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Article

Improving Fodder Beet and Faba Bean Productivity by Intercropping under Phosphorus and Plant Density Levels in Arid Conditions

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Abstract

A two-year study was conducted to test the effect of intercropping faba bean with fodder beet on the productivity of both crops, and land use efficiency of the system, when variable faba bean plant densities (D) were practiced, i.e. 42000 (D1), 84000 (D2), and 125000 (D3) plant ha-1, while three phosphorous fertilization (P) rates were tested, i.e. P1; 36, P2; 54, and P3; 72 kg P ha -1. Field studies were carried out during the growing season of 2017/2018, and 2018/2019. Some influential agronomic, and physiological traits for fodder beet and faba bean were investigated, besides, land equivalent ratio (LER), and dry matter equivalent ratio (DMER), as comparative harvesting indices. Results indicated that 72 kg ha -1 P fertilization could significantly boost production of fodder beet and faba bean. Adjusting suitable planting densities, also emphasized the merit of intercropping optimization for better crop improvement. Plant density of faba bean (84000 plant ha-1) was able to impact the growth of fodder beet, while faba bean was impacted by practicing 125000 plant ha-1 intensification. All LER values recorded > 1, while DMER figured between 0.92 and 1.06. The study evidenced that DMER was more reliable than LER for appraising intercropping, in cops where dry matter dominates an economic component like fodder beet.

Keywords: Fodder beet; faba bean; land equivalent ratio (LER); intercropping; dry matter equivalent ratio (DMER).

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1.Introduction

Most of the newly reclaimed soils in Egypt are located in arid and semi-arid areas, where a belt of harsh conditions is controlling crop production. Sandy, loamy, and/or calcareous textured soils are representing the vast majority of these lands, characterized by low levels of accessible nutrients, organic matter, and water holding capacity (Zohry and Ouda 2020).

Reduction of cultivated land area, together with the over-growing population, have led to widen the gap between food production and consumption (Shaalan and El-salamouni 2016). In this regard, there has been an urgent necessity for increasing in-land productivity, in order to reach the needed yield-consumption balance (Salama et al. 2016). At the same time, climate change impacts are threatening agricultural practices, and alarming for a cascade of food and feed shortage, all over the world, with concerns focused to newly reclaimed, arid, and semi-arid areas (Shaalan et al. 2021). Thereupon, strategies like associated growth of two or more crops on the same field (i.e., intercropping), should be followed by small holders, to increase land productivity, and net return (Maitra et al. 2021; Vico et al. 2021).
Intercropping is known to be very helpful for crop intensification, and may be more advantageous than corresponding monoculture, due to the efficient utilization of resources (Nelson et al. 2021). Intercropping can also lead to raising yield possibility through effective use of natural and added resources in agricultural sustainability (Kugbe et al. 2018). Successful intercrops of expedient association, extend the sharing of available resources, over time and space, besides, exploiting variation between component crops in growth habits, and nutrient demands (Gebru, 2015). The success of intercropping, compared to sole planting, might be a result of various agronomic practices, such as adopting the appropriate plant density of the component crops, which supports maximized utilization of the limited available resources, leading to saving money, time, and effort (Yin et al. 2020; Vico et al. 2021 and Berghuijs 2021).
Among significant factors affecting the success of intercroping in arid environments, are plant density and phosphorus rates (P). Phosphorus, a necessary nutrient for plants, is a major factor for crop production. Its excessive use has resulted in its low use efficiency (Fan et al. 2020). To increase P use efficiency, it is necessary to mitigate the negative impacts associated with its intensive use (Cong et al. 2020). Arrival at that approach can be through the intensification production in so called intercropping (Xiao et al. 2021; Gao et al. 2021).

Crop production can be increased with the increase of P input, but excessive P fertilization may be associated with a reduction in P use efficiency (Hinsinger et al. 2011). Therefore, it is important to increase the efficiency of P utilization which can be achieved through crops diversification, where there are crops that are able to convert soil accumulated P fertilizer to available form (facilitation for the companion crop thus enhancing its growth and development (Xia et al. 2013).

Beneficial effects of intercropping on the intercrop productivity as affected by P application were conducted and have been widely investigated in many studies on different cropping systems (Mndzebele et al. 2020; Fan et al. 2020; Gitari et al. 2020). Rhizobia was also found to enhance P availability in the soil rhizosphere through different mechanisms (Mouradi et al. 2018).
Fodder beet (Beta vulgaris L.) is considered a high energy crop that copes different climates, grows on a wide range of soils, and provides a good source of animal feed, at the time when almost all beef, sheep, and dairy farming sectors are mainly dependent on

closed grazing systems (Khan et al. 2020; Khatab et al. 2016). Also, fodder beet is a winter forage crop in Egypt, that cannot compete with the prevailing berseem forage crop (Egyptian clover crop), and consequently, it cannot be established in the crop rotation, except through intercropping with other winter crops such as faba bean (Ibrahim 2018).

A few studies have been made on fodder beet performance, as one of the climate-resilient crops that can meet the expanding demands of farming communities, besides having a relatively higher yield potential, compared to the rest of arable fodder crops (Rajab et al. 2014). On this account, fodder beet might be an excellent alternative choice for livestock producers with optimistic promises (Salama and Zeid 2017).

Faba bean (*Vicia faba L.*), as a source of protein for food and feed; and fodder beet, as a source of animal feed, are grown as winter crops. On one hand, faba bean offers ecosystem services, as knowable inputs of N into crops, soil through N fixation, and cropping system diversity.

As intercropping components, faba bean and fodder beet are considered good models for studying protocols in intercropping systems, where faba bean has deeper root system, compared to fodder beet, hence they complement each other in the uptake of growth resources (Rajab 2014). Complementarity of the two crops, is also returned to the ability differences between the two components in holding nutrients (Andersen et al. 2014). In addition, faba bean, as a legume plant, needs large quantities of phosphorous (P) as a source of energy for nitrogen (N) fixing symbiosis.

