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Deficit irrigation and crop water productivity for intercropping pattern in new reclaimed area, Assiut, Egypt

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Abstract

A field experiment was conducted during the winter season of 2017/18 and 2018/19 at the experimental farm of Arab El-Awammer Research Station, Agriculture Research Center, Assiut, Egypt (27° 11/ N latitude, longitude 31° 06/ E and 71m altitude ASL) to evaluate the effect of different irrigation regimes (80, 100 and 120% of reference evapotranspiration (ET_o) and various intercropping patterns (wheat and faba bean intercropped with sugar beet) under drip irrigation system on sugar beet yield and its traits, crop water productivity and land equivalent ratio. The obtained results showed that sugar beet yield and its traits were decreased as the irrigation regime increased and with intercropping system with wheat or faba been. On the average bases of both seasons, sugar beet yielded 20.29, 18.17 and 16.64 ton/ feddan (feddan = 4200 m² = 0.420 hectares = 1.037 acres) at 120, 100 and 80% ET_o, respectively. The relative reductions were 21.94 and 9.19% at 120, and 100% ET_o compared to 80% ET_o. Also, sugar beet yielded 19.48, 17.64 and 17.99 ton/feddan at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar beet yield was 9.45 and 7.65% when intercropped with wheat and faba bean, respectively compared to that yielded for sole sugar beet. On the average basis of both seasons, the crop water productivity (CWP) values were 5.21, 5.60 and 6.35 kg/m^3 at 120, 100 and 80% irrigation regime, respectively regardless the intercropping system. At 120% ET_o, the CWP values were 4.82, 5.08 and 5.73 kg/m^3 for sole sugar beet, sugar beet + wheat and sugar beet + faba bean, respectively. At 100% ET_o, the CWP values were 5.24, 5.43 and 6.14 kg/m^3 for the corresponding sole and intercropping system. The CWP values were 6.23, 5.99 and 6.83 kg/m^3 for the corresponding sole and intercropping system at 80% ET_o. The highest land equivalent ratio (LER) value (1.70) was recorded when sugar beet intercropped with faba bean and irrigated at 80% ET_o while the lowest one (1.25) was attained when sugar beet intercropped with wheat and irrigated at 80% ET_o. On the average basis of both seasons, the saved lands were 36.92, 35.51 and 29.71% at 120, 100 and 80% ET_o, respectively regardless the intercropping system.

Keywords: sandy soil, irrigation regime, water productivity, intercropping pattern, land equivalent ratio.

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1. Introduction

Sustainable development is a recommended policy for advance activities in all geographic locations and it is extremely vital for desert regions which is characterized by limited natural resources especially water. Also, the governments paid little attention to utilize and manage these isolated areas. In Egypt, due to the severe limitations of water resources in many areas, the drought is most important factor affecting stress on crops. Since water is the lifeline for accruing desired yield levels, its time of application and method of application plays an important role in increasing the yield levels besides saving water. Further, water is the prime natural resource, which is often costly and limiting input particularly in arid and semi-arid regions, hence needs judicious use to reap the maximum benefit from this limiting resource. The amount and timing of irrigation are two important aspects which determine the efficient use of applied water and maximizing crop yields. In recent years, however, growing competition for scarce water resources has led to applying modified techniques for maximizing water use efficiency and improving crop yields and quality, particularly in arid and semi-arid regions like Egypt (Kalpana and Anita, 2014). Intercropping is an eco-friendly option for sustaining and increasing the productivity of farmlands. Intercropping being a unique property of arid and semi-arid areas is becoming popular day by day among small farmers as it offers the possibility of yield advantage relative to sole cropping through improved and stable yield. It also helps maintaining the soil fertility, making efficient use of nutrients, ensuring economic utilization of land, labor and capital and controlling pest's population. Intercropping of legume crops are beneficial to small land holders in which they can get maximum profit in cheaper way (Epidi *et al*., 2008). Among the important crops in the Egyptian agricultural system are the sugar crops. Sugar beet area had increased significantly, by approximately 25.6%, during last 35 years. Consequently, the contribution of sugar beet to sugar production in Egypt largely increased to reach 35.5 % of the total sugar production in 2012. Increasing the sugar yield per unit area of sugar crops is a national demand and could be achieved by adopting suitable cultural practices and applying intercropping. An agronomic advantage had been demonstrated when sugar beet was intercropped with other winter crops like wheat, barley, and faba bean (Abdel Motagally and Metwally, 2014; Attia *et al*., 2007; Gadallah *et al*., 2006; Khedr and Alla Nemeat, 2006). Topak *et al*. (2011) found that root and white sugar yields of sugar beet significantly decreased by the increasing water deficit in the semi-arid region. Yonts (2011) expressed that root and sugar yield of sugar beet was the highest for full irrigation and sugar content did not significantly change by reducing irrigation to 25%. Ghamarnia *et al*. (2012) found that sugar content of sugar beet increased with the increasing water deficit. Sahin *et al*. (2014) found that irrigation at 4 days interval and with irrigation quantities at the ratios of 0.7 and 0.6 of the Class A pan evaporation in the partial root zone drying technique could be the best irrigation treatment for drip-irrigated sugar beet in a semi-arid region with limited water resources due to high irrigation water use efficiency and low yield reduction. El-Darder *et al*. (2017) found that the total amount of applied irrigation water for 60, 80, and 100% of irrigation water requirement (ET_o) were 1589.3, 2223.0 and 2880.8 mm in the sprinkler irrigation system and they were 1322.0, 1943.5, and 2505.0 mm in the drip irrigation system, respectively. They concluded that drip irrigation system with 1322 m3/ fed water (60% of ET_o) give the best satisfy yield and good quality of sugar beet crop under sandy soil conditions. Dhima *et al*. (2007) demonstrated that intercropping of legumes and cereals with sugar beet had great advantages. Increased productivity and optimal use of available resources (land, labor, time, water and nutrients), increasing the efficiency of land use. Eskandari and Ghainbarf (2010) concluded that intercropping faba bean on other winter crops like sugar beet are important factor which help increased productivity and decrease gap between the local production and human consumption. Aboukhadra *et al*. (2013) reported that the maximum significant root yield of sugar beet was achieved for pure stands followed by the lowest intercropping density of the companion crop, when sugar beet was intercropped with wheat. Mohamed *et al*. (2014) fond that faba bean intercropped with sugar beet increase land and water productivity because no extra irrigation water or fertilizer is applied to faba bean. Heba Salama *et al*. (2016) found that sugar beet produced significantly higher root yield when intercropped with wheat under the 50 and 100% companion crop, while under the 75 %, the root yield of sugar beet was significantly superior when grown with wheat and barley compared to that grown with faba bean, for both growing seasons. Hamdany and El-Aassar (2017) found that intercropping faba been with sugar beet on different ridge width significantly affected sugar beet yield and its components. El-Shamy Moshira *et al*. (2019) found that the highest values for growth traits, yields for sugar beet and faba bean intercropping, applied and consumed water were obtained when plants were irrigated four irrigations (sowing irrigation plus four irrigations) and the furrow width 120 cm, but it was recorded the lowest values of water efficiencies. This research work aims to evaluate the effect of different irrigation regimes and various intercropping patterns under drip irrigation system on sugar beet yield and its traits, crop water productivity and land equivalent ratio.

