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(Original Article)

Mitigation of Water Stress effect on Faba Bean Intercropped with Wheat by using Gibberellic Acid under Sandy Soil Conditions

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Abstract

Food and environmental security, water deficiency, and promoting input use efficiency are global concerns in the agricultural sector. An experiment was conducted at the Al-Ghuraira area, Esna center, Luxor Governorate, Egypt, during the 2020-21, and 2021-22 winter seasons, to evaluate the feasibility of 3 intercropping patterns (IP_1: 100% wheat *cv*. Shandweel-1+50% faba bean, IP_2: 100% wheat *cv*. Giza-171+50% faba bean, and IP_3: 100% wheat *cv*. Sids-12+50% faba bean) that their seeds soaked for 6 hours in certain of three Gibberellic acid (GA) concentrations (0.0, 100 and 200 ppm), under water-deficit for increasing farmer profitability in sandy soil. The results showed that irrigation treatments, soaking in GA_3, and intercropping patterns significantly affected all tested traits for wheat and faba bean crops except water use efficiency trait for faba bean in the first season. Irrigation with 100% of ETc (I_1) for wheat and faba bean as sole crops or intercropping pattern of IP_3 increased yield and its components, and decreased water use efficiency (WUE) and economic water productivity (EWP) in both seasons. Soaking seeds at GA_{200} ppm induced a significantly increased in all studied traits for sole crops and intercrops than un-soaked one, in both seasons. The highest mean value of WUE (1.64 and 1.66 kg m^{-3}) for wheat and (0.379 and 0.387 kg m^{-3}) for faba bean were acquired from the IP_3, in the 1^{st} and 2^{nd} seasons, respectively. As a result, $\mathbf{I_1 \times GA_{200} \times IP_3}$ treatment proved to be the most effective practice on intercrop yield, the lowest competitive pressure, and the highest farmer profitability, hence could be recommended in sand soil under a drip irrigation system.

Keywords: *Intercropping, Wheat cultivars, Drought stress, GA3, WUE.*

Introduction

Nowadays, agriculture and water resources are going through an unsurpassed critical period globally. Wheat and faba bean are imperative staple food crops and strategic in Egypt, due to their essential role in ensuring food security and higher nutritional value. The local production of both crops is not enough to cover the population's consumption, according to the limited arable area in Egypt (El-Saadony *et al*., 2021). Wheat grains are a major source of

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protein, calories, dietary fiber, and minerals, likewise, faba bean seeds contain high protein, amino acids, fat, vitamins, and sugars (El-Shafey *et al*., 2022). Due to rapid population growth, cut down of arable land, and water scarcity, a growing gap for food production enlarged and developing countries are at a high risk of food insecurity. Hence, governments try to reduce this gap by introducing new varieties and reclaiming new lands (Negm and Abu-hashim, 2019). Faba bean (*Vicia faba* L.) is one of the more widely grown legume crops and seems to be very appropriate for intercropping with cereals (Ksiezak *et al*., 2023).

Intercropping can be performed in order to increase land and water use efficiency to overcome the food gap problem, especially under the conditions of water scarcity and anticipated effects of climate change (Layek *et al*., 2018). Wheat intercropped with faba bean produced a maximal yield of 30% compared to sole wheat (Shanka, 2020). Metwally *et al*. (2019) suggested that intercropping legumes with cereal are one of the agricultural practices to increase water production and maximize the utilization of soil moisture by increasing relative atmospheric humidity by about 3.5 to 5.0%, decreasing air temperature by 2.5 to 1.5 ^{o}C and soil temperature by about 3 to 2 ^{o}C than sole legumes cropping.

Drought stress has an enormous effect on crop growth and productivity and is frustrating the (zero hunger) target, with its strength and severity expected to increase in coming years (Raza *et al*., 2023). Irrigated wheat plants of 4 irrigations produced the highest yield and it was superior by 22.30% in grain yield, and 14.74% in straw yield compared to plants that received 2 irrigations, meanwhile, the maximum WUE was obtained under 2 irrigations and it was higher by 24.94% than 4 irrigations (Niwas *et al*., 2023).

Plant growth regulators (PGRs) like GA_3 are the magic chemicals if applied at the optimal dose in pre-sowing, that involve seed hydration and drying intended to improve metabolic processes before germination, seedling growth, and yield. Several studies focused on the influences of pre-soaking faba bean seeds and wheat grains with growth regulators like GA_3 that are low-cost, increased plant growth and productivity, and protein contents. They could give plants an enhanced ability to rapidly and effectively struggle to resist different stress under field conditions (Rashad, 2020; Iqra *et al*., 2022; El-Emshaty *et al*., 2021; and Liu *et al*.,2022). The current study is planned to assess the effect of IP, GA_3 and irrigation regimes on the productivity, profitability of farmers, water use efficiency (WUE), economic water productivity (EWP), and competition indices of faba bean and wheat crops under sandy soil conditions of Luxor Governorate, Egypt.

Materials and Methods

2.1. Site description

The study was conducted during 2020-21 and 2021-22 seasons at the Al-Ghuraira regoin, Esna center, Luxor Governorate, Egypt, situated at 32º34' longitude, 25º18' latitude and 82 m altitude above sea level. The study aimed to evaluate the impact of two irrigation treatments, and three concentrations of gibberellic acid on the productivity of three bread wheat cultivars intercropped with faba bean, intercropping indices, and farmer profitability under a drip irrigation system in sandy soil. Before planting, soil samples (0-30cm) were collected, dried, and sieved through a 2 mm sieve then they were analyzed for physio-chemical properties according to Page *et al*., (1982). The relevant physio-chemical soil properties are shown in Table (1).

Table 1. Some soil properties of the experimental site

Properties	Texture analysis (%)			Textual class	O.M %	EC (ds m^{-1}) (Soil: water ratio, 1:5)	pH 1:2.5 (Soil: water ratio)	Available (ppm)		
	Sand	Silt	Clay					N	P	K
Values	87.70	9.90	5.40	Sandy	0.11	0.31	8.00	11.30	2.50	65.00

Air temperature (T,ºC), relative humidity (RH,%), wind speed at meters (WS, m s-1), solar radiation (SR,MJ/m^2/day), and Reference evapotranspiration rate (ETo, mm day-1) were recorded monthly during the two growing seasons and they are shown in Table 2.

