Zagazig J. Agric. Res., Vol. 49 No. (2) 2022 157-180

Plant Production Science

Available online at http://zjar.journals.ekb.eg
http:/www.journals.zu.edu.eg/journalDisplay.aspx?Journalld=1&queryType=Master

IMPACT OF SOWING DISTANCES AND FERTILIZATION REGIMES ON GROWTH AND PRODUCTIVITY OF WHEAT AND FABA BEAN UNDER INTERCROPPING SYSTEM

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Received: 07/02/2022 ; Accepted: 27/03/2022

ABSTRACT: Two field experiments were conducted at Etay El-Baroud Agricultural Research Station, El-Beheira Governorate to study the effect of wheat and faba bean sowing distances and mineral nitrogen fertilizer (N) + mycorrhiza on growth and productivity under intercropping system during 2018/2019 and 2019/2020 growing seasons. Faba bean was sowing at three hill spaces *i.e.* 10 cm (D_1), 20 cm (D_2) and 30 cm (D_3) and five fertilization regimes of wheat *i.e.* 168 kg mineral nitrogen ha^{-1} as a recommended dose (100% N), 113 kg mineral nitrogen ha^{-1}(75% N), 84 kg mineral nitrogen ha^{-1} (50% N), 113 kg mineral nitrogen ha^{-1} (75% N) + mycorrhiza and 84 kg mineral nitrogen ha^{-1} (50% N) + mycorrhiza (F_1, F_2, F_3, F_4 and F_5, respectively). Faba bean sowing distance 30 cm (D_3) gave the highest wheat shoot dry weight, leaf area (at 75 and 90 days from sowing), yield, its attributes, leaf content of chlorophyll, NPK % in dry leaves and grains content of protein in contrast it decreased plant height of wheat. Respect to fertilization regimes, the results confirmed that 113 kg mineral nitrogen ha^{-1} + mycorrhiza (F_4) had superior effect on most studied characters of wheat and faba bean. The interaction of sowing distances of faba bean and fertilization treatments of wheat it significantly affected on wheat grain yield ton ha^{-1}, the physiological characters and land equivalent ratio (LER). It is concluded that, sowing faba bean at 30 cm (D_3) hill space with 168 kg mineral nitrogen ha^{-1} (recommended dose) or 113 kg mineral nitrogen ha^{-1} (75% N) + mycorrhiza fertilizer for wheat were suitable for increasing productivity and total net return.

Key words: Farmer's benefit, mineral nitrogen, mycorrhiza, *Triticum aestivum* L., *Vicia faba* L., yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the main grain crop in Egypt. It used as human food and animal feed. Wheat grains is the main source of calories, protein, B- group vitamins, dietary fiber and minerals to the diet of world's population than any other cereal crop **(Hussain *et al.*, 2015)**.

Faba bean (*Vicia faba* L.) one of the most important legume crops, it is mainly used as human food. Faba bean seeds contain high proportion of protein (21 to 34%), fat, amino acids and sugars (**Aljubouri, 2006).**

In many parts of the world, particularly in Africa and Asia, food shortage is prevalent, due to the rapid rise in population. To reduce the gap between crop production and consumption would need to maximize the utilization of limited agriculture land by intercropping to increase the productivity **(Khan *et al.*, 2014)**. In terms of farm income, in developing countries, intercropping is superior to monocropping which reaped a double crop and a high income for farmers (**Akhtar *et al.*, 2010).** Intercropping of cereals and legumes is important for food production (**Adesogan *et al.*, 2002).** In intercropping system, if crops differ in the utilization of environmental resources they

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complement each other and grow better than when they are separately (**Ghanbari-Bonjar, 2000).** In cereal-legume intercropping, legume released nitrogenous compounds from roots, decomposition of nodule and thin roots, which increase nitrogen in rhizosphere of the associated cereals (**Gill and Azam, 2006)**. It is known that faba bean is able to fix atmospheric nitrogen, which increased soil fertility and wheat will use this nitrogen, thus inter-specific competition is less than intra-specific competition and lead to increasing productivity (**Hauggaard-Nielsen *et al.*, 2001; Abdel-Wahab and El Manzlawy, 2016)**. Also, intercropping could reduce yield losses caused by weeds, diseases and pests (**Sekamatte *et al.*, 2003; Banik *et al.*, 2006; Brooker *et al.*, 2015).**

Use the suitable planting density of the intercropped crops can reduce the competition for resources and increase the efficiency of the plants (**Porto *et al.*, 2011).** Consequently, the yield of intercrops may exceed the yield sum of the corresponding individual crops **(Aziz *et al.*, 2015; El-Shamy *et al.*, 2016).**

Nitrogen is an essential nutrient for the development of plants because its play great role in enzymes synthesis, proteins and nucleic acids (**Kandil *et al.*, 2010)**. Nitrogen fertilizer has contributed to increase crop production. The extensive used of nitrogen fertilizer caused environmental hazardous (**Qin *et al.*, 2012).** Mycorrhiza form symbiosis with most crops. It takes organic carbon and provides host plants with nitrogen, phosphorous, potassium, zinc, copper, manganese and selenium (**Lehmann and Rillig, 2015).** Mycorrizal bio-fertilizer produced healthy plants and improved seed quality **(Mobasser and Moradgholi, 2012).** Mycorrhiza reduce nitrogen use and increase phosphorous available in the soil **(Abdullahi and Sheriff, 2013)**. Furthermore, it is controlled nutrient loss from the soil via leaching (**Bowles *et al.*, 2017).** Also, it played a role in enhancing soil aggregate stability (**Rillig *et al.*, 2019).** In addition, it uses to increase plant tolerance to both biotic and abiotic stresses (**Cabral *et al.*, 2016; Cui *et al.*, 2018).**

The objective of this study was to recognize the suitable combination of sowing distances of faba bean plants (spaces between hills) with wheat and mineral nitrogen fertilization plus mycorrhiza of wheat for improving growth, productivity, some physiological characters and total net return of both wheat and faba bean under intercropping system.

MATERIALS AND METHODS

Experimental Site

A field experiment was conducted on the experimental farm of Etay El-Baroud Agricultural Research Station, El-Behera Governorate, Egypt (30º 89' E, 30º 65' N, 5 m above sea level) during the two growing seasons of 2018/2019 and 2019/2020. Some physical and chemical properties of experimental site during the two growing seasons were determined according to **(Klute, 1986; Page *et al.*, 1982**) and presented in Table 1.

Layout and Treatments

Experimental design was laid out in a split-plot arrangement in randomized complete block design with four replications. The three faba bean sowing distances *i.e.* 10 cm (D_1), 20 cm (D_2) and 30 cm (D_3) between hills were located in main plots. While, five fertilization regimes *i.e.* mineral nitrogen fertilizer was applied at rates (100% of the recommended N level = 168 kg mineral nitrogen ha^{-1} (F_1), 75% N = 113 kg mineral nitrogen ha^{-1} (F_2) and 50% N = 84 kg mineral nitrogen ha^{-1} (F_3), 113 kg mineral nitrogen ha^{-1} (75% N) + mycorrhiza (F_4) and 84 kg mineral nitrogen ha^{-1} (50% N) + mycorrhiza (F_5) were randomly distributed in the sub plots. Wheat was planted on ridges 120 cm wide at the recommended densities (100%) for sole or intercropping wheat (144 kg ha^{-1}). Faba bean plants were grown on the two sides of wheat ridges (120 cm width). Faba bean was grown as intercropping density two plants $hill^{-1}$, while sole faba bean was planted on ridges 120 cm wide in the 4 rows with 20 cm hill space and two seeds $hill^{-1}$. The cultivars of wheat (Sids 14) and faba bean (Sakha 4) were sown on Nov. 15th and Nov. 20th in the first and second seasons, respectively. Each sub plot (10.80 m^2) included 3 ridges; each ridge was 3 m long and 1.20 m wide. All other agronomic practices for wheat and faba bean production were undertaken as recommended. Both crops were harvested manually at full maturity in 1st and 3rd May for faba bean, while wheat was harvested in 15th and 19rd May in both seasons, respectively.

Table 1. Physical and chemical properties of experimental site during the two growing seasons of 2018-2019 and 2019-2020

Soil properties	2018	2019
Soil texture	Clay	Clay
Sand %	7.13	7.11
Silt %	32.21	32.55
Clay %	60.65	60.64
PH	8.04	7.85
Organic matter %	2.02	1.95
Available N (ppm)	18.11	17.85
Available P (ppm)	13.55	9.99
Available K (ppm)	277.14	293.22
EC(mmhos) cm^{-1} (1:5)	1.85	1.73

Management

All plots received phosphorous fertilizer in the form of super phosphate (15.5% P_2O_5) at a rate of 360 kg ha^{-1} applied during land preparation. Mineral nitrogen fertilizer of wheat was in the form of urea (46.5% N) in the two equal doses, 50% at the first irrigation and 50% at the second irrigation. Mycorrhizal fungi were mixed with wheat grains before sowing directly, while sole wheat was fertilized by recommended dose (168 kg nitrogen ha^{-1}). Trying to exploit the ability of faba bean plants to fix the atmospheric nitrogen, expecting that, the residues of the applied nitrogen will act as an activator dose to the nodules on the roots of faba bean plants. Moreover, a sufficient amount of a bio-fertilizer containing N_2 fixing bacteria was applied to faba bean seeds directly before sowing and the success of nodulation was assessed after 30 days from sowing by counting more than ten healthy nodules per root. The preceding crop was maize in both seasons.

