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Cropping Systems of Fenugreek with Faba Bean to Reduce Broomrape Infestation

Sherif Ibrahim Abdel-Wahab[1], Eman Ibrahim Abdel-Wahab[2]

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ABSTRACT

Background: Broomrape (*Orobanche crenata* Forsk.) is a major threat to faba bean and an important danger parasite. An intercropping is a necessity to curb the spread and progress of the parasite before it leads to much more economic losses. The current study was aimed to evaluate intercropping of fenugreek with faba bean under two plant densities of both crops on broomrape incidence to increase faba bean yield, land usage and economic return in heavy soil infestation of broomrape.

Methods: This study was carried out at Giza Agricultural Research Station (Lat. 30°00′ 30″ N, Long. 31°12′ 43″ E, 26 m a.s.l), Agricultural Research Center, Giza, Egypt. During the winter season of 2017/2018 and 2018/2019 seasons, sixteen treatments were the combinations between two ridge widths (60 “narrow” and 120 cm “wide”) and six cropping systems (50% faba bean + 50% fenugreek, 100% faba bean + 50% fenugreek, 50% faba bean + 100% fenugreek, 100% faba bean + 100% fenugreek, 50% sole faba bean and 100% sole faba bean), as well as sole plantings of fenugreek under heavy soil infestation of broomrape. A split-plot design with three replicates was used. Ridge widths were assigned in the main plots and cropping systems were arranged in sub plots.

Result: Growing faba bean plants in wide ridges had physical barriers with stamping of the vascular system against the parasite. 50% faba bean + 100% fenugreek had higher soil total phenols in faba bean rhizosphere than the others. Growing 50% faba bean + 100% fenugreek in wide ridges had lower number of spikes per m^2 and spikes dry weight per m^2, meanwhile, growing 100% faba bean + 100% fenugreek in wide ridges had higher seed yields of both crops per ha, land usage and economic return. Growing two rows of faba bean (100% of sole cropping) in both sides of wide ridge (120 cm width) with four rows of fenugreek (100% of sole cropping) in middle of the ridge could be an integrated control strategy to increase faba bean productivity, land usage and economic return under heavily soil infested of broomrape.

Key words: Broomrape infestation, Economic return, Faba bean, Fenugreek, Intercropping, Land usage, Ridge width, Soil total phenols.

INTRODUCTION

In Egypt, delaying of faba bean (*Vicia faba* L.) sowing beyond late October or early November to escape from infestation with broomrape (*Orobanche crenata* Forsk.) has negative effects on vegetative growth of this crop which reduced its seed yield attributes (Attia *et al.* 2014). Although Bayoumi *et al*. (2014) mentioned that there were different methods for controlling broomrape, there is no consistent and sustainable method for control of the broomrape in Egypt. The seeds of these parasitic weeds may remain dormant in the soil for many years until germination is stimulated by root exudates from a host plant and the climatic conditions become favorable (Abbes *et al.* 2019). According to Masteling *et al*. (2019), faba bean roots release signaling molecules *(i.e.* strigolactones) that induce the germination of root parasitic weed seeds in the oot-soil interface. After germination, the parasite forms radicles and haustoria, the formation of which is induced by molecules known as haustorium-inducing factors. The haustorium connects to host roots for penetrate it reaching the vascular tissues. The haustorium establishes a vascular connection with the xylem and/or xylem and phloem in order to absorb water and photosynthates from the host plant. Once a functional vascular connection is established, broomrape undergoes vegetative growth, followed by emergence from the soil; in some cases, secondary haustoria are formed allowing for additional connections with the host. After weeks of vegetative growth, broomrape flowering, to form seeds. Consequently, glyphosate spraying does not seem to be effective under heavy soil infestation (Zeid and Hemeid, 2019), particularly Zhang *et al*. (2019) mentioned that it is better to stop the use of glyphosate in order to increase health problems for humans.

On the other hand, the importance of intercropping trap or companion crops with legumes is due to reducing the parasite seed bank, as seeds of the parasite will remain dormant until exudates of the suitable host become

[1]Department of Crop Intensification Research, Field Crops Research Institute, Agricultural Research Center, Egypt.
[2]Department of Food Legumes Research, Field Crops Research Institute, Agricultural Research Center, Egypt.

Corresponding Author: Sherif Ibrahim Abdel-Wahab, Department of Crop Intensification Research, Field Crops Research Institute, Agricultural Research Center, Egypt.
Email: twins00twins60@yahoo.com

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available. A false host "trap crop" stimulates germination without itself being parasitized (Parker, 1991). Fenugreek (*Trigonella foenumgraecum* L.) roots have been suggested to inhibit the *Orobanche crenata* germination, resulting in reduced infection of legumes under intercropping culture (Bakheit *et al.* 2002). Historically, fenugreek is one of the oldest known medicinal plants, used in Greece, Egyptian, Chinese and Arab medicine (Petropoulos, 2002). It is generally inexpensive foods rich in important nutrients such as polyphenols, iron, calcium and other minerals (Radek and Savage, 2008). Particularly, Ghalwash *et al.* (2012) revealed that fenugreek + faba bean gave lower number and dry weight of broomrape spikes/m^2 than sole faba bean. Phenolic compounds are some of the most widespread molecules among plant secondary metabolites that play an important role in ecological processes in many plant communities through their effects on soil ecology (Djurdjević *et al.* 2010). They are leached out from green foliage, decomposing litter, as well as by root exudates and thus reach the soil underneath the canopy. For this reason, one of the quickest strategies for controlling the broomrape in faba bean fields is intercropping fenugreek with faba bean. Accordingly, such mechanism will act after root penetration through negative effects of phenolic compounds on the production of germination stimulants as inhibitors, the formation of physical barriers against the parasite, the release of compounds inducing tubercle necrosis, the occlusion of vascular connections between host root and parasite and a low supply of carbon to the parasite through competition with the faba bean plant carbon sinks (Yoder and Scholes, 2010). Particularly, Turco *et al*. (2016) found that faba bean seeds contain several other bioactive compounds, such as polyphenols. However, the effect of faba bean plant density on growth, yield and its attributes was studied by Bakry *et al*. (2011), Khalil *et al*. (2011) and Abd El-Rahman (2014). Growing faba bean in two sides per row produced higher seed yield per unit area than one side per row (Abou-El-Seba *et al.* 2016). Meanwhile, Safina (2017) showed that difference in appropriate plant arrangement per unit area with the same plant density of faba bean could be influenced by ridge width. These modes of action could enhance nutrient acquisition by faba bean, in particular phosphorous and nitrogen, modulation of host root physiology, that is, alteration of exudation or root architecture and induced systemic resistance. In this concern, Mohamed *et al.* (2018) revealed that wide ridge had higher N, P, total sugars and total free amino acids concentrations in faba bean shoot and seeds in addition to chlorophyll a (Chl a) and chlorophyll b (Chl b) in faba bean shoot, as well as most seed yield attributes than those of the narrow one. So, the susceptibility of faba bean plants to broomrape infection could depend on soil total phenol concentrations with regard to faba bean plant density per unit area. Therefore, the present study was conducted to evaluate intercropping of fenugreek with faba bean under two plant densities of both crops on broomrape incidence to increse faba bean yield, land usage and economic return in heavy soil infestation of broomrape.