Table 2. Average monthly meteorological data of the Al-Ghuraira weather area in 2020-21 and 2021-22 seasons

Month	2020-21 growing season						2021-22 growing season					
	Air temperature		RH	WS	SR	ETo	Air temperature		RH	WS	SR	ETo
	Max	Min					Max	Min				
October	37.65	21.14	26.29	2.61	20.90	6.89	35.32	19.57	28.84	3.45	20.69	7.63
November	26.59	12.77	44.86	3.02	17.80	4.58	30.54	15.53	36.24	2.64	17.35	4.96
December	25.45	10.75	41.20	2.25	15.64	3.50	22.37	9.12	46.27	2.99	15.08	3.61
January	23.90	7.89	40.86	2.59	17.15	3.82	19.08	5.35	47.14	3.05	16.62	3.33
February	24.60	8.73	36.78	3.24	20.51	4.90	22.76	6.78	41.87	3.33	20.51	4.70
March	29.66	12.15	25.82	3.48	24.45	6.95	26.81	9.86	27.84	3.82	23.22	6.71
April	34.51	16.04	18.41	3.25	27.62	8.70	37.51	18.76	15.22	2.93	25.47	8.84
May	39.96	21.70	14.07	3.48	28.71	10.94	37.94	21.30	16.74	4.12	27.08	11.23

Source: the Central Laboratory for Agricultural Climate weather

2.2. Experimental design and treatments

The irrigation treatments were (100 and 60 % of ETc). Three concentrations of gibberellic acid (0.0 (distilled water, control), 100, 200ppm) and three wheat cultivars (Shandweel-1, Giza-171, and Sids-12) intercropped with faba bean. The seeds of wheat cultivars and faba bean (var. Nubaria-1) were obtained from Field Crop Research Department, Field Crops Institute, Agriculture Research Centre, Egypt. The experimental layout was a Randomized Complete Block Design (RCBD) in a strip-split plot arrangement with three replications. The irrigation levels were assigned to the horizontal strips and the vertical blocks were allocated to the three concentrations of gibberellic acid, while the sub-plots were occupied by three wheat cultivars intercropped with faba bean. The experimental sub-plot area was 24 m^2 (1/175 fed), consisting of 5 terraces (120 cm wide and 4.0 m in length). Wheat cultivars were planted as recommended (at a 100% seed rate) using the intercropped system with faba bean (at a 50% seed rate). Faba bean seeds were cultivated at the edge of each terrace 2 rows (120 cm width) distanced at 20 cm between hills (two plants hill^{-1}), to give 50% of monoculture density, while wheat cultivars were sown in 6 rows spaced at 15 cm on the back of the terrace, to give 100% of monoculture density, i.e., (100% wheat for all cultivars + 50% fab bean). Monocultures for wheat cultivars and faba bean were cultivated as recommended for each crop, as well as for use in calculating competitive relationships and economic viability. Gibberellic acid used was solid powder, therefore, an aqueous solution was prepared separately by dissolving the required weight of solid powder in tap water. The wheat grains and faba bean seeds were washed with distilled water, sterilized with 1% sodium hypochlorite (NaCIO) solution for two minutes, then rewashed with distilled water. Grains and seeds were left to dry at room temperature on filter paper for 48 h and then divided into 3 groups, as the 1st group was soaked in distilled water (DW), the 2nd and 3rd groups were soaked in GA_3 with 100 and 200 ppm, respectively, all treatments were soaked for 6 h. The schedule of planting and harvesting dates for both crops is presented in Table 3.

Table 3. Sowing and harvesting dates of wheat and faba bean crops during 2020-2021 and 2021-22 seasons

Crop	Sowing date		Harvest date	
	2020-21	2021-22	2020-21	2021-22
Wheat	7th December	10th December	7th May	10th May
Faba bean	20th October	23rd October	20th March	23th March

All plants received recommended doses of fertilizers, and the required agricultural practices, *i.e*., hoeing, weeding, and plant protection measures were done for both crops in the region as per recommendations at proper times.

2.3. Field measurements

After maturity, sample of 10 plants was randomly taken of wheat and faba bean from each experimental unit to estimate the yield components and the tested characteristics. Grain and seed yields were calculated on an experimental unit basis for wheat cultivars and faba bean, respectively, by weighted in kg and then converted to ardab fed^{-1}.

The studied traits of each crop were measured as follows:

2.3.1. Wheat traits

Plant height (cm), spike length (cm), Number. of grains spike^{-1}, 1000-grain weight (gm), grain yield (ardab fed^{-1} as 1 ardab=150 kg), and straw yield (ton fed^{-1}).

2.3.2. Faba bean traits

Plant height (cm), number of branches plant^{-1}, number of pods plant^{-1}, 100-seed weight (g), seed yield (ardab fed^{-1} as 1 ardab=160 kg), and straw yield (ton fed^{-1}).

2.3.3. Irrigation water and water relation measurements

The amount of irrigation water was applied for each treatment with a drip irrigation system with the drippers spaced at 50 cm apparts. The water supply of the drippers was 4 L h^{-1}. Drip lines were put in every other row. Amounts of irrigation water (m^3 fed^{-1}) were calculated from meteorological data of the Central Laboratory for Agricultural Climate weather (CLAC) of the study area relying on the method of Penman (1984). According to this method, the amount of water for full irrigation (100% of ETc) was equal to 2015 m^3 fed^{-1} and 1209 m^3 fed^{-1} for limited irrigation (60% of ETc) in both seasons.

1. Water use efficiency (WUE) kg fed^{-1} values were calculated as described by (Howell, 2001) as follows equation.

$$\text{WUE} = \text{Grain or Seed yields (kg fed}^{-1}\text{)} / \text{Irrigation water applied (m3 fed}^{-1}\text{)}$$

2. Economic water productivity (EWP) L.E m^{-3}: The EWP value was calculated according to the equation given by Najibnia *et al*., (2014).

$$\text{EWP} = \frac{\text{Monetary value of the achieved yield(L.E m}^{-3}\text{)}}{\text{irrigation water applied (m}^{3}\text{ fed}^{-1}\text{)}}$$

2.3.4. Competitive relationships and yield advantage of intercropping

Competitive indices are used to evaluate the level of competition, and its impacts, as well as help in the interpretation of complex data that enables the comparison of several combinations by using the same index.

1- Land Equivalent Ratio: (LER) was determined according to the following formula of Willey *et al*. (1983):

$$\text{LER} = (\text{Yab} / \text{Yaa}) + (\text{Yba} / \text{Ybb})$$

Where: Yaa= Pure stand of the crop, a (wheat), Ybb= Pure stand of crop, b (faba bean), Yab= Intercrop yield of the crop a, Yba= Intercrop yield of crop b.

