Faba bean yield and water productivity as affected by irrigation and intercropping systems

ABSTRACT

Irrigation with intensive intercropping, in water scarce region is evaluated and optimized. Water productivity (WP) is taken as an indicator and quantified. A field experiment was carried out in Sakha Agricultural Research Station in Egypt during 2019/2020 and 2020/2021 seasons. A split plot design was applied, main plots were devoted for irrigation treatments of two (I_1), three (I_2) and four (I_3) irrigations. Whereas fennouil, red radish and brassica crops were intercropped with faba bean in the sub-plots. Results showed that the highest yield and yield attributes of faba bean were obtained from irrigation treatment of I_3, faba bean with fennouil intercropping and the interaction between faba bean intercropping with fennouil and irrigation treatment of I_3 in both seasons. Water consumptive use was increased by 17% and 24% after irrigation treatment of I_2 and I_3 compared to I_1. Applied water were reduced by 21.6% and 8.2% for I_1 and I_2 compared to I_3. The highest value of WP was obtained from the interaction between irrigation treatment I_3 and faba bean with fennouil intercropping. It could be concluded that applying the interaction of I_1 and faba bean with fennouil intercropping, because it saved significant amount of irrigation water and enhanced water productivity.

Keywords: water productivity; irrigation; intercropping; faba bean; fennouil; red radish; brassica

INTRODUCTION

Globally, water scarcity is the major factor that limit the ambitious hopes to expand the cultivated agriculture area, to cope with the rapid population increasing and reduce the existing food gab between production and consumption, especially in arid and semi-arid regions as in Egypt. In this regard, Egypt is facing shortage of available water and less cultivated area. Therefore, increasing production per each unit of water and land becomes the priority in the national strategy of agricultural production. Intercropping pattern and deficit irrigation strategies are most effective on-farm practices to achieve such target. Intercropping refers to the situation where two different crops are grown together within one field (Allen et all,1998). In intercropping pattern, all the environmental resources are utilized to maximize crop production per unit of area and time. Thus, intercropping pattern has several benefits to the farmers such as, flexibility, profit maximization, risk minimization against total crop failure or disease, weed control, increase land use efficiency, soil conservation, improvement of soil fertility using legumes, enhancing the capture and use of light and water (Dhima *et al.,* 2007; Hamd Alla *et al.,* 2014). Intercropping pattern enhanced water, land and soil nutrients use efficiency, as well as light use by 10–50 % compared to sole crop that grown on the same area (Willey 1979). The proper intercropping pattern saved significant amounts of irrigation water compared to sole crops (Gaballah and Ouda, 2008; Feng *et al.,* 2016; Metwally *et al.,* 2017). In addition to the improvement of soil water spatial distributions in the root zone, enhancement of soil water sharing coordination during the co-growth period, provide compensatory effect for available soil water and enhance water use efficiency (Najibnia et al., 2014; Chen et al., 2018). The advantages of intercropping are derived from the competitive interference principle (Vandermeer, 1989), in which the interspecific competition between intercrop component species will be less than intraspecific competition in sole crops. Yield advantages have been recorded in many legume cereals.

Faba bean *(Vicia faba L.)* is one of the most important legume crops in Egypt. It is grown to fulfil food and feed requirements for human and animal consumption. Its seeds are rich in protein content (26- 28%), in addition to many nutrition elements and components. The increasing production and consumption of legumes are highly desirable considering the high nutritional value and beneficial health effects (Morsy *et al.* 2014). Number of branches per plant, seed yield per plant and seed yield per ha of faba bean were reduced under intercropping condition. The highest values of land equivalent ratio (1.59) and the highest values of competitive ratio of faba bean were obtained when it was intercropped with onion crop (Abou-Keriasha *et al.* 2013). Intercropping faba bean with other winter crops such as wheat, onion, garlic, fennel, sugar beet, sugar cane and tomato has a particular importance to replenish the gap between production and consumption of faba bean and shrinking the cultivated area due to the severe competition with wheat and berseem crops in winter season.

In the best of our knowledge, available review of authors contributing on the assessment of water productivity and intercropping strategies, show for different main crops (except faba bean and association with fennouil, red radish and brassica), the way environmental resources are utilized to maximize crop production per unit of area and time. This contribution is specific and innovative as it is focusing on the assessment of a conjunctive strategy of association of deficit irrigation and specific main and intercropping crops, in semi-arid and arid regions (study is conducted in Egypt) where water challenges are currently important and where faba bean is one of main staple food. The intercropping is defined through the association of currently considered as marketable and cash crops with faba bean: fennouil, red radish and brassica crops.

MATERIALS AND METHODS

A field trial was carried out in Sakha Agricultural Research Station (31^o 07' N latitude, 30^o 57' E longitude), Kafr El-Sheikh Governorate, in 2019/2020 and 2020/2021 seasons. The experiment was laid out in split plot design with three replications, irrigation treatments were in the main plots, two (I_1), three (I_2) and four (I_3) irrigations that include sowing irrigation, in addition to rainfall for all treatments, the irrigation treatments were isolated by 2,5 m ditches to avoid seepage. while the sub plots were assigned for three crops (brassica, fennouil and red radish) that intercropped with faba bean. A supplemental experiment was done in the same field for sole crops with three replications to estimate yield of the sole crops as a reference to compare yield result of the main experiment treatments with the sole yield under the same condition of soil, water quality and climate, irrigation treatment of I_3 only were applied for this supplement experiment. Agronomic practices as fertilizer and pest and weeds management were done as recommended for every crop. The field trial was well prepared after the end of previous maize crop in the two seasons, where it ploughed twice, harrowed, ridged 0.6 m apart and then divided into 6 ×7 m dimensions for each plot. During field preparation, 250kg P_2O_5 as single calcium superphosphate and 125kg K_2O