2. Materials and methods

2.1 The experimental location, design and treatments

A field experiment was conducted during the winter season of 2017/18 and 2018/19 at the experimental farm of Arab El-Awammer Research Station, Agriculture Research Center, Assiut, Egypt (27° 11/ N latitude, longitude 31° 06/ E and 71m altitude ASL). The experimental site was served by drip irrigation system that is set up of GR polyethylene pipe of 16 mm in diameter with auto emitter every 30 cm on the pipe and 60 cm between laterals with flow rate of 4 liters /hour at 1.5 bars. The experiment was laid out in a split plot design with four replicates. The main plots represented the irrigation regimes of 80, 100 and 120% of reference evapotranspiration (ET_o) and they were bordered with buffer zone (3 m width) to prevent horizontal leakage. The spilt plots were assigned for the intercropping patterns of two companion crops; namely, wheat (*Triticum aestivum* L.) and faba bean (*Vicia faba* L.), intercropped with sugar beet (*Beta vulgaris* L.) as a main crop. The three intercropping patterns, assigned to the subplots, were: 1. pure sugar beet; 2. sugar beet + wheat; and 3. sugar beet + faba bean. Management and sampling the sub plots area included two wide beds (1.20 × 3 m) for the intercropping treatments, and either four ridges (0.6 × 3 m) for pure stands of sugar beet. All the experimental treatments were randomly distributed on the respective plots. The plot was 10 m in length and 3 m in width with an area of 30 m^2.

2.2 Soil analysis of the experimental site

Disturbed soil sampling was taken down to 60 cm soil depth with 15 cm increment using a spiral auger as well as undisturbed soil samples were taken using the core method technique. In the laboratory, the samples were air dried, ground and sieved (particle size < 2mm) and prepared for chemical and physical analysis were determined according to Page *et al*. (1982) and Klute (1986) they are presented in Table (1).

Table (1): Some soil physical and chemical properties of the experimental site.