2- Aggressivity (Agg): proposed by Mc-Gilchrist (1965) and was calculated according to the following formula:

$$\text{For crop (a) Aab} = \frac{\text{Yab}}{\text{Yaa} \times \text{zab}} - \frac{\text{Yba}}{\text{Ybb} \times \text{zba}}$$

$$\text{For crop (b) Aba} = \frac{\text{Yba}}{\text{Ybb} \times \text{zba}} - \frac{\text{Yab}}{\text{Yaa} \times \text{zab}}$$

Where: Zab= the respective proportion of crop wheat in the intercropping pattern, Zba: the respective proportion of crop faba bean in the intercropping pattern.

3- Relative crowding coefficient (RCC): RCC, is the measure of the relative dominance of one species over the other in an intercropping system (De Wit, 1960) was calculated as follows:

$$\text{K} = \text{kw} \times \text{kf}$$

$$\text{Kw} = [\text{Yab} \times \text{Zba}] / [(\text{Yaa} - \text{Yab}) \times \text{Zab}]$$

$$\text{Kf} = [\text{Yba} \times \text{Zab}] / [(\text{Ybb} - \text{Yba}) \times \text{Zba}]$$

4- Area Time Equivalent Ratio (ATER): Suggested by (Hiebsch *et al.*, 1987) to compare the yield of intercropping over monoculture in terms of time taken by component crops in the intercropping systems. ATER is computed according to the following formula:

$$\text{ATER} = (\text{LER wheat} \times \text{Dc}) + (\text{LER faba bean} \times \text{Dc}) \,/\, \text{Dt}.$$

Where: LER = denote the land equivalent ratio of crop, Dc= denote duration (days) taken by crop, Dt= denote days taken by whole intercropping system from planting to harvest.

5- Land utilization efficiency (LUE%): LUE% was estimated by utilizing values of LER and ATER, according to (Mead and Willey, 1980) as follows:

$$\text{LUE\%} = (\text{LER} \times \text{ATER} / 2) \times 100$$

6- Land saved (LS%): LS% was calculated using Willey (1985) as follows:

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

7- System productivity index (SPI): was calculated using the following formula of Odo (1991):

$$\text{SPI} = [(\text{SW}/\text{LF}) \times \text{Lf}] + \text{Sw}$$

Where: SW and LF are the yields of wheat and faba bean in pure stand cropping, Sw and Lf are the yields of wheat and faba bean in intercropping.

8- Monetary advantage index (MAI): MAI is calculated by using the following formula (Willey *et al.*, 1983).

$$\text{MAI} = \frac{\text{Value of combined intercrops (L.E)} \times (\text{LER} - 1)}{\text{LER}}$$

Economic evaluation:

It was calculated by determining the net return from intercropping culture compared to the monoculture crops (wheat and faba bean) as follows:

Gross income (fed^{-1}) of intercropping cultures was calculated by the formula: (Price of wheat grain yield + straw yield) + (price of faba bean seed yield + straw yield) (L.E). The prices of the wheat grain yield were 661 and 663 L.E ardab fed^{-1} and 924 and 952 ton fed^{-1} of straw yield, meanwhile, the prices of the faba bean were 1878 and 1870 ardab fed^{-1} of seed and 616 and 948 ton fed^{-1} of straw yield, respectively. These prices were taken from the Bulletin of Statistical Cost Production and Net Return, 2019 and 2020 to calculate the gross income from each treatment in L.E.

Total costs were 11326 and 11643 fed^{-1} for the monoculture of wheat and 10441 and 10835 fed^{-1} for the monoculture of faba bean, during 2019 and 2020, respectively.

$$\text{Net returns (fed}^{-1}) = \text{Gross income} - \text{Total costs}$$

2.7. Statistical analysis

The proper statistical analysis of data was done according to Gomez and Gomez (1984). The differences between the means of the studied treatments were compared using the least significant difference (LSD) at a 5% level of probability.

Results

Yield and its components

Irrigation treatments (I)

1- Wheat traits

According to the data in Table 4, irrigation treatments realized a significant impact on plant height, number of grain spike^{-1}, 1000-grain weight, grain yield, straw yield, WUE, and EWP in both seasons. Wheat plants which were received full irrigation (100% of ETc) showed a significant increase in grain yield by 32.63 and 30.32%, while WUE decreased significantly by 20.79 and 22.22%, and EWP by 20.46 and 21.79% compared to plants exposed to water stress in the 1st and 2nd seasons, respectively

2-Faba bean traits

Data in Table 5 showed that irrigation treatments significantly affected values of plant height, No. of branches plant^{-1}, No. of pods plant^{-1}, 100-seed weight, seed yield, straw yield, water use efficiency, and economic water productivity of faba bean in both seasons. Increasing irrigation water from 60 to 100% of ETc caused significant increases in seed yield by 57.29 and 58.86%, straw yield by 152.08 and 140.74%, and significant decreases in WUE by 5.56 and 4.44%, and EWP by 5.46 and 4.75% in the 1st and 2nd seasons, respectively.

Gibberellic acid (GA3)

1-Wheat traits

Wheat grains presoaking in different concentrations of GA_3 (0.0, 100, and 200 ppm) enhanced all studied traits compared to un-soaked grains in both seasons Table 4. These increases were 10.2 and 10.9%, and 7.3 and 8.3% for grain yield at 100 and 200 ppm of GA_3 over than un-soaked in the 1st and 2nd seasons, respectively.

2-Faba bean traits

Regarding the effect of pretreatment of faba bean seeds, the results presented in Table 5 show that seed presoaked in GA_3 at all concentrations have a significant effect on all studied characters. Increase GA_3 concentration up to 200ppm increased the value of seed yield by 24.5 and 24.3%, WUE by 23.7 and 22.7% and EWP by 23.7 and 22.6% compared to control treatment, in the first and second seasons, respectively.

Intercropping patterns (IP)

1-Wheat traits

The data revealed that the effect of intercropping patterns of wheat and faba bean on wheat traits Table 4 was significant in both seasons. The intercropping pattern of 100% wheat cv. sids-12 with 50% faba bean (IP_3) clearly produced the highest values of grain yield (17.17 and 17.31 ardab fed^{-1}), WUE (1.64 and 1.66 kg m^{-3}) and EWP (7.24 and 7.32 L.E. m^{-3}) of wheat intercropped with faba bean than the other tested intercropping patterns in both seasons, respectively. Likewise, the tallest plant height (98.28 and 99.01 cm) and heaviest straw yield (3.44 and 3.49 ton fed^{-1}) were obtained from intercropping pattern IP_2 in the 1st and 2nd seasons, respectively.