MATERIALS AND METHODS

This study was carried out at Giza Agricultural Research Station (Lat. 30°00′ 30″ N, Long. 31°12′ 43″ E, 26 m a.s.l), Agricultural Research Center, Giza, Egypt during winter seasons 2017/2018 and 2018/2019 seasons to evaluate intercropping of fenugreek with faba bean under two plant densities of both crops on broomrape incidence to increse faba bean yield, land usage and economic return in heavy soil infestation of broomrape. Sixteen treatments were the combinations between two ridge widths (60 "narrow" and 120 cm "wide") and six cropping systems (50% faba bean + 50% fenugreek, 100% faba bean + 50% fenugreek, 50% faba bean + 100% fenugreek, 100% faba bean + 100% fenugreek, 50% sole faba bean and 100% sole faba bean), as well as sole plantings of fenugreek. Seeds of faba bean cultivar Nubaria 1 and fenugreek cultivar Giza 2 were planted on 5th November and 24th October in 2017 and 2018 seasons, respectively. Faba bean plants were harvested on 28th April and 12th April in 2018 and 2019 seasons, respectively. Meanwhile, fenugreek seed yield was harvested on 15th March and 9th March in 2018 and 2019 seasons, respectively. The treatments were as follows:

Narrow ridges

- **The cropping system 50% faba bean + 50% fenugreek**

Drilling one row of fenugreek seeds (8.5 g) in ridges 60 cm width, meanwhile growing one row of faba bean (two plants/ hill spaced at 25 cm) in the other side of the ridge (four seeds/hill) and was later thinned to 8 plants per one meter.

- **The cropping system 50% faba bean +100% fenugreek**

Drilling two rows of fenugreek seeds (17 g) in both sides of ridges 60 cm width, meanwhile, growing one row of faba bean (two plants/hill spaced at 25 cm) in the middle of ridge (four seeds/hill) and was later thinned to 8 plants per one meter.

- **The cropping system 100% faba bean + 50% fenugreek**

Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 60 cm width (four seeds/hill) and were later thinned to 16 plants per one meter, meanwhile, drilling one row of fenugreek seeds (8.5 g) in the middle of ridge.

- **The cropping system 100% faba bean +100% fenugreek**

Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 60 cm width (four seeds/hill) and were later thinned to 16 plants per one meter, meanwhile, drilling two rows of fenugreek seeds (17 g) in the middle of ridge.

- **The cropping system 50% faba bean**

Growing one row of faba bean (two plants/hill spaced at 25 cm) in ridges 60 cm width (four seeds/hill) and was later thinned to 8 plants per one meter.

- **The cropping system 100% faba bean**

Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 60 cm width (four seeds/hill) and were later thinned to 16 plants per one meter.

➢ **The cropping system 50% fenugreek**
Drilling one row of fenugreek seeds (8.5 g) in ridges 60 cm width.
➢ **The cropping system 100% fenugreek**
Drilling two rows of fenugreek seeds (17 g) in both sides of ridges 60 cm width.

Wide ridges

➢ **The cropping system 50% faba bean + 50% fenugreek**
Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 120 cm width (four seeds/hill) and was later thinned to 16 plants per one meter, meanwhile drilling two rows of fenugreek seeds (17 g) in the middle of ridges 120 cm width.
➢ **The cropping system 50% faba bean + 100% fenugreek**
Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 120 cm width (four seeds/hill) and was later thinned to 16 plants per one meter, meanwhile drilling four rows of fenugreek seeds (34 g) in the middle of ridges 120 cm width.
➢ **The cropping system 100% faba bean + 50% fenugreek**
Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 120 cm width (four seeds/hill) that formed 32 plants per one meter, meanwhile drilling two rows of fenugreek seeds (17 g) in the middle of ridges 120 cm width.
➢ **The cropping system 100% faba bean + 100% fenugreek**
Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 120 cm width (four seeds/hill) that formed 32 plants per one meter, meanwhile drilling four rows of fenugreek seeds (34 g) in the middle of ridges 120 cm width.
➢ **The cropping system 50% faba bean**
Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 120 cm width (four seeds/hill) and was later thinned to 16 plants per one meter.
➢ **The cropping system 100% faba bean**
Growing two rows of faba bean (two plants/hill spaced at 25 cm) in both sides of ridges 120 cm width (four seeds/hill) that formed 32 plants per one meter.
➢ **The cropping system 50% fenugreek**
Drilling two rows of fenugreek seeds (17 g) in the middle of ridges 120 cm width.
➢ **The cropping system 100% fenugreek**
Drilling four rows of fenugreek seeds (34 g) in the middle of ridges 120 cm width. The preceding summer crop was maize in both seasons. Furrow irrigation was the irrigation system in the region. All cultural practices such as fertilization and irrigation were performed whenever necessary. Calcium super phosphate (15.5% P_2O_5) at rate of 476 kg/ha and potassium sulfate (K_2SO_4 "48.0 % K_2O") at rate of 238 kg/ha were applied during soil preparation. Mineral N fertilizer was applied for faba bean or fenugreek in form of ammonium nitrate (NH_4NO_3 "33.5% N") at rate of 53.5 kg/ha (50% of sole planting) and 107.1 kg/ha (100% of sole plantings) for different cropping systems, in three equal doses before the first, second and third irrigation. A split-plot design with three replicates was used. Ridge widths were assigned in the main plots and cropping systems were arranged in sub plots. The area of the sub-plot was 10.8 m^2, each plot of ridges consisted of 6 ridges and each ridge was 3.0 m in length and 0.6 m in width, meanwhile each plot consisted of 3 beds (each bed was 3.0 m in length and 1.2 m in width).

Parameters

➢ **Anatomical characters of faba bean root cells**
At 120 days from planting, the cross-section of faba bean root was photographed by light microscopy in Plant Dept., Faculty of Sciences, Cairo University, Giza, Egypt. .
➢ **Soil total phenols**
The determination of total phenols concentration (ppm) was determined in faba bean rhizosphere for each plot at 120 days from planting. These analyses were recorded by Environment, Water and Soil Research Institute, Agricultural Research Center, Giza, Egypt.
➢ **Leaf chlorophyll pigments**
The leaf chlorophylls a (mg/g FW) and b (mg/g FW) contents were analyzed by the General Organization for Agricultural Equalization Fund, ARC, Giza, Egypt according to Holden (1965) at 120 days from planting.
➢ **Broomrape infestation**
Number of emerged broomrape spikes per m^2: it was counted per m^2 at 120 days from planting and referred as number of emerged broomrape spikes per host plant in each treatment (Rubiales *et al.* 2006). Dry weight of broomrape spikes per m^2 at 120 days from planting. Penetration of broomrape into vascular system of faba bean roots was done by using SEM Model Quanta 250 FEG (Field Emission Gun) in the Egyptian Mineral Resources Authority Central Laboratories Sector. Meanwhile, surface preparations and transverse sections of the root of faba bean cultivars were used for observation of various microscopic features.
➢ **Faba bean seed yield and its attributes**
At 173 and 168 days from planting in the first and second seasons, respectively, harvested plants (%) were estimated by number of plants at harvest compared to their numbers at planting in each plot. Samples of five plants were collected randomly from each plot to estimate the following criteria: plant height (cm), number of branches/plant, number of pods/plant, seed yield/plant (g) and 100-seed weight (g). Percentage of the harvested plants was estimated by counting number of faba bean plants at harvest on the basis of the experimental plot and expressed as percentage of the harvested plants per ha (%). Seed yield/ha (t) was recorded on the basis of the experimental plot and expressed as ton per hectare (t/ha).
➢ **Fenugreek seed yield and its attributes**
At harvest (130 and 135 days from planting in the first and second seasons, respectively), samples of five plants were collected randomly from each plot to estimate the following criteria: plant height (cm), numbers of branches and pods/ plant, seed yield/plant (g) and 100-seed weight (g). Seed