as potassium sulphate per ha were added. Nitrogen fertilization with the rate of 75kg N per ha in ammonium sulphate form was added, this dose is considered as suitable for these crops in this clay soil. Nitrogen fertilizer was splitted in two equal doses before the sowing and the following irrigation. The other agricultural practices were done as recommended by the Agricultural Research Center (ARC). Faba bean (*vicia faba cv.*) Sakha 4 seeds were sown on 16th and 14th November in 2019/2020 and 2020/2021 seasons, respectively as a main crop. Brassica (*Brassica rapa subsp. Rapa)* cv. Balady, fennouil (*Anethum graveolens*) cv. Balady, red radish (*Raphanus sativus*) cv. Early Red. Seeds of the three crops were sown on 10th and 8th December in 2019/2020 and 2020/2021 seasons respectively as secondary crops. The harvesting dates for faba bean and the three intercropping crops were on 5th May 2020 and 2nd May 2021, respectively. Growth characteristics, yield and yield components, protein percent, competitive relationships, and the economic return for faba bean were assessed.

The metrological data were collected from Sakha agro-metrological station during the two growing season as shown in Table 1.

Table 1: Monthly mean values of agro-meteorological data of Sakha station in 2019 /2020 and 2020/2021 winter seasons.

Seasons	Months	Air temperature			Relative humidity			Wind Speed	Pan evaporation (mm d^{-1})	Rain (mm)
		Max. (°C)	Min. (°C)	Mean (°C)	Max. (%)	Min. (%)	Mean (%)	Mean (km d^{-1})		
2018/2019	November	25.00	17.40	21.20	86.60	54.60	70.60	24.20	1.60	11.90
	December	19.50	13.90	16.70	88.70	62.40	75.55	24.50	0.84	21.70
	January	18.90	12.30	15.60	82.30	53.30	67.80	33.10	1.14	14.90
	February	19.70	14.30	17.00	86.90	58.20	72.55	28.60	1.78	15.30
	March	21.70	17.60	19.65	87.80	56.60	72.20	45.70	2.86	17.30
	April	25.10	21.30	23.20	80.80	48.60	64.70	44.80	3.70	3.90
	May	33.00	26.29	29.65	71.20	44.20	57.70	104.33	6.15	0.00
2019/ 2020	November	27.40	25.10	26.25	82.80	48.30	65.55	36.60	2.31	0.00
	December	21.40	13.40	17.40	86.90	58.90	72.90	38.50	2.66	60.68
	January	18.40	11.80	15.10	86.70	62.70	74.70	30.00	2.09	67.50
	February	20.40	12.70	16.55	84.60	56.50	70.55	51.00	1.83	14.30
	March	22.60	15.60	19.10	81.10	53.90	67.50	80.10	5.12	60.80
	April	26.00	18.90	22.45	80.00	45.10	62.55	98.80	6.08	0.00
	May	31.90	23.80	27.85	68.90	38.40	53.65	114.40	7.70	0.00

Soil properties.

The soil at the study site is of the Entisol order (Typic Torrifluvent), Soil samples from 0-15, 15-30, 30-45, 45-60 cm soil profile depth were taken from the experimental site before cultivation to analyze soil properties, soil chemical properties were determined according to Jackson (1973). Particle-size distribution was carried out using the pipette method according to Klute (1986), soil field capacity and permanent wilting point were determined by using pressure membrane method at 0.33 and 15 Atm according to James (1988). Soil bulk density was determined according to Vomocil (1957) as shown in Table 2.

Table 2: Some physical and chemical soil properties from the experiment site before cultivation as a mean value of both seasons.

Soil depth, cm	Particle size distribution, (%)			Texture	Soil-Water constants (%)			Bulk density,
	Sand	Silt	Clay		FC	PWP	Aw	(g cm^{-3})
0-15	18.67	25.93	55.4	Clayey	44.22	24.01	20.21	1.16
15-30	19.02	26.71	54.27	Clayey	39.40	19.54	19.86	1.24
30-45	20.21	26.25	53.54	Clayey	37.76	18.02	19.74	1.32
45-60	19.38	25.86	54.76	Clayey	38.08	18.66	19.42	1.38
Mean	19.32	26.19	54.49	Clayey	39.87	20.06	19.81	1.28

Soil chemical properties

Depth (cm)	pH	Ec (dS m^{-1})	Cations (meq. L^{-1})				Cations (meq. L^{-1})			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{--}	Cl^{-}	SO_4^{--}
0-15	8.21	1.98	6.60	4.20	9.87	0.40	0.0	4.60	10.80	5.67
15-30	8.33	2.34	5.90	5.70	12.34	0.20	0.0	3.10	12.70	8.34
30-45	8.52	2.59	7.40	6.90	13.21	0.30	0.0	3.20	11.90	12.71
45-60	8.62	3.17	8.10	7.41	16.10	0.40	0.0	2.10	11.30	18.61
Mean		2.52	7.00	6.05	12.88	0.33	0.0	3.25	11.68	11.33

FC= field capacity, %, PWP= permanent wilting point, %, AW= available water, % as gravimetric water content

Data recorded:

Faba bean seeds and straw yield ton per ha as well as fennouil, red radish and brassica crops yield at harvest time were determined by harvesting the whole plot, while ten plants were randomly chosen for each crop from each plot to determined yield attributes plant height (cm), number of branches per plants, number of pods per plants, number of seeds per pods, number of seeds per plants, seed yield per plant(g), straw yield per plant (g), weight of 100 seeds (g), and protein %.