2-Faba bean traits

The results in Table 5, indicated that intercropping patterns significantly affected all mentioned traits in both seasons, except plant height, No. of branches $plant^{-1}$ and straw yield that were insignificant in the 1st season.

The intercropping pattern IP_3 was superior to other intercropping patterns in all tested traits. Intercropping faba bean with wheat Sids-12 cultivar reduced seed yield and EWP by 48.89and 35.62% in the 1st season, and by 50.00 and 36.93% in the 2nd season, compared to the monoculture faba bean.

The interaction effects

1-wheat traits

The results demonstrated in fig. 1 and 2 revealed that the interactions of I×GA, I×IP, GA×IP, and I×GA×IP significantly affected the majority of the tested traits. The increase in yield and its components of wheat were achieved by plants that irrigated with 100% of ETc and soaked at GA_{200}ppm ($I_1 \times GA_{200}$). The interaction among 3 factors significantly affected grain yield in both seasons.

2-Faba bean traits

Interaction of $I_1 \times GA_{200}$ had a significant effect on the yield and its components in both seasons which increased seed yield by 92.42 and 90.15%, compared to I_2×distilled water in both seasons, respectively.

Competitive relationships and yield advantage of intercropping

The highest values of competitive relationships namely LER, Agg, RCC, ATER, LUE, LS, SPI, MAI, and farmer's total and net income were noticed from $I_1 \times GA_3 \times IP_3$ as shown in Table 6.

Land equivalent ration (LER):

The intercropped yields of wheat and faba bean were greater than their particular monoculture yields Table 6. For all treatments, total LER values were more than 1.0. The highest LER values of 1.68 were realized by $I_1 \times GA_{200} \times IP_3$ treatment.

Table 4. Effect of irrigation treatments, gibberellic acid and intercropping patterns on plant height, No. of grains spike^{-1}, 1000-grain weight, grain yield, straw yield, WUE, and EWP of wheat during 2020-21 and 2021-22 seasons

Traits	Plant height (cm)		Number of grains spike^{-1}		1000-grain weight (g)		Grain yield (ardab fed^{-1})		Straw yield (ton fed^{-1})		WUE (kg m^{-3})		EWP (L.E m^{-3})	
Seasons	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Irrigation treatments (I)														
I_1	97.35	98.09	63.00	63.13	33.14	34.10	18.98	18.87	3.67	3.73	1.41	1.40	6.22	6.21
I_2	91.03	92.05	57.31	57.49	30.88	30.49	14.31	14.48	2.92	3.02	1.78	1.80	7.82	7.94
$LSD_{0.05}$	**1.37**	**0.93**	**0.87**	**0.15**	**0.09**	**0.40**	**0.21**	**0.06**	**0.06**	**0.19**	**0.02**	**0.03**	**0.11**	**0.06**
Gibberellic acid (GA)														
DW	91.31	92.23	57.81	57.96	30.06	30.23	15.55	15.85	3.11	3.23	1.49	1.52	7.82	6.73
GA_{100} ppm	95.31	95.83	60.89	61.25	32.88	33.17	17.14	17.00	3.34	3.41	1.64	1.62	6.57	7.21
GA_{200} ppm	95.94	97.16	61.75	61.72	33.08	33.49	17.24	17.17	3.43	3.48	1.65	1.65	7.21	7.29
$LSD_{0.05}$	**0.72**	**0.61**	**0.44**	**0.37**	**0.33**	**0.26**	**0.12**	**0.19**	**0.06**	**0.07**	**0.01**	**0.02**	**0.03**	**0.07**
Intercropping patterns (IP)														
IP_1	92.91	93.75	58.52	58.80	30.89	31.46	15.96	15.84	3.22	3.30	1.53	1.52	6.74	6.74
IP_2	98.28	99.01	60.31	60.63	32.03	32.42	16.80	16.87	3.44	3.49	1.61	1.62	7.09	7.16
IP_3	91.37	92.45	61.63	61.50	33.10	33.00	17.17	17.31	3.23	3.34	1.64	1.66	7.24	7.32
$LSD_{0.05}$	**0.49**	**0.15**	**0.34**	**0.19**	**0.27**	**0.25**	**0.08**	**0.10**	**0.02**	**0.11**	**0.004**	**0.01**	**0.04**	**0.04**

Table 5. Effect of irrigation treatments, gibberellic acid and intercropping patterns on plant height, No. of branches plant^{-1}, No. of pods plant^{-1}, 100-seed weight, seed yield, straw yield, WUE, and EWP of faba bean during 2020-21 and 2021-22 seasons.

Traits	Plant height (cm)		Number of branches plant^{-1}		No. of pods plant^{-1}		100-seed weight		Seed yield (ardab fed^{-1})		Straw yield (ton fed^{-1})		WUE (kg m^{-3})		EWP (L.E m^{-3})	
Seasons	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
							irrigation treatments (I)									
I_1	100.93	101.84	4.22	4.37	13.67	13.48	108.69	109.30	4.64	2.75	1.21	1.300	0.357	0.366	4.33	4.41
I_2	88.42	89.15	2.61	2.67	7.94	8.17	80.90	78.87	2.95	2.99	0.48	0.54	0.378	0.383	4.58	4.63
$LSD_{0.05}$	**1.66**	**0.06**	**0.09**	**0.09**	**0.82**	**0.14**	**0.82**	**0.14**	**0.16**	**0.02**	**0.03**	**0.04**	**NS**	**0.01**	**NS**	**0.09**
							Gibberellic acid (GA)									
DW	87.57	88.26	2.64	2.77	8.75	9.12	81.28	81.81	3.30	3.38	0.69	0.78	0.321	0.330	3.89	3.99
GA_{100} ppm	97.93	98.87	3.69	3.78	11.14	11.35	99.67	99.35	3.98	4.03	0.89	0.98	0.385	0.388	4.66	4.68
GA_{200} ppm	98.52	99.35	3.91	4.01	11.93	12.02	103.43	101.1	4.11	4.20	0.95	1.01	0.397	0.405	4.81	4.89
$LSD_{0.05}$	**2.76**	**0.19**	**0.21**	**0.13**	**0.56**	**0.10**	**1.08**	**0.29**	**0.17**	**0.07**	**0.09**	**0.05**	**0.02**	**0.01**	**0.25**	**0.09**
							Intercropping patterns (IP)									
IP_1	94.11	94.94	3.36	3.45	10.12	10.35	93.52	92.50	3.69	3.69	0.81	0.85	0.357	0.356	4.32	4.30
IP_2	94.78	95.68	3.44	3.54	10.70	10.88	94.90	94.29	3.80	3.92	0.85	0.94	0.368	0.379	4.45	4.58
IP_3	95.12	95.87	3.45	3.57	10.99	11.26	95.95	95.46	3.91	4.00	0.88	0.98	0.379	0.387	4.59	4.68
$LSD_{0.05}$	**NS**	**0.10**	**NS**	**0.06**	**0.35**	**0.06**	**0.71**	**0.32**	**0.08**	**0.04**	**NS**	**0.02**	**0.009**	**0.004**	**0.10**	**0.06**