yield/ha (kg) was recorded on the basis of the experimental plot and expressed as kilogram per hectare (kg/ha).

➢ **Competitive relationships and intercropping economic advantage**

Land equivalent ratio (LER)

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

$$LER = (Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb})$$

Where

Y_{aa} = Pure stand yield of crop a (faba bean), Y_{bb} = Pure stand yield of crop b (fenugreek), Y_{ab} = Intercrop yield of crop a (faba bean) and Y_{ba} = Intercrop yield of crop b (fenugreek).

To evaluate the economic viability, total return, as well as monetary advantage index (MAI) were calculated as follows: Total return per ha (USD) = Faba bean seed yield × price of faba bean seed + fenugreek seed yield × price of fenugreek seed. The prices were presented by Bulletin of Statistical Cost, Production and Net Returns (2019). One ton of faba bean seeds and fenugreek seeds were 720 and 840 USD, respectively. MAI, it suggests that the economic assessment should be in terms of the value of land saved; this could probably be most assessed on the basis of the rentable value of this land. MAI was calculated according to the formula, suggested by Willey (1979).

MAI = [Value of combined intercrops × (LER – 1)]/LER

MAI value indicates the profit of the cropping system.

Statistical analysis

The statistical analysis of variance according to Snedecor and Cochran (1980) and the least significant differences (LSD) at 5% level of significance tests were done according to Freed (1991).

RESULTS AND DISCUSSION

Anatomical characters of faba bean root cells

The root cells of faba bean that grown in narrow or wide ridges before infestation with broomrape contain a cell wall, cortex and vascular cylinder (Fig 1). Before broomrape infestation, the root cells of faba bean allow the passage of water, nutrients and metabolites to the different parts of the plant with no negative impact on the vascular cylinder (transport vessels; xylem and phloem). Meanwhile, broomrape connected to faba bean root by a haustorium that penetrated the epidermal and cortical cells reaching the vascular tissues of faba bean root cells under broomrape infestation. However, this biological situation led to a little negative effect on faba bean root cells as a result of increasing ridge width from 60 to 120 cm, which maintained water, nutrients and metabolites uptake from root cells to different parts of the plant. These results could be due to the wide ridge decreased intra-specific competition between faba bean plants for basic growth resources especially carbon that enhanced physical barriers formation and the cell walls buildup of faba bean root cells, which prevents a haustorium to develop into the root tissues. According to Hibberd *et al*. (2002), carbon lost by the parasite through respiration was greater than that of control roots, which explains why broomrape receives large amounts of carbon to grow and develop. In this concern, Joel (2007) revealed that plant haustoria penetrated the host tissues for uptake of organic carbon. It is known that the photochemical apparatus is influenced by high light intensity as mentioned by Critchley (1998) which could reflect on beds than ridges. Consequently, photochemical reactions are linked to the CO_2 fixation process by supplying ATP and NADPH and are also regulated by alternative electron sinks, such as photorespiration, Mehler reaction and nitrogen reduction (Cornic and Fresneau, 2002 and Noctor *et al*. 2002). In this concern, Roth *et al*. (2005) showed that beds can make plants more energy-consuming because of the increased volume of soil that must be moved in the beds, compared to ridges. Accordingly, there are two mechanisms to tolerate broomrape by increasing ridge width from 60 to 120 cm including the formation of physical barriers against the parasite (Labrousse *et al.* 2001) or cell walls build-up and stamping of vascular tissues (Pérez-De-Luque *et al.* 2005). These mechanisms could be lead to a low supply of carbon to the parasite through competition with the host plant carbon sinks (Yoder and Scholes, 2010).

Soil total phenols

➢ **Ridge widths**

The results in Table 1 show that ridge widths significantly affected soil total phenols concentration in faba bean rhizosphere. Increasing ridge width from 60 to 120 cm increased soil total phenols concentration by 7.32% in the faba bean rhizosphere. The wide ridge may be enhanced efficiency the photosynthetic process of the faba bean plants due to reduction of intra-specific competition between them for basic growth resources compared with those of the narrow one. Additionally, growing faba plants in wide ridges had physical barriers against the parasite and cell walls build-up which probably reflected on a lower supply of carbon to broomrape. Consequently, this biological situation will increase the ability of faba bean plants to consume low amounts of phenols, most of which will be accumulated in the root cells. Conversely, it is likely that intra-specific competition between faba bean plants was increased for basic growth resources than those of the wide one which negatively reflected on photosynthesis and transpiration rates (Mohamed *et al.* 2018).

Accordingly, an increase of assimilates in faba bean shoot accompanied with reduced RNase and protease activity, especially polyphenols will be bonded with other organic substances such as carbohydrate or protein (Saharan *et al.* 2002). Seven phenolic acids were detected in the rhizosphere that continuously cropped faba bean (Dong *et al.* 2016) where faba bean seeds contain several other bioactive compounds, such as polyphenols (Turco *et al.* 2016).

Table 1: Effect of ridge widths, cropping systems and their interactions on soil total phenols in 2018/2019 season.

Ridge width	Cropping system	Soil total phenols concentration (ppm)
Narrow ridges	50% faba bean + 50% fenugreek	202.20
	50% faba bean + 100% fenugreek	214.60
	100% faba bean + 50% fenugreek	182.10
	100% faba bean + 100% fenugreek	197.80
	50% sole faba bean	136.30
	100% sole faba bean	129.10
	Mean	177.03
Wide ridges	50% faba bean + 50% fenugreek	218.80
	50% faba bean + 100% fenugreek	232.60
	100% faba bean + 50% fenugreek	196.70
	100% faba bean + 100% fenugreek	209.40
	50% sole faba bean	143.60
	100% sole faba bean	138.90
	Mean	190.00
Average of cropping systems	50% faba bean + 50% fenugreek	210.55
	50% faba bean + 100% fenugreek	223.60
	100% faba bean + 50% fenugreek	189.40
	100% faba bean + 100% fenugreek	203.60
	50% sole faba bean	139.95
	100% sole faba bean	134.00
F. test 0.05 Ridge width		*
L.S.D. 0.05 Cropping systems		10.34
L.S.D. 0.05 Interaction		15.75

➢ **Cropping systems**

Soil total phenols concentration in faba bean rhizosphere was significantly affected by the cropping systems (Table 1). 50% faba bean + 100% fenugreek recorded higher soil total phenols concentration than the others, meanwhile, the converse was true for 100% sole faba bean (Table 1). No doubt, increasing fenugreek plant density from 50 to 100% of sole cropping increased total phenols concentration in faba bean rhizosphere. It is important to mention that higher plants produce many phytochemical constituents that not only play a pivotal role in plants producing them but also affect their neighboring plant communities (Madany and Khalil, 2017). Also, they reported that the allelochemical components of fenugreek seed extract were nine phenolic compounds.

