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Biological Stress Impacts on Broad Bean Morpho-Physiological Traits, Yield and Water Productivity under Drip Irrigation System

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IN ORDER to investigate the effects of biological stress resulting from broad bean intensification, two field experiments were conducted during the two successive winter seasons of 2022/23 and 2023/24. It was tested on five different plant densities (D1, D2, D3, D4, and D5) to see what happened to growth, physiological traits, yield, and water productivity. The densities were 12, 10, 8, 6, and 4 plants per emitter, which equaled 120, 100, 80, 60, and 40 ($\times 10^3$ plants fed^{-1}). The results showed that the broad bean most of growth characters all growth stages especially dry matter accumulation were significantly affected by planting density. Under all rates of plant densities, the broad bean leaves significantly contained greater concentrations of photosynthetic pigments.75 days after sowing, the leaves of broad bean plants expanded to their maximum, showing the highest LAI values in higher planting densities than in lower densities. After that, they declined in the subsequent growth stage. Growth analysis revealed that at the (60–75 day) growth stage, NAR, RGR, and CGR attained their maximum rates. The data also show that on the contrary of the low NAR and RGR values at the highest density, CGR values took a reversible magnitude. The seed yield per plant (gm) went up a lot at the lowest planting density, D5 (4 plants per emitter). At the highest planting density, 12 plants per emitter, the seed yield per plant went down the most. Planting broad beans at D1 and D2 planting densities resulted in producing the highest seed yield per feddan. Water productivity values were parallel to those obtained in seed yield per feddan.

Keywords: Broad Bean, Biological Stress, Morpho-Physiological Traits, Yield, Water Productivity, Drip Irrigation System.

Introduction

Among legume crops broad bean is considered to be one of the earliest species with high nutritional value (Altunta and Yıldız 2007; Zong *et al*., 2009). After chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.), and lentil (*Lens culinaris* L.), broad bean is ranked as the fourth-largest cool-season pulse crop produced worldwide in terms of overall production (Rebaa *et al*., 2017; Sallam *et al*., 2017). According to Cruz-Izquierdo (2012), it is the most economically significant species in the *Vicia* genus and has a high productivity rate when compared to other grain legumes (Turpin *et al*., 2002). According to Abid *et al.,* (2015), the average global productivity is 1.5 t. ha^{-1}, which is quite low in some situations. FAOSTAT (2019) reports that the world's broad bean output peaked in 2017 at 4.8 million metric tons, with China, Ethiopia, Australia, the United Kingdom, and Germany being the top five producers. However, under Egyptian conditions production of broad bean especially in the reclaimed sandy soil is affected by different factors such as climatic conditions, soil fertility, varieties or genotypes plant, population density and water supply, low water availability (Bakry *et al.,* 2011, Osman *et al.*, 2010, Ragab *et al.,* 2010 and Dawood *et al.,* 2019, and Bakhoum *et al.,* 2022, Elsonbaty, and Elsherpiny, 2024).

Water crises are becoming more frequent as a result of large-scale land reclamation initiatives, population growth, consistent plans for rural and urban development, and the expansion of the industrial sector (Abu Zeid and Hamdy, 2002). There will be more food shortages and catastrophic droughts in African nations. If low-income countries in Africa or Asia experience a decline in agricultural output due to climate change, many people will be in danger and food insecurity will worsen (Mohamed, 2020). Hence, for the agricultural sector in Egypt, it is essential to modify irrigation

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techniques to save the waste of irrigation water by applying controlled irrigation systems. One of these systems which fit some crops, especially broad bean is drip irrigation (Sarah*et al.,* 2022, Jebril *et al.,* 2023 and Khairo, 2024).

Drip irrigation can reduce irrigation application by 50–80% in comparison to surface irrigation, according to Kadasiddappa and Rao (2018). Moreover, over fertilizing and over watering—two of the most frequent causes of N leaching—may be mitigated by drip irrigation. Drip irrigation has introduced many unique agricultural irrigation technologies that have greatly aided in economic development. As a result, optimal irrigation levels with appropriate methods would help in enhancing the economic yield as well as water use efficiency of maize crop under Egyptian conditions (Mansour and El Melhem, 2015). According to Vieira *et al*., (2014), the planting density strategy provides an additional means of increasing production in addition to the utilization of water deficit. Care must be taken when increasing planting density to prevent intraspecific competition and to make the greatest use of the resources available for grain growth and yield. To confirm the ideal plant density for beans, several studies have been conducted in a range of 100,000 to 400,000 plants ha^{-1}. (Augustine and Godfre, 2019; Kamara, *et al.,* 2018). Nonetheless, there is still a dearth of knowledge regarding the interaction between broad bean planting density and water deficit, including research on the physiological traits of the plant grown on drip irrigation.

Water-scarce areas, like the study area, make it more crucial than ever to look for management strategies that make better use of available water resources in order to guarantee productivity in a sustainable way. Thus, the purpose of this study is to assess how drip irrigation affects the morpho-physiological characteristics of broad beans as well as water productivity at various planting densities.

Materials and Methods

Two field experiments were conducted during the two successive winter seasons of 2022/23 and 2023/24 in a private farm, Tawfiq El Hakim village, Nubaria District, Behaira governorate.

The experiments aimed to study growth characters, physiological attributes, yield and water productivity of broad bean var. Giza 461 under drip irrigation system. Each experiment included five plant densities D1, D2, D3, D4 and D5 (12, 10, 8, 6 and 4 plants/emitter), respectively. The plant densities represented 120,100, 80, 60 and 40 ($\times 10^3$ plants fed^{-1}). The plant densities were randomly nested within the plots. Each plot consisted of five polyethylene lateral drip lines (Twin-wall IV, 16 mm in diameter, and 0.3 m emitter spacing) with a length of 5 m. The lateral line was laid out along each broad bean row at 1.4 m. The plot area was 35 m^2 (Fig. 1).