To develop a successful faba bean - fodder beet intercropping, it is necessary to understand how the two crops can respond to intercropping, based upon biological, chemical, physical, and climatic variables, and how can this response be affected by agricultural practices (Sheha et al. 2020). Intercropping yield advantage can be achieved through the modifications of competitive interference, and complementarity interactions by intercrops in the cropping system (Bedoussac et al. 2015). Competitive interference of the intercrops drives yield advantage, provided that intercrops competition must be less than the sole crops intra competition (Wiley 1979).

Generally, intercropping designs, mixed cropping, or polycultures, are conventional farming practices with diversified crop cultivation that use comparatively low inputs, and improve the quality of agro-ecosystem. Crop intensification can be accompanied with both spatially, and temporally through the use of an intercropping system, designed to meet future demands. Intercropping through justifying proper plant densities provides numerous benefits; including increased yield, environmental security, production sustainability, and increased ecosystem services, where also employing legume crops in the process, will lead to keep three key crop sequence activities: (1) supplying of high-protein foods and feed, (2) provision of N to the system via symbiotic N2 fixation, and (3) maintenance of the crucial diversity of the agricultural system (Maitra et al. 2021; Salama et al. 2021).

In this context, the current investigation was mainly conducted, aiming to investigate the productivity of fodder beet and faba bean when additively intercropped using different faba bean plant densities under variable P fertilizer rates.

MATERIALS AND METHODS

Experimental site, design and treatments

Two field experiments were conducted during the winter season of two successive years of 2017/2018 and 2018/2019 at Fuka Research Station, Faculty of Desert and Environmental Agriculture, Matrouh Governorate, Egypt, to study the performance of fodder beet (Voroshenger, multigerm cultivar) and faba bean (Giza 843 cultivar) in monoculture and associations, and to estimate yield advantages of intercropping of two crops together under three rates of phosphorus fertilizer applications. The experimental site is characterized as follows in (Figure 1) and (Table 1):

A split plot experimental design, with three replications, was used in both seasons, where the three phosphorus rates (P1= 36, P2= 54 and P3= 72 kg P ha-1) occupied the main plots and the three plant densities, in additive pattern, (42000 (D1), 84000 (D2), and 125000 (D3) plants ha-1 of faba bean) were assigned to the sub plots, in addition to pure faba bean and fodder beet plots. Pure fodder beet (the plot included four ridges, 0.6 width x 3 length), at seeding rate 7 kg ha-1 was sown in hills, 20 cm apart, on the upper half of one side of each ridge. While Pure faba bean plots (the plot included four ridges) was sown in hills 20 cm apart, on one side of ridges spaced 60 cm apart and thinned to two plants per hill.

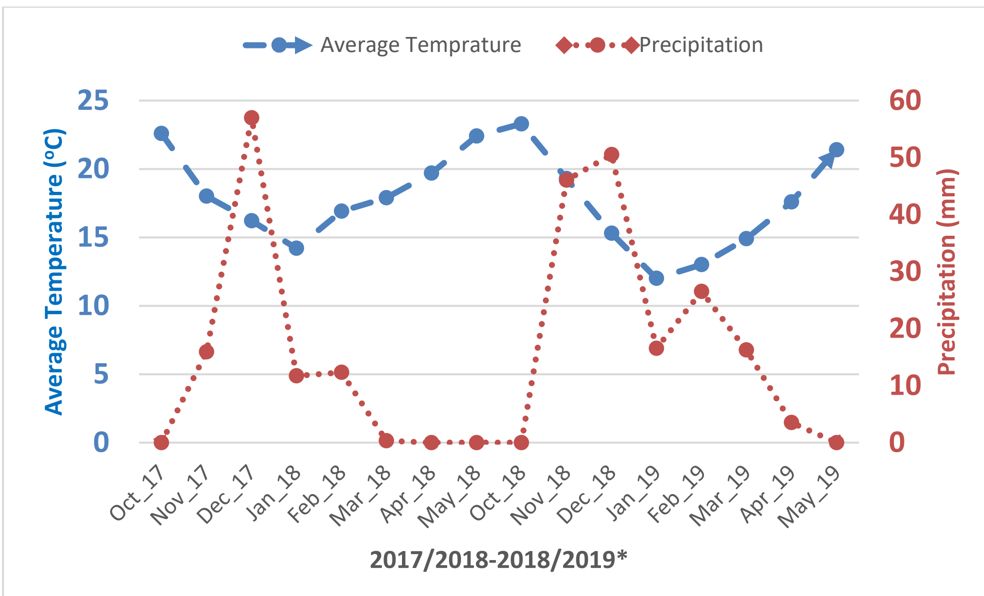

Figure 1. Climatic conditions of the experimental site during the two experimental seasons 2017/2018 and 2018/2019.

* Source: Marsa Matrouh Research station, Agricultural Research Central (ARC), Egypt.

Table 1. Physical and chemical soil properties during 2017/2018 and 2018/2019 seasons.

Soil properties	2017/2018 season	2018/2019 season
1- Particles size distribution % (Texture Loamy sand)		
Clay	10.44	9.60
Silt	1.31	1.40
Sand	88.25	89.00
2- Chemical analysis		
pH	8.20	8.23
EC (ds/m)	2.30	2.35
Total N %	0.31	0.34
P	81.5	80.4
Ca^{++} (meq/l)	3.9	4.1
Mg^{++} (meq/l)	3.6	3.4
Na^{+} (meq/l)	16.6	17.0
K^{+} (meq/l)	0.5	0.4
CO_3^{--}(meq/l)	0.0	0.0
HCO_3^{-}(meq/l)	5.6	5.9
Cl^{-}(meq/l)	14.3	15.1
SO_4^{--}(meq/l)	4.7	5.2
SAR	8.56	8.92
$CaCO_3$ %	12.04	12.82
O.M %	0.53	0.50

Management and sampling

The sub plots area included 6 wide beds (1.20 m width x 3 m length) for the intercropping treatments. The main crop, fodder beet, was sown in hills 20 cm apart on two side of beds spaced 60 cm for intercropping treatments. In the intercropping treatments, faba bean was sown in hills (20 cm apart) above wide beds as 42000 (D_1), 84000 (D_2) and 125000 (D_3) plants ha^{-1} (25, 50 and 75 % of recommended faba bean plant density, respectively).