Land equivalent ratio (LER)

Defined as the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield (Willey, 1979). It

It was calculated according to the following equation 1:

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb} \qquad (1)$$

where: Yaa and Ybb were sole yield of crop a and b respectively, Yab is mixture yield of a and Yba is mixture yield of b crop.

Monetary advantage index (MAI)

MAI suggests the economic assessment, which should be terms of the value of land saved; this could probably be most assessed based on the rentable value of this land. MAI was calculated according to the formula 2, as suggested by Willey (1979).

$$\text{MAI} = \frac{\text{value of combined intercrops} \times \text{LER} - 1}{\text{LER}} \qquad (2)$$

The prices of studied crops always change from year to another depending on the prices of inputs and outputs, the market prices of these crops during the studied seasons were taken from (Bulletin of Agriculture Statistical Cost Production and Net Return, 2019, 2020) as shown in Table 3.

Table 3: Yield prices of the studied crops during 2018/2019 and 2019/2020 seasons.

crop	Price US dollars t^{-1}							
	Faba bean		Fennouil		Red radish		Brassica	
	Seeds	Straw	seeds	fresh	seeds	fresh	seeds	fresh
2018/2019	938	75	2500	1563	2500	141	2500	141
2019/2020	1250	78	2500	1563	2188	141	2188	141
Mean	1094	76.5	2500	1563	2344	141	2344	141

Water consumptive use (CU)

Water consumptive use was determined using soil moisture depletion (SMD) according the following equation 3 (Israelsen and Hansen, 1962).

$$\text{CU (SMD)} = \sum_{i=1}^{n=4} D_i \times Bd_i \times (\theta 2_i - \theta 1_i) / 100 \qquad (3)$$

where: CU is water consumptive use (cm), D_i is soil layer depth (15 cm), Bd_i is soil bulk density, (g cm^{-3}) for this depth, $\theta 1_i$ is gravimetric soil moisture (%)

before irrigation, $\theta 2_i$ is gravimetric soil moisture (%), 48 hours after irrigation and n is number of soil layers.

Applied Irrigation Water

The applied irrigation water for each experimental plot was measured using spile tubes, two spiles of 5 cm inner diameter PVC tubes and 80 cm length were used to let water from field ditches into each plot. The effective head of water above the cross-section center of irrigation spile was measured several times during the irrigation. The water in the canal of the field was controlled to maintain a constant head by means of fixed sliding type gates. Stage gauges were placed in each plot to measure the depth of water flowing through the spile and the time of the applied water was monitored using a stopwatch.

The amount of water delivered through the spile tube was calculated according to Majumdar (2002) by the following equation 4.

$$q = CA\sqrt{2gh} \quad (4)$$

where: q is the discharge of irrigation water ($cm^3 s^{-1}$), C is coefficient of discharge = 0.62 (determined by experiment), A is the inner cross section area of the irrigation spile (cm^2), G is the gravity acceleration ($cm\ s^{-2}$) and H is the average effective head (cm).

The volume of water delivered for each plot was calculated by substituting Q in the following equation 5:

$$Q = q \times T \times n \quad (5)$$

where: Q is the volume of water $m^3\ plot^{-1}$, q is the discharge ($m^3\ min^{-1}$), T is the total irrigation time (min) and n is the number of spiles tube per plot.

Seasonal applied water (AW), was calculated as described by Giriappa (1983) as follows:
AW=IW+Rf, where IW is applied irrigation water, Rf is the rainfall. Effective rainfall (ER) = incident rainfall×0.7 (Novica, 1979)

Water productivity (WP)

Water productivity is defined as the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water (Molden *et al*., 2003). Water productivity, WP in kg faba bean seeds yield per m^3 of total water use, irrigation water productivity (WP_{irrig}) in kg faba bean seeds yield per m^3 of irrigation water use and economic water productivity (EWP) in monetary value of the achieved yield US$ per m^3 of total water use were calculated using the following equations 6, 7 and 8, respectively according to (Pereira *et al*., 2012).

$$WP = \frac{Ya}{TWU} \quad (6)$$

$$WP_{irrig} = \frac{Ya}{IWU} \quad (7)$$

$$EWP = \frac{Value\ (Ya)}{TWU} \quad (8)$$

Where WP is water productivity (kg m^{-3}), Ya is the actual harvestable yield (kg faba bean seeds yield per ha), TWU is total water use (m^3ha^{-1}) the summation of the seasonal total amount of irrigation, the seasonal amount of effective rainfall, the amount of water obtained from capillary rise, and the difference in soil water storage between planting and harvesting, all expressed in m^3ha^{-1} (in the current study due to deep water table more than1.5m, and the amount of water stored in the root zone area is almost the same at planting and harvest dates, so both of capillary rise and the difference in soil water storage between planting and harvesting were equal zero and excluded), WP_{irrig} is irrigation water productivity (kg m^{-3}), IWU is the irrigation water use (m^3ha^{-1}), EWP is the economic water productivity (US$ m^{-3}), value (Ya) is the value U$ of achieved yield (faba bean seeds and straw yield, and the fresh and seeds yield of the intercropped crops) was calculated as a mean value of the both seasons.