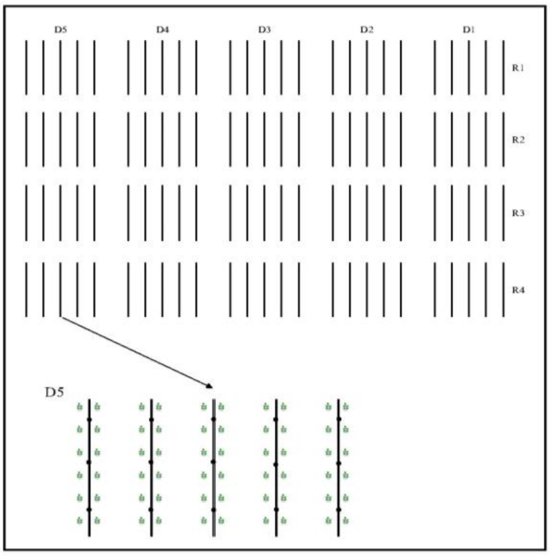


Fig. 1. layout of experiment.

The total amount of irrigation water was measured by water flow-meter for each treatment. Plants were irrigated by using drippers of 2 l/h capacity. The experimental design was Complete Randomized Block Design with four replicates. Broad bean seeds were inoculated with the specific rhizobium strain R. Legumin Sarum and immediately were sown with the planned density for each experimental plot. Sowing dates were 11 and 8 November in 2022/23 and 2023/24. During seedbed preparation, a uniform application of phosphatic fertilizer at 150 Kg calcium superphosphate (15.5% P_2O_5) was applied. At sowing, a starter dose of nitrogen at 15 kg/fed. was applied in the form of ammonium nitrate (33.5% N). Two weeks later, the plants were thinned to obtain the required density. Potassium was applied at 48 kg K_2O/fed. before the first irrigation (Feddan) fed= 4200 m^2.

During the growing season, four vegetative samples were taken from each experimental unit at 45, 60, 75 and 90 days from sowing. Each sample consisted of 5 plants taken at random and the following characters were studied:

(a) Plant height (cm).

(b) Number of branches per plant.

(c) Number of leaves per plant.

(d) Total dry weight per plant (g).

Growth attributes were determined as follows:

Leaf area index (LAI) at each vegetative sample was estimated according to (Watson, 1952), Growth attributes, i.e., Relative growth rate (RGR), in (mg/g/day); net assimilation rate (NAR) in (g/m^2/day) and crop growth rate (CGR) in (g/m^2/day) were calculated at the growth stages 45-60, 60-75 and 75-90 days from sowing according to the formula described by Radford (1967).

Photosynthetic Pigments

A vegetative leaf sample was taken at 60 days from sowing in each season, the leaves were separated, grounded and the photosynthetic pigments were extracted using 85% aqueous acetone. The concentrations of chlorophyll a, b and carotenoids were calculated according to the formula of Von Wetstein (1957) in mg/dm^2 fresh weight.

Optical extinction coefficient (K)

Light intensity was measured above and under broad bean canopies at noon using Lux-meter at 60, 75 and 90 days for sowing. The Optical extinction coefficient (K) was determined using the Beer Lambert equation (1) (Sarmadnia and Koocheki, 1994).

$$\ln I_t/Io = - k \times LAI \qquad (1)$$

Where, I_t = amount of the light in the lower part of the canopy (MJ m^{-2} s^{-1}), I_0 = amount of the light in the upper part of the canopy (MJ m^{-2} s^{-1}), k = Optical extinction coefficient and LAI = leaf area index.

At harvest time, ten plants were randomly taken from each experimental unit and the following characters were studied:

1- Number of pods per plant
2- Number of seeds per pod
3- Number of seeds per plant
4- 100-seeds weight (g)
5- Seed yield per plant (g).

Three rows of each plot were pulled out to obtain the criteria per square meter and per feddan and left to dry, then threshing was done to obtain:

6- Seed yield (kg /fed)
7- Straw yield (ton /fed)
8- Harvest index (%)

The obtained data were subjected to the statistical analysis of the Complete Randomized Block Design. Then the homogeneity test was applied using Bartlet's test, then the data were pooled and the combined analysis was carried out according MSTAT-C, (1988). Treatment means were compared using the Least Significant Difference test LSD at 5% probability level.

Results and Discussion

Data presented in Table 1 and Fig. 2 show the overall water requirements and the monthly water consumption under the drip irrigation system. Mean water requirements were 800 m^3 fed^{-1} and the water requirements varied according to the climatic conditions during the months of the growing season. The lowest water consumption was recorded in November and April (germination and full maturity stages) while the greatest was recorded in March (grain filling stage). Regarding the water consumption under different plant densities, the data showed that the highest water consumption was recorded with D1 (12 plants/emitter) but there was no clear tendency for the other densities. Data in the same Table indicate that water saving under drip irrigation system for the different Broad bean planting densities compared to the conventional irrigation practice in the district (sprinkler irrigation). The overall saving of irrigation water was about 39.9%. The data coincide with the water requirements presented in Table 1.

Table 1. Monthly Water supplied to Broad bean under drip irrigation system (m^3/fed).

	Water consumption under drip irrigation system (m^3/fed)						Water saving % (relative to sprinkler irrigation consumption in the district)					
Month	D1	D2	D3	D4	D5	Mean	D1	D2	D3	D4	D5	Mean
November	718	414	519	620	460	546.3	68.1	60.1	52.3	64.6	58.0	60.62
December	1222	842	902	1075	936	995.3	35.2	30.7	17.3	28.0	23.4	26.92
January	1043	813	778	932	903	893.6	37.5	40.2	28.3	30.5	31.3	33.56
February	1016	807	822	988	897	906.0	37.9	36.7	24.0	31.0	30.3	31.98
March	1085	903	960	1144	1003	1019.1	30.5	26.2	12.0	22.8	21.6	22.62
April	324	434	449	537	482	445.2	66.6	65.5	58.7	62.9	65.8	63.90
Mean	901	702	738	883	780	800.9	46.0	43.2	32.1	40.0	38.4	39.94