Fodder beet was sown on 20 and 22 October, while faba bean was sown on 18 and 20 November, in the two seasons, respectively. Fodder beet plots were sprayed with borax (11.3 % Boron) at the rate of 1.2 kg ha^{-1}, twice after 4 and 5 months from sowing.

Plots were irrigated by using sprinkler system, as equivalent to an approximate amount of 5280 m^3 ha^{-1}. Water was applied every 5 days at early stages of growth, then the period was extended according to weather conditions (temperature and rainfall incidence). Phosphorus was applied as calcium super phosphate (15.5 % P_2O_5) during seedbed preparation for the three evaluated rates. While nitrogen in the form of ammonium nitrate (33.5 % N) was applied at the rate of 168 kg N ha^{-1}, at three doses, the first at 40 days after sowing (DAS) and the second at 30 days after the first dose, then another 30 days were left before the third dose. Leaf worms were sprayed with 239 g Lannate (S-methyl-N-[(methylcarbamoyl) oxy] thioacetimidate) dissolved in 477 Liter water/ha at twenty days after sowing date and weeds were hoed when necessary.

All other practices were uniformly applied upon the recommendations for both crops in the region. Faba bean seeds were inoculated with nitrogen fixing bacteria (*Rhizobium leguminosarum)*, prior to seeding, at the rate of 480 g ha^{-1}.

Investigated parameters

At harvest, three guarded plants of fodder beet were taken randomly from each sub-plot to determine root diameter (cm), root weight $plant^{-1}$ (kg), shoot weight $plant^{-1}$ (kg), while the fodder yield (shoot yield t ha^{-1}, root weight t ha^{-1} were determined from the whole plot (inner guarded rows) then air dried for two days then dried in an air oven at 70 ^{o}c until constant weight. On the other hand, the studied characteristics in faba bean were plant height (cm), number of branches $plant^{-1}$, number of pods/main stem as an average of five plants, respectively. In addition, seed yield t ha^{-1}, 100-seed weight (g) from each sub plot, and harvest index % were, also, investigated.

Land equivalent ratio (LER) as stated by de Wit and van den Bergh, (1965)

A simple procedure was used for evaluating intercropping treatment. This is the calculation of land equivalent ratio (LER). Land equivalent ratio is defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping as for pure cropping.
according to:

$$\text{LER} = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

where, Yab= Yield of fodder beet intercropped with faba bean, Yaa= Yield of pure fodder beet, Yba= yield of faba bean intercropped with fodder beet, Ybb= Yield of pure faba bean.

An intercropping system exhibits a yield advantage if LER > 1.0 and conversely, a disadvantage if LER < 1.0.

Dry matter equivalent ratio (DMER) Shaalan et al, 2015

Determined as the sum of the dry yield of the main crop (intercropped fodder beet) and the intercrop crop (faba bean) relative to the dry matter yield of the pure main crop as follows:

$$\text{DMER} = \frac{DMYFO+DMYFA}{DMYP}$$

Where: DMYFO = Dry matter yield of fodder beet at sub plot, DMYP = Dry matter yield of pure fodder beet, DMYFA = Dry matter yield of the faba bean crop.

Statistical analysis

Data were tested for significance using Proc Mixed of SAS 9.4 (SAS 2012). Data of each growing season are separately presented and discussed. Also, after running the statistical analysis separately for the two experimental years, the homogeneity of variance error was determined according to Hartley's test (Winer et al., 1971); it was not homogeneous and data were therefore presented in a two seasons separately. Significance was declared at *P*< 0.05 and means were compared with the least significant difference (L.S.D) procedure.

RESULTS

Data of the main effects only of the studied factors will be presented and discussed when the interaction is not significant.

Table 2. Levels of significance of the root diameter, root weight plant^{-1} shoot weight plant-1, shoot fresh yield, and root fresh yield in 2017/2018 and 2018/2019 growing season.

S.O.V.	d.f.	Root diameter (cm)		Root weight plant $^{-1}$ (kg)		Shoot weight plant -1 (kg)		Shoot fresh yield (t ha $^{-1}$)		Root fresh yield (t ha^{-1})	
		Growing season									
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Phosphorus rate (P)											
	2	0.727^{NS}	0.743^{NS}	0.001**	0.004**	0.02*	0.03*	0.003**	0.001**	0.002**	0.003**
Plant density (D)											
	2	0.002**	0.02*	0.008**	0.001**	0.04*	0.02*	0.008**	0.002**	0.003**	0.002**
P*D	**4**	0.675^{NS}	0.560^{NS}	0.005**	0.003**	0.342^{NS}	0.159^{NS}	0.002**	0.001**	0.002**	0.006**

*Significant at 0.05 level of probability - **Significant at 0.01 level of probability - NS: non-significant. S.O.V.: Source of variation - d.f.: Degrees of Freedom

Performance of fodder beet:

Analysis of variance presented in (Table 2) revealed that the root weight plant $^{-1}$, shoot weight plant^{-1}, shoot fresh yield and root fresh yield of fodder beet significantly varied among the three phosphorus rates and plant densities in both seasons. However, root diameter showed insignificant variation for phosphorus rates in both seasons.