Statistical analysis

The results were statistically analyzed according to Gomez and Gomez (1984) for every single season. The comparisons of means were carried out using the least significant differences (LSD) at the 5% probability level to compare the differences among the treatments means (Steel *et al*., 1997). The statistical analyses for the recorded data were conducted using COSTATv.6.400 software.

RESULTS AND DISCUSSION

Faba bean yield, its components and intercropping

Data presented in Table 4 shows the values of plant height, number of branches per plant, number of pods per plant, number of seeds per pod, number of seeds per plant, seed yield per plant, straw yield per plant, 100 seeds weight, seeds yield (t ha^{-1}), straw yield (t ha^{-1}) and protein percentage of faba bean crop as influenced by irrigation treatments. Significant differences were obtained of all abovementioned faba bean yield and its component between all irrigation treatments in both studied seasons. The highest values of number of branches per plant, number of pods per plant, number of seeds per pod, number of seeds per plant, seed yield per plant, straw yield per plant, 100 seeds weight, seeds yield (t ha^{-1}) and straw yield (t ha^{-1}) were recorded of irrigation treatment I_3, while the lowest values of the same crop characteristics were found after irrigation treatment I_1 in both studies seasons. Seeds yield after irrigation treatments I_1 and I_2 reduced by 13.7% and 8.2 % respectively compared to irrigation treatment I_3 as an average of both seasons, this may be due to deficit irrigation which happened for irrigation treatments I_1 and I_2 compared to I_3 (Abdel-fattah, 2014)

Otherwise, the highest values of plant height and protein percentage were recorded of irrigation treatment I_1, while the lowest values of these parameters were obtained after I_3 irrigation treatment, this may be due to the lower available soil moisture in the soil, that caused increasing protein content (Mahmoud *et al.*, 2018).

Table 4: Effect of irrigation treatments on plant height, yield, and yield components of faba bean in 2019/2020 and 2020/2021 seasons.

Irrigation treatments	Plant height (cm)	Number of branches per plant	Number of pods per plant	Number of seeds per pods	Number of seeds per plant	Seed yield per plant (g)	Straw yield per plant (g)	100 seed weight (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Protein (%)
2019/2020											
I_1	127.32	3.22	30.33	3.06	64.05	35.77	30.75	66.30	3.26	5.57	25.69
I_2	126.33	3.63	31.36	3.61	65.13	37.47	32.38	67.94	3.48	6.09	24.71
I_3	122.94	3.94	32.70	3.67	66.16	38.26	33.33	69.26	3.78	6.12	24.09
LSD at 0.05	0.67	0.28	0.30	0.11	0.16	0.37	0.22	0.44	0.02	0.03	0.18
2020/2021											
I_1	127.43	3.40	30.44	3.16	64.15	35.82	30.83	66.37	3.28	5.71	25.76
I_2	126.57	3.74	31.53	3.71	65.22	37.58	32.46	68.02	3.49	6.14	24.79
I_3	123.46	4.03	32.87	3.76	66.26	38.33	33.42	69.35	3.80	6.19	24.16
LSD at 0.05	1.39	0.16	0.25	0.09	0.17	0.35	0.33	0.43	0.02	0.03	0.19

LSD at 0.05: Least Significant Difference at the probability level of 5%.

Data presented in Table 5 shows the effect of intercropping treatments on plant height, number of branches per plant, number of pods per plant, number of seeds per pod, number of seeds per plant, seed yield per plant straw yield per plant, 100 seeds weight, seeds yield (t ha^{-1}), straw yield (t ha^{-1}) and protein percentage of faba bean crop. High significant differences of the abovementioned growth, yield and yield components were obtained between intercropping treatments with faba bean. The values of number of branches per plant, number of pods per plant, number of seeds per pod, number of seeds per plant, seed yield per plant straw yield per plant, 100 seeds weight, seeds yield (t ha^{-1}), straw yield (t ha^{-1}) and protein percentage of faba bean were taken the descending order: faba bean with fennouil > faba bean with red radish > faba bean with brassica in the two studied seasons, these results are agreed with those obtained by (Hamd Alla *et al*., 2014; Mahmoud *et al*., 2018). Grain yield and straw yield were reduced by 10.75% and 8.2%, 12.0% and 10.25, and 12.5% and 11.5 % respectively after faba bean with fennouil, faba bean with red radish and faba bean with brassica intercropping treatments respectively compared to sole faba bean as mean of 1st and 2nd seasons, this may be due to the beneficial of intercropping on weed control, increase land use efficiency, improvement of soil fertility, enhancing the capture and use of light and water (Eskandari and Ghanbari 2010; Abou-Keriasha *et al*., 2013) as shown in Table 5. Fennouil crop had less impact on growth, yield, and yield components of faba bean, when it was intercropped with faba bean than brassica crop (Abou- Keriasha et al., 2013; Hamd Alla *et al*. 2014).

The interaction effect between irrigation treatments and faba bean intercropping with three crops on growth, yield, and yield components of faba bean is presented in Table 6. There was a significant effect of the interaction between irrigation treatments and faba bean intercropping in all traits in both seasons, the highest values of all studied traits except plant height and protein % were recorded of faba bean intercropping with fennouil under irrigation treatment(three irrigations plus sowing irrigation and rainfall) in both seasons , whereas the lowest values were obtained of faba bean intercropping with brassica under the first irrigation treatment (one irrigation plus sowing irrigation and rainfall) in both seasons.

Table 5: Effect of intercropping systems on growth, yield, and yield components of faba bean in 2019/2020 and 2020/2021 seasons.