Property	Soil depth (cm)			
	0 - 15	15 - 30	30 - 45	45 - 60
Gravel (%)	34.50	30.20	46.60	46.30
Sand (%)	90.90	90.20	89.40	89.00
Silt (%)	6.70	6.80	7.40	7.50
Clay (%)	2.40	3.00	3.20	3.50
Texture class	Sand	Sand	Sand	Sand
Bulk density (g/cm^3)	1.57	1.65	1.75	1.55
Saturation percentage	25.20	23.30	21.70	23.00
Field capacity (w/w) (%)	12.50	10.00	9.50	11.80
Wilting point (w/w) (%)	4.90	4.20	4.00	4.90
Available water (w/w) (%)	7.60	5.80	5.60	6.90
Hydraulic conductivity (cm/h	63.00			
Soil pH (1:1)	8.18	8.51	8.56	8.38
EC 1: 1 (dS/m)	0.52	0.49	0.36	0.34
Soluble ions (meq/L) $CO_3 + HCO_3$	2.25	1.90	1.42	1.15
Cl	2.10	1.90	1.27	0.99
SO_4	0.56	0.42	0.13	0.39
Ca	2.16	1.46	1.08	1.01
Mg	1.40	1.52	0.89	0.82
Na	0.39	0.29	0.24	0.23
K	0.96	0.95	0.61	0.47
Available N (ppm)	82.00	70.00	51.00	45.00
Available P (ppm)	8.82	8.82	8.70	8.58
Available K (ppm)	90.00	86.00	78.00	76.00
Organic matter (%)	0.27	0.21	0.17	0.11
$CaCO_3$ (%)	32.20	33.80	25.40	32.00

2.3 Field capacity (FC) and permanent wilting point (PWP)

Field capacity (FC) and permanent wilting point (PWP) were determined using the pressure cooker and pressure membrane apparatus. A saturated undisturbed and disturbed soil samples were equilibrated at suction pressures of 0.33 and 15 bar, respectively, according to Shawky (1967). The available water capacity (AWC) was calculated by the differences in water content at field capacity and permanent wilting point as follows:

$$AWC = FC - PWP$$

2.4 Agronomic practices

The main crop, sugar beet, was planted at the recommended seeding rate (10 kg/ha) by the Egyptian Ministry of Agriculture, for both the intercropping treatments and pure stands on 24th and 23rd of October 2017 and 2018 growing seasons, respectively. In the intercropping treatments it was sown in hills (20 cm apart) on both sides of the prepared seed bed, and later thinned to one plant per hill. In the pure stands it was sown also in hills (20 cm apart) but on only one side of the ridge. Sugar beet crop were harvested on 17th and 20th of April 2018 and 2019 growing seasons, respectively. Concerning the monocot intercrops; wheat in the intercropping treatments, was hand drilled in rows (30 cm apart) on top of the seed bed on 29th and 23rd of November 2017 and 2018 growing seasons, respectively. The used seeding rate was 120 kg/ ha. Wheat crop was harvested on 13th and 15th of April 2018 and 2019 growing seasons, respectively. On the other hand, intercropped faba bean was sown in rows in hills (20 cm apart) on top of the seed bed on 24th and 23rd of October 2017 and 2018 growing seasons, respectively. Later it was thinned to two plants per hill. Faba been crop was harvested on 31st and 30th of March 2018 and 2019 growing seasons, respectively. All experimental plots were treated similarly, *i.e*., fertilized and irrigated at the same intervals in each growing season. Nitrogen fertilizer was applied in the form of urea (46.5% N) at rate of 100 kg N/feddan in two equal doses. The first dose was added before the first irrigation, while the second one in addition to potassium dose (potassium sulphate 48% K_2O) at a rate of 50 kg K/feddan was applied before the second irrigation. Phosphorus fertilizer in the form of supper phosphate (15.5% p_2O_5) at a rate of 150 kg/feddan was added during soil preparation. All the agronomic practices were applied in accordance with the usual cultural operations followed in Assiut, Egypt for growing sugar beet and carried out according to the recommendation of the Egyptian Ministry of Agriculture.

2.5 Land equivalent ratio and land saving

The biological efficiency and productivity of different of sugar beet, wheat and faba been were compared by the partial (Individual crop) land equivalent ratio

(LER) and the total LER were calculated according to the formula proposed by Mead and Riley (1981) as follows:

$$\text{Total LER} = \text{PLER}_{\text{Sugar beet}} + \text{PLER}_{\text{Wheat or faba been}}$$

$$\text{PLER}_{\text{Sugar beet}} = \text{Sugar beet yield in intercrop / solid sugar beet yield}$$

Land saved was calculated using the equation proposed by Willey (1985) as follows:

$$\text{Land saved \%} = (100 - 1/\ \text{LER}) \times 100$$

2.6 Irrigation water requirement and water supply

The experimental plots received volumes of water to boost the moisture of 60 cm soil depth to the field capacity. The volume of applied water was equal to the difference between moisture at the field capacity and the soil moisture content before irrigation (for each irrigation treatment) plus 10% of applied water to ensure a uniform distribution.

2.7 Time of irrigation

Reference evapotranspiration (ET_o) was determined using mean monthly meteorological data according to FAO (2012). Irrigation time was determined by setting the ET_o to be equal to the allowable available soil moisture depletion (50% of available water).

2.8 Crop water productivity

Crop water productivity (CWP) was calculated according to Vites (1965) using the following equations:

$$\text{CWP} = \text{grain yield (kg/ feddan) / seasonal ET (m}^3\text{/feddan)}$$

2.9 Sugar beet yield and its components

Ten guarded plants were chosen from each experimental plot and labeled. Thus, the following characteristics were recorded at harvest time: root diameter (cm), root yield (ton/feddan), sucrose (%), purity (%), sugar yield (ton/feddan), root nitrogen percentage.