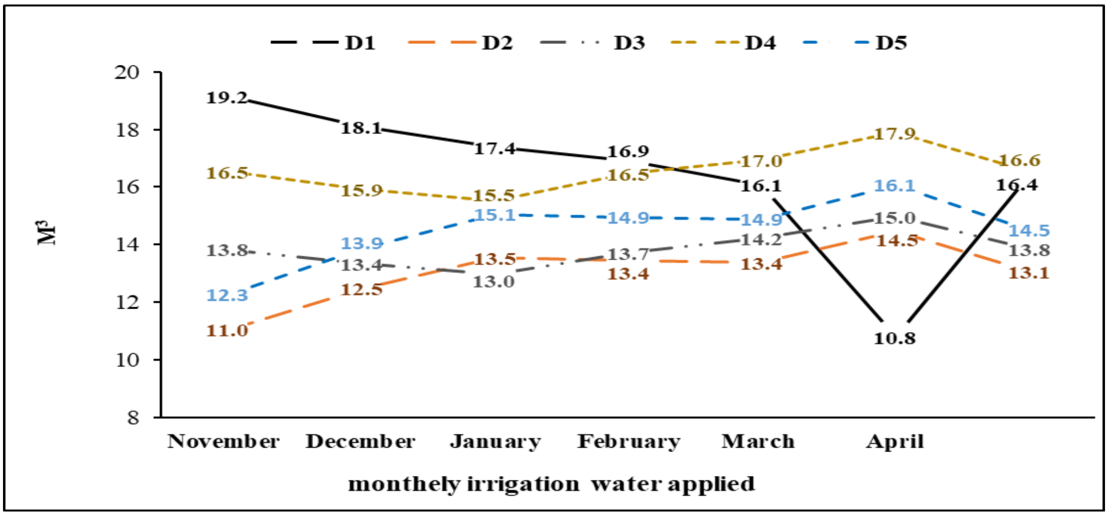


Fig. 2. The monthly water consumption of different plant densities under drip irrigation system.

Growth characters

Table (2) shows that plant height was affected by planting densities at all sampling dates. In general, the tallest plants were recorded with higher densities, while the shortest were the lower one's Broad bean plants. Tended to be taller at the higher density D1 (12 plants /emitter) compared with those planted at lower densities. The tallest plants were recorded at D1 (12 plants /emitter) planting density, while the shortest ones were obtained with D5 (4 plants/emitter) planting density, respectively.

Table (2) shows the amount of branches/plant after 45, 60, 75 and 90 days from sowing as affected by broad bean plant density. Significant differences in number of branches per plant were recorded due to planting density. Lower density D5 (4 plants/emitter) resulted in a significant increase in the number of branches per plant after 60, 75, and 90 days from sowing. The greatest number of branches was formed with D5 (4 plants/emitter) which resulted in the greatest number of branches per plant at all sampling dates. D1 (12 plants /emitter) gave the lowest and the greatest number of branches per plant. Data presented in Table (2) show that as the planting density decreased from D1 (12 plants /emitter) greater number of leaves were formed at 60, 75, and 90 days from sowing date.

Data presented in Table (2) show significant differences among different plant densities in dry matter production /plant at 90 days from sowing. Generally, greatest DM /plant was reported in the lower plant density D5 (4 plants /emitter) than the other planting densities. From the same Table, the results indicate that dry matter accumulation was significantly affected by planting densities at 90 days sampling dates.

Table 2. Effect of Broad bean plant density on growth characters under drip irrigation system.

	Plant height (cm)					No. of branches/plant				
	Days after sowing (DAS)				Mean	Days after sowing (DAS)				Mean
	45	60	75	90 days		45	60	75	90 days	
D1	22.3	45.4	67.4	84.8	52.5	2.0	2.4	3.1	2.5	2.5
D2	21.3	39.3	62.2	79.4	48.2	2.2	3.1	3.7	3.1	3.0
D3	21.2	37.2	59.3	76.6	46.4	2.3	3.6	4.1	3.9	3.5
D4	20.5	35.3	57.4	73.8	44.6	2.4	3.2	3.9	4.1	3.5
D5	20.2	31.0	58.5	63.8	41.4	2.6	3.5	4.2	4.2	3.7
LSD	NS	1.42	2.34	2.42		NS	0.34	0.6	1.15	
	No. of leaves /plant					DM (g/plant)				
D1	12.3	20.7	29.1	29.9	20.7	3.0	7.1	12.4	21.8	11.1
D2	13.1	25.7	31.0	31.6	23.3	3.1	7.9	13.0	24.8	12.2
D3	12.0	25.8	32.3	31.5	23.4	3.2	8.2	13.5	26.7	12.9
D4	11.8	23.6	34.4	38.0	23.3	3.2	8.5	13.5	28.0	13.3
D5	12.5	23.8	37.7	35.7	24.7	3.3	8.6	14.7	31.0	14.4
LSD	0.98	1.3	2.63	NS		Ns	NS	NS	0.90	

Data in Table 3 and Fig. 3 show that planting density significantly affected photosynthetic pigments content in Broad bean leaves. In general, as planting density increased significant reduction in chl. b, carotenoids and the total pigments content occurred in Broad bean leaves. Such reduction in photosynthetic pigments at highest density D1 (12 plants /emitter) may be due to the increase in competition for environmental such as nutrients and light.

Table 3. Effect of Broad bean plant density on photosynthetic pigments content (mg/dm^2 Fresh weight) under drip irrigation system.

Planting density	Chl. a	Chl. b	Carotenoids	Total
D1	7.205	2.013	2.343	11.561
D2	7.513	2.354	2.272	12.139
D3	7.623	3.091	3.003	13.717
D4	8.041	3.234	3.432	14.707
D5	8.305	3.685	3.542	15.532
LSD	NS	0.60	0,52	1.10

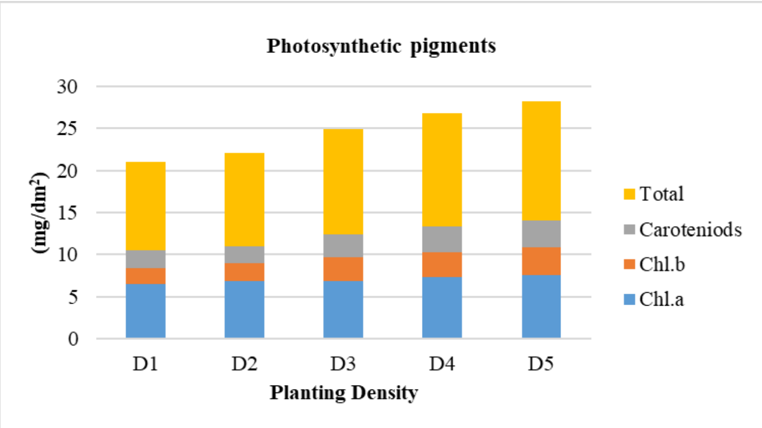


Fig. 3. Effect of Broad bean plant density on photosynthetic pigments content under drip irrigation system.