Studied Characters

Growth, yield and its attributes as well as physiological characters of wheat and faba bean

Estimation of shoot dry weight (g) and leaf area (cm^2) of wheat from 20 x 20 cm in each plot samples were randomly collected at 75 and 90 days after sowing, while shoot dry weight (g) and leaf area plant^{-1} (cm^2) for faba bean were estimated as average of five plants randomly chosen at 75 and 90 days after sowing. To determine leaf area plant^{-1} (LA) for faba bean, the area of 10 desks (10 x 3.14 x (1.5)^2) = 70.65 cm^2 was calculated according to **Hunt (1990)** using the following formula:

LA = 70.65 x dry weight of leaves plant^{-1}/ dry weight of leaves desks

Plant samples were dried in an electric oven with drift fan at 70^{o}C for 48 hr., till constant dry weight.

At harvest ten plants of wheat were randomly taken from each plot to determine: plant height (cm), number of tillers m^{-2}, spike length (cm), and 1000-kernel weight (g). Conversion of grain and straw yields obtained from each sub-plot to its equivalent grain and straw yields (ton ha^{-1}). Also, ten plants of faba bean were randomly taken from each plot at harvest to estimate: plant height (cm), number of branches plant^{-1}, number of pods plant^{-1}, seed yield plant^{-1} (g) and 100-seed weight (g). Conversion of seed and straw yields obtained from each sub-plot to its equivalent seed and straw yields (ton ha^{-1}).

After 75 days from sowing chlorophyll a, b and a+b (mg/g fresh weight of leaves) were determined according to **Metzner *et al.* (1965)**. Also, phosphorous and potassium % were determined in the dry leaves by (**Chapman and Pratt, 1978**). Total carbohydrates % in grain or seed was determined using phenol sulphuric according to (**Dubois *et al.*, 1956**). Total nitrogen % in dry leaves (at 75 days), grain or seed was determined by using Micro-Kjeldahl method (**AOAC, 1988**). Protein % was calculated by multiplying total nitrogen values by the factor of 6.25.

Evaluation of Intercropping System

Land equivalent ratio (LER)

The ratio of area need under sole cropping to that of intercropping at same management level to produce an equivalent yield, according to **Mead and Willey (1980):**

$$LER = Yab/Yaa + Yba/Ybb$$

Where, Yaa and Ybb are the sole crop yields of crops a and b, respectively, Yab is the intercrop yield of crop a, and Yba is the intercrop yield of crop b.

Farmer's benefit

Net return of wheat ha^{-1} was calculated by subtraction the total cost of wheat from income of wheat yield ha^{-1} (grain + straw). Also, net return of faba bean ha^{-1} was calculated by subtraction the total cost of faba bean from income of faba bean ha^{-1} (seed + straw) for each treatment. By using the average price for the two seasons, the price of wheat was 233 dollars ton^{-1} grain and 127 dollars ton^{-1} straw, while the price of faba bean was 954.81 dollars ton^{-1} seed and 63.65 dollars ton^{-1} straw **(Bulletin of Statistical Cost Production and Net Return, 2019 and 2020).** Total net return was calculated by summation net return of wheat yield and net return of faba bean yield.

Statistical Analysis

All data were subjected to the analyses of variance (ANOVA) for split-plot design followed by compared means with LSD at 5% level of probability according to (**Gomez and Gomez, 1984).**

RESULTS AND DISCUSSION

Wheat Growth Characters

Results present in Table 2 showed that, the distances between faba bean plants significantly affected shoot dry weight and leaf area for wheat at 75 and 90 days after sowing in both seasons. The faba bean distance 30 cm (D_3) gave the highest values of shoot dry weight (15.08 and 15.46 g) and (27.69 and 27.72 g). Also, the distance (D_3) had the highest values (1910.35 and 1951.45 cm^2) and (2799.95 and 2839.70 cm^2) for leaf area at (75 and 90 days) in both growing seasons, respectively. The sowing distance of 10 cm (D_1) recorded the lowest values for the previous parameters in the two seasons due to increase inter-specific competition between wheat plants for basic resources. The decreasing faba bean sowing distance increased the shading effect of faba bean shoots, which negatively affect the rate of photosynthesis and reduced plant development and growth (**Abdel-Wahab and El Manzlawy, 2016; Zohry and Ouda, 2019**).

Shoot dry weight and leaf area were significantly affected by fertilization treatments at 75 and 90 days from sowing in both seasons. 100% mineral nitrogen (F_1) had superior effect on shoot dry weight compared with all other fertilization treatments. **Bedoussac and Justes (2010)** showed that the intercropped and sole wheat dry weight increased by nitrogen fertilizer. Also, **Mohammed (2014)** found that recommended nitrogen fertilizer increased growth of wheat plants under intercropping. Application of 75% nitrogen + mycorrhiza (F_4) gave the highest leaf area in both growing seasons. Mycorrhiza increased plant growth and nutrient absorption due to a symbiotic association between mycorrhiza and plant roots **(Wangiyana *et al.*, 2021)**. It produces an extensive network of microscopic hyphal threads that extend into the surrounding soil (**Hajiboland *et al.*, 2010).)**

The interaction among sowing distances x fertilization regimes had significant effect on shoot dry weight and leaf area except for shoot dry weight at 90 days in the first season and leaf area at 75 days in the first and 90 days in the second season.

Wheat Yield and its Attributes

The results in Tables 3 and 4 indicated that, plant height, number of tillers m^{-2}, spike length, 1000-kernel weight, grain and straw yields were significantly affected by faba bean sowing distances and wheat fertilization regimes except of sowing distance on 1000-kernel weight in the second season.

Table 2. Shoot dry weight and leaf area of wheat as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Shoot dry weight after 75 days (g)		Shoot dry weight after 90 days (g)		Leaf area after 75 days (cm^2)		Leaf area after 90 days (cm^2)	
Season / Factor	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020
Sowing distances (D)								
10 cm (D$_1$)	14.13^{b}	14.19^{c}	24.29^{c}	24.46^{c}	1632.45^{c}	1693.30^{c}	2656.30^{c}	2701.40^{b}
20 cm (D$_2$)	14.75^{a}	15.02^{b}	26.03^{b}	26.31^{b}	1726.50^{b}	1739.40^{b}	2725.0^{ab}	2780.05^{a}
30 cm (D$_3$)	15.08^{a}	15.46^{a}	27.69^{a}	27.72^{a}	1910.35^{a}	1951.45^{a}	2799.95^{a}	2839.70^{a}
Fertilization regimes (F)								
100% N (F$_1$)	16.02^{a}	16.08^{a}	28.17^{a}	28.27^{a}	1878.91^{a}	1898.00^{a}	2867.16^{a}	2932.50^{a}
75% N (F$_2$)	14.51^{b}	14.84^{b}	25.70^{b}	16.12^{b}	1758.41^{b}	1780.16^{b}	2708.00^{b}	2697.50^{b}
50% N (F$_3$)	12.69^{c}	13.21^{c}	22.68^{c}	22.40^{d}	1560.16^{d}	1617.58^{c}	2539.41^{d}	2659.66^{b}
75% N+ Mycorrh. (F$_4$)	15.83^{a}	15.77^{a}	28.05^{a}	28.53^{a}	1915.66^{a}	1930.00^{a}	2898.00^{a}	2934.08^{a}
50% N+ Mycorrh. (F$_5$)	14.23^{b}	14.55^{b}	25.41^{b}	25.51^{c}	1669.00^{c}	1747.83^{b}	2622.83^{c}	2644.83^{b}
Interaction (D x F)								
10 cm (D$_1$)								
100% N (F$_1$)	15.75b	15.72	26.26	26.65	1746.75	1801.50	2749.25	2798.75
75% N (F$_2$)	13.58	14.45	23.96	24.31	1630.75	1682.25	2670.75	2668.00
50% N (F$_3$)	12.73	12.80	21.45	21.13	1477.00	1567.50	2520.00	2594.00
75% N+ Mycorrh. (F$_4$)	14.91	13.98	26.05	26.15	1727.75	1797.00	2715.75	2830.25
50% N+ Mycorrh. (F$_5$)	13.69	14.01	23.73	24.08	1580.00	1618.25	2625.75	2616.00
20 cm (D$_2$)								
100% N (F$_1$)	16.07a	15.88	28.46	28.01	1862.50	1858.25	2901.00	2975.00
75% N (F$_2$)	14.90	14.95	25.63	26.31	1705.00	1717.50	2691.50	2693.50
50% N (F$_3$)	12.52	12.94	22.35	22.19	1508.00	1517.50	2538.25	2616.75
75% N+ Mycorrh. (F$_4$)	16.28	16.66	28.02	29.27	1881.50	1817.50	2886.25	2954.00
50% N+ Mycorrh. (F$_5$)	14.00	14.68	25.67	25.76	1675.50	1786.25	2608.00	2661.00
30 cm (D$_3$)								
100% N (F$_1$)	16.23	16.64	29.79	30.14	2027.50	2034.25	2951.25	3023.75
75% N (F$_2$)	15.04	15.11	27.50	27.73	1939.50	1940.75	2761.75	2731.00
50% N (F$_3$)	12.81	13.90	24.23	23.88	1695.50	1767.75	2560.00	2768.25
75% N+ Mycorrh. (F$_4$)	16.30	16.68	30.08	30.16	2137.75	2175.50	3092.00	3018.00
50% N+ Mycorrh. (F$_5$)	15.00	14.97	26.83	26.70	1751.50	1893.00	2634.75	2657.50
LSD 0.05 (D)	0.47	0.23	0.34	0.54	54.18	34.62	79.97	67.30
LSD 0.05 (F)	0.30	0.38	0.46	0.47	88.48	59.40	77.97	116.90
LSD 0.05 (D x F)	0.52	0.67	NS	0.82	NS	102.99	135.17	NS
Sole wheat	16.58	15.96	28.74	28.41	1935.16	1943.54	2957.11	2978.20