2.10 Statistical analysis

Analysis of variance (ANOVA) was performed using the SPSS statistical 11.0 package. For comparison of the means, a posthoc test (Duncan's multiple range tests) was used for significant differences ($p < 0.05$).

3. Results and Discussion

Sugar beet yield and its quality as affected by irrigation regime under intercropping system during 2017/18 and 2018/19 growing season is shown in Table (2). In general, sugar beet yield in the 2nd season was higher than that in the 1st one. The primary reason for lower root yields in 2017/18 growing season could probably be attributed to the higher air temperatures during the growing period in 2017/18 since the increasing air temperature has an adverse effect on the root yield (Kenter *et al*., 2006). Sugar beet yield and its traits were decreased as the irrigation regime increased and with intercropping system with wheat or faba been.

Table (2): Effect of irrigation regime and intercropping system on sugar beet yield and its component.

Irrigation regime	Intercropping system	2017/2018						
		Root diameter (cm)	Root yield (ton/feddan)	Sucrose (%)	Purity (%)	Sugar yield (ton/feddan)	Nitrogen (%)	IWUE (kg/m^3)
120% ET_o	Sole sugar beet	9.63A	20.29A	17.32AB	90.5A	3.51A	0.80DE	4.43D
	Sugar beet + Wheat	8.87BC	18.77BC	16.23CD	88.9BC	3.05BC	0.67F	4.10FG
	Sugar beet + Faba bean	9.13AB	18.93B	16.90ABC	88.4BCD	3.20B	0.97ABC	4.14EF
	Average	9.21A	19.33A	16.81A	89.26A	3.25A	0.81C	4.22C
100% ETo	Sole sugar beet	8.93BC	18.13CD	17.68A	89.9AB	3.20B	0.87CDE	4.75C
	Sugar beet + Wheat	7.77EF	16.65EF	16.48BC	88.0CDE	2.74D	0.83DE	4.36D
	Sugar beet + Faba bean	8.50CD	16.85EF	16.90ABC	86.6E	2.88CD	0.97ABC	4.41D
	Average	8.40B	17.21B	17.02A	88.17A	2.94B	0.89B	4.51B
80% ET_o	Sole sugar beet	8.27DE	17.37DE	16.53BC	84.2F	2.86CD	1.00AB	5.69A
	Sugar beet + Wheat	5.97H	14.96G	15.20DE	83.4FG	2.27E	0.90BCD	4.90BC
	Sugar beet + Faba bean	6.83G	15.07G	15.33DE	84.2F	2.31E	1.07A	4.94B
	Average	7.02C	15.80C	15.69B	83.93B	2.48C	0.99A	5.18A
Seasonal Average	Sole sugar beet	8.94	18.60	17.18	88.20	3.19	0.89	4.96
	Sugar beet + Wheat	7.54	16.79	15.97	86.77	2.69	0.80	4.45
	Sugar beet + Faba bean	8.15	16.95	16.38	86.40	2.80	1.00	4.50
General average		8.21	17.45	16.51	87.12	2.89	0.90	4.64
2018/2019								
120% ET_o	Sole sugar beet	10.13A	21.95A	17.68A	92.2A	3.88A	0.77F	5.21EF
	Sugar beet + Wheat	9.37BCD	20.55C	16.55AB	90.3B	3.40AB	0.73F	4.88GH
	Sugar beet + Faba bean	9.77AB	21.26B	17.24A	90.3B	3.67AB	0.90BCD	5.05FG
	Average	9.76A	21.25A	17.16AB	90.93A	3.65A	0.80B	5.05C
100% ET_o	Sole sugar beet	9.50BC	20.09C	18.55A	92.9A	3.72AB	0.87BCDE	5.72CD
	Sugar beet + Wheat	8.37EF	18.44E	17.24A	90.3B	3.18BCD	0.80EF	5.25E
	Sugar beet + Faba bean	9.10CD	18.86DE	17.33A	89.8BC	3.27ABC	0.97AB	5.37E
	Average	8.99B	19.13B	17.71A	91.00A	3.39A	0.88A	5.45B
80% ET_o	Sole sugar beet	8.80DE	19.01D	13.44B	86.1D	2.56DE	0.93ABC	6.77A
	Sugar beet + Wheat	6.30H	16.45FG	15.49AB	84.5E	2.55D	0.87CDE	5.86BC
	Sugar beet + Faba bean	7.40G	16.98F	15.62AB	84.7E	2.65CDE	1.03A	6.04B
	Average	7.50C	1748C	14.85B	85.10B	2.59B	0.94A	6.22A
Seasonal Average	Sole sugar beet	9.48	20.35	17.56	90.40	3.39	0.86	5.90
	Sugar beet + Wheat	8.01	18.48	16.43	88.37	3.05	0.80	5.33
	Sugar beet +Faba bean	8.76	19.03	16.73	88.27	3.20	0.97	5.49
General average		8.75	19.29	16.90	89.01	3.21	0.87	5.57