Accordingly, fenugreek roots secreted large quantities of total phenols in faba bean rhizosphere due to low consumption of total phenols in their metabolic reactions, meanwhile, faba bean roots secreted large quantities of total phenols in their rhizosphere (Table 1). So, it may be possible that soil total phenols concentration was increased by increasing fenugreek plant density with decreasing faba bean plant density per unit area which explains increased soil total phenols concentration with 100% sole faba bean. These results are confirmed by Candido *et al.* (2016) who found that allelochemicals *(i.e.* phenolic and terpenoid constituents) released into the environment either by exudation from roots or leaching from the aerial parts and affect the structure of the plant community.

➢ **The interaction between ridge widths and cropping systems**

Soil total phenols concentration in faba bean rhizosphere was significantly affected by the interaction between ridge widths and cropping systems (Table 1). Growing 50% faba bean + 100% fenugreek in wide ridges had higher soil total phenols concentration than the others in faba bean rhizosphere, meanwhile, the reverse was true for growing 100% sole faba bean in the narrow ones.

Broomrape infestation and leaf chlorophylls a and b

➢ **Ridge widths**

The results in Table 2 show that ridge widths significantly affected number of spikes per m^2 and spikes dry weight per m^2 and leaf chlorophylls a and b in both seasons. Expressing tolerance by number of spikes per m^2 and dry weight of spikes per m^2 showed considerable variation between two ridge widths. Growing faba bean in wide ridges reduced number of spikes per m^2 and dry weight of spikes per m^2 by 15.90 and 25.84% in the first season and 19.14 and 28.11% in the second one, respectively, compared with those grown in the narrow ones. Meanwhile, increasing ridge width from 60 to 120 cm increased leaf chlorophylls a and b by 4.78 and 7.81% in the first season and 4.05 and 6.77% in the second one, respectively, under heavily soil infested with broomrape. These results show that the wide ridges played a major role in maintaining soil moisture which provided suitable conditions for early germination and growth of faba bean seedlings compared with those grown in the narrow

Table 2: Effect of ridge widths, cropping systems and their interactions on number of spikes/m^2 and spikes dry weight/m^2, as well as leaf chlorophylls a and b in both seasons.

Ridge width	Cropping system	Spikes/m^2 (no.)		Spikes dry weight/m^2 (g)		Chlorophyll a (mg/g FW)		Chlorophyll b (mg/g FW)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Narrow ridges	50% faba bean + 50% fenugreek	18.83	30.87	29.93	53.40	3.72	3.61	0.68	0.62
	50% faba bean + 100% fenugreek	6.56	14.58	12.39	29.59	3.80	3.73	0.83	0.75
	100% faba bean + 50% fenugreek	22.94	33.09	46.79	71.80	3.54	3.44	0.65	0.58
	100% faba bean + 100% fenugreek	16.58	28.75	28.51	54.62	3.62	3.50	0.73	0.70
	50% sole faba bean	81.49	97.19	189.05	241.03	3.34	3.25	0.52	0.49
	100% sole faba bean	101.88	115.25	261.83	310.02	3.28	3.17	0.47	0.41
	Mean	41.38	53.28	94.75	126.74	3.55	3.45	0.64	0.59
Wide ridges	50% faba bean + 50% fenugreek	15.77	23.76	23.97	38.72	3.87	3.81	0.73	0.66
	50% faba bean + 100% fenugreek	4.03	11.79	4.59	14.73	3.98	3.90	0.86	0.80
	100% faba bean + 50% fenugreek	20.48	26.24	35.84	50.11	3.70	3.57	0.68	0.66
	100% faba bean + 100% fenugreek	12.34	19.33	16.16	28.60	3.78	3.66	0.79	0.72
	50% sole faba bean	68.93	79.26	135.10	167.23	3.55	3.36	0.59	0.53
	100% sole faba bean	87.27	98.14	205.95	247.31	3.47	3.27	0.54	0.44
	Mean	34.80	43.08	70.26	91.11	3.72	3.59	0.69	0.63
Average of cropping system	50% faba bean + 50% fenugreek	17.30	27.31	26.95	46.06	3.79	3.71	0.70	0.64
	50% faba bean + 100% fenugreek	5.29	13.18	8.49	22.16	3.89	3.81	0.84	0.77
	100% faba bean + 50% fenugreek	21.71	29.66	41.31	60.95	3.62	3.50	0.66	0.62
	100% faba bean + 100% fenugreek	14.46	24.04	22.33	41.61	3.70	3.58	0.76	0.71
	50% sole faba bean	75.21	88.22	162.07	204.13	3.44	3.30	0.55	0.51
	100% sole faba bean	94.57	106.69	233.89	278.66	3.37	3.22	0.50	0.42
F test 0.05 Ridge width		N.S.	*	**	**	*	*	*	*
L.S.D. 0.05 Cropping system		4.43	4.77	5.30	4.34	0.11	0.09	0.03	0.02
L.S.D. 0.05 Interaction		6.27	6.75	7.50	6.14	N.S.	N.S.	0.08	0.09

ones, indicating escaping from severe infestation with broomrape. A flat-topped ridge, similar to a wide bed, conserved moisture better than a sharply sloped ridge and hastened emergence by four to five days (Prestt and Carr, 1984). Also, they showed that dry areas of sharply sloped ridges tended to form beneath the sides of the ridges and the steep sides encouraged runoff. This means that more irrigation water probably flowed into the depths of the soil by growing faba bean in the narrow ridge compared with those grown in the wide one, which induces broomrape seeds for germination. Moreover, growing faba bean plants in wide ridges had physical barriers with stamping of the vascular system in the root cells that probably reflected on a lower supply of carbon to broomrape (Fig 1). It is known that the seeds need to be exposed to a moist environment (called preconditioning) for several days at a suitable temperature (optimum 15 to 20°C) before seeds respond to germination stimulants (Kebreab and Murdoch, 1999). These results are in parallel with Safina (2017) who showed that there was more shading around the plants of the narrowest ridge (moist environment) than those of the widest ridge. Also, Zohry and Ouda (2017) reported that germination and growth of faba bean seedlings of the widest ridge were faster than those grown of the narrowest one. In the same trend, increasing wide ridge width from 60 to 120 cm increased total phenols concentration in the rhizosphere of faba bean roots (Table 1) which reduced broomrape growth and maintained leaf chlorophylls pigment from deterioration. These results are in parallel with Mohamed *et al*. (2018) who showed that faba bean plants of the wide ridge had higher shoot chlorophylls a and b concentrations than those of the narrow one.