Optical extinction coefficient

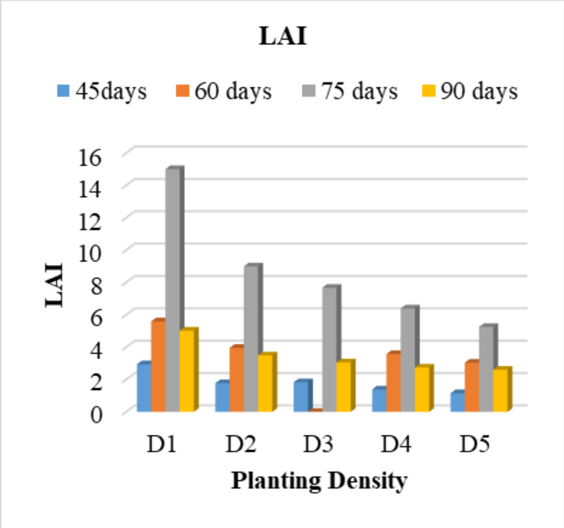
The Optical extinction coefficient (K) expresses the amount of light extinction along biological canopy, it is expressed as the term (K). Data in Table (4) and Figure 4 show significant differences in (K) values among broad bean planting densities at all sampling dates studied. Thus, high K values mean greater light interception by broad bean canopy.

Physiological attributes

The results in Table (3) reveal that broad bean leaves expanded to their maximum width at 75 days after sowing, then fell sharply at 90 days after sowing. Table (3) and Figure 4 show that planting density had a substantial effect on all growth phases evaluated 45, 60, and 75 days after sowing. Leaf area index values at higher densities tended to be the greatest and gradually decreased as they lowered.

Table 4. Effect of broad bean plant density on leaf area index (LAI) and Optical extinction coefficient (K) under drip irrigation system

	LAI					Optical extinction coefficient			
	Days after sowing (DAS)				Mean	Days after sowing (DAS)			Mean
	45	60	75	90 days		60	75	90 days	
D1	3.2	6.1	16.5	5.5	7.9	1.16	0,22	0.3	0.56
D2	1.9	4.3	9.9	3.8	5.0	2.09	0,29	0. 41	0.93
D3	2.0	4.4	8.4	3.4	4.6	2.54	0,35	0.48	1.51
D4	1.5	3.9	7.0	3.0	3.9	2.71	0,38	0.51	1.61
D5	1.3	3.3	5.8	2.9	3.3	2,85	0.45	0.70	0.58
LSD	0.37	0.56	0.57	NS		0.21	0.03	0.08	



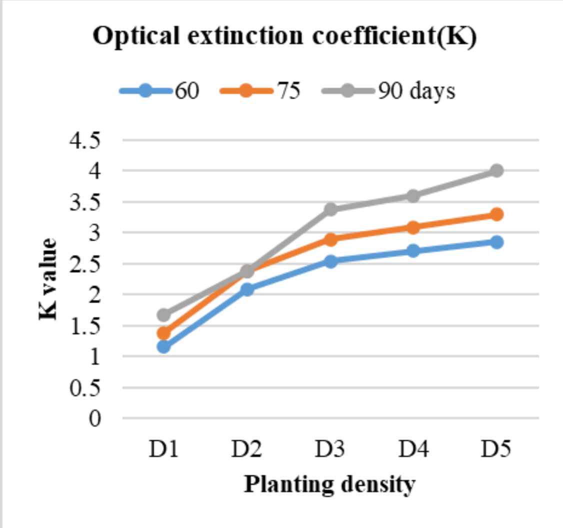


Fig. 4. Effect of broad bean plant density on leaf area index (LAI) and Optical extinction coefficient (K) under drip irrigation system.

Data in Table (5) and Fig. 5 show that broad bean planting densities show significant difference in NAR except at the growth stage of (60-75) days from sowing. As plant densities became lower significant increase in NAR was reported. Moreover, as broad bean plants advanced in age only difference the between D1 (12 plants/emitter) and D5 (4 plants/emitter) was significant at 45-60 and 75-90 days of sowing. Such results indicate the biological stress resulted from the higher density.

Significant effects on RGR were reported due to broad bean planting density at the growth stages of 45-60, 60-75 and 75-90 days from sowing Table (5) and Fig 5. In general, broad bean plants reached their maximum RGR at the growth stage of 60-75 days stage from sowing and decreased in the further stage 75-90 days from sowing. In addition, successive reductions in RGR were reported as planting densities increased at the three growth stages mentioned.

Data in Table (5) and Fig. 5 show significant effects due to planting densities on CGR at the three growth stages 45-60, 60-75 and 75-90 days from sowing. Broad bean possessed the ability to grow more rapidly at highest planting densities. Also, as planting densities increased Broad bean plants tended to be grow faster with high significant rates. The data clearly show that both Broad bean plants reached their peak CGR at 60-75 days from sowing, and then they declined.

Flowering and pod setting

It is worthy to note that the mean No of flowers formed by broad bean plants regardless the planting density was 26.97 flowers /plant while the mean number of pods was 11.14 pods /plant. Data presented in Table (6) and Fig. 6 reveal that flower shedding percentage ranged between 75.1 and 43.9% for D1 (12 plants /emitter) and D5(4 plants /emitter), respectively. Meanwhile, pod setting %/plant under different plant densities ranged between 24.9 and 56.1% for D1 (12 plants /emitter) and D5 (4 plants /emitter), respectively. In general, the data show greater shedding percentage and sharp declining in pod setting as planting density increased up to D1 (12 plants /emitter) while reversal magnitude was evident for lower planting densities.