The effects of faba bean plant density (D_1; 42000 plants ha^{-1}, D_2; 84000 plants ha^{-1}, and D_3; 125000 plants ha^{-1}), and phosphorus levels (P_1; 36, P_2; 54 and P_3; 72 kg P ha $^{-1}$) on some studied parameters of fodder beet during 2017, and 2018 growing seasons are presented in Table (3).

Root diameter (cm) of fodder beet recorded no significant difference in response to the studied P rates during both seasons as an average of 14.11 and 14.46 cm for 2017 and 2018 growing seasons, respectively. On the other hand, root diameter was affected significantly by plant densities treatment in both seasons, where D_1 recorded the highest significant root diameter of 15.47 cm, followed by D_2 and D_3 in 2017 season. Moreover, in 2018 season, intercropped faba bean as 42000 plant ha^{-1} of (D_1) showed highest root diameter and no significant different with D_2 followed by D_3 with lowest significant root diameter.

Means of shoot weight plant $^{-1}$ (kg) of fodder beet were found to be considerably affected by phosphorus rate and faba bean plant densities during both 2017 and 2018 cultivating seasons. Data in (Table 3) revealed that applying 72 Kg P ha^{-1} (P3) gave highest significant values (0.20 and 0.19 kg) in 2017 and 2018 seasons, respectively. On the other hand, insignificant difference between P_2 and P_1 and gave the lowest shoot weight plant^{-1} in both growing seasons. Also, data showed that the highest significant shoot weight plant^{-1} were obtained from the lowest and intermediate density (D_1 and D_2), which were insignificantly different, amounting to 0.18 and 0.16 cm as an average for 2017 and 2018 seasons, respectively.

Table 3. Effect of cropping patterns and phosphorus levels on some studied characters of fodder beet in 2018 and 2019 seasons.

Treatments	Root diameter (cm)		Shoot weight plant^{-1} (kg)	
	Growing season			
	2017	2018	2017	2018
Phosphorus rate: (Kg P ha $^{-1}$)				
36 (P1)	14.16 a*	14.44 a	0.13 b	0.14 b
54 (P2)	14.16 a	14.56 a	0.16 b	0.15 b
72 (P3)	14.01 a	14.39 a	0.20 a	0.19 a
LSD 0.05	**NS**	**NS**	**0.04**	**0.03**
Plant density (plants ha^{-1})				
42000 (D_1) = 25%	15.47 a	15.37 a	0.18 a	0.18 a
84000 (D_2)= 50 %	13.86 b	15.12 a	0.17 a	0.16 a
125000 (D_3) = 75 %	12.69 c	11.29 b	0.13 b	0.12 b
LSD 0.05	**1.24**	**2.04**	**0.03**	**0.02**

* Means followed by different small letter(s) within the same column, for each year and studied parameter, are significantly different according to the L.S.D. test at 0.05 level of probability.

Means of fodder beet shoot and root fresh yields (t ha^{-1}), and root weight per plant as affected by the interaction between the faba bean plant density and applied P rate are presented in (Table 4).

For both growing seasons, results revealed that under the low and moderate P rates, the lowest significant fodder beet shoot yield was achieved accompanying the plantation of the lowest faba bean plant density (42000 plant ha^{-1}), while the application of the highest P rate (72 kg P ha^{-1}) allowed for the production of the highest fodder beet shoot yield while planting 84000 plant faba bean ha^{-1}. On the other hand, planting the highest faba bean plant density (125000 plant ha^{-1}) led to the production of the lowest significant fodder beet shoot yield under the three evaluated P rates. Nonetheless, under the highest and the lowest faba bean plant densities, applying 54 or 72 kg P ha^{-1}, was enough to achieve the highest significant fodder beet shoot yield, while under the middle faba bean plant density (84000 plant ha^{-1}), the application of 72 kg P ha^{-1} was mandatory to achieve the highest significant shoot yield.

Results of the root fresh yield were similar to the shoot fresh yield in the inferiority of the low and moderate P rates in producing the highest significant root fresh yield with the lowest faba bean plant density, while with increased faba bean plant density to 84000 plant ha^{-1}, more P should be applied (54 or 72 kg P ha^{-1}) in order to achieve the highest significant root fresh yield. Meanwhile, under the lowest plant density (42000 plant ha^{-1}), the highest significant fodder beet root fresh yield was achieved with the application of either 36 or 72 kg P ha^{-1}. On the other hand, under the moderate and high faba bean plant densities, the application of the highest P rate (72 kg P ha^{-1}) was essential to achieve the highest significant fodder beet root fresh yield.

Under the lowest faba bean plant density (42000 plant ha^{-1}), no significant influence for the evaluated P rate was detected, while, under the increased faba bean plant densities (84000 and 125000 plant ha^{-1}), applying the highest P rate was important to achieve the highest fodder beet root weight per plant. For the three evaluated P rates, the highest root weight per plant was achieved when faba bean was planted at 84000 plant ha^{-1}.

Performance of faba bean crop:

Analysis of variance presented in (Table 5) revealed that all studied faba bean (companion crop) characteristics significantly varied among the three phosphorus rates and three plant densities in both seasons. On the other hand, interaction between phosphors rates (P) and plant density (D) showed significantly affected the seed yield (ton ha^{-1}) and harvest index in both growing seasons.

Results in (Table 6) shows the effect of phosphorus rate and faba bean plant density on vegetative characters; yield and yield components of faba bean, in 2017 and 2018 cultivation seasons.

Noticeable, means of plant height as affected by the phosphors rate and plant density (Table 6), where the P_3 gave the tallest significant plants, reaching 79.82 and 81.71cm in 2017 and 2018 seasons, respectively. Reducing the plant density from D_3 to D_1 was accompanied with a consequent reduction in plant height in both seasons. Generally, the difference between the tallest (D_3) and shortest plants (D_1) reached 17.74 and 18.85 cm, for the two respective growing seasons 2017 and 2018.