The reduction in sugar beet yield and its traits was more obvious when sugar beet intercropped with wheat than that with faba been. In the 1st season and on the average bases, sugar beet yielded 19.33, 17.21 and 15.80 ton/feddan at 120, 100 and 80% ET_o, respectively. The relative reductions were 22.34, 8.92% at 120, and 100% ET_o compared to 80% ET_o. Also, sugar beet yielded 18.60, 16.79 and 16.95 ton/feddan at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar beet yield was 9.73 and 8.87% when intercropped with wheat and faba bean, respectively compared to that yielded for sole sugar beet. In the 2nd season and on the average bases, sugar beet yielded 21.25, 19.13 and 17.48 ton/feddan at 120, 100 and 80% ET_o, respectively (Table 2). The relative reductions were 21.57 and 9.44% at 120, and 100% ET_o compared to 80% ET_o. Also, sugar beet yielded 20.35, 18.48 and 19.03 ton/ fed. at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar beet yield was 9.19 and 6.49% when intercropped with wheat and faba bean, respectively compared to that yielded for sole sugar beet. This might be attributed to the effect of even sugar beet arrangement and companion crop plants which resulted in greater exposure of the plant canopy to the solar radiation. This better effect of the solar radiation was reflected on better root growth and higher root yield. These findings are in harmony with those obtained by Salama Heba *et al*. (2016). Sugar beet root diameter as affected by irrigation regime under intercropping system during 2017/18 and 2018/19 growing season is shown in Table (2). In general, sugar beet root diameter realized the same trend of sugar beet yield since it was higher in the 2nd season than that of 1st one. In the 1st season and on the average bases, sugar beet root diameter achieved values of 9.21, 8.40 and 7.02 cm at 120, 100 and 80% ET_o, respectively. The relative reductions were 31.20 and 19.66% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of sugar beet root diameter were 8.94, 7.54 and 8.15 cm at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar beet root diameter was 15.66 and 8.84% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. In the 2nd season and on the average bases, sugar beet root diameter reached values of 9.76, 8.99 and 7.50 cm at 120, 100 and 80% ET_o, respectively. The relative reductions were 30.13 and 19.87% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of sugar beet root diameter were 9.48, 8.01 and 8.76 cm at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar beet root diameter was 15.51 and 7.59% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. The reduction of sugar beet root diameter may be due to the shading effect, in addition to the high competition for light which negatively affect the rate of photosynthesis and, thus, reduces the sugar beet root diameter. This result is in accordance with that obtained by Abo Mostafa *et al*. (2012). It was noticed that intercropped sugar beet with faba been realized higher sugar beet yield or root than those attained when sugar beet intercropped with wheat. This observation was true in both growing seasons. Such effect of intercropped faba bean with sugar beet could be attributed mainly to its role in the growth stages and the competition between all plants on nutrition and light and the effect of various physiological process including cell division and cell elongation of internodes resulting in more tillers formation, leaf numbers and photosynthetic area (leaf area), which resulted in more photosynthetic production. These results are in harmony with those obtained by Mohammed *et al*. (2005). The sucrose percentage as affected by irrigation regime under intercropping system during 2017/18 and 2018/19 growing season is shown in Table (2). In general, sucrose percentage was higher in the 2nd season than that of 1st one. Also, sucrose % decreased with intercropping system and irrigation regime. In the 1st season and on the average bases, sucrose % was 16.82, 17.02 and 15.69% at 120, 100 and 80% ET_o, respectively. The relative reductions were 7.20 and 8.48% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of sucrose % were 17.18, 15.97 and 16.38% at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sucrose % was 7.04 and 4.66% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. In the 2nd season and on the average bases, sucrose % values were 17.16, 17.71 and 15.85% at 120, 100 and 80% ET_o, respectively. The relative reductions were 8.26 and 11.74% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of sucrose % were 17.56, 16.43 and 16.73 % at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sucrose % was 6.44 and 4.73% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. This effect might be resulted from the increase of plant roots volume, which increased vegetative growth, photosynthetic area, which resulted in more assimilates products and consequently increased dry matter accumulation and translocation of more photosynthesis to seeds (El-Shamy Moshira *et al*., 2015). These results are in agreement with those obtained by Mohammed *et al*. (2005), Abou-Elela (2012) and Abdel Motagally *et al*. (2014). The purity percentage as affected by irrigation regime under intercropping system during 2017/18 and 2018/19 growing season is shown in Table (2). In general, purity % was higher in the 2nd season than that of 1st one. Also, purity % decreased with intercropping system and irrigation regime. In the 1st season and on the average bases, purity % was 89.27, 88.17 and 83.93% at 120, 100 and 80% ET_o, respectively. The relative reductions were 6.36 and 5.05% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of purity % were 88.20, 86.77 and 86.40% at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in purity % was 1.62 and 2.04% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. The same trend was noticed in the 2nd season since the purity % was 90.93, 91.0 and 85.10% at 120, 100 and 80% ET_o, respectively. The relative reductions were 6.85 and 6.93% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of purity % were 90.40, 88.37 and 88.27% at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in purity percentage was 2.25 and 2.36% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. The sugar yield as affected by irrigation regime under intercropping system during 2017/18 and 2018/19 growing season is shown in Table (2). In general, sugar yield was higher in the 2nd season than that of 1st one. Also, sugar yield decreased with intercropping system and irrigation regime. In the 1st season and on the average bases, sugar yield was 3.25, 2.94 and 2.48 ton/feddan at 120, 100 and 80% ET_o, respectively. The relative reductions were 31.05 and 18.55% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of sugar yield were 3.19, 2.69 and 2.80 ton/ fed. at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar yield was 15.67 and 12.23% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. The same trend was noticed in the 2nd season since the sugar yield was 3.65, 3.39 and 2.59 ton/feddan at 120, 100 and 80% ET_o, respectively. The relative reductions were 40.93 and 30.89% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of sugar yield were 3.39, 3.05 and 3.20 ton/feddan at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The reduction in sugar yield was 10.03 and 5.60% when intercropped with wheat and faba bean, respectively compared to that of sole sugar beet. Nitrogen percentage as affected by irrigation regime under intercropping system during 2017/18 and 2018/19 growing season is shown in Table (2). In general, nitrogen percentage was higher in the 1st season than that of 2nd one. Also, nitrogen percentage increased with intercropping system and irrigation regime. In the 1st season and on the average bases, nitrogen % was 0.81, 0.89 and 0.99% at 120, 100 and 80% ET_o, respectively. The relative increases were 18.18 and 10.10% at 120, and 100% ET_o compared to 80% ETo. Also, the values of nitrogen % were 0.89, 0.80 and 1.0% at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The increase in nitrogen % was 11.0 and 20.0% for sole sugar beet and when intercropped with wheat, respectively compared to that of intercropped with faba bean. The same trend was noticed in the 2nd season since the nitrogen % was 0.80, 0.88 and 0.94% at 120, 100 and 80% ET_o, respectively. The relative increases were 14.89 and 6.38% at 120, and 100% ET_o compared to 80% ET_o. Also, the values of nitrogen percentage were 0.86, 0.80 and 0.97% at sole sugar beet, intercropped sugar beet with wheat and intercropped sugar beet with faba bean, respectively. The increase in nitrogen % was 11.34 and 17.53% for sole sugar beet and when intercropped with wheat, respectively compared to that of intercropped with faba bean.