Yield and yield components

From table (6), it is clear that there was significant reduction in the number of pods per plant was given as planting densities were reduced and the greatest reduction was recorded at D1 (12 plants/emitter). It is worthy to note that broad bean plants seem to be favorable for sowing with higher densities than the lower ones. Furthermore, although the number of pods formed were significantly lower under the higher planting densities D1 (12 plants/emitter) and D2 (10 plants/emitter) but in terms of unit area broad bean plants could compensate such reduction.

From the same table it is clear that increasing planting densities significantly reduced number of seeds per pod than those at lower densities. Similar magnitude was reported on number of seeds per plant due to planting densities. Successive increases in number of seeds/plants were seen as planting densities became lower. Also, the data in same table show that except for the D5 (4 plants/emitter)) none of the other treatments significantly affected 100-seeds weight.

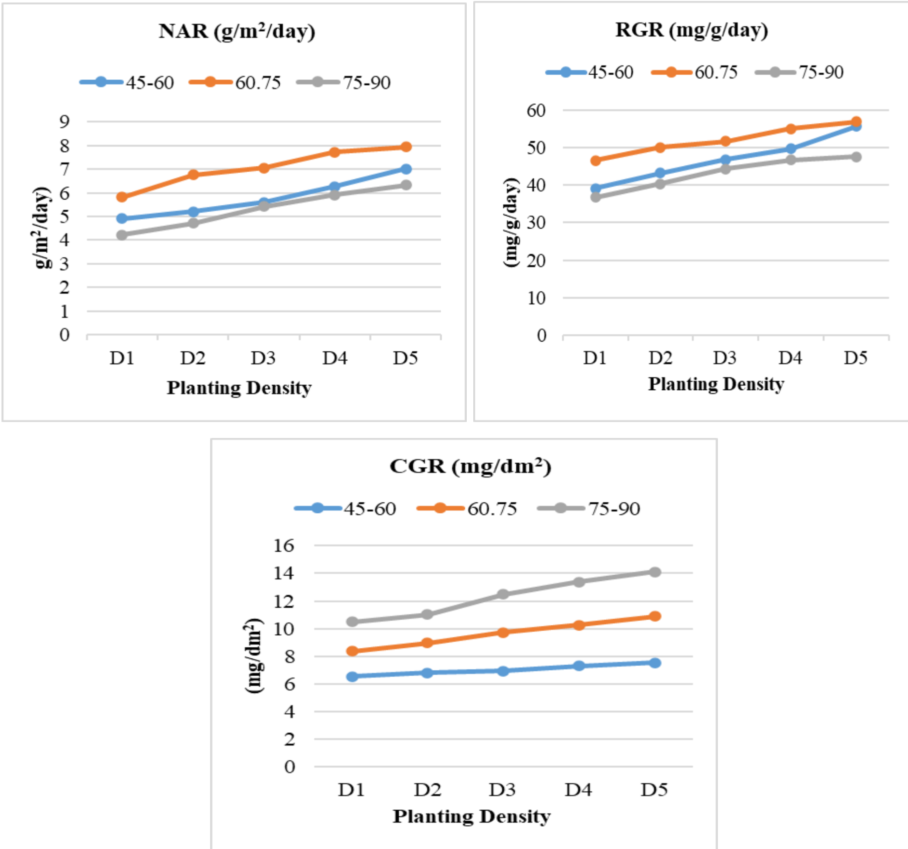


Fig. 5. Effect of Broad bean plant density on Net Assimilation Rate (NAR) and Relative growth rate, (RGR) and Crop growth rate, (CGR) under drip irrigation system.

Table 5. Effect of broad bean plant density on Net Assimilation Rate (NAR) and Relative growth rate, (RGR) and Crop growth rate, (CGR) under drip irrigation system.

	NAR (g/m^2/day)				RGR (mg/g/day)				CGR (g/m^2/day)			
	45-60	60-75	75-90	Mean	45-60	60-75	75-90	Mean	45-60	60-75	75-90	Mean
D1	4.91	5.81	4.22	5.0	39.17	46.63	36.79	40.9	6.55	1.83	2.13	3.5
D2	5.21	6.76	4.72	5.6	43.2	50.03	40.4	44.5	6.83	2.14	2.065	3.7
D3	5.61	7.06	5.42	6.0	46.86	51.67	44.36	47.6	6.93	2.81	2.73	4.2
D4	6.26	7.73	5.92	6.6	49.71	54.99	46.69	50.5	7.31	2.94	3.12	4.5
D5	7.01	7.94	6.32	7.1	55.7	56.97	47.55	53.4	7.55	3.35	3.22	4.7
LSD	1.03	NS	0.95		2.20	3.1	1.70		1.12	NS	0.83	

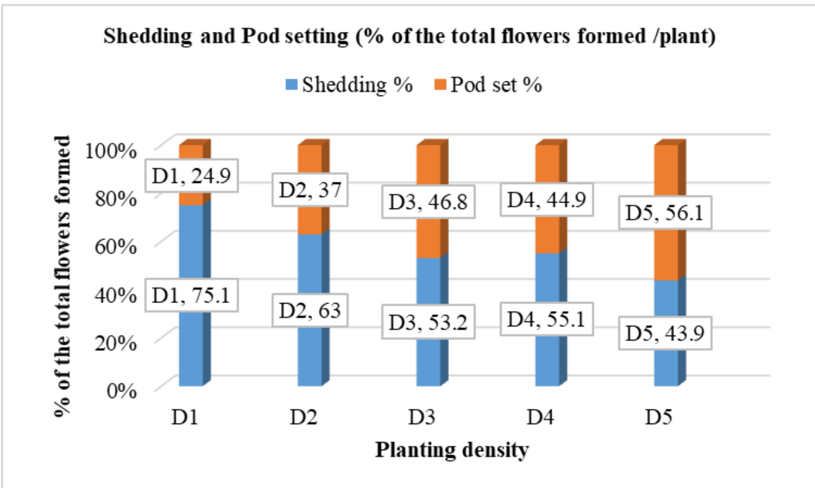


Fig. 6. Effect of broad bean plant density on flower shedding and pod setting percentage under drip irrigation system.