➢ **Cropping systems**

The results in Table 2 show that cropping systems significantly affected number of spikes per m^2 and spikes dry weight per m^2 and leaf chlorophylls a and b in both seasons. All intercropping treatments of fenugreek with faba bean had a lower number of spikes per m^2 and spikes dry weight per m^2 and higher leaf chlorophylls a and b than sole faba bean in both seasons. In other words, 50% faba bean + 100% fenugreek had lower number of spikes per m^2 and spikes dry weight per m^2 by 69.42 and 68.49% in the first season and 51.73 and 51.88% in the second one, respectively, compared with 50% faba bean + 50% fenugreek. Also, 50% faba bean + 100% fenugreek increased leaf chlorophylls a and b by 2.63 and 20.00% in the first season and 2.69 and 20.31% in the second season, respectively, compared with 50% faba bean + 50% fenugreek.

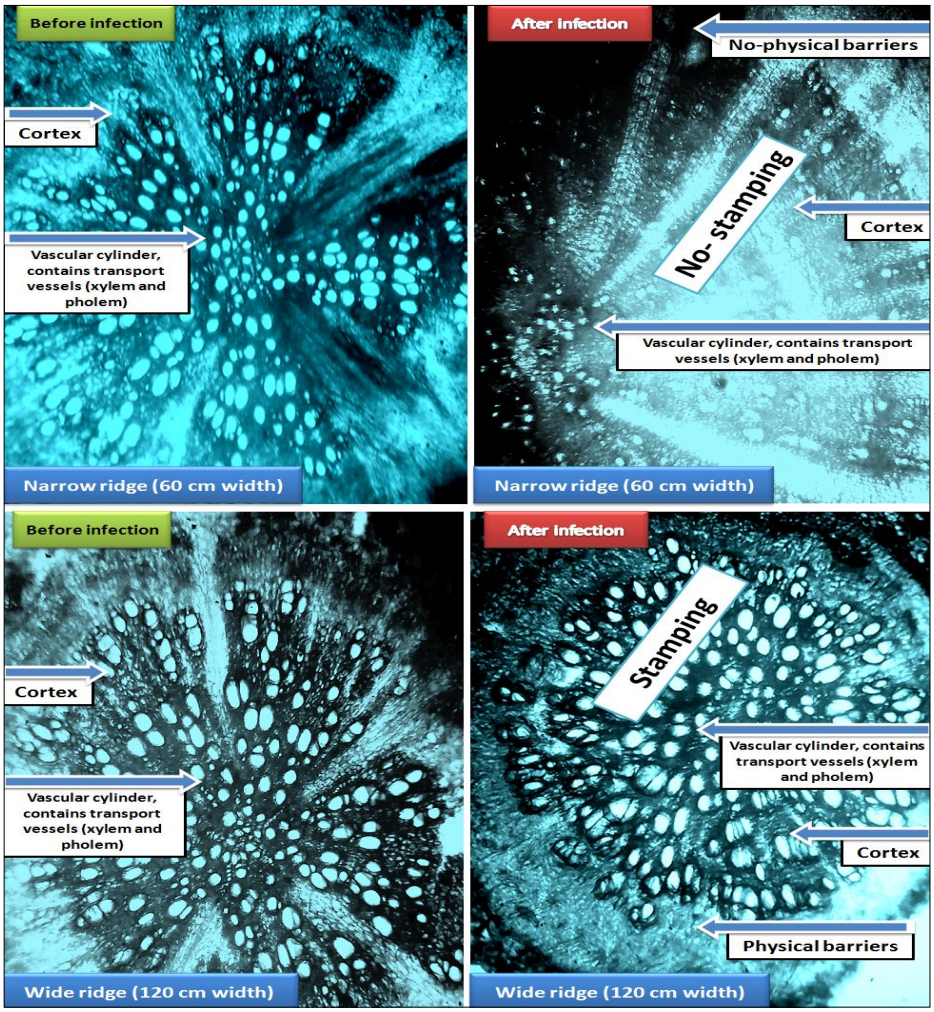

Fig 1: Vascular system in root cells of faba bean that grown in two ridge widths (60 and 120 cm) before and after infestation with broomrape.

Meanwhile, 100% faba bean + 100% fenugreek decreased number of spikes per m^2 and spikes dry weight per m^2 by 33.39 and 18.94 % in the first season and 45.94 and 31.73 % in the second season, respectively, compared with 100% faba bean + 50% fenugreek. Meanwhile, 100% faba bean + 100% fenugreek increased leaf chlorophylls a and b by 2.20 and 15.15% in the first season and 2.28 and 14.51% in the second season, respectively, compared with 100% faba bean + 50% fenugreek. These results were attributed to increasing fenugreek plant density per unit area from 50 to 100% of sole cropping in the two cropping systems (50% faba bean + 100% fenugreek and 100% faba bean + 100% fenugreek) increased soil total phenols concentration in faba bean rhizosphere (Table 1). Moreover, decreasing faba bean plant density from 100 to 50% of sole cropping could be reduced stimulators of broomrape seed germination by increasing soil total phenols concentration in faba bean rhizosphere due to reduce intra-specific competition between faba bean plants for basic growth resources. Particularly, Bouwmeester *et al.* (2003) and Plakhine *et al.* (2009) indicated that the germination of these obligate root parasites depends on the receipt of a chemical signal, which is present in the rhizosphere of potential hosts. So, increasing fenugreek plant density increased soil total phenols concentration in faba bean rhizosphere which negatively affected broomrape seed germination under heavily soil infested with broomrape. Also, it is expected that the broomrape that penetrated faba bean root cells, its life cycle will not be completed as a result of the accumulation of the total phenols in faba bean root cells. Inhibition of *Orobanche crenata* seed germination by allelochemicals released by fenugreek roots is the mechanism for reduction of this parasite (Fernández-Aparicio *et al.* 2008 and 2011). This biological situation will maintain leaf chlorophyll pigment from deterioration. It is known that the total leaf area of faba bean seedlings was significantly increased by increasing fenugreek extract concentration (Madany and Khalil, 2017), meanwhile, high densities of faba bean plants can cause the plants to senesce earlier (Gezahegn, 2019).

➢ **The interaction between ridge widths and cropping systems**

Number of spikes per m^2 and their dry weight per m^2 and leaf chlorophyll b were significantly affected by the interaction between ridge widths and cropping systems in both seasons (Table 2). Growing 50% faba bean + 100% fenugreek in wide ridges had a lower number of spikes per m^2 and spikes dry weight per m^2 and a higher leaf chlorophyll b followed by 100% faba bean + 100% fenugreek, meanwhile, the converse was true for growing 100% sole faba bean in the narrow one. These results were attributed to formation of physical barriers with stamping of the vascular system in the root cells (Fig 1) and higher total phenols in faba bean rhizosphere (Table 1) which reduced broomrape growth and maintained leaf chlorophyll pigment from deterioration (Table 2). This interaction probably reflected on a lower supply of carbon to the parasite.