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 3. Plant height, number of tillers/m^2 and spike length of wheat as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Plant height (cm)		No. of tillers/m^2		Spike length (cm)	
Season / Factor	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Sowing distances (D)						
10 cm (D_1)	100.46^a	101.11^a	200.71^c	203.02^c	7.75^c	8.41^b
20 cm (D_2)	98.73^b	99.53^a	219.39^b	222.66^b	8.44^b	8.40^b
30 cm (D_3)	97.26^b	97.13^b	231.69^a	239.90^a	9.18^a	9.07^a
Fertilization regimes (F)						
100% N (F_1)	101.44^{ab}	102.77^a	238.05^a	243.16^a	8.64^{ab}	9.06^a
75% N (F_2)	99.00^b	97.88^b	222.54^{ab}	228.11^{ab}	8.30^b	8.50^b
50% N (F_3)	94.33^c	95.30^b	177.50^c	182.22^c	8.13^b	8.39^b
75% N+ Mycorrh.(F_4)	103.44^a	104.33^a	236.10^a	241.11^a	8.77^a	8.95^a
50% N+ Mycorrh. (F_5)	95.88^c	96.00^b	212.13^b	214.70^b	8.45^{ab}	8.24^b
Interaction (D x F)						
10 cm (D_1)						
100% N (F_1)	103.00	104.66	225.50	228.33	7.75	8.40
75% N (F_2)	99.00	99.66	199.33	202.66	7.65	8.10
50% N (F_3)	96.33	97.25	160.00	163.33	7.62	8.19
75% N+ Mycorrh. (F_4)	107.00	106.00	226.00	226.66	7.85	9.06
50% N+ Mycorrh. (F_5)	97.00	98.00	192.75	194.11	7.90	8.30
20 cm (D_2)						
100% N (F_1)	102.00	103.00	240.33	242.50	8.79	9.20
75% N (F_2)	100.00	99.00	229.97	235.82	8.25	8.20
50% N (F_3)	93.66	94.66	177.00	179.16	8.02	8.26
75% N+ Mycorrh. (F_4)	102.33	105.00	236.66	240.00	8.71	8.35
50% N+ Mycorrh. (F_5)	95.66	96.00	213.00	215.83	8.45	8.00
30 cm (D_3)						
100% N (F_1)	99.33	100.66	248.33	258.66	9.40	9.59
75% N (F_2)	98.00	95.00	238.33	245.83	9.01	9.20
50% N (F_3)	93.00	94.00	195.50	204.16	8.75	8.73
75% N+ Mycorrh. (F_4)	101.00	102.00	245.63	256.67	9.75	9.43
50% N+ Mycorrh. (F_5)	95.00	94.00	230.66	234.16	9.00	8.43
LSD 0.05 (D)	1.62	2.18	4.50	12.97	0.37	0.16
LSD 0.05 (F)	2.59	2.47	16.20	14.20	0.34	0.44
LSD 0.05 (D x F)	NS	NS	NS	NS	NS	NS
Sole wheat	104.11	105.01	273.12	284.23	9.40	8.93

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 4. Thousand kernel weight, grain yield and straw yield of wheat as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	1000-kernel weight(g)		Grain yield (ton ha^{-1})		Straw yield (ton ha^{-1})	
Season / Factor	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020
Sowing distances (D)						
10 cm (D_1)	43.43^b	45.00	3.333^c	3.357^c	6.369^b	6.460^b
20 cm (D_2)	43.71^b	45.26	3.925^b	4.084^b	8.337^a	8.894^a
30 cm (D_3)	45.25^a	46.29	4.405^a	4.564^a	8.568^a	8.817^a
Fertilization regimes (F)						
100% N (F_1)	45.62^b	47.27^a	4.424^a	4.491^a	8.914^a	8.953^a
75% N (F_2)	43.71^c	45.10^b	4.133^b	4.143^b	7.532^b	7.735^b
50% N (F_3)	41.13^d	42.42^c	3.920^d	2.953^c	6.241^c	6.540^c
75% N+ Mycorrh. (F_4)	47.23^a	48.43^a	4.280^{ab}	4.394^a	8.771^a	9.397^a
50% N+ Mycorrh. (F_5)	42.98^c	44.38^b	3.680^c	4.027^b	7.333^b	7.660^b
Interaction (D x F)						
10 cm (D_1)						
100% N (F_1)	44.96	45.19	3.884	3.955	7.661	7.845
75% N (F_2)	42.30	44.68	3.370	3.394	5.876	5.814
50% N (F_3)	40.17	42.43	2.376	2.460	5.261	5.211
75% N+ Mycorrh. (F_4)	46.96	48.95	3.706	3.645	7.625	7.805
50% N+ Mycorrh. (F_5)	42.81	43.79	3.331	3.332	5.425	5.627
20 cm (D_2)						
100% N (F_1)	45.63	48.62	4.391	4.454	9.338	9.537
75% N (F_2)	43.56	44.93	4.314	4.361	8.399	9.052
50% N (F_3)	41.82	42.14	2.612	2.816	6.006	6.671
75% N+ Mycorrh. (F_4)	44.62	47.34	4.325	4.536	9.358	10.199
50% N+ Mycorrh. (F_5)	42.95	43.30	3.986	4.256	8.586	9.010
30 cm (D_3)						
100% N (F_1)	46.28	48.00	4.999	5.065	9.745	9.477
75% N (F_2)	45.29	45.71	4.715	4.676	8.322	8.342
50% N (F_3)	41.41	42.70	3.774	3.585	7.458	7.738
75% N+ Mycorrh. (F_4)	47.62	49.00	4.812	5.001	9.330	10.187
50% N+ Mycorrh. (F_5)	43.19	46.07	3.725	4.494	7.988	8.345
LSD 0.05 (D)	1.16	NS	0.174	0.178	0.979	0.470
LSD 0.05 (F)	1.35	1.40	0.240	0.184	0.750	0.636
LSD 0.05 (D x F)	2.34	NS	0.416	0.334	NS	NS
Sole wheat	45.13	44.71	5.966	5.893	10.668	10.213

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

By decreasing faba bean sowing distance from 30 to 10 cm between hills lead to a decrease in all previous traits, except plant height. The increase of faba bean seed rate resulted in reduced wheat grain yield (**Agegnehu *et al.*, 2008)**. Decreasing faba bean sowing distance increase the shading effect of faba bean shoots, which negatively affect the rate of photosynthesis and increase the competition for assimilate between organs of wheat that, lead to decrease in yield (**Abdel-Wahab and El Manzlawy, 2016; Zohry and Ouda, 2019).** The lowest plant height was recorded at faba bean sowing distance of 30 cm without any significant difference with 20 cm (97.26 and 97.13 cm) in the first and second seasons, respectively. On the contrary, plant height increased at faba bean sowing distance 10 cm (100.46 and 101.11 cm) in both seasons, respectively. These alterations in plant height for helping the plants to intercept more light (**Abdel-Wahab and El Manzlawy, 2016**).

Wheat plants with fertilization regimes of 100% mineral nitrogen or 75% mineral nitrogen + mycorrhiza gave the highest plant height, number of tillers m^{-2}, spike length, 1000- kernel weight, grain and straw yields in both seasons. A constant supply of nitrogen to wheat plants under the previous treatments increase the metabolic process, photosynthesis assimilates and tillering of plants, resulting in improving yield and its components **(Jan and Khan, 2000**).