Intercropping treatments	Plant height (cm)	Number of branches per plant	Number of pods per plant	Number of seeds per pods	Number of seeds per plant	Seed yield per plant (g)	Straw yield per plant (g)	100 seed weight (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Protein (%)
					2019/2020						
Faba bean +fennouil	123.17	3.63	32.41	3.45	64.94	36.68	31.98	65.26	3.48	5.85	25.06
Faba bean+ red radish	124.14	3.32	30.02	3.22	63.79	36.17	31.37	64.70	3.43	5.71	24.61
Faba bean+brassica	125.23	3.02	28.69	3.06	62.40	35.20	30.88	63.74	3.40	5.64	24.40
LSD at 0.05	0.556	0.166	0.556	0.158	0.327	0.271	0.220	0.175	0.034	0.031	0.115
Sole Faba bean	130.25	4.35	34.88	4.08	69.53	40.68	34.45	76.64	3.88	6.43	25.22
					2020/2021						
Faba bean +fennouil	123.30	3.73	32.50	3.54	65.03	36.72	32.05	65.34	3.50	5.97	25.14
Faba bean+ red radish	124.27	3.53	30.13	3.33	63.89	36.22	31.45	64.79	3.45	5.85	24.68
Faba bean+brassica	125.40	3.14	28.88	3.16	62.42	35.25	30.96	63.83	3.43	5.76	24.48
LSD at 0.05	0.633	0.102	0.571	0.154	0.322	0.274	0.319	0.184	0.034	0.029	0.115
Sole Faba bean	130.55	4.42	34.90	4.12	70.03	42.35	35.28	77.42	3.93	6.45	25.23

LSD at 0.05: Least Significant Difference at the probability level of 5%.

Table 6: Effect of interaction between irrigation treatments and intercropping systems on growth, yield, and yield components of faba bean in 2019/2020 and 2020/2021seasons.

Intercropping treatments	crops	Plant height (cm)	Number of branches per plant	Number of pods per plant	Number of seeds per pods	Number of seeds per plant	Seed yield per plant (g)	Straw yield per plant (g)	100 seed weight (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Protein (%)
						2019/2020						
I_1	Fennouil	124.80	3.10	31.49	3.09	64.37	36.13	30.83	64.18	3.24	5.64	25.89
	Red radish	125.56	2.93	28.37	2.65	63.04	35.31	30.21	63.36	3.19	5.43	25.38
	Brassica	126.18	2.58	27.14	2.54	61.29	34.09	29.75	62.73	3.17	5.36	25.24
I_2	Fennouil	123.93	3.68	32.36	3.59	64.75	36.65	32.21	65.42	3.47	5.90	24.95
	Red radish	124.63	3.25	29.87	3.49	63.53	36.29	31.72	64.84	3.45	5.81	24.46
	Brassica	125.91	3.06	28.10	3.31	62.46	35.45	31.1	63.65	3.40	5.74	24.35
I_3	Fennouil	120.78	4.11	33.34	3.67	65.70	37.26	32.90	66.18	3.71	6.02	24.35
	Red radish	122.21	3.79	31.84	3.53	64.79	36.90	32.19	65.91	3.67	5.90	23.98
	Brassica	123.59	3.42	30.82	3.35	63.47	36.05	31.80	64.83	3.62	5.81	23.63
LSD at 0.05		0.963	0.288	0.962	0.274	0.567	0.470	0.382	0.302	0.058	0.053	0.199
						2020/2021						
I_1	Fennouil	124.94	3.31	31.59	3.18	64.46	36.19	30.90	64.27	3.26	5.81	25.95
	Red radish	125.67	3.34	28.47	2.73	63.16	35.36	30.29	63.42	3.21	5.59	25.45
	Brassica	126.27	2.66	27.24	2.63	61.38	34.13	29.82	62.82	3.19	5.52	25.33
I_2	Fennouil	124.89	3.78	32.46	3.66	64.83	36.80	32.28	65.49	3.50	6.05	25.04
	Red radish	124.83	3.57	29.95	3.60	63.63	36.34	31.79	64.93	3.48	5.97	24.52
	Brassica	126.24	3.21	28.51	3.42	62.55	35.51	31.18	63.74	3.43	5.93	24.42
I_3	Fennouil	120.88	4.23	33.45	3.77	65.80	37.33	32.98	66.25	3.74	6.09	24.42
	Red radish	122.30	3.88	31.95	3.62	64.89	36.97	32.27	66.01	3.69	5.97	24.06
	Brassica	123.66	3.51	30.90	3.43	63.67	36.12	31.87	64.92	3.67	5.85	23.69
LSD at 0.05		1.096	0.176	0.989	0.267	0.557	0.474	0.380	0.319	0.060	0.050	0.199

LSD at 0.05: Least Significant Difference at the probability level of 5%.

Exhibited data in Table 7 shows a comparison between sole yield of fennouil, red radish and brassica crops and the yield of the same crops when they were grown in intercropping with faba bean. Higher reduction in seeds and fresh yield of fennouil, red radish and brassica crops were founded when they were grown in intercropping with faba bean compared to sole cropping system. The seeds and fresh yield of fennel, red radish, and brassica when they were grown in intercropping with faba bean were reduced by 29% and 33%, 19% and 25%, and 19% and 16%, respectively compared to the same sole crops as an average of both studied seasons. This may be due to the high competition on light, water and nutrients compared to sole crops Abou- Keriasha et al. (2013).

Table 7: Effect of intercropping of fennouil, red radish and brassica with faba bean systems on yield of these crops compared to their sole grown during 2019/2020 and 2020/2021 seasons.