3.1 Irrigation water applied

The amount of seasonal irrigation water applied as affected by irrigation regimes under intercropping system through 2017/18 and 2018/19 growing season is presented in Table (3). In general, the amount of applied water decreased as the irrigation regime increased and with intercropping system. On the average basis of both growing seasons, the amounts of applied irrigation water were 4046.10, 3371.73 and 2697.38 m^3/feddan at 120, 100 and 80% ET_o, respectively regardless the intercropping system. It was noticed that the amount of applied irrigation water was higher in the 1st season than that of the 2nd one (Table 3). Ouda *et al*. (2007) found that the applied irrigation of both intercropped maize and the sole maize was the highest under irrigation at PEC equaled to 1.2 compared to those at 1.0 and 0.8 PEC. Masoero *et al*. (2013) found that the total amount of irrigation water was 494 mm under full irrigation for maize crop. Atta (2007) reported that the amount of applied water for maize under full irrigation was 8143.0 m3/ha. Ewis *et al*. (2016) stated that the amount of irrigation water applied for planting and second irrigation watering through complete emergence was 480 and 490 and it was 365 and 368 m^3/feddan in the 1st and 2nd seasons, respectively for all treatments.

3.2 Crop water productivity

Crop water productivity (CWP) as affected by irrigation regime with intercropping system as well as mono-cropping through 2017/18 and 2018/19 growing season is shown in Table (3). In general, the CWP increased as the irrigation regime increased and with intercropping system during both seasons; the increase is more pronounced in the 2nd season.

Table (3): Crop water productivity as affected by irrigation regime and intercropping system during the growing season of 2017/2018 and 2018/2019.

