compared to sole cropping [32]. Is likely that the cereal-(maize) based intercropping systems benefit with the legume (peanut) component, as the legume component supplies the nitrogen to the associated cereal partner. The legumes fix atmospheric N_2 and use for its own growth and part is transferred to the associated cereal component (maize). These relations can be affected by soil fertility status, arrangements of planting and choice of intercropping components [10].

This study clearly showed that the intercropping systems affected pod and kernel yields significantly and resulted in more efficiency of irrigation water and land use. The maize+peanut intercropping system demonstrated the benefits of intercropping on productivity and economic advantage. Previous studies have also indicated the advantageous impacts of the intercropping system on yield, productivity and economic benefits [33, 34] which emphasized the importance of using intercropping systems in sustainable agriculture to reduce the pressure in intensive farming systems with high inputs and high outputs [35,36]. The above peanut and maize traits were improved by the increased irrigation water regimes. Irrigation regimes with 120% ETc gave higher values of the peanut and maize traits as compared to the 100 and 80% ETc irrigation regimes treatments. This was to be expected given the water has an important function in plants and deficiency of irrigation could have a harmful impact on most physical processes.

In addition, in the root zone, the impact of increasing available soil moisture may encourage the plants to increase the absorption of more water and thus increase the cortex development, cell enlargement causing the increased cularization, cell division, and photosynthesis activity. Similar results were reported by [4-31-7]. The excess of irrigation water applied under 120% ETc compared to 100 and 80% ETc may be attributed to the increase in direct evaporation. The irrigation water use efficiency values of peanuts were higher than those of maize mainly due to the plant density of peanuts. Increasing the maize ratio in intercropping systems increased the water use efficiency for maize but decreased the water use efficiency of peanuts. This decrease may be due to the competition between the intercropping systems for water and its direct impact on the yield [3].

The values of the water equivalent ratio were high under 120 and 100% ETc compared to the sole peanut or sole maize. Similar results were obtained [4,7,31,37]. The results also showed that the yield and its component of peanut and maize in all the studied intercropping systems were lower as compared to the sole cropping for both the crops, except for the plant height of peanut and maize plants, the studied intercropping systems had the tallest plants compared to the sole of both crops. These results may be due to the competition between the intercropped crops for the light intensity. These findings are in agreement with those obtained by [38]. For the intercropping treatment 100% P + 25% M, the yield and its component of peanut were the highest during the 2 years compared to the 100% P + 33% M and 100% P + 50% M, whereas the highest values of the yield and its component of maize resulted from 100% P + 50% M compared to the 100% P + 33% M and 100% P + 25% in the two growing seasons. These results ascribed to the highest planting pattern of maize in 100% P + 50% M compared to the lowest planting pattern of maize in 100% P + 25% M. Moreover, this result is due to the planting pattern of maize per unit area and which is one of the major factors in determining the yield and its components per unit area. Also, it appears that the shading impacts of maize plants were higher under the treatment of intercropping system and all of these studied intercropping systems had different canopy structure, growth natures, plant habits, rooting patterns, duration of crops in soil, and days to maturity. So, these crops (peanut and maize) differ in return potential and have varying competitiveness. Similar results were obtained by [7,36,38-40].

We found that land use efficiency measured by the land equivalent ratio ranged from 1.07 to 1.49 as the average of two seasons from 1.15 to 1.16 over the two growing seasons (Table 6). The land equivalent ratio values in the intercropping systems were greater than one indicating that intercropping systems had more advantages in environmental resource utilization than when grown separately (sole cropping). This could be attributed to the lower competitiveness of peanuts compared to the maize crop. This could be attributed to the lower competitiveness of peanuts compared to the maize crop. Maize plants were dominant as they had higher relative crowding coefficient values than peanut plants in the two growing seasons indicating a more competitive effect of maize over peanut plants.

The competitive ratio values of maize plants showed that they were the most competitive with the peanut plants during both seasons. This indicated that maize plants had higher competitive ability as compared to the peanut plants. The net returns- economic profit for the intercropping system when irrigated 100% P + 50% M with sufficient water irrigation 120 ETc was 1,441 US$/ha which was higher than sole peanut (655 US$/ha), higher than sole maize (158 US$/ha), respectively. Here too, we can conclude that the actual productivity was higher than the expected one. Therefore, the intercropping system can be economically suitable for the smallholders, but full costs and advantages assessment must also take into the differences in costs, such as, mechanical and labor costs. Similar results were obtained [4,31,36,39-41].

5. CONCLUSION

Intercropping peanuts with maize is important for small-scale farmers and more land-use efficient than monoculture, mainly due to maize. It is also a promising practice to achieve highly profitable sustainability in crop production. In summary, we found the highest yield and its components in peanuts were obtained under the irrigation regime of 120% ETc with 100% P + 25% M. While the highest mean values for yield and attributes of maize were obtained with 100% P + 50% M under the 120% ETc. The highest water equivalent ratio, land equivalent ratio and net return values were obtained under the irrigation regime of 120% ETc with 100% P + 25% M. While, the lowest values were obtained with 100% P + 50% M when irrigated with 80% ETc, in the first and second seasons, respectively.

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