Number of branches plants^{-1} varied as been affected by treatments. In 2017 season, P_3 recorded the largest number (2.18), while P_2 recorded a relatively moderate number of 1.90, and P_1 recorded the lowest one of 1.64. On the other hand, D_1 recorded the highest number (2.02), while D_2, and D_3 recorded almost the same value of 1.76 and 1.71, respectively. In the second season 2018, P rate displayed a significant difference between values, where P_1 valued 1.65, P_2 valued 1.83, and P_3 valued the highest of 2.10. D_1 and D_3 valued 1.87 and 1.91, without showing a significant difference, however, D_2 valued 1.79 as the lowest one among values (Table 6).

Data in (Table 6) refers to the change in number of pods/main stem of faba bean among treatments. Number of pods/main stem was significantly affected by changing P rates, ranged from 8.41 for P_1, up to 11.09 for P_3, with an average of 9.71, during 2017 cultivating season. It was also affected by altering plant densities (D), where D_1 recorded the highest number (10.31), while D_2, and D_3 recorded 9.72, and 9.37, respectively. During 2018 cultivating season, nearly, the same trend was noticed, as P_3 recorded the highest value of 10.40, while P_1 recorded the lowest value of 7.20, however, P_2 recorded a relatively moderate value of 8.37, with an overall average of 8.65. Alike, D_1 figured 9.08, while D_2 figured 8.68, and D_3 figured 8.41.

The 100-seed weight of (g) of faba bean is shown in (Table 6), and was noticed to be significantly affected, as a result of P and D treatments. P_3 could score significantly heaviest 100-seed weight over P_1 and P_2, with an increased percentage of 16.76 %, and 13.12 % respectively, in 2017 season. In the same season, D_1 and D_2, scored almost the same value of 63.68 g, and 63.12 g, while D_3 scored a lower value of 59.03 g. Similarly, in 2018 season, P_3 scored the highest significant weight among P treatments with an increasing rate of 44.44 %, and 24.25%, for each of P_1, and P_2, whereas lower plant density ranked the highest among D treatments, with an increased rate of 4.6 % and 7.96 %, for D_2 and D_3, respectively (Table 6).

Table 4. Fodder beet variations in shoot fresh yield^{-1}, root fresh yield $^{-1}$ and root weight plant^{-1} as affected by the interaction between the phosphorus rate and plant density for both growing seasons.

Phosphorus rate (Kg P ha $^{-1}$)	**Shoot fresh yield (t ha $^{-1}$) (2017/2018)**		
	D_1 (42000 plant ha^{-1})	**D_2 (84000 plant ha^{-1})**	**D_3 (125 000 plant ha^{-1})**
36 (P1)	13.82 bA	11.45 cC	12.53 bB
54 (P2)	14.65 aA	13.62 bB	13.07 abB
72 (P3)	14.76 aB	16.33 aA	13.70 aC
LSD 0.05		**0.80**	
	Shoot fresh yield (t ha $^{-1}$) (2018/2019)		
36 (P1)	13.20 bA	11.40 cC	12.45 bB
54 (P2)	14.56 aA	13.81 bB	13.18 aB
72 (P3)	14.83 aB	16.46 aA	13.82 aC
LSD 0.05		**0.72**	
	Root fresh yield (t ha $^{-1}$) (2017/2018)		
36 (P1)	111.90 aA	94.41 cB	91.44 cC
54 (P2)	103.82 bA	102.93 bA	97.33 bB
72 (P3)	110.82 aB	114.93 aA	111.33 aB
LSD 0.05		**1.09**	
	Root fresh yield (t ha $^{-1}$) (2018/2019)		
36 (P1)	112.80 aA	99.50 cB	88.27 cC
54 (P2)	102.51 bA	103.82 bA	99.10 bB
72 (P3)	111.93 aB	113.81 aA	101.20 aC
LSD 0.05		**1.33**	
	Root weight plant $^{-1}$ (2017/2018)		
36 (P1)	1.40 aA	1.25 cB	0.89 bC
54 (P2)	1.36 aA	1.37 bA	0.99 bB
72 (P3)	1.44 aAB	1.56 aA	1.39 aB
LSD 0.05		**0.13**	
	Root weight plant $^{-1}$ (2018/2019)		
36 (P1)	1.40 aA	1.31 bA	0.88 cB
54 (P2)	1.43 aA	1.45 bA	1.09 bB
72 (P3)	1.51 aAB	1.60 aA	1.44 aB
LSD 0.05		**0.14**	

* Means followed by different small letter(s) within the same column, and different capital letters within the same row, for each studied parameter, are significantly different according to the L.S.D. test at 0.05 level of probability.

Table 5. Levels of significance of plant height, no. branches plant $^{-1}$, no. pods/main stem, 100-seed weight, seed yield and harvest index in growing seasons 2017 and 2018.

S.O.V.	d.f	Plant height (cm)		No. branches plant $^{-1}$		No. pods/main stem		100-seed weight (g)		Seed yield (t ha^{-1})		HI (%)	
		Growing season											
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Phosphorus rate (P)	2	0.03*	0.001**	0.002**	0.001**	0.001**	0.004**	0.001**	0.002**	0.003**	0.002**	0.001**	0.003**
Plant density (D)	2	0.002**	0.004**	0.03*	0.002**	0.004**	0.001**	0.001**	0.001**	0.002**	0.001**	0.002**	0.001**
P*D	4	0.42^{NS}	0.87^{NS}	0.16^{NS}	0.10^{NS}	0.15^{NS}	0.32^{NS}	0.24^{NS}	0.30^{NS}	0.005**	0.004**	0.002**	0.002**

*Significant at 0.05 level of probability - **Significant at 0.01 level of probability - NS: non-significant. S.O.V.: Source of variation - d.f.: Degrees of Freedom.