Irrigation regime	Intercropping system	Irrigation water applied (m^3/feddan)		Sugar beet root yield (kg/feddan)		Wheat seed yield (kg/feddan)		Faba bean seed yield (kg/feddan)		Crop water productivity (kg/m^3)		
		2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	Average
120% ET_o	Sole Sugar beet	4580.40	4211.60	20290.00	21950.00	------	-----	------	------	4.43	5.21	4.82
	Sugar beet + Wheat	4266.80	3854.20	18770.00	20550.00	993.90	784.50	------	-------	4.63	5.54	5.08
	Sugar beet + Faba bean	3852.00	3511.50	18930.00	21260.00	-------	-------	782.90	1026.70	5.12	6.35	5.73
	Mean	4233.07	3859.10	19330.00	21253.33	993.90	784.50	782.90	1026.70	4.73	5.70	5.21
100% ET_o	Sole Sugar beet	3817.00	3509.70	18130.00	20090.00	------	-------	-------	--------	4.75	5.72	5.24
	Sugar beet + Wheat	3555.60	3211.90	16650.00	18440.00	757.70	717.30	-------	------	4.90	5.96	5.43
	Sugar beet + Faba bean	3210.00	2926.20	16850.00	18890.00	-------	-------	781.40	974.70	5.49	6.79	6.14
	Mean	3527.53	3215.93	17210.00	19140.00	757.70	717.30	781.40	974.70	5.05	6.16	5.60
80% ET_o	Sole Sugar beet	3053.60	2807.70	17370.00	19010.00	------	------	------	------	5.69	6.77	6.23
	Sugar beet + Wheat	2844.50	2569.50	14960.00	16450.00	521.20	350.00	------	------	5.44	6.54	5.99
	Sugar beet + Faba bean	2568.00	2341.00	15070.00	16980.00	-------	-------	464.30	855.50	6.05	7.62	6.83
	Mean	2822.03	2572.73	15800.00	17480.00	521.20	350.00	464.30	855.50	5.73	6.98	6.35

On the average basis of both seasons, the CWP values were 5.21, 5.60 and 6.35 kg/m^3 at 120, 100 and 80% irrigation regime, respectively regardless the intercropping system. At 120% ET_o, the CWP values were 4.82, 5.08 and 5.73 kg/m^3 for sole sugar beet, sugar beet + wheat and sugar beet + faba bean, respectively. At 100% ET_o, the CWP values were 5.24, 5.43 and 6.14 kg/m^3 for the corresponding sole and intercropping system. The CWP values were 6.23, 5.99 and 6.83 kg/m^3 for the corresponding sole and intercropping system at 80% ET_o irrigation regime. These results are in agreement of those obtained by Chimonyo *et al*. (2016), they found that deficit irrigation was more effective resulting in yield (12.84%) and WUE (11.09%) improvements. Arunkumar *et al*. (2017) showed that the 0.7 IW/CPE recorded significantly higher WUE compared to other treatments. In terms of intercropping system, the groundnut equivalent yield and WUE was higher (11.34) under groundnut + maize. While least groundnut equivalent yield WUE was registered with sole crop of groundnut. Hajibol *et al*. (2018) found that instant water use efficiency (WUE) was not influenced in wheat plants either by P supply or intercrop (IC), while in sugar beet it was significantly higher in IC plants irrespective the P supply level. Soil moisture or water availability to plants is a determining factor in intercropping systems and efficient water use leads to use of other resources. Cereal-legume combination is known to use available water resources more efficiently than pure stands of crops. It could be one of the best options as soybean as a deep-rooted crop having efficiency to use soil moisture from deeper layer (below 1 m) of the soil (Maitra et al., 2019). Abd El-Hafeez and Bashandy Samah (2019) revealed that irrigation at 0.7 of A pan evaporation coefficient (APE) gave the highest values of WUE since it was almost 1.08 kg grains/m^3 in both seasons, followed by irrigation at 1.3 of APE (1.02 kg maize grains/m^3 in both seasons). Moghazy (2021) found that the CWP decreased by reducing the cumulative pan evaporation and the opposite trend was noticed with nitrogen level under mono or intercropping system during both seasons.

3.3 Land equivalent ratio

In general, LER recorded higher values when sugar beet intercropped with faba bean than those attained when it intercropped with wheat regardless the irrigation regimes (Table 4). In both growing seasons, the maximum value of partial LER (0.97) was recorded when sugar beet intercropped with faba bean and irrigated at 120% ET_o (Table 4). Whereas the lowest one (0.39) was obtained when sugar beet intercropped with wheat and irrigated at 80% ET_o. The LER of sugar beet was almost 0.93 at 120 and 100% irrigation regimes and it was 0.87 at 80% irrigation regime regardless the intercropping system. In the 1st season, the highest LER value (1.69) was recorded when sugar beet intercropped with faba bean and irrigated at 100% ET_o while the lowest one (1.40) was attained when sugar beet intercropped with wheat and irrigated at 80% ET_o. In the 2nd season, the highest LER value (1.70) was recorded when sugar beet intercropped with faba bean and irrigated at 80% ET_o while the lowest one (1.25) was attained when sugar beet intercropped with wheat and irrigated at 80% ET_o. The LER 1.70 suggests that there is 70 % greater land area requirement for the monoculture system or 70 % greater relative yield for intercropping of sugar beet and faba bean and/or 70 % greater biological efficiency for intercropping these two crops.

Table (4): Land equivalent ratio and saved land as affected by irrigation regime and intercropping system of 2017/2018 and 2018/2019 growing seasons.