Whereas, during critical phases of wheat growth, decreasing of applied nitrogen lead to decrease yield (**Tosti and Guiducci, 2010).** On the other side, hyphae of mycorrhiza take up and transfer nitrogen from the soil to the host plant (**Wipf *et al.*, 2019).** Also, it increased yield of cereal crops in intercropping systems **(Wangiyana *et al.*, 2021)**.

The interaction between sowing distances of faba bean x fertilization regimes of wheat had significant effect on 1000- kernel weight in the first season and grain yield in the two seasons. Similar results were obtained by **El-Shamy *et al.* (2016)**.

Wheat Physiological Characters

Results present in Table 5 showed that faba bean sowing distances and fertilization treatments had significant effect on wheat chlorophyll content (a, b and a+b) in the two growing seasons.

The highest leaf content of chlorophyll a (1.13 and 1.17), chlorophyll b (0.51 and 0.54) and chlorophyll a+b (1.64 and 1.70) were obtained under faba bean sowing distance 30 cm in both seasons, respectively. Optimum plant density increased photosynthetic rate and yield of maize and cucumber (**Seran and Brintha, 2010; Xiaolei and Zhifeng, 2002)**.

Also, the results indicated that 75% mineral nitrogen + mycorrhiza increased chlorophyll content in wheat leaves and followed by 100% mineral nitrogen. Wheat plants that treated with 75% mineral nitrogen + mycorrhiza had the highest content of chlorophyll a+b (1.75 and 1.79) in the first and second seasons, respectively. Application of mycorrhiza increased photosynthesis which, lead to more plant biomass (**Aroca *et al.*, 2013).**

The interaction between sowing distances x fertilization regimes had insignificant effect on chlorophyll content.

Resluts in Table 6 showed that, sowing distances had significant effect on leaf content of N, P and K in second season. Sowing distance of 30 cm (D_3) gave the highest leaf content of nitrogen, phosphorous and potassium (1.69, 0.64 and 1.37) in the second season, respectively.

Fertilization with 75% mineral nitrogen + mycorrhiza produced the highest content of N and P (1.72 and 0.67) in wheat leaves. Similar results were obtained by (**Merwad *et al.*, 2014)**. In intercropping system, nitrogen uptake and accumulation increased in wheat plant (**Ismail *et al.*, 2012)**. Moreover, 100% mineral nitrogen gave the highest value for K content (1.40) in wheat leaves in the second season.

P and K percentages in wheat leaves were significantly affected by the interaction of sowing distances x fertilization regimes.

In the same Table, no significant effect was showed on nitrogen leaf content, total carbohydrates and protein content (in grains) by sowing distances and fertilization treatments. Faba bean sowing distance 30 cm as well as wheat plants treated with 75% mineral nitrogen + mycorrhiza had superior effect on grains content of protein (11.34 and 11.52) in the second season, respectively.

Table 5. Chlorophyll content of wheat at 75 days (mg/g fresh weight) as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Chlorophyll a		Chlorophyll b		Chlorophyll a+b	
Season / Factor	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020
Sowing distances (D)						
10 cm (D_1)	1.05^c	1.07^c	0.47^b	0.49^c	1.53^c	1.57^c
20 cm (D_2)	1.11^b	1.12^b	0.50^a	0.53^b	1.62^b	1.65^b
30 cm (D_3)	1.13^a	1.17^a	0.51^a	0.54^a	1.64^a	1.70^a
Fertilization regimes (F)						
100% N (F_1)	1.16^b	1.18^a	0.55^a	0.59^a	1.71^b	1.77^b
75% N (F_2)	1.07^c	1.08^c	0.48^b	0.50^c	1.55^c	1.58^c
50% N (F_3)	1.03^d	1.04^d	0.43^d	0.45^e	1.47^e	1.50^d
75% N+ Mycorrh. (F_4)	1.19^a	1.19^a	0.55^a	0.58^b	1.75^a	1.79^a
50% N+ Mycorrh. (F_5)	1.04^d	1.11^b	0.46^c	0.48^d	1.51^d	1.57c
Interaction (D x F)						
10 cm (D_1)						
100% N (F_1)	1.12	1.15	0.54	0.58	1.66	1.73
75% N (F_2)	1.03	1.04	0.46	0.48	1.49	1.52
50% N (F_3)	0.98	1.01	0.41	0.42	1.39	1.43
75% N+ Mycorrh. (F_4)	1.16	1.17	0.53	0.55	1.68	1.72
50% N+ Mycorrh. (F_5)	1.00	1.02	0.44	0.46	1.44	1.48
20 cm (D_2)						
100% N (F_1)	1.15	1.16	0.55	0.59	1.70	1.75
75% N (F_2)	1.10	1.09	0.48	0.51	1.58	1.59
50% N (F_3)	1.05	1.06	0.43	0.46	1.49	1.52
75% N+ Mycorrh. (F_4)	1.19	1.20	0.58	0.61	1.77	1.81
50% N+ Mycorrh. (F_5)	1.07	1.11	0.47	0.49	1.54	1.60
30 cm (D_3)						
100% N (F_1)	1.22	1.23	0.56	0.62	1.78	1.85
75% N (F_2)	1.09	1.12	0.50	0.54	1.59	1.65
50% N (F_3)	1.06	1.08	0.45	0.47	1.51	1.55
75% N+ Mycorrh. (F_4)	1.23	1.25	0.57	0.60	1.80	1.84
50% N+ Mycorrh. (F_5)	1.08	1.13	0.49	0.50	1.57	1.63
LSD 0.05 (D)	0.01	0.03	0.02	0.01	0.01	0.02
LSD 0.05 (F)	0.02	0.03	0.01	0.01	0.02	0.02
L SD 0.05 (D x F)	NS	NS	NS	NS	NS	NS
Sole wheat	1.18	1.21	0.53	0.58	1.71	1.79

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 6. Nitrogen (N), phosphorous (P), potassium (K) % in dry leaves at 75 days, total carbohydrates and protein content in wheat grains as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2019-2020 season

Parameter / Factor	N %	P %	K %	Total carbohydrates %	Protein %
			Sowing distances (D)		
10 cm (D_1)	1.65^b	o.61^c	1.32^b	58.67	10.81^c
20 cm (D_2)	1.65^b	0.63^b	1.36^a	61.11	11.06^b
30 cm (D_3)	1.69^a	0.64^a	1.37^a	61.71	11.34^a
			Fertilization regimes (F)		
100% N (F_1)	1.70^b	0.67^a	1.40^a	61.43	11.44^a
75% N (F_2)	1.66^c	0.62^b	1.33^d	58.39	11.00^b
50% N (F_3)	1.60^e	0.58^d	1.31^e	60.13	10.56^d
75% N+ Mycorrh. (F_4)	1.72^a	0.67^a	1.36^b	61.81	11.52^a
50% N+ Mycorrh. (F_5)	1.63^d	0.61^c	1.35^c	60.74	10.84^c
			Interaction (D x F)		
			10 cm (D_1)		
100% N (F_1)	1.70	0.65	1.37	60.42	11.26
75% N (F_2)	1.67	0.60	1.30	60.02	10.80
50% N (F_3)	1.58	0.58	1.28	59.53	10.27
75% N+ Mycorrh. (F_4)	1.72	0.66	1.38	60.80	11.12
50% N+ Mycorrh. (F_5)	1.62	0.59	1.31	60.11	10.63
			20 cm (D_2)		
100% N (F_1)	1.69	0.67	1.41	61.43	11.43
75% N (F_2)	1.65	0.64	1.36	61.00	10.96
50% N (F_3)	1.60	0.59	1.33	60.26	10.50
75% N+ Mycorrh. (F_4)	1.71	0.68	1.39	61.99	11.57
50% N+ Mycorrh. (F_5)	1.63	0.61	1.34	60.91	10.87
			30 cm (D_3)		
100% N (F_1)	1.73	0.70	1.43	62.46	11.65
75% N (F_2)	1.68	0.62	1.35	61.65	11.25
50% N (F_3)	1.64	0.57	1.32	60.61	10.92
75% N+ Mycorrh. (F_4)	1.75	0.69	1.44	62.65	11.89
50% N+ Mycorrh. (F_5)	1.66	0.63	1.40	61.22	11.03
LSD 0.05 (D)	0.01	0.01	0.03	NS	0.15
LSD 0.05 (F)	0.01	0.01	0.01	NS	0.15
LSD 0.05 (D x F)	NS	0.01	0.02	NS	NS
Sole wheat	1.67	0.65	1.38	62.05	11.96

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Plant density had no effect on protein percentage of wheat grains (**Chen and Neill, 2006; Abdel-Wahab and El Manzlawy, 2016**). Moreover, application of nitrogen fertilizers increased protein content in wheat grain (**Liu and Shi, 2013)**.