Faba bean seed yield and its attributes

➢ **Ridge widths**

Ridge widths significantly affected the percentage of the harvested plants, plant height, seed yield per plant, 100-seed weight and seed yield per ha in both seasons, meanwhile numbers of branches and pods per plant were not affected (Table 3). Increasing ridge width from 60 to 120 cm increased the percentage of the harvested plants, seed yield per plant, 100-seed weight and seed yield per ha than the other one, meanwhile, the converse was true for plant height. In other words, growing faba bean in wide ridges gave a higher percentage of the harvested plants by 12.45 and 11.46% in the first and second seasons, respectively, than the other one. Also, growing faba bean in wide ridges had a higher seed yield per plant by 16.18 and 26.20% in the first and second seasons, respectively, than the other one. Moreover, growing faba bean in wide ridges had a higher 100-seed weight by 4.19 and 3.12% in the first and second seasons, respectively, than the other one. Furthermore, growing faba bean in wide ridges had a higher seed yield per ha by 19.48 and 20.73% in the first and second seasons, respectively, than the other one. These results were due to lower infestation with broomrape by growing faba bean plants of the wide ridges that had a higher ability to maintain soil moisture which furnished suitable environmental conditions for germination and early growth of faba bean seedlings than growing faba bean in the narrow one. In this concern, Zohry and Ouda (2017) showed that the widest ridge had high moisture which provided suitable conditions for germination and early growth of faba bean seedlings compared to those grown in the narrowest one, thus escaping from severe infestation with broomrape. Also, growing faba bean in wide ridges had physical barriers with stamping of the vascular system in the faba bean root cells (Fig 1) which reduced broomrape growth and maintained leaf chlorophyll pigment from deterioration (Table 2). These defense mechanisms lead to high dry matter accumulation in different tissues of the plant during growth and development. These results are in the same context as Fisher *et al*. (1995) who found increased yield in wide beds attributable to moisture conservation in the beds. Also, Safina (2017) reported that increasing ridge width from 60 to 120 cm increased the number of pods per plant, seed yield per plant, seed index and seed yield per ha by 5.68, 3.02, 4.98 and 5.20%, respectively. Moreover, Mohamed *et al*. (2018) reported that growing faba bean in wide ridges had lower values of plant height and higher values of seed yields per plant and per ha than those of the narrow one.

➢ **Cropping systems**

Cropping systems significantly affected the percentage of the harvested plants, plant height, seed yield per plant, 100-seed weight and seed yield per ha in both seasons, meanwhile numbers of branches and pods per plant were not affected (Table 3). A lower percentage of the harvested plants and seed yield per ha was achieved by 50% sole faba bean than the others. These results were due to a lower soil total phenols concentration in faba bean rhizosphere (Table 1) which led to higher infestation with broomrape and maintained leaf chlorophyll pigment from deterioration (Table 2). *Orobanche* induced growth inhibition of faba bean due to parasitism might result from depletion of host nutrition (Nemat Alla *et al.* 2007). *Orobanche* induced yield reductions are not primarily due to competition for water, but rather due to carbohydrate loss to the parasite (Bayoumi *et al.* 2014). Conversely, 100% faba bean + 100% fenugreek had a higher percentage of the harvested plants, plant height and seed yield per ha than the others. These results were attributed to increase faba bean plant density from 50 to 100% of sole cropping increased seed yield per hectare. This biological situation increased plant height. Meanwhile, 50% faba bean + 100% fenugreek had a higher seed yield per plant and 100-seed weight than the others. These results were due to 50% faba bean + 100% fenugreek increased soil total phenols concentration in faba bean rhizosphere (Table 1) which reduced infestation with broomrape and increased leaf chlorophylls a and b during growth and development (Table 2). These results are in harmony with Elsakhawy *et al.* (2020) who showed that plant height, pod number per plant, seed yield per plant and 100-seed weight were significantly decreased under broomrape infestation.

➢ **The interaction between ridge widths and cropping systems**

The interaction between ridge widths and cropping systems significantly affected seed yield per plant in the first season, meanwhile, the other studied traits were not affected (Table 3). Growing 50% faba bean + 100% fenugreek in wide ridges had a higher seed yield per plant than the others. These results were due to wide ridges furnished suitable environmental conditions for tolerance of broomrape infestation (Table 1). This tolerance was improved by increasing fenugreek plant density from 50 to 100% of sole cropping which reduced number of spikes per m^2 and spikes

Table 3: Effect of ridge widths, cropping systems and their interactions on faba bean seed yield and its attributes in both seasons.