Yield (tha^{-1})											
Fennouil				red radish				Brassica			
Sole		Intercrop		Sole		intercrop		sole		Intercrop	
Seed	Fresh	Seed	Fresh	Seed	Fresh	Seed	Fresh	Seed	Fresh	Seed	Fresh
2019/2020											
1.16	10.35	0.37	3.46	6.81	24.32	1.26	6.07	3.14	17.85	0.62	2.98
2020/2021											
1.23	11.78	0.32	3.93	6.85	24.51	1.27	6.11	3.45	18.54	0.63	2.99

Land equivalent ratio (LER) and monetary advantage index (MAI)

The values of LER and MAI as affected by the intercropping systems are shown in Table 8. The highest values of LER and MAI were found of intercropping of faba bean with fennouil compared to others intercropping systems to be 1.23 and 2.02 US$ respectively as an average of both seasons. The values of LER for the intercropping of faba bean with fennouil and red radish were increased by 17.7% and 6.9% respectively compared to faba bean and brassica intercropping as mean values over both seasons. The values of MAI were taken the descending order faba bean with fennouil > faba bean with red radish > faba bean with brassica to be 2.02 US$> 829 US$> 247 US$ as an average of 2019/2020 and 2020/2021 seasons. These results agreed with that pointed out by Willey (1979); Liben *et al.* (2001); Eskandari and Ghanbari (2010); Abou-Keriasha *et al.* (2013). These values of MAI were positive due to LER which were greater than one. These results are agreement with those obtained by Abou-Keriasha *et al.* (2013); Hamd Alla *et al.* (2014) stated that economic benefit expressed with the higher MAI values in intercropping

Table (8): Effect of intercropping system on land equivalent ratio (LER) and monetary advantage index (MAI) US dollar of 2019/2020 and 2020/2021.

Irrigation treatments	Cropping system	Land equivalent ratio (LER)						Monetary advantage index (MAI) US $	
		2019/2020			2020/2021				
		Faba bean	Intercrop	LER	Faba bean	intercrop	LER	2019/2020	2020/2021
I_1	Faba bean+ fennouil	0.84	0.40	1.23	0.83	0.34	1.17	1958.26	1923.83
	Faba bean+ red radish	0.82	0.39	1.21	0.82	0.39	1.20	1483.22	1696.58
	Faba bean+ brassica	0.82	0.44	1.26	0.81	0.42	1.24	1329.57	1596.80
I_2	Faba bean+ fennouil	0.89	0.51	1.40	0.89	0.45	1.34	3106.92	3553.79
	Faba bean+ red radish	0.89	0.40	1.29	0.89	0.40	1.29	2059.18	2447.68
	Faba bean+ brassica	0.88	0.48	1.35	0.87	0.46	1.33	1841.96	2247.13
	Faba bean+ fennouil	0.96	0.60	1.55	0.95	0.60	1.55	3965.95	5147.34

I_3	Faba bean+ red radish	0.95	0.42	1.37	0.94	0.42	1.36	2579.53	2959.30
	Faba bean+ brassica	0.93	0.51	1.44	0.93	0.48	1.42	2269.47	2711.04

Water consumptive use (CU)

Data in Table 9 shows the values of water consumptive use as affected by irrigation treatments, intercropping systems and the interaction between irrigation and intercropping systems. Water consumptive use is representing the used portion of applied water in growing plants and consequently in crop production. The values of water consumptive use were changed for different intercropping systems; they were taken the descending order faba bean with brassica > faba bean with red radish > faba bean with fennouil to be 35.6 cm > 33.7 cm > 32.5 cm, respectively as a mean over both seasons. It should be notified herewith that the CU values of the single faba bean crop (34.9 cm not presented in the table) has a slight difference with that of the intercropping pattern. That finding is owing to the fact that under both cases of sole and/ or intercropping pattern the foliage cover is nearly equaled the cultivated area, beside Kc of faba bean is almost equal the Kc under the intercropping cultivation. There are noticeable differences of water consumptive use between different irrigation treatments, it was increased by 17% and 24% for I_2 and I_3 irrigation treatments, respectively compared to I_1 as an average of both seasons. Increasing number of irrigations which resulted in increasing available water in the effective root zone and hence increasing water consumptive use values. In this concern Gao *et al.* (2014) and Imran *et al.* (2015) reported that evapotranspiration was significantly increased with the increasing amount of water applied, and the number of irrigations.

Table (9): Seasonal water consumptive use (cm) for irrigation treatments, intercropping systems and the interaction between them in 2019/2020 and 2020/2021 seasons.

Intercropping	Irrigation treatments	Overall

treatments	I_1			I_2			I_3			Mean
	2019/ 2020	2020/ 2021	Mean	2019/ 2020	2020/ 2021	Mean	2019/ 2020	2020/ 2021	Mean	
Faba bean + Fennouil	27.2	28.8	28.0	33.5	34.1	33.8	35.3	36.1	35.7	32.5
Faba bean + Red radish	28.7	29.5	29.1	34.8	35.4	35.1	36.6	37.0	36.8	33.7
Faba bean + Brassica	31.4	32.7	32.1	35.7	36.3	36.0	38.5	39.1	38.8	35.6
Mean	29.1	30.3	29.7	34.7	35.3	35.0	36.8	37.4	37.1	

Applied water (Wa).