Faba Bean Growth Traits

Results present in Table 7 revealed that shoot dry weight plant^{-1} was significantly affected by sowing distances at 90 days only. Sowing faba bean at 30 cm (D_3) hill space gave the highest shoot dry weight plant^{-1}(15.53 and 16.24 g) in the two seasons, respectively. Leaf area plant^{-1} was significantly influenced by the intercropping densities of faba bean plants (at 90 days) in both seasons. Sowing faba bean at 30 cm (D_3) had the highest leaf area plant^{-1} (1571.89 and 1632.39 cm^2) in both seasons, respectively. The wide sowing distance 30 cm decreased the competition between plants on nutrition and light which increased the volume of root and leaf area of plants and increased vegetative growth of faba bean. These results are in agreement with those obtained by **Abdel Motagally and Metwally (2014) and El-Shamy *et al.* (2015)**.

Fertilization regimes had significant effect on shoot dry weight and leaf area plant^{-1} at 75 and 90 days in both growing seasons. 75% mineral nitrogen + mycorrhiza (F_4) gave the highest values for both traits in the two seasons without significant differences with 100% mineral nitrogen (F_1). **El-Shamy *et al.* (2016)** found that mineral nitrogen plus microorganisms in the soil increased available nitrogen and that leads to increase the metabolites in faba bean, which improve vegetative growth.

The interaction between sowing distances x fertilization treatments had insignificant effect on shoot dry weight and leaf area plant $^{-1}$ in both seasons.

Faba Bean Yield and its Attributes

Results in Table 8 showed that significant differences were observed by faba bean sowing distances on plant height in the first season only and on number of branches and number of pods plant^{-1} in both seasons. In this regard, sowing faba bean at 10 cm (D_1) recorded the tallest plants (115.62 cm) in the first season. Similar results were obtained by **El Hag (2017)** who found that plant height of faba bean was increased by increasing plant density, due to crowding plants. So plant height increases to absorb solar energy and decrease shading effect (**Hamdany and Aassar, 2017)**. In the contrast, faba bean plants that sowing at 30 cm hill space (D_3) had the highest number of branches plant^{-1} (2.83 and 3.13) and number of pods plant^{-1} (12.50 and 12.70) in the two seasons, respectively. Similar results were obtained by **El-Shamy *et al.* (2016) and El Hag (2017)**.

Seed yield plant^{-1}, seed yield and straw yield ton ha^{-1} were significantly affected by sowing distances of faba bean; however 100-seed weight was insignificantly affected by sowing distances in both seasons Table 9. The highest seed yield plant^{-1} (35.16 and 35.94 g) resulted from sowing faba bean at 30 cm (D_3). Decrease of faba bean plant density lead to a decrease in intra-specific competition between faba bean plants for environmental resources. **Mekkei (2014)** showed that seed yield plant^{-1} highly increased by increasing sowing distance between hills. On the other side, sowing faba bean plants at 10 cm (D_1) had highest seed yield (2.327 and 2.407 ton ha^{-1}) and straw yield (2.858 and 3.077 ton ha^{-1}) in both seasons, respectively. Under intercropping system increasing faba bean seed rate was increased faba bean seed yield kg ha^{-1} (**Agegnehu *et al.*, 2008; Klimek-Kopyra *et al.*, 2015)**). Moreover, sole faba bean exceeded all intercropping sowing distances for straw yield and seed yield ton ha^{-1}.

Results in Table 8 cleared that plant height, number of branches and of pods plant^{-1} were significantly affected by fertilization regimes for wheat. The maximal increase of plant height was obtained from 100% mineral nitrogen (F_1) fertilizer application (112.10 and 118.50 cm), while 75% mineral nitrogen + mycorrhiza (F_4) gave the highest number of branches (2.50 and 2.83) and number of pods plant^{-1} (10.84 and 11.06) in the first and second seasons, respectively. Also, fertilizer treatments had significant effect on 100-seed weight, seed yield plant^{-1}, seed and straw yields Table 9. Contrarily, 75% mineral nitrogen + mycorrhiza (F_4) recorded the maximal values in 100-seed weight (65.99 and 66.70 g), seed yield plant^{-1}

Table 7. Shoot dry weight and leaf area of faba bean as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Shoot dry weight plant^{-1} after 75 days (g)		Shoot dry weight plant^{-1} after 90 days (g)		Leaf area plant^{-1} after 75 days (cm^2)		Leaf area plant^{-1} after 90 days (cm^2)	
Season / **Factor**	**2018/ 2019**	**2019/ 2020**	**2018/ 2019**	**2019/ 2020**	**2018/ 2019**	**2019/ 2020**	**2018/ 2019**	**2019/ 2020**
				Sowing distances (D)				
10 cm (D$_1$)	**6.49**	6.93	14.35^{c}	14.46^{b}	647.69	637.66^{b}	1507.51^{b}	1541.97^{b}
20 cm (D$_2$)	**6.66**	7.17	14.80^{b}	14.98^{b}	642.55	645.68^{b}	1534.10^{b}	1595.08^{a}
30 cm (D$_3$)	**6.92**	7.37	15.53^{a}	16.24^{a}	668.81	676.15^{a}	1571.89^{a}	1632.39^{a}
				Fertilization regimes (F)				
100% N (F$_1$)	7.21^{a}	7.84^{a}	15.52^{a}	15.82^{a}	671.45^{ab}	684.08^{a}	1595.59^{a}	1674.35^{a}
75% N (F$_2$)	6.68^{ab}	6.96^{b}	14.57^{b}	14.97^{b}	666.48^{b}	660.29^{b}	1516.19^{b}	1547.79^{b}
50% N (F$_3$)	6.04^{b}	6.37^{b}	14.14^{b}	14.41^{b}	631.41^{b}	624.97^{c}	1461.44^{c}	1528.05^{b}
75% N+ Mycorrh. (F$_4$)	7.29^{a}	7.97^{a}	15.89^{a}	16.18^{a}	676.49^{a}	691.55^{a}	1603.61^{a}	1669.37^{a}
50% N+ Mycorrh. (F$_5$)	6.22^{b}	6.63^{b}	14.34^{b}	14.75^{b}	619.24^{b}	604.92^{c}	1512.35^{b}	1529.50^{b}
				Interaction (D x F)				
				10 cm (D$_1$)				
100% N (F$_1$)	7.13	7.63	14.79	14.57	644.45	658.41	1584.18	1618.34
75% N (F$_2$)	6.49	6.60	14.12	14.06	616.15	625.45	1505.85	1519.17
50% N (F$_3$)	5.74	6.11	13.65	13.97	579.83	583.89	1421.20	1503.85
75% N+ Mycorrh. (F$_4$)	7.07	7.77	14.98	15.29	650.14	682.14	1532.11	1556.36
50% N+ Mycorrh. (F$_5$)	6.05	6.54	14.26	14.44	615.39	613.42	1494.25	1512.15
				20 cm (D$_2$)				
100% N (F$_1$)	7.29	7.82	15.53	15.56	667.08	681.43	1529.25	1698.96
75% N (F$_2$)	6.89	7.08	14.37	14.64	641.47	639.98	1503.55	1529.49
50% N (F$_3$)	6.09	6.56	13.98	14.10	598.15	620.11	1482.50	1497.21
75% N+ Mycorrh. (F$_4$)	6.92	7.73	15.83	15.77	685.02	689.30	1626.96	1724.71
50% N+ Mycorrh. (F$_5$)	6.13	6.69	14.23	14.83	610.03	622.60	1528.27	1525.07
				30 cm (D$_3$)				
100% N (F$_1$)	7.23	8.09	16.26	17.35	702.84	712.43	1673.37	1705.76
75% N (F$_2$)	6.69	7.21	15.25	16.22	691.84	715.45	1539.18	1594.74
50% N (F$_3$)	6.31	6.47	14.80	15.16	633.78	645.92	1480.63	1583.18
75% N+ Mycorrh. (F$_4$)	7.90	8.44	16.81	17.49	694.32	703.22	1651.76	1727.06
50% N+ Mycorrh. (F$_5$)	6.51	6.67	14.57	15.00	621.32	603.78	1514.56	1551.29
LSD 0.05 (D)	NS	NS	0.40	0.74	NS	23.39	36.08	52.23
LSD 0.05 (F)	0.60	0.50	0.61	0.71	42.49	22.05	44.08	43.64
LSD 0.05 (D x F)	NS	NS	NS	NS	NS	NS	NS	NS
Sole faba bean	7.34	7.99	15.78	16.28	665.44	698.17	1598.14	1629.31