The highest significant HI during both seasons, was reported for the application of the highest P rate (72 kg P ha-1) for all plant densities. Noticeably, the cultivation of the highest plant density (125000 plant ha-1) resulted in the production of the highest significant HI under the three tested P rates, accompanied with 84000 plant ha-1 for the application of 54 kg P ha-1, during both seasons, and with the application of 72 kg P ha-1, during 2018.

Table 6. Effect of cropping patterns and phosphorus levels on vegetative characters, yield and yield components of faba bean in 2018 and 2019 seasons.

Treatments	Plant height (cm)		No. branches plant $^{-1}$		No. pods/main stem		100-seed weight (g)	
	Growing season							
	2017	2018	2017	2018	2017	2018	2017	2018
Phosphorus rate (kg ha $^{-1}$)								
36 (P1)	73.90 b*	69.60 b	1.64 c	1.65 c	8.41 c	7.20 c	57.81 c	56.09 c
54 (P2)	81.43 a	79.26 b	1.90 b	1.83 b	9.64 b	8.37 b	59.67 b	61.66 b
72 (P3)	79.82 a	81.71 a	2.18 a	2.10 a	11.09 a	10.40 a	67.50 a	68.33 a
LSD 0.05	**3.28**	**4.41**	**0.18**	**0.06**	**0.18**	**0.11**	**1.17**	**0.65**
Plant density (plants ha^{-1})								
42000 (D_1) = 25%	66.43 c	66.28 c	2.02 a	1.87 a	10.31 a	9.08 a	63.68 a	64.61 a
84000 (D_2) = 50 %	79.29 b	78.51 b	1.76 b	1.79 b	9.72 b	8.68 b	63.12 b	63.53 b
125000 (D_3) = 75 %	84.17 a	85.13 a	1.71 b	1.91 a	9.37 c	8.41 c	59.03 c	58.01 c
LSD 0.05	**2.27**	**3.38**	**0.07**	**0.05**	**0.16**	**0.14**	**0.68**	**0.40**

* Means followed by different small letter(s) within the same column, for each studied parameter, are significantly different according to the L.S.D. test at 0.05 level of probability

Table 7. Faba bean variations in seed yield t ha^{-1} and harvest index (%) as affected by the interaction between the phosphorus rate and plant density for both growing seasons.

Phosphorus rate (Kg P ha $^{-1}$)	D_1 (42000 plant ha^{-1})	D_2 (84000 plant ha^{-1})	D_3 (125000 plant ha^{-1})
		Seed yield t ha $^{-1}$ (2017/2018)	
36 (P1)	1.70 aA*	1.72 bA	2.11 cA
54 (P2)	1.81 aB	2.32 aAB	2.98 bA
72 (P3)	2.26 aB	2.63 aB	4.19 aA
LSD 0.05		**0.68**	
		Seed yield t ha $^{-1}$ (2018/2019)	
36 (P1)	2.20 bA	2.51 aA	2.60 cA
54 (P2)	2.25 abB	2.70 abB	3.54 bA
72 (P3)	2.80 aB	3.07 aB	4.51 aA
LSD 0.05		**0.56**	
		HI % (2017/2018)	
36 (P1)	26.90 cB	27.30 cB	29.14 cA
54 (P2)	30.60 bB	31.99 bAB	32.10 bA
72 (P3)	33.14 aB	34.91 aA	35.43 aA
LSD 0.05		**0.74**	
		HI % (2018/2019)	
36 (P1)	28.75 cC	29.85 cB	30.98 cA
54 (P2)	33.05 bB	33.75 bA	34.15 bA
72 (P3)	35.05 aC	36.75 aB	37.88 aA
LSD 0.05		**0.52**	

* Means followed by different small letter(s) within the same column, and different capital letters within the same row, for each studied parameter, are significantly different according to the L.S.D. test at 0.05 level of probability.

Land use efficiency and yield advantage

Land use efficiency and yield advantage are shown in (Figure 2), as indicated by LER and DMER. Both harvesting incises are calculated for the two cultivation seasons, 2017/2018 and 2018/2019, respectively. As been affected by different P and D rates, it is obviously noticed that LER vales are dominantly figuring more than one (LER > 1), while DMER are recording a variation of figures between 0.92 and 1.06 (DMER values are mostly < 1).

Faba bean was included into the current additive intercropping model to offer some 'bonus' seed yield, but only to the degree that it did not substantially compromise fodder beet productivity. The results of the yield gain and land use efficiency analysis revealed that all of the LER values for the four treatments were more than 1, indicating that intercropping fodder beet and faba bean was preferable than solitary cropping both crops. When fodder beet and faba bean intercrops received the greatest P rate and were exposed to different planting densities, the largest LER value (1.88) was attained. The lowest LER, on the other hand, was 1.27, which was attained with the lowest P rate.