Data in Table (6) show that broad bean seed yield per plant (gm) significantly increased at the lowest planting densities D5 (4 plants /emitter) and the lowest seed yield per plant was produced at (12 plants /emitter) planting density. Similarly, increasing planting densities D5 up to D1 showed lower yield/plant than the other planting densities. The data show insignificant differences among planting densities in HI. As planting densities D5 (4 plants/emitter) and D2 (6 plants /emitter) applied. HI was increased to reach the maximum values, respectively.

Broad bean straw yield significantly affected by planting densities (Table 6). On contrast of other yield components, increasing planting densities decreased straw yield per feddan. The highest straw yield was obtained for broad bean plants at D5 (12 plants /emitter) planting density.

Data in Table (6) show clearly that seed yield /fed is significantly affected by planting densities under drip irrigation system. Planting broad bean at D1 and D2 planting densities resulted in producing the highest seed yield per feddan. The lowest seed yield per feddan was obtained at D5 planting density. The differences in the yield of broad bean at D4, D3, D2 were insignificant and exceeded significantly D1 planting density indicating that it is favorable to higher planting densities. On contrast, broad bean gave its higher yield at D1 planting density which was significantly superior to the other planting densities treatments.

The data showed that the broad bean plants gave their highest seed yield at D1 planting density at (12 plants /emitter) Such results indicate broad bean plants give their potential yield at higher density than lower ones in terms of unit area.

Table 6. Effect of Broad bean plant density on yield and its component and water productivity under drip irrigation system.

	Shedding %	Pod set %	No. of pods/ plant	No. of seeds/ plant	No. of seeds/ pod	Seed yield/ plant g//plant	100 - seeds weight	HI %	Straw yield t/fed	Seed yield kg/fed	Water productivity kg/m^3
D1	75.1	24.9	7.7	16.3	3.4	20.6	81.6	35.45	2.12	1392.0	0.679
D2	63.0	37.0	10.1	24.0	3.5	24.6	82.3	41.05	1.73	1267.2	0.618
D3	53.2	46.8	10.7	24.9	3.8	27.0	83.8	42.69	1.39	1208.0	0.589
D4	55.1	44.9	12.3	26.1	3.8	30.5	83.1	45.30	1.31	1144.0	0.558
D5	43.9	56.1	13.9	27.5	4.1	32.1	82.1	48.50	1.67	1051.2	0.513
LSD	11.4	6.69	NS	1.98	0.15	0.6	NS	NS	0.11	96	0.054

Water Productivity (kg/m^3)

From the same table it is clear that there were significant differences among broad bean planting densities in water productivity (kg/m^3). The results revealed that successive increases in water productivity were evident as planting density increased. The highest significant water productivity was obtained with the highest planting density D1 (12 plants /emitter), meanwhile the difference between D2 and D3 was insignificant. The same tendency was reported for D4 and D5 where the difference was insignificant.

Discussion

Water consumption

The obtained results revealed the monthly water consumption ranged between (33 and 60%) The overall saving of irrigation water was about 39.9% compared with water duty of the traditional irrigation system adopted in the district (sprinkler irrigation). The data coincide with the water requirements and in parallel with those obtained by Kada Siddappa and Rao (2018). Under Egyptian conditions, drip irrigation has introduced numerous diverse agricultural irrigation methods that have contributed significantly to economic development (Mansour and El Melhem 2015).

Growth characters

plant height of broad bean seemed to be sensitive to the changes in plant population density and the competition was higher at the higher planting density. The similar magnitude was recorded for other planting densities on number of branches, leave and the accumulation of dry matter /plant at 60, 75 and 90 days from sowing date It can be noticed that successive increases in dry matter/plant were reported as planting density decreased. The sensitivity of growth parameters could be attributed to inter plant competition on water and nutrients. These findings are consistent with those provided by Khalil *et al*., (2015) and confirm those reported by Abdallah (2014), who discovered that increasing planting density from 25 to 33 plants/m2 dramatically reduced the number of branches and pods per plant. Similar findings were reported by López-Bellido *et al.,* (2005). Abd El-Salam and Abd El Lateef (2015) Abd El Lateef *et al.,* (2017).

The significant reduction in chl. b, carotenoids and the total pigments content occurred in broad bean due to the increase in plant density especially under the highest density D1 (12 plants /emitter) may be due to the increase in competition for environmental resource such as nutrients and light. The reduction in photosynthetic pigments was attributed to the disturbance of photosynthetic efficiency which linked with the other primary metabolic processes such as carbohydrate metabolism. Such effect may lead to the reduction in total carbohydrates of leaves of broad bean concurrently with slowed shoot growth and a decrease in leaf photosynthetic pigments, (Bakhoum *et al.,* 2022). Ulyanych *et al*., 2021 indicated that biometric analysis revealed that irrigation-based wide bean farming increases plant height by 4.7-12.2%, the number of branches per plant increases by 17.3-30.0%, and the leaf area of broad bean crops increases by 21.2-24.9%. The overall chlorophyll concentration increased by 16.9-40.5%.

Optical extinction coefficient

The fluctuations in Optical extinction coefficient (K) at the studied growth stages could be attributed to the canopy development where at the early growth stages, the arrangement of the plants permits light penetration along the canopy freely more than at subsequent stages. Meanwhile, it is worthy to notice that the data of K sharply contrasted with LAl values where the latter were smaller at 60 days and reached the peak at 75, days from sowing, then it decreased at 90 days. In this regard, Derogar and Mojaddam (2014) observed that the optical extinction coefficient was significantly influenced by either varied plant densities or cultivars of broad beans, such that the optical extinction coefficient dropped with increasing plant density. The optical extinction coefficient decreases as a result of the increase in leaf area index that arises naturally when plant density increases. Furthermore, when environmental conditions are favorable, competition between plants for sun radiation typically limits development. Under Mediterranean circumstances, there is no competition for radiation and plant growth may be restricted by water, especially at high plant densities (Loss *et al.,* 1998, Abd El-Salam and Abd El Lateef, 2015 and Abd El Lateef *et al.,* 2017).