Irrigation regime	Intercropping system	2017/2018			
		$LER_{sugar\ beet}$	$LER_{intercropping}$	LER_{total}	Saved land (%)
120% ET_o	Sugar beet + Wheat	0.93	0.66	1.59	37.11
	Sugar beet + Faba bean	0.93	0.68	1.61	37.89
100% Et_o	Sugar beet + Wheat	0.92	0.53	1.45	31.03
	Sugar beet + Faba bean	0.93	0.76	1.69	40.83
80% Et_o	Sugar beet + Wheat	0.86	0.54	1.40	28.57
	Sugar beet + Faba bean	0.87	0.54	1.41	29.08
2018/2019					
120% ET_o	Sugar beet + Wheat	0.94	0.56	1.49	32.89
	Sugar beet + Faba bean	0.97	0.69	1.66	39.76
100% Et_o	Sugar beet + Wheat	0.92	0.54	1.46	31.51
	Sugar beet + Faba bean	0.94	0.70	1.63	38.65
80% Et_o	Sugar beet + Wheat	0.87	0.39	1.25	20.00
	Sugar beet + Faba bean	0.89	0.81	1.70	41.18

In both seasons, the total LER under irrigation treatments were greater than one, indicating that all treatments had an advantage in land use. These results are in agreement of those obtained by El-Shamy Moshira *et al*. (2016) who revealed that the highest values of relative yield (RY), LER and net income of sugars beet when intercropped with faba bean. Such favorable effect of intercropping system might have been resulted from improve in faba bean and sugar beet productivity which reverse on relative yield (RY), net income for faba bean and sugar beet and land equivalent ratio (LER). El-Shamy Moshira *et al*. (2019) stated that the highest land equivalent ratio (LER, 1.533) as average of two seasons was obtained when the intercropped sugar beet and faba bean plants were irrigated four times and the furrow width was 120 cm. Moghazy (2021) found that the maximum value of partial LER (1.07) was recorded when maize irrigated with highest amount of irrigation water at pan evaporation coefficient (PEC) of 1.2 and fertilized by 150 kg N/feddan. Whereas the lowest one (1.03) was obtained when plants irrigated with the least amount of irrigation water PEC of 0.8 and fertilized by 120 kg N/feddan. The total LER in intercrops was 1.48, 1.42 and 1.36 at PEC of 1.2, 1.0 and 0.8, respectively throughout the cropping seasons of maize and green bean.

3.4 Land saved percentage

The saved land as affected by irrigation regimes and intercropping system is shown in table (4). In general, irrigation regime decreased the area of the saved land. Intercrop sugar beet with faba bean realized higher values of saved land than sugar beet intercropped with wheat. On the average basis of both seasons, the saved land were 36.92, 35.51 and 29.71% at 120, 100 and 80% ET_o, respectively regardless the intercropping system. The saved land values were 37.11, 31.03 and 28.57% at 120, 100 and 80% ET_o, respectively when sugar beet intercropped with wheat in the 1st season. The corresponding values were 32.89, 31.51 and 20.0% in the 2nd season. Also, the saved land values were 37.89, 40.83 and 29.08% at 120, 100 and 80% ET_o, respectively when sugar beet intercropped with faba bean in the 1st season. The corresponding values were 39.76, 38.65 and 41.18% in the 2nd season. The highest value of saved land (41.18%) was attained at 80% ET_o and sugar beet intercropped with faba bean in the 2nd season while the lowest one (20.0%) was recorded at 80% ET_o and sugar beet intercropped with wheat in the 2nd season.In line with the results of the current study, El-Sherif and Ali (2015) found that under 100, 85 and 70% of ET_o treatments the saved land was 28.83, 21.71 and16.24 % respectively, which could be used for other agricultural purposes. Yang *et al*. (2018) found that pea/ maize intercropping improved land use efficiency significantly compared to sole crops. Li *et al*. (2020) revealed that both the low- and high-yield intercropping strategies saved 16–29% of the land and 19–36% of the fertilizer compared to monocultures grown under the same management as the intercrop. Also, they found that the land savings in intercrops with maize were 13% larger than in intercrops without maize. Nassary *et al*. (2020) concluded that the land equivalent ratios (LERs) of intercrops between maize and common bean showed that the saved lands were 48 and 55 %, which would have been required as additional land for monoculture of each crop (maize or common bean) if not intercropped. On average basis of both seasons, Moghazy (2021) found that the percentages of saved land were 32.25, 29.48 and 26.67% at pan evaporation coefficient of 1.2, 1.0 and 0.8, respectively in the 1st season. They were 32.65, 30.13 and 26.07% in the 2nd season for the corresponding treatments. It might be concluded that intercropped sugar beet with faba bean that irrigated at 80% of ET_o provides the best agricultural practices that realize the highest yield of both crops quantities and qualities. The effect of intercropping on the root yield of sugar beet mainly depends on the nature and growth habit of the companion crop. There are many approaches and practices for successful crop production that have the ability to adapt with the drought stress such intercropping with legumes and soil management etc. Among all these practices, intercropping is considering as a multifunctional practice, which can keep contribution in both adaptation and mitigation to drought stress. The intercropping can use less irrigation water and increase water productivity as two crops are using the applied water to one of them. Furthermore, intercropping can help in solving food insecurity problem through increase land productivity. Thus, innovations are required to increase water and land productivity under water scarcity conditions. Furthermore, these innovations should be easy to be implemented by farmers to increase their adoption to these new technologies.

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