Table 6. Competitive relationships of wheat intercropped with baba bean as affected by the interaction between irrigation treatments, gibberellic acid, and intercropping patterns (average of the two seasons)

Irrigation treatments	Gibberellic acid (GA)	Intercropping patterns (IP)	Land equivalent ratio (LER)			Aggressivity (Agg)		Relative crowding coefficient (RCC)			Area time equivalent ratio (ATER)	Land utilization efficiency (LUE)	Land Saved%	System productivity index (SPI)	Monetary advantage index (MAI)
			Lw	Lf	LER	Aw	Af	Kw	Kf	K					
I_1: Full irrigation	Distilled water	IP_1	0.88	0.50	1.38	-0.21	0.21	3.76	2.04	7.67	1.05	72.45	27.54	26.23	6159.09
		IP_2	0.88	0.52	1.40	-0.25	0.25	3.57	2.14	7.64	1.06	73.68	28.06	27.84	6565.31
		IP_3	0.93	0.52	1.45	-0.18	0.18	6.84	2.17	14.84	1.10	79.48	30.84	29.43	7451.60
	GA_{100}: 100 ppm	IP_1	0.99	0.61	1.60	-0.38	0.38	41.63	3.13	130.30	1.21	95.52	36.90	28.72	9433.18
		IP_2	0.99	0.64	1.63	-0.48	0.48	41.92	3.63	152.17	1.24	100.35	38.46	32.84	10462.97
		IP_3	0.99	0.66	1.65	-0.52	0.52	56.00	4.09	229.04	1.25	102.50	39.02	33.53	10712.88
	GA_{200}: 200 ppm	IP_1	0.99	0.64	1.63	-0.45	0.45	58.25	3.55	206.79	1.24	100.04	38.27	31.04	10029.29
		IP_2	0.99	0.67	1.66	-0.54	0.54	50.06	3.97	198.74	1.26	104.27	39.58	33.43	10965.43
		IP_3	1.00	0.68	1.68	-0.57	0.57	84.68	4.26	360.74	1.27	106.05	40.12	34.16	11221.06
I_2: Water stress	Distilled water	IP_1	0.70	0.33	1.03	0.05	-0.05	1.16	0.99	1.14	0.78	40.43	2.91	19.23	490.17
		IP_2	0.69	0.34	1.01	-0.02	0.02	1.11	1.05	1.17	0.79	40.45	2.88	20.36	505.69
		IP_3	0.69	0.37	1.06	-0.08	0.08	1.11	1.17	1.30	0.80	42.47	5.21	21.51	923.53
	GA_{100}: 100 ppm	IP_1	0.75	0.37	1.12	-0.06	0.06	1.49	1.20	1.79	0.86	47.89	10.71	21.47	1921.65
		IP_2	0.75	0.40	1.15	-0.11	0.11	1.42	1.35	1.92	0.87	49.59	12.28	22.97	2334.44
		IP_3	0.74	0.41	1.15	-0.06	0.06	1.37	1.37	1.88	0.87	49.59	12.28	23.18	2336.33
	GA_{200}: 200 ppm	IP_1	0.76	0.39	1.15	-0.07	0.07	1.54	1.33	2.05	0.88	50.10	12.66	21.93	2332.99
		IP_2	0.76	0.41	1.17	-0.12	0.12	1.50	1.39	2.09	0.88	51.04	13.79	23.32	2672.98
		IP_3	0.75	0.42	1.17	-0.15	0.15	1.47	1.45	2.132	0.88	51.04	13.79	23.70	2688.18

IP_1 = 100% Giza-171+50% faba bean *IP_2 = 100% Shandweel-1+50% faba bean* *IP_3 = 100% Sids-12+50% faba bean*

Table 7. Economic evaluation of wheat intercropped with baba bean as affected by the interaction between irrigation treatments, Gibberellic acid, and intercropping patterns during 2020-21 and 2021-22 seasons