Physiological attributes

The results of LAI at the different growth stages indicate that the peak leaf expansion stage was (60 and 75 days from sowing while, D1 (12 plants /emitter) recorded the highest LAI values. Leaf area is regarded as a significant element in light interception, water utilization, and, ultimately, photosynthesis (Togashi *et al.,* 2015). It is well understood that in optimal conditions, leaf area rises, resulting in more photosynthesis and, ultimately, greater rate of growth (Zlatev and Lidon 2012). The growth of leaf area is an important component in increasing the effectiveness of light interception, which is linked to leaf enlargement, and senescence (Ricaurte *et al.,* 2016). LópezBellido *et al.,* (2005) came to similar conclusions on the effect of planting density on LAI. According to Derogar and Mojaddam's (2014) findings, a rise in plant density is accompanied by an increase in leaf area and light absorption. According to Kiniry *et al.,* (2009), a plant's ability to absorb light and compete will increase if it has a greater leaf area index, a reduced optical extinction coefficient, or a higher density of leaf area in the upper levels of the canopy. According to Tawaha *et al*., (2005), the leaf area index rises as the proportion of plants per unit area increases.

The obtained results revealed lower significant increase in NAR was reported as plant densities became lower. Moreover, as broad bean plants advanced in age only the biological stress resulted from the higher density in lower NAR. Ghalandari and Sakinezhad (2021) found that vegetative development before flowering had highest quantity of NAR and the lowest one related to pod emergence until filing of grain.

Relative growth rate results revealed that successive reductions in RGR were reported as planting densities increased at the three growth stages mentioned. The amount of dry matter that a plant accumulates in a given amount of time is indicated by its relative growth rate. As plants age, there is a diminishing trend in the relative growth rate of crops during the plant life cycle. The accumulation of dry matter, primarily in undifferentiated tissues, is the cause of the declining trend in the relative growth rate.

These results could be attributed to the inter plant competition and light interception which affect RGR. Similar results on the effect of plant density on RGR were obtained by Ghalandari and Sakinezhad (2021), they made the point that variations in photosynthesis and plant respiration affect the relative growth rate, and as a result, plant growth eventually drops to zero as respiration increases at the conclusion of the growing season. Additionally, it can be said that the occurrence of leaves shadowing one another is helpful in this decrease (Sadi, 2016).

The obtained results of the effect of planting densities show that the highest CGR value was reported at D5 (4 plants /emitter) planting density. Meanwhile, the data of CGR are parallel to those obtained on DM, LAI, NAR, RGR criteria in the peak growth stage. The obtained results are in harmony with those obtained by Ghalandari and Sakinezhad (2021) the highest CGR was found in the vegetative growth preceding blooming, while the lowest CGR was found in the pod emergence through grain filing.

In general, the dry matter and LAI values obtained throughout the course of the different crop stages are related to how other growth indices behave in response to changes in plant density.

The relationship among growth parameters and growth attributes were assessed by Abunyewa *et al.,* (2009) who found a substantial and positive correlation between sorghum grain yield, plant height, and the leaves number per plant. The influence of other growth factors that improved crop growth and eventually led to more assimilates production and partitioning for high grain filling that contributed to yield may be responsible for the direct and indirect effects of plant height, number of leaves per plant, crop growth rate, relative growth rate, and net assimilation rate as some of the primary determinants for yield. Similar conclusions were confirmed by (Gomma *et al.,* 2022).

Flowering and pod setting

In general, the data show greater shedding percentage and sharp declining in pod setting as planting density increased up to D1 (12plants /emitter) while reversal magnitude was evident for lower planting densities. These results are generally in accordance with those obtained by Henderson and Dean 2004; Norouzi and Vazin 2011) who mentioned that flowering signifies the change from a vegetative (or juvenile) to a reproductive phase and is the most significant phenological stage in the life cycle of a plant. The development of leaf area index (LAI) is often influenced by environmental conditions and agronomic techniques; higher plant densities are typically associated with greater LAI (Derogar *et al*., 2014; and Ghavidel *et al.,* 2016).

It makes sense that broad bean plants that flowered more frequently in shorter amounts of time—especially during the early stages of growth—would have more time to accumulate assimilate and, as a result, develop stronger sinks than flowers that formed later (Saitoh *et al.*, 2004; Biswas *et al.*, 2005). According to Mondal *et al*., (2011), mung bean leaf chlorophyll and nitrogen increased with plant age until just before pod development began, and then decreased with pod age until physiological maturity, suggesting that early-setting pods have access to more assimilates than later-setting ones for growth and development. This contributes to a high yield by generating a high rate of pod set. . Limited pod –set is explained by the competition for assimilates at the reproductive stage in broad bean. Moreover, Schwartz *et al*., (2010) revealed that flowering causes resource diversion "from the continual production of photosynthetic material (leaves) to the terminal production of reproductive tissue (flowers, seeds, and fruit)," which can result in an increase in biomass yield.

Yield and yield components

The results of number of pods /plants revealed that although the number of pods formed was significantly lower under the higher planting densities D1 (12 plants /emitter) and D2 (10 plants /emitter) but in terms of unit area broad bean plants could compensate such reduction. Tadesse *et al.*, (2011) discovered that the primary factor influencing broad bean production was the quantity of pods produced by a plant.

The results of the 100-seed weight test and the number of seeds per pod per plant agreed with the conclusions of Dahmardeh *et al.*, (2010). Assimilates are often devoted to filling the grains following the pods, and heavier seeds are anticipated to raise the seed production and, as a result, the harvest index. Corresponding findings in soybean have been mentioned by De Bruin and Pedersen (2008). According to Biswas *et al.*, (2005), there would be significant competition among plants at higher densities, which will result in a decline in the number of seeds per pod, number of seeds per plant, 100-seed weight, and harvest index even while the leaf area index and dry matter yield improve. Also, Yucel (2013) discovered that plant density significantly impacted the number of pods and seeds per plant.