Seasonal values of applied water which equal both of irrigation water and effective rainfall are presented in Table 10, whereas the contribution percentage of both irrigation water and rainfall in applied water as an average of the two seasons are clarified in Fig. 1. It is cleared that rainfall in the second season was more than double of the first season. Therefore, irrigation water in the second season is less than that of the first season I.e., more rainfall, less irrigation water. Mean contribution of effective rainfall on applied water were 30.5%, 25.9% and 23.7% for treatments I_1, I_2 and I_3, respectively as an average of both studied seasons as shown in Fig. 1. This is very interesting finding regarding two principal remarks I. e., effective rainfall is partially fulfilling crop water needs and consequently decreasing the amount of irrigation water, particularly under the current water shortage that, facing Egypt. These results agree with those obtained by El-Mansoury (2016); rainfall can contribute effectively on faba bean water requirements under deficit irrigation strategy. The highest values of applied water were recorded of irrigation treatment I_3, while the lowest values were found of irrigation treatment I_1 in the two seasons, the average amount of water saving in comparison with the third irrigation treatment I_3 (four irrigations + rainfall) were 22.3% and 8.5% for I_1 (two irrigations + rainfall) and I_2 (three irrigations + rainfall), respectively. This may be due to the increase of number of irrigations, these results are in the same direction with that obtained by Alderfasi and Alghamdi (2010); Abdel-Fattah (2014); El-Shamy et al. (2015) and El-Mansoury (2016).

Table (10): Seasonal irrigation water, effective rainfall and total applied water of faba bean for irrigation treatments.

Irrigation treatments	Irrigation water (cm)	Effective rainfall (cm)	Applied water (cm)	Applied water ($m^3 ha^{-1}$)
		2019/2020		
I_1	27.60	5.95	33.55	3355
I_2	34.00	5.95	39.95	3995
I_3	37.30	5.95	43.25	4325
		2020/2021		
I_1	18.30	14.23	32.53	3253
I_2	23.70	14.23	37.93	3793
I_3	27.60	14.23	41.83	4183

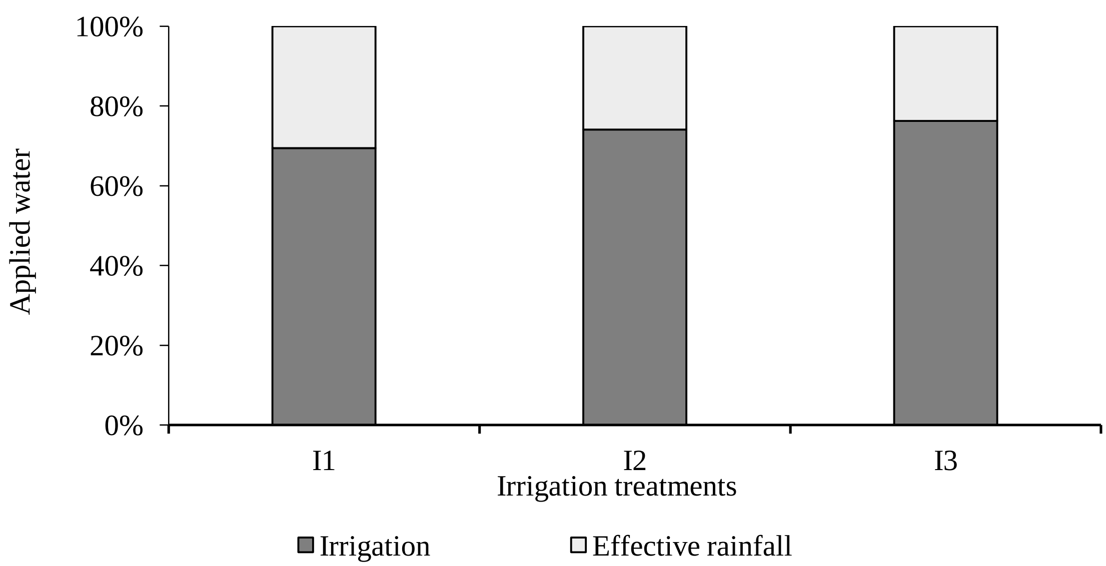

Fig 1. The contribution percentage of irrigation water and rainfall in applied water of faba bean for the studied irrigation treatments as a mean of the two studied seasons.

Water productivity (WP).

Mean values of Water productivity, WP in kg faba bean seeds yield per m^3 of total water use, irrigation water productivity, WP_{irrig} in kg faba bean seeds yield per m^3 irrigation water use and economic water productivity, EWP in US$ of the economic yield of both faba bean and its intercropped crops per m^3 total water use as affected by irrigation treatments, intercropping systems and the interaction between irrigation and intercropping as a mean values of the two seasons are presented in Table 11. Significant differences of WP, WP_{irrig} and EWP were found between the irrigation treatments, the highest values of WP and WP_{irrig} were obtained of I_1, while the lowest values were found of I_3, this may be due to the increase of faba bean yield and/ or reduction of applied water (Abdel- Fattah, 2014 and El-Mansoury, 2016). But EWP was taken the contrary trend, irrigation treatment of I_3 was achieved the highest values of EWP compared to other irrigation treatments as a mean of the two studied seasons. There are no significant differences were recorded of WP and WP_{irrig} values between the intercropping systems, whereas a significant difference of EWP was founded between intercropping treatments. The values of WP, WP_{irrig} and EWP were taken the descending order faba bean with fennouil intercropping > faba bean with red radish intercropping > faba bean with brassica intercropping. The values of EWP were reduced by 26% and 44% for faba bean with red radish and faba bean with brassica intercropping respectively compared to faba bean with fennouil intercropping. The highest values of WP and WP_{irrig} were obtained for the interaction between I_1 and the all intercropping system without any difference between them, while the highest values of EWP were found between I_3 and faba bean with fennouil followed by the same intercropping with irrigation treatments I_1 and I_2 without significant differences between them, followed by the interaction between faba bean with red radish and irrigation treatment I_3, while the lowest values of WP, WP_{irrig} and EWP were obtained of the interaction between faba bean with brassica intercropping and irrigation treatment I_3 as an average of both seasons.