Irrigation treatments	GA	Intercropping patterns	Actual wheat		Actual faba bean		Gross income (LE)	Total cost (LE)	Net return (LE)	Actual wheat		Actual faba bean		Gross income (LE)	Total cost (LE)	Net return (LE)
			Grain (ardab fed^{-1}) (LE)	Straw (ton fed^{-1}) (LE)	Seed (ardab fed^{-1}) (LE)	Straw (ton fed^{-1}) (LE)				Grain (ardab fed^{-1}) (LE)	Straw (ton fed^{-1}) (LE)	Seed (ardab fed^{-1}) (LE)	Straw (ton fed^{-1}) (LE)			
			2020-21season							2021-22 season						
I_1: Full irrigation	DW	IP_1	10959.38	3067.68	7305.42	659.12	21991.60	16547	5444.60	11105.25	3217.76	7386.50	1033.32	22742.83	17061	5681.83
		IP_2	11494.79	3354.12	7455.66	566.72	22871.29	16547	6324.29	11794.77	3531.92	7573.50	1014.36	23914.55	17061	6853.55
		IP_3	12426.80	3150.84	7493.22	585.20	23656.06	16547	7109.06	12650.04	3360.56	7629.60	1090.20	24730.40	17061	7669.40
	GA_{100}: 100 ppm	IP_1	12446.63	3400.32	8939.28	745.36	25531.59	16647	8884.59	12026.82	3579.52	8789.00	1213.44	25608.78	17161	8447.78
		IP_2	13200.17	3575.88	9183.42	788.48	26747.95	16647	10100.95	12974.91	3760.40	9611.80	1317.72	27664.83	17161	10503.83
		IP_3	13246.44	3335.64	9502.68	825.44	26910.20	16647	10263.20	13372.71	3493.84	9742.70	1384.08	27993.33	17161	10832.33
	GA_{200}: 200 ppm	IP_1	12466.46	3455.76	9220.98	782.32	25925.52	16647	9278.52	12219.09	3636.64	9387.40	1251.36	26494.49	17161	9333.49
		IP_2	13206.78	3659.04	9596.58	862.40	27324.80	16647	10677.80	13054.47	3827.04	9817.50	1393.56	28092.57	17161	10931.57
		IP_3	13385.25	3501.96	9803.16	874.72	27565.09	16647	10918.09	13385.97	3570.00	10023.20	1393.56	28372.73	17161	11211.73
I_2: Water stress	DW	IP_1	9599.61	2494.80	4713.78	215.60	17023.79	15905	1118.79	8884.20	2694.16	4862.00	369.72	16810.08	16368	442.08
		IP_2	8969.77	2725.80	4845.24	258.72	16799.53	15905	894.53	9368.19	2808.40	5123.80	445.56	17745.95	16368	1377.95
		IP_3	9214.34	2457.84	5333.52	277.20	17282.90	15905	1377.90	9394.71	2865.52	5366.90	464.52	18091.65	16368	1723.65
	GA_{100}: 100 ppm	IP_1	9339.93	2698.08	5558.88	289.52	17886.41	16005	1881.41	9414.60	2836.96	5273.40	492.96	18017.92	16468	1549.92
		IP_2	9809.24	2836.68	5803.02	308.00	18756.94	16005	2751.94	9878.70	2951.20	5871.80	559.32	19261.02	16468	2793.02
		IP_3	9809.24	2670.36	5878.14	332.64	18690.38	16005	2685.38	9958.26	2875.04	5927.90	597.24	19358.44	16468	2890.14
	GA_{200}: 200 ppm	IP_1	9412.64	2735.04	5821.80	301.84	18271.32	16005	2266.32	9507.42	2875.04	5722.20	483.48	18588.14	16468	2120.14
		IP_2	9934.83	2919.84	5915.70	338.80	19109.17	16005	3104.17	10031.19	3027.36	6002.70	587.76	19649.01	16468	3181.01
		IP_3	10027.37	2762.76	6009.60	344.96	19144.69	16005	3139.69	10124.01	2913.12	6171.00	625.68	19833.81	16468	3365.81
Sole wheat cv Giza-171			12539.17	2287.06	-	-	14826.23	11326	3500.23	12437.88	3217.76	-	-	15655.64	11643	4012.64
Sole wheat cv Shandweel-1			13305.93	3779.16	-	-	17085.09	11326	5759.09	13240.11	3950.80	-	-	17190.91	11643	5547.91
Sole wheat cv Sids-12			13477.79	2458.92	-	-	15936.71	11326	4610.71	13452.27	3579.52	-	-	17031.79	11643	5388.79
Sole faba bean			-	-	14366.70	1078.00	15444.70	10441	5003.70	-	-	14960.00	1706.40	16666.40	10835	5831.40

GA= Gibberellic acid *DW= Distilled water*

IP_1 = 100% wheat cv. Giza-171+50% faba bean *IP_2 = 100% wheat cv. Shandweel-1+50% faba bean* *IP_3 = 100%wheat cv. Sids-12+50% faba bean*

Fig. 1. Effect of the interaction between I, GA and IP on plant height, number of gains spike^{-1}, 1000-grain weight, straw yield, grain yield, water use efficiency and economic water productivity of wheat during significantly different seasons.

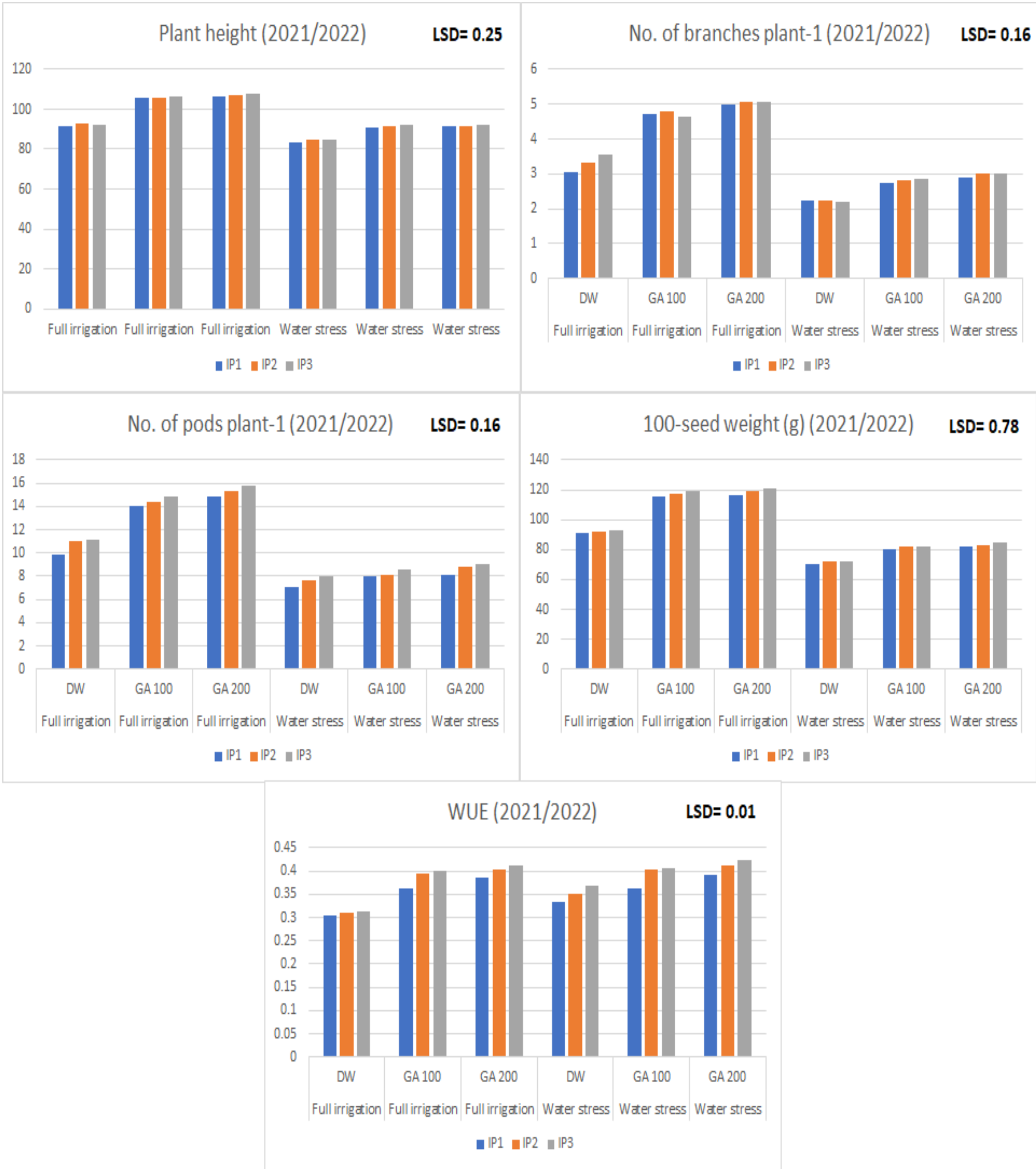

Fig. 2. Effect of the interaction between I, GA and IP on plant height, number of branches plant^{-1}, number of pods plant^{-1}, 100-seed weight and water use efficiency of faba bean during 2021/2022 season.