The superiority of the lowest planting densities D5 (4 plants/emitter) in seed yield per plant could be attributed to their its greater photosynthetic area, more dry matter accumulated, greater number of seeds per pod and per plant. According to the literature, individual plants that received drip irrigation performed better than those that received flood irrigation. However, reversible magnitude impacts were reported on an area-based basis, even though none of the benefits were statistically significant. Abd-Elmonsef and Abd El lateef (2020) attributed the superiority of broad bean yield /plant due to the large difference in plant densities caused by the wider row spacing to allow for drip irrigation, compared with normal density under traditional irrigation (49,600 plants per feddan). The obtained results are in harmony with those obtained by Dahmardeh *et al.*, (2010), who demonstrated that plant density had a significant impact on a few characteristics but not on plant height, the height of the lowest surface pods, the weight of 100 seeds, the number of pods per plant, or the number of seeds per pod. Plant density raised from 12.5 to 20 plants m-2 led to a considerable improvement in both biological and economical yield.

It was found that because of leaf loss during senescence, HI in grain legumes like broad beans is extremely variable and challenging to measure (Loss and Siddique 1997). The relationship between plant growth and sink strength improvement is the primary determinant of HI (Confalone *et al.,* 2010). According to Abd-Elmonsef and Abd El Lateef (2020), larger individual plants with more pods were generated with drip irrigation, however the seed weight was lower due to the reduced plant density. As a result, the harvest index performed better with surface irrigation—the typical irrigation technique—and had the highest area-based yields of straw and seeds.

The straw yield increase may be due to its greater height and larger canopy per unite area and mainly due to the increase in plant population. In this respect, some investigators mentioned that increasing plant density by closer spacing increased significantly the straw yield per feddan, Abd El Lateef *et al.,* (2005).

The higher increase in seed yield by increasing broad bean plant population reported by Ulyanych, *et al.,* (2021) and Abd El Lateef *et al.,* (2014). Yucel (2013) found that the plant density had a significant effect on pods number plant^{-1}, seed number plant^{-1}, seed weight plant^{-1}, 100-seed weight and seed yield ha^{-1} in two seasons. Plant height greatly increased when plant density was increased from 11 to 44 plants per m^{2}, but plant number, pod number, seed number, seed weight, and 100-seed weight dramatically dropped. At a density of 22 plants m^{-2}, the maximum seed production ha-1 was recorded. According to Dergar *et al.,* (2014), densities of 12 plants m^{-2} and 8 plants m^{-2} produced the maximum and minimum grain yields. According to Vieira *et al.,* (2014), there was no effect of the treatments on plant height, number of pods, or insertion height of the first pod; nevertheless, there was a significant difference in the variables of leaf chlorophyll index, weight of 1000 seeds, and number of grains per pod. These results confirm the variability of broad bean yields due to the planting density under certain environment. Several investigators came to similar conclusion (Yücel, 2013; Sharifi 2014; Tofiq *et al.,* 2016; Abd-Elmonsef and Abd El lateef 2020).

Water productivity

The results of water productivity were parallel to those of seed yield/fed. According to Kadasiddappa and Praveen Rao (2018), the best irrigation practices would increase both the economic yield and the efficiency of water consumption. According to Alves Souza *et al.,* (2020), planting density resulted in the best water-efficient usage.

Conclusion

Under the circumstances of this study, the overall saving of irrigation water was substantial compared with the water duty of the traditional irrigation system adopted in the district (sprinkler irrigation). The results confirm the variability of broad bean yields due to the planting density under certain environments. Although the performance of individual plant yields under lower densities was superior to the highest ones, it could not compensate for the reduction in stand Such results indicate broad bean plants give their potential yield at higher density than lower ones in terms of unit area.

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تأثير الإجهاد البيولوجي على الصفات المورفولوجية والفسيولوجية والمحصول وإنتاجية المياه للفول البلدي تحت نظام الري بالتنقيط

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أجريت هذه الدراسة بهدف تقييم تأثير الاجهاد البيولوجي الناتج عن تكثيف زراعة الفول البلدي وتم خلال الدراسة إجراء تجربتان حقليتان خلال موسمي الشتاء المتتاليين 23/2022 و24/2023 حيث جرى اختبار خمس كثافات نباتية D1، D2، D3، D4 وD5 (12،10،8،6،4 نباتات/ نقاط) على التوالي والتي مثلت 120 و100 و80 و60 و40 ألف نبات/فدان) على صفات النمو والصفات الفسيولوجية والمحصول وكذلك إنتاجية المياه. أظهرت النتائج أن الفول تأثر بشكل كبير بكثافة الزراعة في معظم صفات النمو وجميع مراحل النمو وخاصة تراكم المادة الجافة. تحت جميع معدلات كثافات النباتات، احتوت أوراق الفول العريض بشكل ملحوظ على تركيزات أكبر من الصبغات الضوئية. وصلت مساحة أوراق نبات الفول إلى أقصى قيم لها عند 75 يومًا من الزراعة وسجلت اعلى قيم لمساحة الأوراق عند كثافات الزراعة الأعلى من الكثافات المنخفضة، ثم انخفضت في مرحلة النمو اللاحقة. أظهر تحليل النمو أن صافي معدل التمثيل الضوئي والمعدل النسبي للنمو ومعدل نمو المحصول وصلوا إلى معدلاتهم القصوى عند مرحلة النمو (60-75) يومًا من الزراعة. كما أظهرت البيانات أنه على عكس انخفاض قيم صافي معدل التمثيل الضوئي والمعدل النسبي للنمو عند أعلى كثافة، فإن قيم معدل نمو المحصول أخذت حجمًا قابلًا للعكس. زاد محصول البذور/ نبات (جم) بشكل ملحوظ عند أدنى كثافات الزراعة D5 (4 نباتات / نقاط) وتم الحصول على أقل محصول بذور لكل نبات عند كثافة الزراعة (12 نبات / نقاط). كما أدت زراعة الفول البلدي عند كثافات الزراعة D1 وD2 عن إنتاج أعلى محصول بذور للفدان. وكانت قيم إنتاجية المياه مماثله لتلك التي تم الحصول عليها في محصول البذور/فدان.