Ridge width	Cropping system	Harvested plants (%)	Plant height (cm)	Branches /plant (no.)	Pods /plant (no.)	Seed yield/plant (g)	100-seed weight (g)	Seed yield/ha (kg)
				1st season				
Narrow ridges	50% faba bean + 50% fenugreek	37.53	110.55	3.32	14.02	20.04	83.88	1633
	50% faba bean + 100% fenugreek	42.71	112.23	3.17	13.83	20.62	84.63	1927
	100% faba bean + 50% fenugreek	44.62	111.81	3.51	14.36	19.31	82.34	2034
	100% faba bean + 100% fenugreek	48.04	113.58	3.39	14.10	19.82	83.15	2238
	50% sole faba bean	23.42	105.16	3.32	12.27	15.49	80.72	668
	100% sole faba bean	19.93	106.02	3.28	12.12	15.21	80.29	771
	Mean	36.04	109.89	3.33	13.45	18.41	82.50	1545
Wide ridges	50% faba + 50% fenugreek	42.86	107.70	3.39	14.39	22.69	87.24	1957
	50% faba + 100% fenugreek	48.41	109.18	3.22	14.11	23.23	88.01	2303
	100% faba + 50% fenugreek	49.17	108.89	3.62	14.71	21.91	85.96	2356
	100% faba + 100% fenugreek	53.69	109.69	3.47	14.48	22.66	86.72	2642
	50% sole faba bean	26.78	102.88	3.45	13.14	19.03	84.11	867
	100% sole faba bean	22.31	104.33	3.39	12.97	18.87	83.77	951
	Mean	40.53	107.11	3.42	13.96	21.39	85.96	1846
Average of cropping system	50% faba + 50% fenugreek	40.19	109.12	3.35	14.20	21.36	85.56	1795
	50% faba + 100% fenugreek	45.56	110.70	3.19	13.97	21.92	86.32	2115
	100% faba + 50% fenugreek	46.89	110.35	3.56	14.53	20.61	84.15	2195
	100% faba + 100% fenugreek	50.86	111.63	3.43	14.29	21.24	84.93	2440
	50% sole faba bean	25.10	104.02	3.38	12.70	17.26	82.41	767
	100% sole faba bean	21.12	105.17	3.33	12.54	17.04	82.03	861
F test 0.05 Ridge width		*	*	N.S.	N.S.	1.57	2.44	**
L.S.D. 0.05 Cropping system		4.02	5.32	N.S.	N.S.	1.03	1.89	235.72
L.S.D. 0.05 Interaction		N.S.	N.S.	N.S.	N.S.	1.85	N.S.	N.S.
				2nd season				
Narrow ridges	50% faba bean + 50% fenugreek	33.24	108.11	3.02	13.34	14.95	83.22	1081
	50% faba bean + 100% fenugreek	38.54	110.62	2.91	13.03	15.31	84.10	1268
	100% faba bean + 50% fenugreek	40.16	110.25	3.28	13.66	14.37	81.87	1355
	100% faba bean + 100% fenugreek	45.67	111.02	3.12	13.40	14.82	82.68	1573
	50% sole faba bean	28.25	104.02	3.08	12.23	13.28	79.95	661
	100% sole faba bean	25.11	105.69	3.01	12.12	12.93	79.68	746
	Mean	35.16	108.28	3.07	12.96	14.27	81.91	1114
Wide ridges	50% faba bean + 50% fenugreek	37.54	105.94	3.16	13.79	18.57	85.82	1285
	50% faba bean + 100% fenugreek	43.96	107.69	2.90	13.52	18.84	86.47	1552
	100% faba bean + 50% fenugreek	46.22	106.55	3.37	14.11	17.88	84.39	1672
	100% faba bean + 100% fenugreek	48.16	108.21	3.20	13.88	18.37	85.20	1790
	50% sole faba bean	31.22	101.14	3.17	13.12	17.31	82.74	843
	100% sole faba bean	28.08	102.78	3.05	12.97	17.13	82.21	932
	Mean	39.19	105.38	3.14	13.56	18.01	84.47	1345
Average of cropping system	50% faba bean + 50% fenugreek	35.39	107.02	3.09	13.56	16.76	84.52	1183
	50% faba bean + 100% fenugreek	41.25	109.15	2.90	13.27	17.07	85.28	1410
	100% faba bean + 50% fenugreek	43.19	108.40	3.32	13.88	16.12	83.13	1513
	100% faba bean + 100% fenugreek	46.91	109.61	3.16	13.64	16.59	83.94	1681
	50% sole faba bean	29.73	102.58	3.12	12.67	15.29	81.34	752
	100% sole faba bean	26.59	104.23	3.03	12.54	15.03	80.94	839
F test 0.05 Ridge width		*	*	N.S.	N.S.	2.26	2.18	**
L.S.D. 0.05 Cropping system		4.62	3.85	N.S.	N.S.	1.58	1.63	281.55
L.S.D. 0.05 Interaction		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 4: Effect of ridge widths, cropping systems and their interactions on fenugreek seed yield and its attributes in both seasons.

Ridge width	Cropping system	Plant height (cm)	Branches/plant (no.)	Pods/plant (no.)	Seed yield /plant (g)	Seed yield /ha (kg)
		1st season				
Narrow ridges	50% faba bean + 50% fenugreek	68.35	3.12	17.74	4.01	367.86
	50% faba bean + 100% fenugreek	68.88	3.06	17.22	3.90	652.11
	100% faba bean + 50% fenugreek	71.55	2.87	15.43	3.49	288.47
	100% faba bean + 100% fenugreek	72.06	2.81	15.02	3.38	561.61
	50% sole fenugreek	62.56	4.37	19.04	4.31	423.54
	100% sole fenugreek	63.02	4.25	18.63	4.22	701.07
	Mean	67.73	3.41	17.18	3.88	499.11
Wide ridges	50% faba bean + 50% fenugreek	62.32	4.36	20.15	4.57	426.72
	50% faba bean + 100% fenugreek	62.74	4.33	19.91	4.50	720.97
	100% faba bean + 50% fenugreek	64.56	3.93	18.66	4.23	392.15
	100% faba bean + 100% fenugreek	64.90	3.89	18.49	4.18	686.05
	50% sole fenugreek	58.73	5.24	21.88	4.96	487.43
	100% sole fenugreek	59.07	5.18	21.56	4.87	751.33
	Mean	62.05	4.48	20.10	4.55	577.44
Average of cropping system	50% faba bean + 50% fenugreek	65.33	3.74	18.94	4.29	397.29
	50% faba bean + 100% fenugreek	65.81	3.69	18.56	4.20	686.54
	100% faba bean + 50% fenugreek	68.05	3.40	17.04	3.86	340.31
	100% faba bean + 100% fenugreek	68.48	3.35	16.75	3.78	623.83
	50% sole fenugreek	60.64	4.80	20.46	4.63	455.48
	100% sole fenugreek	61.04	4.71	20.09	4.54	726.20
F test 0.05 Ridge width		**	N.S.	N.S.	*	*
L.S.D. 0.05 Cropping system		3.90	N.S.	N.S.	0.35	176.47
L.S.D. 0.05 Interaction		N.S.	N.S.	N.S.	0.83	N.S.
		2nd season				
Narrow ridges	50% faba bean + 50% fenugreek	65.11	2.99	16.44	3.67	331.98
	50% faba bean + 100% fenugreek	65.48	2.93	16.01	3.59	618.85
	100% faba bean + 50% fenugreek	68.74	2.75	14.65	3.22	250.26
	100% faba bean + 100% fenugreek	69.01	2.69	14.18	3.16	529.75
	50% sole fenugreek	60.25	4.21	17.82	3.97	391.41
	100% sole fenugreek	60.88	4.12	17.37	3.92	676.24
	Mean	64.91	3.28	16.07	3.58	466.41
Wide ridges	50% faba bean + 50% fenugreek	60.72	4.27	18.88	4.21	392.11
	50% faba bean + 100% fenugreek	60.88	4.21	18.63	4.12	675.55
	100% faba bean + 50% fenugreek	62.38	3.86	17.22	3.85	357.73
	100% faba bean + 100% fenugreek	62.51	3.79	16.95	3.81	640.21
	50% sole fenugreek	57.44	5.11	20.32	4.59	461.58
	100% sole fenugreek	57.60	5.01	20.07	4.51	750.06
	Mean	60.25	4.37	18.67	4.18	546.20
Average of cropping system	50% faba bean + 50% fenugreek	62.91	3.63	17.66	3.94	362.04
	50% faba bean + 100% fenugreek	63.18	3.57	17.32	3.85	647.20
	100% faba bean + 50% fenugreek	65.56	3.30	15.93	3.53	303.99
	100% faba bean + 100% fenugreek	65.76	3.24	15.56	3.48	584.98
	50% sole fenugreek	58.84	4.66	19.07	4.28	426.49
	100% sole fenugreek	59.24	4.56	18.72	4.21	713.15
F test 0.05 Ridge width		*	N.S.	N.S.	*	*
L.S.D. 0.05 Cropping system		5.81	N.S.	N.S.	0.29	172.30
L.S.D. 0.05 Interaction		N.S.	N.S.	N.S.	N.S.	N.S.

dry weight per m^2 and increased leaf chlorophylls a and b (Table 2).