Aggressivity (Agg)

The value of aggressivity of faba bean was positive, meanwhile, its values were negative for wheat, meaning that faba bean was the dominant crop and wheat was dominated Table 6. The best result for Agg (0.57) was acquired by $I_1 \times GA_{200} \times IP_3$ treatment.

Relative crowding coefficient (RCC)

As average of both seasons, the highest total RCC of 360.74 was obtained from $I_1 \times GA_{200} \times IP_3$ treatment.

Area time equivalent ratio (ATER)

The highest ATER (1.27) was obtained from I_1×GA_{200}×IP_3 as an average value of both seasons. The ATER values in all treatments were lesser than LER values which means the excess of resource utilization.

Land utilization efficiency (LUE), Land saved (LS) and System productivity index (SPI)

On the average basis of both seasons, the highest value of LUE (106.05), LS (40.12), and SPI (34.16) were recorded from I_1×GA_{200}×IP_3 treatment.

Monetary advantage index (MAI), gross income and Net return (L.E)

The highest value of MAI (10918.09 and 11221.06), gross income (27565.09 and 28372.73 L.E), and net return (10918.09 and 11211.73 L.E) were achieved by I_1×GA_{200}×IP_3 treatment in the 1^{st} and 2^{nd} seasons, respectively. The I_1×GA_{200}×IP_3 treatment increased net return by 118.20 and 92.26% than with faba bean mono-cropping, in both seasons, respectively (Tables 6 and 7).

Discussion

Yield and its components

Irrigation treatments (I)

Drought stress delays plant growth and crop yield by disrupting the biosynthesis of chlorophyll contents, slowing down the efficiency of photosynthesis activity, and lowering CO_2 assimilation rates due to a decrease in stomatal conductance. Increases WUE and EWP are related to the crop production of wheat and the amount of water applied (Abdelrehim, 2022), and an increase in irrigation water applied leads to an increase in the consumptive use of water and a decrease in WUE (Niwas *et al*., 2023).

Faba bean crop is more sensitive to water stress, and reductions in yield are positively correlated with the quantity of water available. Under severe drought (I_{50}), significantly decreased growth traits, seed yield and components, and LUE, and significantly increased water productivity, and EWP compared to full irrigation I_{100} (Morsy and Mehanna, 2022). The useful effect of the application of full irrigation on wheat and faba bean yields is well documented by Kenawy *et al*. (2022). In addition to, the increase in WUE and EWP for wheat Sids-12 cultivar than faba bean Nubaria-1 cultivar is due to the higher productivity, water efficient use, and ability adaptability under water deficit conditions.

Gibberellic acid (GA3)

Seed priming with GA_3 can significantly enhance morphological characters, yield, and its related traits in wheat both under drought and normal conditions (Ulfat *et al*., 2017). Treated wheat grains with GA_3 produced the tallest plant height due to early germination, this helped in accessing more water, light, and nutrients and thereby rapid cell elongation, division, and enlargement, consequently, achieving a higher grain yield m^{-3} of water used (Patra *et al*., 2020). Soaking wheat grains in GA_3 with 2 g L^{-1} increased grain yield by 4.57% compared to the control (Rashad, 2020), and enhanced the plant's ability to utilize water efficiently, which increased wheat crop production (Iqra *et al.*, 2022).

Waad (2023) demonstrates that seeds treated with GA_3 at 100 and 200 ppm were superior to the comparison treatment in promoting seed germination, plant height, number of branches, and moist weight of seedlings after 45 days of faba bean planting. Ultimately, seed priming allows plants to obtain an enhanced capacity to quickly and effectively battle various stresses in order to mitigate the impacts of drought stress by enhancing the effective use of water, plant metabolic processes, physiological efficiency, photosynthesis, and all the yield components which resulted in an increment in its yield (El Saadony *et al.*, 2021 and Liu *et al.*,2022)

Intercropping patterns (IP)

It has been demonstrated that intercropping produces a higher and more stable yield than mono-crops due to the efficiency of the environmental resources, particularly nutrients, light, and water (Amanullah *et al.*, 2021). The maximum values of WUE were recorded at wheat + faba bean intercropping than wheat and faba bean separately when using intercropping pattern under the same irrigation water applied.

1-Wheat traits

The interpretation for an increase in yield and yield components for wheat cultivar Sids-12 intercropped with faba bean (IP_3) is attributed to the differences in their genetic constitution and their interaction with the environmental conditions prevailing in the area, which reflected positively on yield and its components compared to the rest of the cultivars in other intercropping patterns. Supported our results, Abd-Rabboh and Koriem (2022) indicated that the Misr-1 wheat cultivar recorded greater values in yield and its components when intercropped with peas, followed by the Giza-171 cultivar, while the Gemmiza-11 cultivar intercropped with peas got the lowest values in both seasons.

2-Faba bean traits

Intercropped faba bean with wheat cultivar Sids-12 realized the greatest values in all traits of faba bean than other cultivars in both seasons. This decrease in all traits of faba bean under intercropping was due to the low plant density of faba bean (50 % of monoculture) with the highest plant density of wheat (100 %), resulting in a lower interception of solar radiation by faba bean plants compared to the monoculture faba bean. Abdel-Wahab and El Manzlawy (2016) found the intercropping of 50% faba bean with 100% wheat reduced faba bean productivity by 234.47% than sole faba bean under sandy soil conditions.