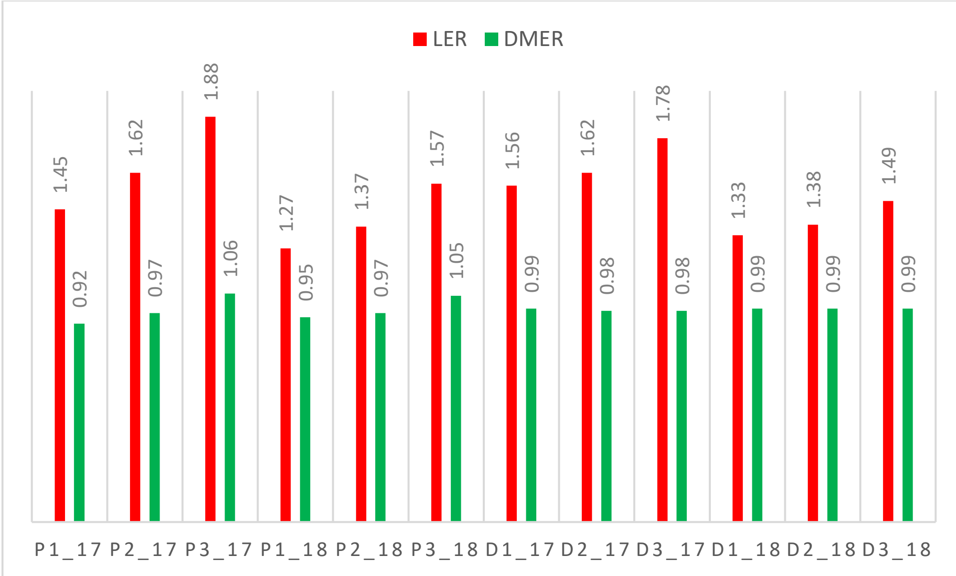

Figure 2. LER and DMER values as affected by Phosphorus rates (P_1, P_2, and P_3), and plant densities (D_1, D_2, and D_3) during the two winter seasons 2017/2018 and 2018/2019.

DISCUSSION

This study aimed to utilize intercropping over a two-year experiment, conducted at Fuka Research Station, Faculty of Desert and Environmental Agriculture, Matrouh University, Egypt. Assessment of "faba bean/ fodder beet intercropping" at three different densities of faba bean was targeted to find if this could maximize intercropping yield at varied P concentrations.

Findings in this research revealed that faba bean plant densities and applied P rates could significantly affect faba bean yield and its components. It was obviously noticed that by increasing P levels, yield and its components also increased. Sensibly, parameters like number of pods/main stem, 100-seed weight (g), and seed yield (t ha^{-1}) showed increasing values among the three P levels, as P increased. P_3; 72 kg P ha $^{-1}$, ranked the highest records during 2017, and 2018 growing seasons. This could be interpreted as referred to the growth enhance-ability of P, being an essential nutrient (Schnug and De Kok 2016), whereas the same trend could be recorded in previous investigations (Hajiboland et al. 2018; Hinsinger et al. 2011; Ibrahim 2018; Li 2020; Mndzebele et al. 2020). The importance of P fertilization has been known to affect growth enhancement and production of legumes (Tian et al. 2020), particularly when using plant growth promoting microorganisms (PGPM), for creating symbiotic plant-microbe interactions (Mouradi et al. 2018; Rose et al. 2010; Nebiyu et al. 2016). P is demonstrated to master, not only energy transfer activities, but also serious metabolic reactions, starting from respiration, nucleic acid synthesis, stress signaling, enzymatic activities, and ending with photosynthesis itself (Mitran et al. 2018; Schnug and De Kok 2016; Li 2020).

Intercropping may similarly increase P absorption (Mobasser et al. 2014). P is a limiting element for several soil types, while the roots of some crops, such as beans, exude organic acids and phosphatases into the soil biota, thus increasing P availability (Li et al. 2013). As a result, intercrops cultivated with these crops would be able to obtain more P, leading to improved crop quality and production (Maitra et al. 2021). Hence, in our case, our results indicated that some studied characters of fodder beet could also be responsive to the effect of cropping patterns and phosphorus levels in 2017 and 2018 seasons. Fodder beet shoot fresh yield increased up to 16.33 and 16.46 t ha^{-1} with P_3 and D_2, in 2017 and 2018 seasons, respectively. The same pattern was also noticed with other agronomic parameters like, root fresh weight which recorded 114.3 and 113.8 t ha^{-1}, over the two respective seasons, and was found to be increased with P3 treatment, and a moderate faba bean density (50 %). Root weight was also found to be increased with the same treatments, which gives a clue about the importance of P fertilization in boosting growth of crops like fodder beet. When elevated P rates caused elevated root and shoot weights, the lowest faba bean intensification, resulted in obtaining the highest fodder beet production. By reason, as planting density of faba bean increases, yield production of fodder beet decreases. This inversely proportional relationship would be associated to the competition between intercropped species, and hence prompt the importance of adjusting the most suitable practiced cropping pattern for better production.

Increasing faba bean plant density, in the current study, led to increasing the competition between the two intercrops. By decreasing crop intensification, competition is decreased, and vice versa. Consequently, some yield parameters were found to be high, while others were also found to be low, as being affected by planting density. For example, the stated plant height values were higher when sowing faba bean at 125000 plants ha^{-1}. Greater densities would lead to produce taller plants for gaining more light (Faramarzi et al. 2011). Plants desire for more sun radiation, and one frequent way to do so, is stem elongation (Shaalan 2021). Under these circumstances,100-seed weight (g) was found to record its highest values (67.50 and 68.33 g) with the highest P treatments in 2017 and 2018 seasons, respectively.

On the other hand, decreased planting density, resulted in raising up the number of pods/main stem, as well as the weight of 100 seeds, since the number of branches/plants was increased 25%, representing the lowest applied planting density, showed also increased values (63.68 and 64.1 g) for 100-seed weight in the same respective seasons as well. Competition between plants is known to be affected by increasing planting density, and so, 100-seed weight would be decreased at this point, while seed yield was demonstrated to be increased, due to increasing number of plants per unit area (no. of plants ha^{-1}). Moreover, seed yield gave the highest values (4.19, and 4.51 t ha^{-1}), over 2017 and 2018, seasons, respectively, when applying a combination between the highest P rate (72 kg P ha^{-1}) with the highest planting density (75%).