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 8. Plant height, number of branches plant^{-1} and number of pods plant^{-1} of faba bean as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Plant height (cm)		No. of branches plant^{-1}		No. of pods plant^{-1}	
Factor / Season	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Sowing distances (D)						
10 cm (D_1)	115.62^a	118.75	1.59^c	1.74^c	7.81^c	8.09^c
20 cm (D_2)	108.00^b	112.70	2.41^b	2.54^b	10.41^b	10.20^b
30 cm (D_3)	104.36^c	110.40	2.83^a	3.13^a	12.50^a	12.70^a
Fertilization regimes (F)						
100% N (F_1)	112.10^a	118.50^a	2.36^{ab}	2.63^b	10.43^{ab}	10.53^{ab}
75% N (F_2)	109.41^{ab}	111.50^b	2.32^b	2.30c^d	10.28^{ab}	10.23^b
50% N (F_3)	108.35^b	109.83^b	2.15b^c	2.15^d	9.48^b	9.68^b
75% N+ Mycorrh. (F_4)	111.84^a	117.16^a	2.50^a	2.83^a	10.84^a	11.06^a
50% N+ Mycorrh. (F_5)	104.94^c	112.75^b	2.05^c	2.44^c	10.15^{ab}	10.13^b
Interaction (D x F)						
10 cm (D_1)						
100% N (F_1)	120.27	127.50	1.60	1.90	8.00	8.50
75% N (F_2)	116.20	115.50	1.60	1.50	8.20	7.80
50% N (F_3)	112.60	113.00	1.53	1.43	7.00	7.65
75% N+ Mycorrh. (F_4)	118.33	123.50	1.67	2.10	8.47	8.60
50% N+ Mycorrh. (F_5)	110.73	112.50	1.57	1.77	7.40	7.92
20 cm (D_2)						
100% N (F_1)	110.31	114.00	2.60	2.70	10.47	10.23
75% N (F_2)	108.23	110.00	2.53	2.40	10.20	10.30
50% N (F_3)	106.65	109.50	2.07	2.30	10.00	9.40
75% N+ Mycorrh. (F_4)	109.01	115.00	2.67	2.80	11.00	11.10
50% N+ Mycorrh. (F_5)	105.83	115.00	2.20	2.50	10.40	9.95
30 cm (D_3)						
100% N (F_1)	105.73	114.00	2.91	3.30	12.60	12.85
75% N (F_2)	103.80	109.00	2.83	3.00	12.47	12.60
50% N (F_3)	105.80	107.00	2.87	2.73	11.47	12.00
75% N+ Mycorrh. (F_4)	108.20	113.00	3.17	3.60	13.07	13.50
50% N+ Mycorrh. (F_5)	98.27	109.00	2.40	3.06	12.67	12.55
LSD 0.05 (D)	1.90	NS	0.18	0.20	0.72	0.86
LSD 0.05 (F)	2.49	3.55	0.19	0.18	0.88	0.60
LSD 0.05 (D x F)	NS	NS	NS	NS	NS	NS
Sole faba bean	116.98	121.54	2.40	2.14	10.21	11.16

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 9. Hundred seed weight, seed yield plant^{-1}, seed yield and straw yield of faba bean as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	100-seed weight (g)		Seed yield plant^{-1} (g)		Seed yield (ton ha^{-1})		Straw yield (ton ha^{-1})	
Season / Factor	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020
Sowing distances (D)								
10 cm (D_1)	62.56	63.57	20.82^{c}	22.02^{c}	2.327^{a}	2.407^{a}	2.858^{a}	3.077^{a}
20 cm (D_2)	62.89	64.17	31.44^{b}	31.70^{b}	2.218^{ab}	2.277^{b}	2.618^{b}	2.906^{a}
30 cm (D_3)	63.79	64.67	35.16^{a}	35.94^{a}	2.149^{b}	2.162^{c}	2.459^{c}	2.522^{b}
Fertilization regimes (F)								
100% N (F_1)	64.55^{a}	65.50^{ab}	29.58^{a}	30.85^{a}	2.321^{a}	2.389^{a}	2.789^{ab}	3.009^{ab}
75% N (F_2)	62.68^{b}	63.29^{b}	29.03^{ab}	29.31^{b}	2.216^{ab}	2.219^{ab}	2.579^{b}	2.826^{b}
50% N (F_3)	60.60^{c}	61.57^{b}	27.66^{b}	28.42^{b}	2.033^{b}	2.153^{b}	2.466^{b}	2.612^{c}
75% N+ Mycorrh. (F_4)	65.99^{a}	66.70^{a}	30.33^{a}	31.54^{a}	2.359^{a}	2.418^{a}	2.866^{a}	3.090^{a}
50% N+ Mycorrh. (F_5)	61.58^{bc}	63.62^{b}	29.10^{ab}	29.33^{b}	2.228^{ab}	2.232^{ab}	2.525^{b}	2.639^{bc}
Interaction (D x F)								
10 cm (D_1)								
100% N (F_1)	63.67	64.67	21.14	22.79	2.461	2.517	3.060	3.261
75% N (F_2)	62.54	63.13	21.00	21.54	2.370	2.406	2.749	3.107
50% N (F_3)	60.77	60.80	19.66	20.86	2.092	2.188	2.561	2.872
75% N+ Mycorrh. (F_4)	64.54	66.37	21.67	23.48	2.431	2.591	3.320	3.459
50% N+ Mycorrh. (F_5)	61.29	62.88	20.67	21.36	2.283	2.336	2.600	2.713
20 cm (D_2)								
100% N (F_1)	64.33	65.30	31.55	32.93	2.326	2.366	2.771	3.117
75% N (F_2)	62.87	63.87	31.00	31.22	2.121	2.216	2.571	2.824
50% N (F_3)	60.10	62.59	30.67	30.33	2.019	2.155	2.513	2.660
75% N+ Mycorrh. (F_4)	65.21	65.53	32.00	33.20	2.397	2.393	2.693	3.177
50% N+ Mycorrh. (F_5)	61.96	63.58	31.90	30.84	2.230	2.260	2.545	2.755
30 cm (D_3)								
100% N (F_1)	65.65	66.54	36.05	36.84	2.178	2.286	2.536	2.650
75% N (F_2)	62.65	62.89	35.00	35.06	2.159	2.035	2.418	2.548
50% N (F_3)	60.96	61.33	32.67	34.08	1.990	2.119	2.327	2.306
75% N+ Mycorrh. (F_4)	68.22	68.20	37.33	37.96	2.250	2.273	2.586	2.659
50% N+ Mycorrh. (F_5)	61.51	64.42	34.75	35.80	2.172	2.101	2.432	2.450
LSD 0.05 (D)	NS	NS	1.23	0.85	0.138	0.095	0.113	0.324
LSD 0.05 (F)	2.04	2.42	1.24	0.97	0.184	0.160	0.228	0.189
LSD 0.05 (D x F)	NS	NS	NS	NS	NS	NS	NS	NS
Sole faba bean	64.11	65.55	30.84	32.57	3.761	3.709	5.400	5.820

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

(30.33 and 31.54 g), seed yield (2.359 and 2.418 ton ha^{-1}) and straw yield (2.866 and 3.090 ton ha^{-1}) in the same respect. Application of nitrogen fertilizer for wheat under intercropping increased the seed yield of faba bean **(Lv *et al.*, 2021).** In cereal-legume intercropping systems, mycorrhiza regulate of nitrogen and phosphorus uptake by intercropping plants (**Qiao *et al.*, 2015)**. In addition, mycorrhiza transfers nitrogen via common mycorrhizal networks between non-legume and legume crops (**Moyer-Henry *et al.*, 2006)**.

Interaction between sowing distances x fertilization regimes had insignificant effect on all previous traits.

Faba Bean Physiological Characters

The results in Table 10 showed that faba bean sowing distances had significant effect on chlorophyll a, b and a+b in both seasons. Sowing faba bean at 30 cm between hills (D_3) gave the highest leaf content of chlorophyll a (1.23 and 1.24), chlorophyll b (.48 and .47) and chlorophyll a+b (1.71 and 1.72) in the two growing seasons, respectively. **Bhatt *et al.* (2010)** reported that plant density can influence chlorophyll content and photosynthesis, which it can affect the yield of the intercropping system.

With regard to fertilization regimes, there were significant differences on chlorophyll a, chlorophyll b and chlorophyll a+b of faba bean in the two seasons. In this regard, 75% mineral nitrogen + mycorrhiza (F_4) recorded the maximum increase these traits followed by 100% mineral nitrogen without significant differences. **Haghighi and Barzegar (2017)** found that inoculation of mycorrhiza increased chlorophyll content which, improved light absorption.

Moreover, the interaction between sowing distances x fertilization regimes had significantly affected chlorophyll a, b and a+b in the second season only.

Results in Table 11 revealed that faba bean sowing distances, fertilization regimes of wheat and their interaction had significant effects on faba bean leaves content of nitrogen (N), phosphorous (P), potassium (K) and seeds content of total carbohydrates and protein. Similar results were obtained by **El-Shamy *et al.* (2016)** on protein content.