Competitive relationships and yield advantage of intercropping

Generally, all values of LER indicated that all of the intercropping had a yield advantage compared to their respective mono-crops. The highest LER (1.68) was recorded from ($I_1 \times GA_3 \times IP_3$), indicating that intercropping is advantageous by 68% in yield than monoculture, which is due to the best utilization of available resources for plant growth and its development. Similarly, Abd-Rabboh and Koriem (2022) detected that in all treatments, the land usage of wheat-peas intercrop (LER_{total}) was higher than that of crops grown separately which varying between 56 and 65% in the first and second seasons, respectively. Some studies exhibited that various intercrops utilize environmental resources more effectively %25-50 compared to mono-cropping (Bekele *et al*., 2022; Nurgi *et al*., 2023 and Li *et al*., 2023). Using intercropping under a drip irrigation system could play a substantial role in maximizing the LER under sandy soil conditions (Metwally *et al*., 2019).

The higher value of Agg denotes a bigger difference in competitive ability and a greater difference between actual and expected yield in both crops, hence faba bean crop had a higher competitive ability in absorbing the water and light than the wheat crop. Also, Hamada and Hamd-Alla (2019) illustrated that Agg wheat was dominant with positive values whereas faba bean was dominant with negative values in both growing seasons. The values of RCC for wheat were higher than faba bean in all intercropping patterns. This shows a specific yield advantage for wheat compared to faba bean in the intercropping patterns that were tested, it may be due to the strong nutrient and water competitiveness related to wheat roots than to faba bean. When RCC is less than one (<1), there is competition between intercrops, which indicates an intercropping disadvantage. ATER has a strong association with LER for either sole crops or intercropping. The increase in ATER could be due to that intercropping systems can give more efficient total resource exploitation and increased values of yield than monocrops. Hamada and Hamd-Alla (2019) revealed that ALTER values were lesser in wheat-faba bean intercrops compared with LER values which mean the over-estimation of resource utilization contrary to LER. All calculated indices in intercrops were strongly correlated to the LUE index, indicating a strong coherence between yielding and other treatment in the study. So, intercropping was more advantageous for LUE (103%) and (18%) for ATER (Kherif *et al*., 2021). IP_3 intercropping pattern provides the best agricultural practices that attain the highest yield of both crops due to the highest of the land saved. Intercrops resulted in both 19% land savings and evinced 19% higher average LUE than sole crops (Li *et al*., 2023). Galanopoulou *et al*., (2019) noted that the LER, RCC, and SPI values were greater for the faba bean-barley intercrops indicating the advantage of intercropping over sole cropping. The MAI is considered an index of the economic feasibility for irrigation, GA_3, and intercropping patterns. IP3 intercropping pattern that received 100% of ETc and treated by 200ppm of GA_3 attained the highest MAI and economic advantage compared to the others may be due to the high-yielding capacity of the Sids-12 cultivar, high land equivalent ratio, the better utilization of environmental resources and better supplementary effect of the component crops, hence could be recommended. Intercropping pattern faba bean with wheat increased productivity, LER, and net return of farmers, over those of sole crops, because of more efficient utilization of resources in intercropping (Abdel-Wahab and El manzlawy, 2016 and Hamada and Hamd-Alla, 2019). According to Nurgi *et al*. (2023), who stated that intercropping cereal with legumes recorded increasing land utilization efficiency expressed as LER and also higher net return per unit area expressed as a higher effective monetary advantage index compared to either sole crop. Supported our results by Amanullah *et al*. (2020) who reported that wheat+faba bean intercropping had realized the highest advantages of intercropping in terms of LER (30%), RCC (60%), ATER (27%), LUE (83%), and MAI (46456).

Conclusions

Intercropping systems are one of the technologies being used to conserve irrigation water, especially in a current water-scarce situation. Concisely, selecting the appropriate cultivars of wheat and faba beans for intercropping and using the accurate water regime for irrigation and gibberellic acid is important because of its effects on productivity. It could be concluded that the interaction between $I_1 \times GA_{200} \times IP_3$ gained the maximum productivity, MAI, and LUE (higher LER and ATER), and the highest farmer's net income, compared to sole wheat under the ecological conditions of Luxor Governorate, Egypt.

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اعلية حامض الجبريليك للتخفيف من الإجهاد المائي للفول البلدي المحمل مع القمح تحت ظروف التربة الرملية

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الملخص

الأمن الغذائي والبيئي، ونقص المياه، وتعزيز كفاءة استخدام المدخلات من الاهتمامات العالمية في المجال الزراعي. أقيمت تجربة حقلية بمنطقة الغريرة - مركز اسنا - محافظه الأقصر - مصر خلال موسمي 2021/2020 و2021/ 2022 لدراسة تقييم جدوى ثلاث أنظمة تحميل (1) 100% قمح صنف جيزة 171 + 50% فول بلدي (2) 100% قمح صنف شندويل 1 + 50% فول بلدي (3) 100% قمح صنف سدس 12 + 50% فول بلدي، والتي تم نقعها مع ثلاث تركيزات من حمض الجبريليك (صفر، 100 و 200 جزء في المليون) تحت ظروف نقص مياه الري (60 و 100 % من النتح بخر المحسوب) بالأرض الرملية لزيادة ربحية المزارع.

أظهرت النتائج المتحصل عليها الآتي: أثرت معاملات الري والنقع في حمض الجبريليك وأنظمة التحميل معنوياً على جميع الصفات تحت الدراسة للقمح والفول. أدي الري الكامل للقمح والفول البلدي كمحاصيل نقية وكذلك نظام التحميل الثالث (100% قمح صنف سدس 12 + 50% فول بلدي) إلى تسجيل أعلي القيم للمحصول ومكوناته، وأدنى القيم لكفاءة استخدام المياه والإنتاجية الاقتصادية للمياه في كلا الموسمين.

نقع حبوب القمح وبذور الفول بـ 200 جزء في المليون أدى إلى زيادة معنوية في جميع الصفات للمحاصيل النقية وأنظمة التحميل مقارنة مع غير المنقوعة في موسمي النمو. نظام التحميل الثالث سجل أعلي قيمة لكفاءة استخدام الماء (1.64 و 1.66 كجم م $^{-3}$) للقمح و (0.379 و 0.387 كجم م $^{-3}$) للفول في كلا الموسمين، على التوالي.

للحصول على أعلي عائد من انظمة التحميل، وأقل تنافس وأعلي ربح للمزارعين يتم تطبيق الري بمعدل 100% من النتح بخر المحسوب واستخدام حمض الجبريليك بتركيز 200 جزء في المليون وزراعة 100% صنف القمح سدس 12 مع 50% من الفول البلدي صنف نوبارية 1، وبالتالي يوصي بزراعتها بالأرض الرملية تحت الظروف البيئية لمحافظة الأقصر.