Fenugreek seed yield and its attributes

➢ **Ridge widths**

Ridge widths significantly affected plant height, seed yields per plant and per ha in both seasons, meanwhile numbers of branches and pods per plant were not affected (Table 4). Increasing ridge width from 60 to 120 cm increased seed yields per plant and per ha in both seasons, meanwhile, the converse was true for plant height. Growing fenugreek in wide ridges gave higher seed yields per plant and per ha by 17.26 and 15.69% in the first season and 16.75 and 17.10% in the second season, respectively, than those grown in the narrow one. These results may be due to wide ridges provided suitable environmental conditions for germination and early growth of fenugreek seedlings compared with those grown in the narrow one. These results are in parallel with Tuncturk (2011) who showed that some yield parameters were increased with increasing row spacing.

➢ **Cropping systems**

Cropping systems significantly affected plant height, seed yields per plant and per ha in both seasons, meanwhile numbers of branches and pods per plant were not affected (Table 4). Higher plant height and seed yield per plant was obtained by 50% of sole fenugreek than the others. These results could be due to lower intra-specific competition between fenugreek plants for basic growth resources which positively reflected on dry matter accumulation during growth and development. However, increasing fenugreek plant density from 50 to 100% of sole cropping did not increase number of pods per plant. These results are in accordance with Bismillah Khan *et al.* (2005) who showed that spatial arrangement did not have any significant effect on number of pods per plant. Meanwhile, 100% faba bean + 100% fenugreek had higher plant height and lower seed yield per plant than the others. These results could be due to increase fenugreek plant density from 50 to 100% of sole cropping increased inter and intra-specific competition between both and same species, respectively, for basic growth resources which negatively affected photosynthesis process. However, 100% faba bean + 50% fenugreek had a lower seed yield per ha than the others. These results may be attributed to increase faba bean plant density from 50 to 100% of sole cropping had negative effects on metabolic reactions in different tissues of fenugreek plant, this biological situation positively interacted with lower fenugreek plant density per unit area to reduce photosynthesis process and dry matter accumulation during growth and development.

➢ **The interaction between ridge widths and cropping systems**

The interaction between ridge widths and cropping systems significantly affected seed yield per plant in the first season, meanwhile, the other studied traits were not affected (Table 4). Growing 50% or 100% sole fenugreek in wide ridges recorded a higher seed yield per plant than the others. These results demonstrate that wide ridges decreased intra-specific competition between fenugreek plants for basic growth resources, which increased dry matter accumulation during growth and development. These results are confirmed with Tiwari *et al.* (2016) who indicated that significantly higher seed yield (494.45 kg/ ha) was observed with a plant spacing of 20 cm × 10 cm than the others.

Table 5: Relative yields of both species, LER and economic return of cropping systems between faba bean and fenugreek in both seasons.

Ridge width	Cropping system	$RY_{faba\ bean}$	$RY_{fenugreek}$	LER	Total return/ha (USD)	MAI
		1st season				
Narrow ridges	50% faba bean + 50% fenugreek	2.11	0.52	2.63	1484.76	920.21
	50% faba bean + 100% fenugreek	2.49	0.93	3.42	1935.21	1369.35
	100% faba bean + 50% fenugreek	2.63	0.41	3.04	1706.79	1145.34
	100% faba bean + 100% fenugreek	2.90	0.80	3.70	2083.11	1520.10
Wide ridges	50% faba bean + 50% fenugreek	2.53	0.60	3.13	1767.48	1202.79
	50% faba bean + 100% fenugreek	2.98	1.02	4.00	2263.77	1697.82
	100% faba bean + 50% fenugreek	3.05	0.55	3.60	2025.72	1463.02
	100% faba bean + 100% fenugreek	3.42	0.97	4.39	2478.52	1913.93
Recommended sole faba bean		1.00	1.00	1.00	555.12	-
		2nd season				
Narrow ridges	50% faba bean + 50% fenugreek	1.44	0.49	1.93	1057.18	509.41
	50% faba bean + 100% fenugreek	1.69	0.91	2.60	1432.79	881.71
	100% faba bean + 50% fenugreek	1.81	0.37	2.18	1185.81	641.86
	100% faba bean + 100% fenugreek	2.10	0.78	2.88	1577.55	1029.79
Wide ridges	50% faba bean + 50% fenugreek	1.72	0.57	2.29	1254.57	706.72
	50% faba bean + 100% fenugreek	2.08	0.99	3.07	1684.90	1136.07
	100% faba bean + 50% fenugreek	2.24	0.52	2.76	1504.33	959.28
	100% faba bean + 100% fenugreek	2.39	0.94	3.33	1826.57	1278.05
Recommended sole faba bean		1.00	1.00	1.00	537.12	-

Competitive relationships and intercropping economic advantage

➢ **Land equivalent ratio (LER)**

The total LER values were better than one in all the studied treatments. Fenugreek + faba bean in narrow or wide ridges increased LER compared with sole plantings of faba bean (Table 5). LER ranged from 2.63 by growing 50% fenugreek + 50% faba bean in narrow ridges to 4.39 by growing 100% fenugreek + 100% faba bean in wide ridges in the first season. Also, LER ranged from 1.93 by growing 50% fenugreek + 50% faba bean in narrow ridges to 3.33 by growing 100% fenugreek + 100% faba bean in wide ridges in the second season. The advantage of higher LER by fenugreek + faba bean in wide ridges over sole plantings of faba bean were due to wide ridge formed physical barriers with stamping of the vascular system in the root cells (Fig 1) and higher soil total phenols concentration in faba bean rhizosphere (Table 1) which decreased infestation with broomrape and maintained leaf chlorophyll pigment from deterioration (Table 2). This biological situation reduced intra-specific competition between faba bean plants and broomrape for basic growth resources. These results are in accordance with Safina (2017) who found that LER ranged from 1.63 for flax + Giza-2 variety in ridges 60 cm width.

➢ **Intercropping economic advantage**

Data presented in Table (5) indicate that fenugreek + faba bean in narrow or wide ridges was more profitable to farmers than sole plantings of faba bean in both seasons. Total return varied from 1484.76 USD/ha by growing 50% fenugreek + 50% faba bean in narrow ridges to 2478.52 USD/ha by growing 100% fenugreek + 100% faba bean in wide ridges in the first season. Also, total return varied from 1057.18 USD/ha by growing 50% fenugreek + 50% faba bean in narrow ridges to 1826.57 USD/ha by growing 100% fenugreek + 100% faba bean in wide ridges in the second season. With respect to MAI, it varied from 920.21 by growing 50% fenugreek + 50% faba bean in narrow ridges to 1913.93 by growing 100% fenugreek + 100% faba bean in wide ridges in the first season Also, MAI varied from 509.41 by growing 50% fenugreek + 50% faba bean in narrow ridges to 1278.05 by growing 100% fenugreek + 100% faba bean in wide ridges in the second season. It is important to mention that 100% fenugreek + 100% faba bean with wide ridges recorded the highest economic return compared with the others, indicating this system was more profitable to the farmers than the others and it should be recommended under heavily soil infested with broomrape.

CONCLUSION

Growing two rows of faba bean in both sides of wide ridge 120 cm width with four rows of fenugreek in middle of the ridge increased faba bean productivity, land usage and economic return, hence it should be recommended under heavily soil infested with broomrape.

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