Faba bean plants that sowing at 30 cm (D_3) had the highest leaf content of N (3.08%), P (0.55%) and K (1.87%). As well as the highest seeds content of total carbohydrates (47.81%) and protein (21.47%) in the second season. Plant density had no significant effect on total carbohydrates and protein percentages of faba bean seeds (**Abdel-Wahab and El Manzlawy, 2016**).

The highest leaf content of N (3.35%), P (0.60%), K (1.92%), total carbohydrates (48.26%) and protein (21.95%) of faba bean were obtained under 75% mineral nitrogen + mycorrhiza (F_4) followed by 100% mineral nitrogen (F_1) without any significant differences in the second season. **Abdullahi and Sheriff (2013)** found that fertilization plus mycorrhiza increased nutrients concentration of (NPK) in plant shoot. Mycorrhizal fungi in intercropping increased nitrogen and phosphorus uptake of faba bean by increasing nitrogen fixation and phosphorus mobilization in the rhizosphere **(Qiao *et al.*, 2015)**. Intercropping rice with mung bean improved mycorrhiza formation which, increased protein content in mung bean **(Li *et al.*, 2009)**.

Advantages of Intercropping

The results in Table 12 revealed that sowing distances of faba bean had significantly effected on relative yield (RY) of wheat and land equivalent ratio (LER), while no significant effect was observed on relative yield of faba bean in both seasons. Sowing distance (D_3) gave highest values for RY of wheat (0.738 and 0.774) and LER (1.310 and 1.357) in the two seasons, respectively. These results revealed that wide space between hills (D_3) gave more space for plants to grow well and improve productivity. Similar results were obtained by **Agegnehu *et al.* (2008) and Abdel-Wahab and El Manzlawy (2016)**.

With regard to fertilization treatment 75% mineral nitrogen + mycorrhiza or 100% mineral nitrogen, they had superior effect for RY and LER in the two seasons. These results are in agreement with those obtained by **Mohammed (2014)**. All intercropping patterns exhibited land equivalent ratio (LER) greater than unity, except F_3D_1 and F_3D_2 in the first season.

Interaction between faba bean sowing distances x fertilization regimes had significant effect on LER in both seasons and RY of wheat in the first season.

Results in Table 13 revealed that highest values of net return were obtained from the

Table 10. Chlorophyll content of faba bean at 75 days (mg/g fresh weight) as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Chlorophyll a		Chlorophyll b		Chlorophyll a+b	
Season / Factor	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Sowing distances (D)						
10 cm (D_1)	1.18[c]	1.18[c]	0.43[b]	0.45[b]	1.61[c]	1.63[c]
20 cm (D_2)	1.20[b]	1.22[b]	0.47[a]	0.48[a]	1.67[b]	1.70[b]
30 cm (D_3)	1.23[a]	1.24[a]	0.48[a]	0.47[a]	1.71[a]	1.72[a]
Fertilization regimes (F)						
100% N (F_1)	1.23[a]	1.25[b]	0.51[a]	0.51[a]	1.74[a]	1.76[a]
75% N (F_2)	1.20[b]	1.22[c]	0.47[b]	0.45[b]	1.68[b]	1.67[b]
50% N (F_3)	1.16[c]	1.19[d]	0.40[d]	0.42[c]	1.56[d]	1.61[c]
75% N+ Mycorrh. (F_4)	1,24[a]	1.26[a]	0.50[a]	0.51[a]	1.75[a]	1.77[a]
50% N+ Mycorrh. (F_5)	1.17[c]	1.17[e]	0.43[c]	0.44[b]	1.60[c]	1.61[c]
Interaction (D x F)						
10 cm (D_1)						
100% N (F_1)	1.21	1.22	0.48	0.50	1.69	1.72
75% N (F_2)	1.18	1.19	0.43	0.44	1.61	1.63
50% N (F_3)	1.14	1.15	0.40	0.41	1.54	1.56
75% N+ Mycorrh. (F_4)	1.22	1.20	0.47	0.49	1.70	1.70
50% N+ Mycorrh. (F_5)	1.15	1.16	0.41	0.42	1.56	1.59
20 cm (D_2)						
100% N (F_1)	1.23	1.25	0.52	0.51	1.75	1.74
75% N (F_2)	1.19	1.23	0.50	0.48	1.69	1.71
50% N (F_3)	1.18	1.21	0.39	0.46	1.57	1.67
75% N+ Mycorrh. (F_4)	1.24	1.27	0.51	0.52	1.75	1.79
50% N+ Mycorrh. (F_5)	1.16	1.17	0.46	0.43	1.62	1.60
30 cm (D_3)						
100% N (F_1)	1.26	1.29	0.53	0.54	1.79	1.83
75% N (F_2)	1.25	1.24	0.49	0.45	1.74	1.69
50% N (F_3)	1.17	1.22	0.42	0.40	1.59	1.62
75% N+ Mycorrh. (F_4)	1.28	1.31	0.54	0.53	1.82	1.84
50% N+ Mycorrh. (F_5)	1.20	1.18	0.45	0.47	1.64	1.65
LSD 0.05 (D)	0.01	0.01	0.02	0.02	0.02	0.01
LSD 0.05 (F)	0.02	0.01	0.02	0.02	0.02	0.02
LSD 0.05 (D x F)	NS	0.02	NS	0.03	NS	0.12
Sole faba bean	1.21	1.22	0.50	0.48	1.71	1.70

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 11. Nitrogen (N), phosphorous (P), potassium (K) % in dry leaves at 75 days, total carbohydrates and protein content in faba bean seeds as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2019-2020 season

Parameter / Factor	N %	P %	K %	Total carbohydrates%	Protein %
			Sowing distances (D)		
10 cm (D_1)	2.89[b]	0.51[c]	1.81[b]	46.15[c]	20.66[b]
20 cm (D_2)	3.06[a]	0.53[b]	1.82[b]	46.86[b]	20.90[ab]
30 cm (D_3)	3.08[a]	0.55[a]	1.87[a]	47.81[a]	21.47[a]
			Fertilization regimes (F)		
100% N (F_1)	3.32[a]	0.60[a]	1.87[b]	48.16[a]	21.87[a]
75% N (F_2)	2.86[c]	0.51[b]	1.81[c]	47.20[b]	20.60[b]
50% N (F_3)	2.57[d]	0.43[c]	1.76[e]	45.40[c]	19.88[c]
75% N+ Mycorrh. (F_4)	3.35[a]	0.60[a]	1.92[a]	48.26[a]	21.95[a]
50% N+ Mycorrh. (F_5)	2.94[b]	0.51[b]	1.80[d]	45.67[c]	20.76[b]
			Interaction (D x F)		
			10 cm (D_1)		
100% N (F_1)	3.06	0.59	1.84	47.01	21.30
75% N (F_2)	2.86	0.50	1.79	46.32	20.70
50% N (F_3)	2.55	0.43	1.76	45.07	19.81
75% N+ Mycorrh. (F_4)	3.11	0.55	1.92	46.69	21.11
50% N+ Mycorrh. (F_5)	2.89	0.48	1.77	45.69	20.43
			20 cm (D_2)		
100% N (F_1)	3.33	0.60	1.86	48.40	21.60
75% N (F_2)	2.97	0.53	1.81	47.38	20.13
50% N (F_3)	2.61	0.42	1.76	44.68	19.51
75% N+ Mycorrh. (F_4)	3.45	0.62	1.90	48.34	21.97
50% N+ Mycorrh. (F_5)	2.95	0.52	1.80	45.50	20.05
			30 cm (D_3)		
100% N (F_1)	3.58	0.63	1.93	49.09	22.73
75% N (F_2)	2.75	0.51	1.85	47.93	20.99
50% N (F_3)	2.58	0.44	1.78	46.47	20.33
75% N+ Mycorrh. (F_4)	3.51	0.65	1.97	49.77	22.78
50% N+ Mycorrh. (F_5)	3.00	0.54	1.83	45.83	20.55
LSD 0.05 (D)	0.06	0.01	0.02	0.27	0.59
LSD 0.05 (F)	0.08	0.01	0.01	0.31	0.52
LSD 0.05 (D x F)	0.13	0.02	0.02	0.54	0.91
Sole faba bean	3.18	0.58	1.73	48.35	21.89