The effect of planting densities and fertilization by essential elements like, P and nitrogen (N), on spectra of crops for additive intercropping, in order to increase yield and land use efficiency, has been always representing a major concern for crop developers. Legumes in general, and faba bean in specific, have been playing the main role in this harmony. Results in the current investigation are in agreement with previous results, obtained on different examples like: maize and forage millet (Shaalan 2016); wheat, barley, and faba bean with sugar beet (Salama 2016); sugar beet–clover (El-

Nakhlawy and Ismail 2018); sunflower and soybean (Nawar 2020); faba bean with sugar beet (El-Ghobashi and Eata 2020; El-Mehy et al. 2020; Ibrahim 2018); onion with faba bean (Farghly et al. 2021); tomato and potato with onion (Gao et al. 2021); and wheat on faba bean (Xiao et al. 2021).

Faba been plant height tended to increase consistently when the applied P fertilizer rate increased in the current study. This was most likely owing to P's beneficial effects on vegetative growth, root development, and greater nutrient absorption (Ali et al. 2014; Awais et al. 2015). The tallest plants were recorded with the highest P fertilizer rate and plant density. Salama et al. (2022) concluded that adjusting proper interspaces to fertilization rates, would guarantee better crop performance and productivity, under intercropping systems.

Land equivalent ratio (LER), together with dry matter equivalent ratio (DMER), were proposed to evaluate the impact of intercropping pattern used in this research.

LER is among the most considerable featured intercropped yielding property (De Wit et al. 1960; De Wit and Van den Bergh 1965). Conversely, recent LER estimates, indicated that it has been known to appraise over-estimated values (Nawar 2020). While LER is the master pointer for intercropping efficacy in the replacement intercropping series, it is not in the additive intercropping one (Willey 1979). The sum of the dry yields of the main crop (fodder beet), in addition to the intercropped crop (faba bean), relative to the dry matter yield of the pure main crop, is valued as DMER. DMER was earlier demonstrated and proved to be a more realistic index for intercrops (Shaalan et al. 2015). Some similar results pointed out the same LER outputs (Liu et al. 2018; Hata et al. 2019; Yildirim et al. 2020; Rustiana 2021).When LER and DMER resulted values are compared, the DMER values were found to be invariably lower than the LER ones. This endorses the hypothesis that LER was not considered to be the most precise index for calculating the anticipated gain in an additive intercropping model, forming a "LER over-estimation", where all LER values are > 1. However, as compared to producing solitary crops, DMER produced a more reliable estimation for the effect of intercropping (Salama 2016), chiefly for crops where dry matter dominates an economic component (Nawar et al. 2018) like the current case, concerning fodder beet.

CONCLUSION

This research represents an addition for studying fodder beet intercropping under arid conditions as a promising green fodder crop, where literature occasionally focuses mainly on sugar beet studies. Results revealed that increasing production could be achieved when raising P levels up to 72 kg ha^{-1} and adjusting suitable planting densities to accommodate intermediate plant density (84000 plant ha^{-1}) of faba bean with 100 % fodder beet. If low P application were mandatory, according to soil condition, it is recommended to intercrop 25 % of faba bean plants with 100 % fodder beet. Consequently, the research pointed out the importance of intercropping, and its advantages to new reclaimed soils for better usage, as well as providing a confirmatory guide, and reference for citing the difference between LER and DMER harvest indices. The study also evidenced that DMER was more reliable than LER. When should a breeder select to use any of the two indices, would be an expected raised question, that needs a suitable answer choice to help evaluating, and improving the crop yielding efficiency.

AUTHOR CONTRIBUTIONS

Authors contributed evenly in this research. A. M. Shaalan contributed to the methodology, design, and implementation of the research resources, conducted the field experiments, sampling, and measurements, data statistical analysis, writing and preparing the first draft of manuscript; G. A. G. Ammar contributed to the validation analysis of the results, writing— original draft, preparation, writing—review and editing of the manuscript.

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تحسين إنتاجية تحميل بنجر العلف والفول البلدى تحت مستويات من الفوسفور والكثافة النباتية فى الظروف الجافة

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الملخص العربي

أجريت دراسة لمدة عامين لاختبار تأثير تحميل الفول البلدى مع بنجر العلف على إنتاجية كل من المحصولين وكفاءة استخدام الأرض تحت كثافات مختلفة من الفول البلدى (D) 42000 (D1) 84000 (D2) 125000 (D3) نبات/هكتار ، بينما تم اختبار ثلاثة معدلات للتسميد الفسفوري (P) ؛ 36 P1 ، 54 P2 و 72 P3 كجم /هكتار -1. أجريت التجربة الحقلية خلال موسم النمو 2018/2017 و 2019/2018. تمت دراسة بعض الصفات الفسيولوجية والمحصولية في بنجر العلف والفول البلدى ، هذا بالإضافة إلى نسبة مكافئ الأرض (LER) ونسبة المادة الجافة المكافئة (DMER) كمؤشرات للحصاد. أشارت النتائج إلى أن 72 كجم/هكتار من التسميد الفوسفورى يمكن أن يزيد بشكل كبير من إنتاج بنجر العلف والفول البلدى. كما أن أختيار كثافة الزراعة المناسبة يعمل على تحسين أنتاجية المحصولين بشكل أفضل. أعطت كثافة نبات الفول (84000 نبات/هكتار) التأثير على نمو بنجر العلف ، بينما كانت الكثافة بمعدل 125000 نبات/هكتار تأثير أفضل على نبات الفول البلدى. تم تسجيل جميع قيم نسبة مكافئ الأرض الى أقل من 1، بينما تراوحت قيم نسبة المادة الجافة المكافئة DMER بين 0.92 الى 1.06. أثبتت الدراسة أن DMER كانت أكثر موضوعية من LER لتقييم زراعة المحاصيل بالتحميل ، حيث تعتبر المادة الجافة هى المكون الأقتصادى لبنجر العلف.

الكلمات المفتاحية :

بنجر العلف – الفول البلدى – نسبة مكافئ الأرض – التحميل – التسميد الفوسفورى - نسبة المادة الجافة المكافئة .