Economic water productivity for faba bean as sole crop was 1.12 US$$m^{-3}$ lower than EWP of faba bean with fennouil, red radish and brassica intercropping systems of all irrigation treatments, this may be due to the reduction of input irrigation water in double intercropping and higher yield compared to sole crops (Najibnia et al., 2014). while the values of water productivity of fennouil, red radish and brassica as sole crop were higher than when they were intercropped with faba bean as shown in Table 11 and Fig 2 (Mahmoud et al., 2018). The obtained results are in the same line with that reported by Abdel- Fattah(2014) and El-Mansoury(2016).

Table 11: Water productivity (kg m^{-3}), irrigation water productivity and economic water productivity (US$ m^{-3}) of faba bean as affected by irrigation treatments, intercropping systems and the interaction between irrigation, and intercropping as a mean value of 1st and 2nd seasons.

Treatments		WP (kg m^{-3})	WP_{Irrig} (kg m^{-3})	EWP (US$ m^{-3})
Irrigation treatments	I_1	0.97	1.40	2.04
	I_2	0.89	1.20	2.13
	I_3	0.87	1.14	2.33
	LSD at 0.05	0.019	0.025	0.034
Intercropping systems	Faba bean +Fennouil	0.92	1.26	2.83
	Faba bean + Red radish	0.91	1.24	2.10
	Faba bean + Brassica	0.90	1.23	1.58
	LSD at 0.05	0.027	0.038	0.039
Interaction				

	Faba bean +Fennouil	0.98	1.42	2.76
I_1	Faba bean + Red radish	0.97	1.39	1.90
	Faba bean + Brassica	0.96	1.39	1.47
	Faba bean +Fennouil	0.89	1.21	2.79
I_2	Faba bean + Red radish	0.89	1.20	2.03
	Faba bean + Brassica	0.88	1.18	1.57
	Faba bean +Fennouil	0.88	1.15	2.93
I_3	Faba bean + Red radish	0.87	1.13	2.36
	Faba bean + Brassica	0.86	1.12	1.70
LSD at 0.05		0.047	0.066	0.067

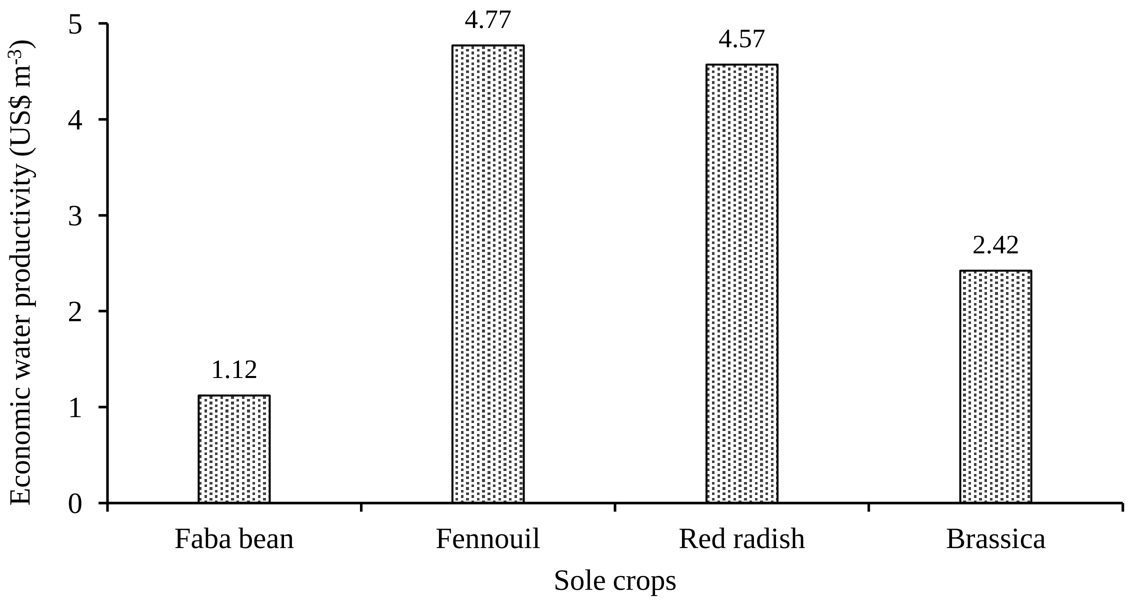

Fig 2. Economic water productivity of faba bean, fennouil, red radish and brassica as sole crops under irrigation treatment of I_3 as a mean value of the two studied seasons

CONCLUSION

Under water scarcity conditions, it could be concluded that applying the interaction between two irrigations plus rainfall treatment and faba bean with fennouil intercropping, because it saved about 29.2% of applied irrigation water compared to the interaction between four irrigations plus rainfall treatment and faba bean with fennouil intercropping. This interaction was recorded the highest values of water productivity and irrigation water productivity to be 0.94 and 1.42 kgm^{-3} respectively, whereas reasonable value of economic water productivity 2.65 $US\$m^{-3}$ as an average of 2018/2019 and 2019/2020 seasons.

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