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 12. Relative yield (RY) and land equivalent ratio (LER) as influenced by sowing distances, fertilization regimes and their interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Relative yield (RY)				Land equivalent ratio (LER)	
Season	Wheat		Faba bean			
Factor	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020
Sowing distances (D)						
10 cm (D_1)	0.559^{c}	0.570^{c}	0.620	0.649	1.185^{c}	1.218^{c}
20 cm (D_2)	0.680^{b}	0.693^{b}	0.590	0.614	1.248^{b}	1.307^{b}
30 cm (D_3)	0.738^{a}	0.774^{a}	0.572	0.583	1.310^{a}	1.357^{a}
Fertilization regimes (F)						
100% N (F_1)	0.742^{ab}	0.762^{a}	0.617^{a}	0.645^{a}	1.359^{a}	1.407^{a}
75% N (F_2)	0.693^{b}	0.703^{b}	0.590^{ab}	0.599^{ab}	1.283^{b}	1.301^{b}
50% N (F_3)	0.490^{d}	0.501^{c}	0.541^{b}	0.581^{b}	1.031^{d}	1.082^{d}
75% N+ Mycorrh. (F_4)	0.754^{a}	0.746^{a}	0.625^{a}	0.652^{a}	1.343^{a}	1.398^{a}
50% N+ Mycorrh. (F_5)	0.617^{c}	0.683^{b}	0.593^{ab}	0.602^{ab}	1.210^{c}	1.285^{c}
Interaction (D x F)						
10 cm (D_1)						
100% N (F_1)	0.651	0.671	0.654	0.679	1.305	1.350
75% N (F_2)	0.565	0.576	0.633	0.649	1.198	1.225
50% N (F_3)	0.398	0.417	0.556	0.590	0.954	1.007
75% N+ Mycorrh. (F_4)	0.621	0.618	0.646	0.699	1.268	1.317
50% N+ Mycorrh. (F_5)	0.558	0.565	0.607	0.630	1.166	1.195
20 cm (D_2)						
100% N (F_1)	0.736	0.756	0.618	0.638	1.354	1.394
75% N (F_2)	0.723	0.740	0.564	0.598	1.287	1.338
50% N (F_3)	0.438	0.478	0.537	0.581	0.975	1.059
75% N+ Mycorrh. (F_4)	0.725	0.770	0.637	0.645	1.362	1.415
50% N+ Mycorrh. (F_5)	0.668	0.722	0.593	0.609	1.261	1.332
30 cm (D_3)						
100% N (F_1)	0.838	0.859	0.579	0.617	1.417	1.476
75% N (F_2)	0.790	0.793	0.574	0.549	1.365	1.342
50% N (F_3)	0.633	0.608	0.529	0.571	1.162	1.180
75% N+ Mycorrh. (F_4)	0.807	0.849	0.593	0.613	1.401	1.461
50% N+ Mycorrh. (F_5)	0.624	0.763	0.578	0.566	1.202	1.329
LSD 0.05 (D)	0.055	0.014	NS	NS	0.045	0.043
LSD 0.05 (F)	0.038	0.036	0.030	0.056	0.035	0.021
LSD 0.05 (D x F)	0.066	NS	NS	NS	0.061	0.036
Sole wheat	1.000	1.000	---	---	1.000	1.000
Sole faba bean	---	---	1.000	1.000	1.000	1.000

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05.

Table 13. Net return and total net return as influenced by sowing distances and fertilization regimes interaction under intercropping during 2018-2019 and 2019-2020 seasons

Parameter	Net return($ ha^{-1})				Total net return ($ ha^{-1})	
Factor / Season	Wheat		Faba bean			
	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020	2018/ 2019	2019/ 2020
10 cm (D$_1$)						
100% N (F$_1$)	1403.56	1443.37	2067.39	2133.95	3470.95	3577.32
75% N (F$_2$)	1067.15	1064.17	1971.80	2028.61	3038.94	3092.78
50% N (F$_3$)	770.06	784.14	1707.00	1818.16	2477.06	2602.30
75% N+ Mycorrh. (F$_4$)	1366.15	1374.93	2054.22	2225.73	3420.33	3600.66
50% N+ Mycorrh. (F$_5$)	1011.54	1037.37	1889.96	1947.42	2901.50	2984.79
20 cm (D$_2$)						
100% N (F$_1$)	1786.44	1826.59	1971.34	2031.56	3757.78	3858.14
75% N (F$_2$)	1659.66	1753.67	1774.26	1880.72	3433.92	3634.39
50% N (F$_3$)	969.14	1101.33	1683.38	1822.48	2652.52	2923.81
75% N+ Mycorrh. (F$_4$)	1797.55	1938.71	2043.00	2093.52	3840.55	4032.23
50% N+ Mycorrh. (F$_5$)	1615.76	1732.81	1885.18	1927.20	3500.94	3660.01
30 cm (D$_3$)						
100% N (F$_1$)	1997.03	1978.18	1832.50	1948.55	3829.53	3926.73
75% N (F$_2$)	1760.44	1753.74	1817.91	1707.79	3578.35	3461.53
50% N (F$_3$)	1444.77	1433.38	1661.15	1783.35	3102.92	3216.73
75% N+ Mycorrh. (F$_4$)	1909.38	2065.85	1913.58	1939.57	3822.96	4002.42
50% N+ Mycorrh. (F$_5$)	1495.82	1720.46	1839.41	1773.08	3335.23	3493.54
Sole wheat	2416.92	2341.99	---	---	2416.92	2341.99
Sole faba bean	---	---	3553.70	3530.78	3553.70	3530.78

interaction between 100% mineral nitrogen with 30 cm sowing distance (1997.03 $ ha^{-1}) for wheat and with sowing distance 10 cm (2067.39 $ ha^{-1}) for faba bean in the first season. In the second season, 75% nitrogen + mycorrhiza combination with 30 cm sowing distance had superior effect (2065.85 $ ha^{-1}) on net return of wheat and with 10 cm sowing distance for net return of faba bean (2225.73 $ ha^{-1}).

In the same Table 75% nitrogen + mycorrhiza with 20 cm sowing distance,100% nitrogen with 30 cm sowing distance or 75% nitrogen + mycorrhiza with 30 cm sowing distance gave the highest values (3840.55, 3829.53 and 3822.96 $ ha^{-1}) for total net return in the first season, respectively. Sowing distance 20 cm and 30 cm with 75% mineral nitrogen + mycorrhiza had the highest values (4032.23 and 4002.42 $ ha^{-1}) for total net return in the second season, respectively. These results are in parallel with those obtained by **Mohammed (2014) and Abdel-Wahab and El Manzlawy (2016)**.

Conclusion

Synthetic fertilizer increased environmental problems. Inoculation of mycorrhizal fungi form a symbiotic association with host plant thus, enhanced nutrient uptake and increased plant growth. Results of this study revealed that under intercropping system planting of faba bean at the sowing distance of 30 cm between hills in both side of ridge 120 cm width with six rows of wheat in the middle of the ridge fertilized by 100% mineral nitrogen (recommended dose) or 75% mineral nitrogen + mycorrhiza improved most characteristics of vegetative growth, productivity, physiological traits, land equivalent ratio (LER) and total net return. From the previous results, we can use mycorrhiza for decreasing the amount of mineral nitrogen fertilizer of wheat plants without any negative effect on intercropped faba bean.

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تأثيــر مسـافــات الـزراعــة ونظـم التســميد على النمو والإنتاجية لكل من القمح والفــول البلدى تحـت نظــام التحميـــل

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أقيمت تجربتان حقليتان في محطة البحوث الزراعية بايتاى البارود، بمحافظة البحيرة، مصر لدراسة تاثير مسافات الزراعه للفول البلدى مع التسميد النيتروجينى المعدنى+ ميكورهيزا لنبات القمح على النمو والانتاجية لمحصولي القمح والفول البلدي تحت نظام التحميل خلال موسمى الزراعه 2019/2018 و2020/2019. وكانت هناك ثلاث مسافات لزراعة الفول وهى 10و 20 و30 سم بين الجوره والاخرى مع خمس معاملات لتسميد القمح وهى 100% الموصى به = 168 كجم نيتروجين معدنى للهكتار و75% من الموصى به = 113 كجم نيتروجين معدنى للهكتار و50% من الموصى به = 84 كجم نيتروجين معدنى للهكتار و 113 كجم نيتروجين معدنى للهكتار (75%)+ ميكورهيزا و84 كجم نيتروجين معدنى للهكتار (50%) + ميكورهيزا. أشارت النتائج إلى أن زراعة الفول على مسافة 30 سم اعطت اعلى القيم لنبات القمح للوزن الجاف والمساحه الورقيه (عند عمر 75 و 90 يوم من الزراعه) والمحصول ومكوناته ومحتوى الكلوروفيل فى الأوراق الطازجة مع الزيادة فى نسبة النيتروجين والفوسفور والبوتاسيوم فى الأوراق الجافه وكذلك نسبة البروتين فى حبوب القمح إلا أن هذه المعامله ادت الى نقص فى طول النبات. وكان التسميد بـــ 75% من النيتروجين المعدنى مع الميكورهيزا الاكثر تفوقاً في جميع القياسات السابقه مع كل من الفول والقمح تحت نظام التحميل. وتوصى الدراسة بزراعة الفول البلدى على مسافة 30 سم بين الجوره والاخرى مع تسميد القمح بالتسميد النيتروجينى الموصى به او بـــ 75% من الموصى به مع اضافة الميكورهيزا لزيادة الانتاجيه وتحسين العائد الاقتصادى تحت نظام التحميل.

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